KU LEUVEN

FACULTY OF ECONOMICS AND BUSINESS

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Importing CO2

Evolution of Emissions due to Extra-EU Air Freight to Belgium (2001-2015) and their Social Cost

Jeroen Barrez & Mathieu Mal

r0386350 & r0388432

Thesis submitted to obtain
the degree of

MASTER IN DE BELEIDSECONOMIE

Promotor: Prof. Dr. Filip Abraham
Assistant: Jan-Pieter Laleman

Academic year 2016-2017

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As international trade increases in our globalized world, considering its environmental impact and consequently its social cost is becoming more and more relevant. Until recently most scientific research regarding international trade focused on production based emissions. The environmental impact of international transport was largely overlooked. Therefore, we follow an emerging trend in literature which looks at international transport emissions. More specifically, this paper focuses on aviation which is the most rapidly developing international transport sector. We analyze the CO2 emissions due to extra-EU air freight imports to Belgium in the period 2001-2015. To support policy-making we translate these carbon emissions into a monetary value by applying the Social Cost of Carbon with a value of 109.43 euros/tCO2. Multiplied by the 684 thousand tonnes of CO2 emitted in 2015, we obtain a total amount of little under 75 million euros. This is a cost to society that, because of the absence of the aviation sector in CO2 regulations, is not compensated for.

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Acknowledgements

We would like to thank professor Filip Abraham and Jan-Pieter Laleman for the opportunity to work on this topic. Addressing climate change is one of the biggest challenges facing society, both in everyday life as in scientific research. International transportation is one of the main challenges within the transformation process towards a low carbon economy. Therefore, we were happy to work on this topic.

Besides that, we are grateful for our study in general. Studying economic policy was an eye-opener and very complementary to our education at the Faculty of Arts. We will be very happy if our thesis will be an eye-opener as well.

We hope you enjoy the reading.

Jeroen Barrez and Mathieu Mal

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Table of Contents

Introduction

Environmentalists claim that free trade is not good for the climate. In fact the relationship between trade liberalization and the environment is far more complex. Distinguishing between scale, composition and technique effects (Copeland and Taylor, 2001, 2004) immediately shows the complexity of the relation between free trade and the environment. Besides that, globalization and along with that international trade, are increasingly becoming the reality.

International trade generates greenhouse gas emissions in two ways: first of all by producing goods for trade and secondly by transporting these goods between trading partners. Most literature focuses on the production based emissions. Nevertheless, the emissions due to international transport should not be underestimated. International transport is responsible for approximately one third of global trade-related emissions (Cristea et al., 2011).

When only looking at the output emissions, it looks as if the Belgian economy is getting “cleaner” (EUROSTAT, Greenhouse gas emissions by source sector). However, as stated above, output does not depict the whole story. Therefore, we will focus on transport emissions, more specifically we will investigate the evolution of carbon emissions due to international air transport of goods to Belgium over the period 2001-2015. At this point no one is accountable for the emissions caused by this transportation. Therefore, we assume that a country - in our case Belgium - is responsible for the emissions caused by air freight imports. Next, we monetize the amount of CO2 emissions by applying the concept of the Social Cost of Carbon. Policy makers need this quantitative, monetized value to be able to perform Cost-Benefit Analyses of emission mitigation projects. This exercise has not yet been carried out for the specific case of Belgium and in this way we aspire to contribute to the literature supporting policy and decision-making.

We found that the emissions of interest show a general rising trend over the period considered. Due to the increasing international trade and the growing importance of the aviation sector, the numbers are very likely to keep moving in this direction in the near future. Using an adapted value of the PAGE09 Integrated Assessment Model of 109.43 euros/tCO2, multiplied by the 684 thousand tonnes of CO2 emitted in 2015, we obtain a total amount of little under 75 million euros. This is a cost to society that, because of the absence of the aviation sector in CO2 regulations, is not compensated for.

The first chapter includes a literature study regarding air freight emissions: how to calculate and monetize them and how policy addresses the environmental impact of aviation. The second and third chapter respectively explain the methodology and data that are used for the analysis of emissions due to Belgian air freight imports. The results of this analysis are described in the fourth chapter. In chapter five, which is the discussion, the Belgian emissions, the Social Cost of Carbon and the policy perspective all come together.

1 Literature

The first chapter of this paper consists of a concise literature study on the topics that are touched upon in this paper. These include air freight emissions, the emission factor, the Social Cost of Carbon and the EU policy regarding aviation emissions.

1.1 Air freight emissions

This paper focuses on air freight - which is equal to air cargo without mail - for several reasons. The first one is the rising importance of this transport sector. It accounts for almost 40% of today's world trade when measured in terms of value (OECD, 2010) and it will increase over the coming years. Aviation emissions are expected to rise annually by 3-4% (IPCC, 2007). Second, the aviation industry has a large impact on environmental pollution and climate change. Total CO2 aviation emissions account for approximately 2% of the Global Greenhouse Emissions (IPCC, 2007). Although there are many levels of other pollutants like CH4 and N2O that are also affected by international trade and should not be neglected, the primary focus of this paper is on CO2 emissions. This choice is merely due to the fact that carbon dioxide accounts for more than 60% of the greenhouse gases that have a human cause (Proost and Rousseau, 2012). Secondly, most literature on transport emissions focuses on CO2 and this project aims for results that can be compared to previous studies.

Most research focuses on production based pollution and emissions due to international transport are largely overlooked. However, the last decade an emerging literature is developing about international transport emissions. For instance, Andersen et al. (2010) argue - in their study about CO2 emissions due to the transport of China's exported goods - that emissions from international aviation (and shipping) are not accounted for by any nation. They emphasize the need for transport-focused emission inventories to understand the mechanism behind it, as the first step to develop climate policy. Furthermore Helm et al. (2007) investigated the overall trade of the UK between 1990 and 2005. They found that when emissions due to international aviation, international shipping and outsourcing are included, the national emissions of the UK may have increased by 19% instead of the proposed decline of 12.5% when taking only output related emissions into account. Many studies using a consumption-based input-output analysis demonstrate the importance of “shadow emissions” caused by the (re)allocation of production abroad (Li and Hewitt (2008), Munksgaard et al. (2005)), but still few of them include the transport emissions that are necessary to bring these import products to the domestic consumers (Aall and Hille, 2010). As already mentioned in the introduction we endorse this consumer perspective. More specifically, we follow the 'broad consumer responsibility' concept postulated by Cardarso et al. (2010). These authors state that international freight transport emissions should be included and assigned to the country that finally consumes the transported goods. Following this concept, we assume that Belgium is responsible for transport emissions of imported goods.

The paper of Howitt et al. (2011) is really central in our research, because these authors focus on the carbon dioxide emissions caused by international air freight. Moreover, they contributed to the literature by calculating emissions factors which are necessary to apportion the quantity of emissions due to air transport. Besides that, they developed an entire methodology to calculate air freight emissions that we will apply in our research.

1.2 Emission factor

Howitt et al. (2011) calculated emission factors for air freight in New Zealand, but they claim these values are applicable for other countries or regions as well. The authors calculated these emission factors by taking into account the air fleet (which types and frequency of use), fuel uplift data, distance, and so on. To approximate an emission factor for planes that export goods to Belgium one would need to incorporate all this information which is beyond the set of this paper. Of course there will be differences between countries, but we argue that these values will be similar due to high rotation of the global air fleet and the domination of only two airplane producers (Howitt et al., 2011).

Moreover, most of the short-haul flights still cover a considerable distance, as it is the case for New Zealand. Because we only focus on extra-EU trade, really short journeys - for example from Germany to Belgium - are not included (except for Switzerland). Without intra-EU trade, you could say that Belgium is on an economical island and air freight has to cover a significant distance. Regarding the emission factor for long-haul flights, other values in the literature are very similar. For example, the DEFRA (Department of Environment, Food and Rural Affairs) uses an emission factor of 0.61 kg CO2 per tonne-kilometer. Using the same values makes the results consistent with the carbon emissions calculated in Howitt et al. (2011). The emission factor depends mainly, but not only on the flight distance. The values we use are empirically tested for New Zealand, but as already stated, deviations arise due to a different air fleet, geographic location, and so forth. Moreover, there are differences in methodology: the DEFRA of the UK for instance uses specific fuel-oil consumption rates instead of fuel uplift data (DEFRA, 2008).

Several other studies on air freight apply the emission factors of DEFRA. For example, Saunders and Hayes (2007) use these values for their air freight life-cycle analyses of fresh fruit and vegetables. In addition Andersen et al. (2010) adopt the emission factors of DEFRA (2008) in their study that estimates the CO2 emissions due to the transport of China's exported goods. Compared with Howitt et al. (2011), the emission factor for short-haul flights of DEFRA is much higher: 1.32 against 0.82 kg CO2 per tonne-km. However, in 2012 DEFRA revised their emission factors for air freight transport to 1.23 and 0.70 kg CO2 per tonne-kilometer for short-haul and long-haul flights, which brings them closer to the emission factors Howitt et al. (2011) estimated. Furthermore, the UK has much more really short flights compared with New Zealand. Finally, emission factors are averages: individual flights can be over- or underestimated due to various circumstances, but on average these conditions will cancel each other out.

Table 1: Air freight emission factors (kg CO_2 per tonne-km)

Source	Short-haul flights	Long-haul flights
Howitt et al. (2011)	0.82	0.69
DEFRA (2008)	1.32	0.61
DEFRA (2012)	1.23	0.70

1.3 Social Cost of Carbon

The Social Cost of Carbon (SCC) reflects the marginal global net damage cost of an additional tonne of CO2 emitted today, aggregated over time and discounted back to the present day. It is, put differently, the marginal cost of one additional tonne of emissions, or the marginal benefit of reducing emissions by one tonne. Yet another way to put it, it is the carbon tax that would be imposed by a benevolent social planner (Tol, 2013).

We offer a concise overview of the different Impact Assessment Models (IAM) that are currently used in literature and policymaking. These models combine climate change, economic growth and the effects of climate change on the economy. The most prominent, aggregated and used models are PAGE09, FUND and DICE (Rose, 2014). Almost 90% of the peer-reviewed SCC values have been produced by one of these models (adding RICE, the regional version of DICE) (Isacs et al., 2016). These models are not restricted to calculating the SCC. They have a much broader scope and calculate the economic cost of different consequences of climate change (effects on the agricultural sector, forestry, water supplies, coastal zones due to sea level rise, energy use, air quality, human health, and the cost of adaptation) in different areas around the world, but also the reduction of costs through technological innovation. The SCC can be derived from these impacts. PAGE09, FUND and DICE calculate how greenhouse gas emissions cause changes in atmospheric greenhouse gas concentrations and thereby impact global warming, which leads to economic damage. This is called the 'causal chain' (Rose, 2014). The monetary damage that results over time is discounted to obtain a net present value (van den Bergh and Botzen, 2015). For the SCC there is no distinction between geographical areas of pollution. Since the economical and societal impact of CO2 emissions is worldwide, we speak of a global externality.

The variation between estimates of different models is considerable and the values have great margins because of the uncertainty that comes with estimating the potential cost and (economic) impact of climate change. Weitzman's Dismal Theorem even states that the uncertainty about the impacts of climate change, or any other area characterized by fat-tailed risk, is so important that expected utility maximization is either undefined or arbitrary. With this statement, Weitzman challenges the use of quantitative analysis such as cost-benefit analysis within the area of climate change (Anthoff and Tol, 2013).

Besides the variation between the different models, there is also a large variation between values produced by the same model. The reason for this is that most models calculate values for different pollution scenarios, make different assumptions about economic growth and use different social discount rates (van den Bergh and Botzen, 2015). A study from 2008 by Tol gives an overview of the published values for the SCC that range from a net benefit of 3 dollar per tonne of CO2 (due to fertilization effects on agriculture) to a net damage of 652 dollar per tonne. The wide range of published values (588[1] estimates over 75 studies according to Tol (2013)) leads to very heterogeneous conclusions, actions and outcomes. Moreover, translating new findings regarding potential damages into formulations suitable for SCC modeling requires time and effort,

[1] The number is criticized by van den Bergh and Botzen (2015), but even if arbitrary to some extent, it shows the great variety of values present in literature.

which makes that the IAMs are never perfectly adjusted to the most recent findings in climate science (Rose, 2014).

Weitzman's Dismal Theorem puts the use of IAMs into question, the great amount of SCC values in literature hinder a straightforward translation to policy (Botzen, 2014) and the IAMs constantly lag behind on climate science. However, the SCC estimations from IAMs remain at the basis of policy decisions on topics such as the price for carbon offsetting, carbon taxation and CBAs on environmental mitigation. Therefore it is important to further develop the framework and create a better understanding of how to estimate the SCC in an appropriate way. In the meantime, policymakers still need quantitative information to develop climate policy.

To monetize the CO2 emissions of interest in this paper, we decided to use SCC Values obtained by the PAGE09 model. The main reason for this choice is that the SCC estimations show a rising trend for all models as the models get updated. PAGE09 estimates the highest cost and it is likely that values produced by other models will continue their evolution towards these values (Isacs et al., 2016). This is confirmed by van den Bergh and Botzen (2014): SCC values should be treated with caution and seen as downward biased because of the various damage categories not included and the high discount rates applied, among other reasons. An additional reason for which we decided to stick to a value produced by one model instead of averaging different models' outcomes, is the complexity and ambiguity that goes with combining the different models (the discussion on the USG approach in Rose (2014) and on aggregated values in general in Botzen (2014)).

1.4 Aviation emissions in present EU policy

In January 2012 the European Union extended its Emission Trading System (ETS) to the aviation sector. The initial idea was to include all airlines operating in the EU, covering the emissions of each plane that departs or lands in the EU (Anger and Kohler, 2009, Meleo et al., 2015). However, great diplomatic controversy about the consequences of this policy for international trade resulted in a suspension of the ETS for non-EU airlines (Cui et al., 2016). The Commission decided to limit the scope of the measure to flights within the EEA for the period 2013-2016 awaiting the International Civil Aviation Organisation's (ICAO) proposal for a global market based measure, thus completely excluding extra-EU flights (European Commission, 2017). In the meantime, the 2015 Paris Agreement did not specify how international aviation emissions should be addressed.

The ICAO reached an agreement in 2016 and a pilot with a voluntary phase will start in 2021. In 2017, the Commission decided to prolong the limitations of scope for aviation activities (European Commission, 2017). This means that so far and probably up to 2021, extra-EU trade emissions are not included in any regulative framework. Moreover, the EU ETS has until now failed to deliver an adequate and stable price for CO2 (Wong et al., 2016). On the first of May 2017 the EU ETS price for a tonne of CO2 was 4.57 euros per tonne. In April 2013 the price even reached a historic low of 3.03 euros per tonne. In 2015, 32.3 million free allowances were allocated to the aviation sector (European Commission, 2017). The enormous gap between the European carbon market price and the SCC value discussed above, and the allocation of free allowances imply that even the aviation emissions included in the EU ETS are far from capturing the caused externality.

2 Methodology

Up to now there is no consensus on the methodology for the estimation of carbon emissions due to air freight (Wood et al., 2010; Howitt et al., 2011). One of the main problems is that air companies are cautious with sharing their fuel uplift data because this includes commercially sensitive information. The alternative would be estimating carbon emissions by using the numbers of bunker fuel sales. This, however, leads to statistical discrepancies. Moreover, most of the literature on aviation emissions is focused on passenger air transport (Jardine, 2009).

Our research method is mainly based on Howitt et al. (2011) who calculated carbon dioxide emissions from international air freight for New Zealand. We apply their methodology and more specifically their emission factors in our analysis. Compared with the emission factors of DEFRA these numbers differ due to the different types of planes, the engine type, the distance covered, the weather conditions, the flight altitude and so on. However, both methodologies are in general the same. To calculate carbon emissions we multiply the mass-distance of commodities transported by international air freight by emission factors, which is completely coherent with other research calculating aviation emissions (Jardine, 2005, 2009; Cadarso et al., 2010).

More specifically, we work as follows. First, we calculate the carbon emissions per tonne of air freight. Next, we analyze the recent evolution of carbon emissions due to air freight by classifying the imported goods by export country and type of product. By doing this, we investigate which countries are transporting goods to Belgium by air and which goods are mainly carried.

The formula to calculate total emissions is the following:

$$E(CO2) = \sum mj * dj * EFCO2 * 1.09$$

mj = mass of air freight (in tonnes)
dj = distance travelled by airplane (in kilometers)
EFCO2 = emission factor (kilogram CO2 per tonne-kilometer)
1.09 = correction factor for taxiing at airports, circling and indirect flights

This calculation is first of all based on mass instead of volume, because it gives a more accurate representation of the energy that is required for transport. Secondly, regarding the correction factor there is no international standard. We will use an average factor of 1.09 which is postulated by Penner et al. (1999) and is considered a rather conservative value. This correction factor takes into account the deviation of the actual flight from the great circle distance, taxiing at airports, circling and indirect flights (Howitt et al., 2011).

In our research we will use two different emission factors: 0.82 kg CO2 per tonne-kilometer for a short-haul flight and 0.69 kg CO2 per tonne-kilometer for a long-haul flight. We select these values mainly because Belgium's air transport without intra-EU trade is similar to New Zealand, it has not many very short flights. We assume that these emission factors are constant between 2001 and 2015. You could argue that energy efficiency improved over this period, but opportunities for energy efficiency gains diminished in the 2000s. The major improvements in emission intensity already occurred in the 1990s (Macintosh and Wallance, 2009).

In addition, we endorse the belly-hold assumption made by Howitt et al. (2011). This includes that all air freight is transported on passenger flights. In the case of New Zealand this was a very good estimator because 95% of air freight was transported this way. However, for Belgium we have no numbers on this matter. Nevertheless, DEFRA does not differentiate between passenger and freight transport either, because the nexus between both services is high and difficult to unravel. Moreover, they argue that approximately 70% of freight transport is carried in the belly-hold of passenger aircrafts in the UK. In general, belly-hold is capturing more and more market share and will continue to do so in the future, especially for long-haul flights (Airbus GMF 2014). Lastly, the emission factors estimated by Howitt et al. (2011) are applicable for both freight and passenger transport because freight and passengers were treated on an equal basis.

A practical reason why this paper only considers emissions due to imports is to avoid double counting. Logically the imports of Belgium correspond with exported goods of another country. A further simplification includes that we make no distinction between imported inputs and imported final goods. Belgium is a transit country for many intermediate goods but this paper treats them like final goods that are imported.

In our calculation of carbon emissions, the distance between the exporting country and Belgium is crucial. We assume this distance is equal to the flight distance between the capital of the exporting country and Brussels. Of course this is a simplification of reality, but we think this is the most consistent and straightforward way to do this. To cover a certain distance, one needs a certain amount of fuel, which can be translated into carbon emissions. However, in contrast to overland transport the relation between fuel consumption and the distance is not linear (Jardine, 2005). Analysis of the cycle of a flight shows that the takeoff and landing are most fuel intensive. Moreover, every plane has to climb and descend, which also boosts the fuel consumption during a flight. Once a certain flight altitude is reached, the plane cruises at a constant altitude and the level of fuel efficiency is stable.

Following this reasoning, fuel efficiency improves with the distance that is covered. This means that very short flights are carbon inefficient, because the climb and descent increase the average fuel consumption. For that reason we make a distinction between short-haul and long-haul flights. The applied cut-off value is 3700 km and corresponds with Howitt et al. (2011), who adopt this value from the DEFRA. On the other hand Jardine (2005) suggests a cut-off value of 3500 km between short and long distance flights, which is very similar. Given that no distance in our data set lies between 3500 and 3700, both cut-off values would lead to the exact same results in this particular case.

Using two emission factors is a simplification of reality. It does not capture the sharp decrease in carbon efficiency with declining distance, which is especially remarkable for flights shorter than 1000 km. For example, for a flight between Switzerland and Belgium (approximately 500 km) you could easily argue for a higher emission factor. However, we choose to stay consistent with the factor we use for other short-haul flights.

Finally, short distance flights are fuel inefficient due to the large impact of the takeoff and landing, but the relation between carbon efficiency and distance is not straightforward. Carbon efficiency will not rise endlessly with a longer flight distance. In fact there is a second and inferior effect that we do not take into account. There is a slight decrease in carbon efficiency with long-haul flights due to the fact that longer flights have to carry more fuel (Jardine, 2005, 2009).

3 Data

We will focus on the air freight exported goods to Belgium from non-EU countries by using the Eurostat database 'EXTRA EU trade since 1999 by mode of transport'. The reason why we focus on extra-EU imports is on the one hand a result of the available data. On the other hand this approach is also interesting from a policy perspective: rules for regulating air freight on a national or supranational level (such as the EU) are at this point politically more feasible than on a global scale.

In our research we will focus on the main 25 non-EU countries that export air freight to Belgium, which account for approximately 90% of the mass of non-EU imports by air in 2015.[2] Our estimation of the carbon dioxide emissions will be based on the mass (tonne) - which can be found in the abovementioned database of Eurostat - and the distance (km). We will use the NSTR level to differentiate between different types of products.[3] This is the standard good classification of Eurostat for transport statistics. The database also contains the value of the exported goods. Combined with the mass (in tonnes), we will use this monetary value to calculate the unit value price of different product categories.

[2] More specifically these countries are: Bangladesh, Benin, Canada, Cameroon, China, Côte d'Ivoire, Egypt, Ethiopia, Iceland, India, Israel, Japan, Kenya, Mexico, Morocco, Pakistan, South Korea, Switzerland, Taiwan, Tanzania, Thailand, Togo, Turkey, Uganda, United States of America.

[3] We will use the classification of EUROSTAT: agricultural products and live animals; foodstuffs and animal fodder; solid minerals and fuels; petroleum products; ores and metal waste; metal products; crude and manufactured minerals, building materials; fertilizers; chemicals; machinery, transport equipment, manufactured articles and miscellaneous articles.

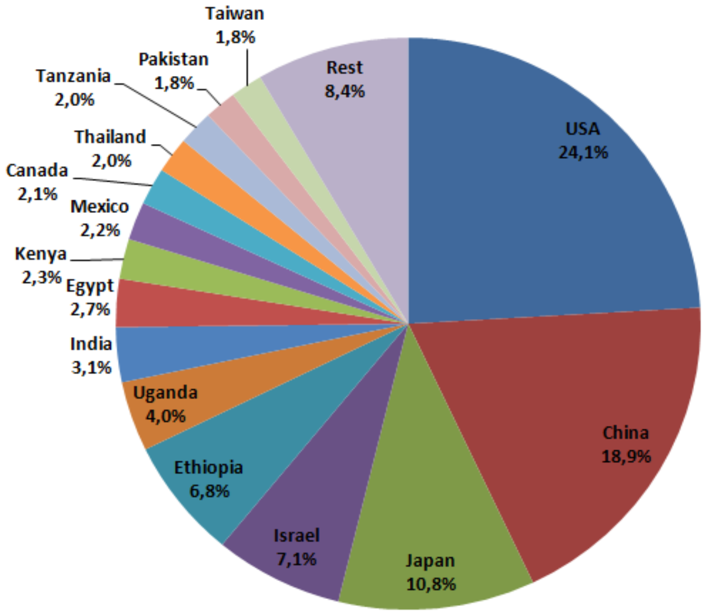
4 Results

In this chapter we present our results. First, we describe how CO2 emissions due to extra-EU air freight imports to Belgium evolved over the period 2001-2015. Second, we demonstrate which countries and world regions export their goods by air to Belgium. Third, the products that are imported by air to Belgium are explained. Fourth, we translate the amount of CO2 emissions into a monetary value. Lastly, we put the results in a broader context.

4.1 Global picture

Once again, we only look at the top 25 extra-EU air freight exporters to Belgium, which account for approximately 90% of the total mass of extra-EU imports by air in 2015. Of these countries only Egypt, Iceland, Israel, Morocco, Switzerland and Turkey are short-haul flights. They account for 22.8% of the total mass of air freight imports which corresponds with 12.6% of the CO2 emissions of the extra-EU top 25 air freight exporters to Belgium in the period 2001-2015. Logically most of the extra-EU imports are long-haul flights accounting for 77.2% of the gross mass and 87.4% of carbon emissions due to air freight imports. To put this ratio in perspective: in the case of New Zealand 34% of the international journeys were short-haul (Howitt et al., 2011). The top 5 extra-EU exporters (USA, China, Japan, Israel and Ethiopia) of air freight to Belgium cover 63.7% of the total mass and 67.7% of all carbon emissions over the period 2001-2015.

Figure 1: CO2 emissions due to extra-EU air freight to Belgium (top 25 countries)

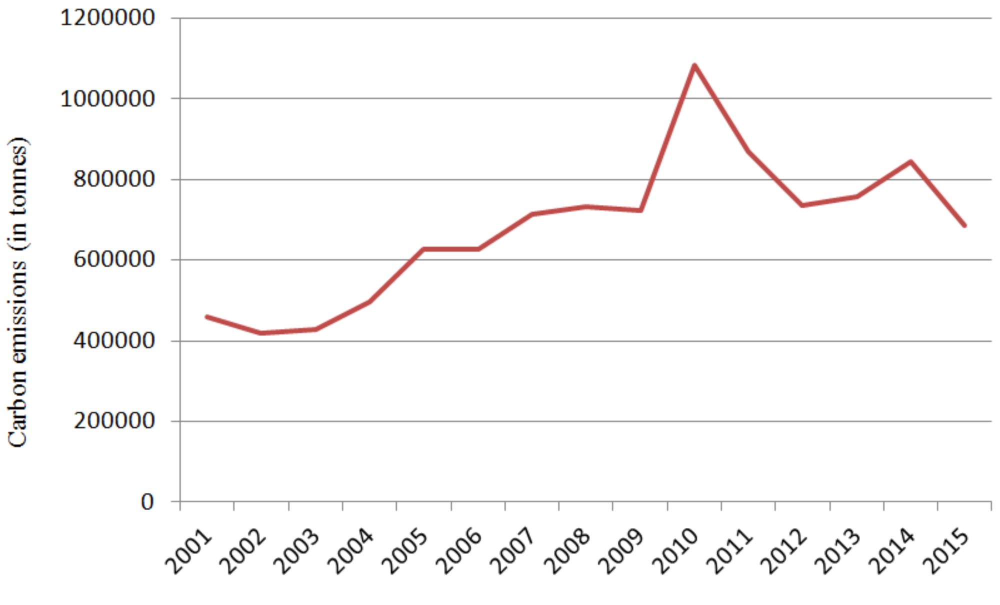


4.2 Evolution of CO2 emissions

There is an undeniable and general rising trend in the total mass imported by air freight and consequently in the carbon emissions due to extra-EU air freight to Belgium between 2001 and 2015 (see 'Figure 2'). In this period there was an increase from approximately 458 to 684 thousand tonnes of CO2. If we take a linear regression of this graph, it becomes clear that the increase over the period of 2001-2015 is much larger between fitted values than it is between the observed values. The fitted values of the total CO2 emissions augment from approximately 470 to 890 thousand tonnes, which is almost a doubling. On average the CO2 emissions rose annually with 4.6% in the covered period.

Surprisingly, the economic crisis of 2009 had no impressive impact on the extra-EU exports to Belgium by air. We see a slowdown in the rise of air freight imports in 2008-2009, but in contrast with the general trend of exports to Belgium and Europe there was no absolute decline. In 2010-2011 there was a sharp upsurge, followed by a decrease which corresponds with the second European economic crisis in 2012. It is important to mention that the curvature of this graph is not only affected by the Great Recession. For instance, the sharp rise in 2010 was caused by a sudden and single increase of imports from Japan of transport equipment. The drop in 2015 was mainly induced by a sharp decline of agricultural imports from Ethiopia due to the worst drought in decades. However, these irregularities are not relevant regarding the general rising trend of extra-EU air freight to Belgium.

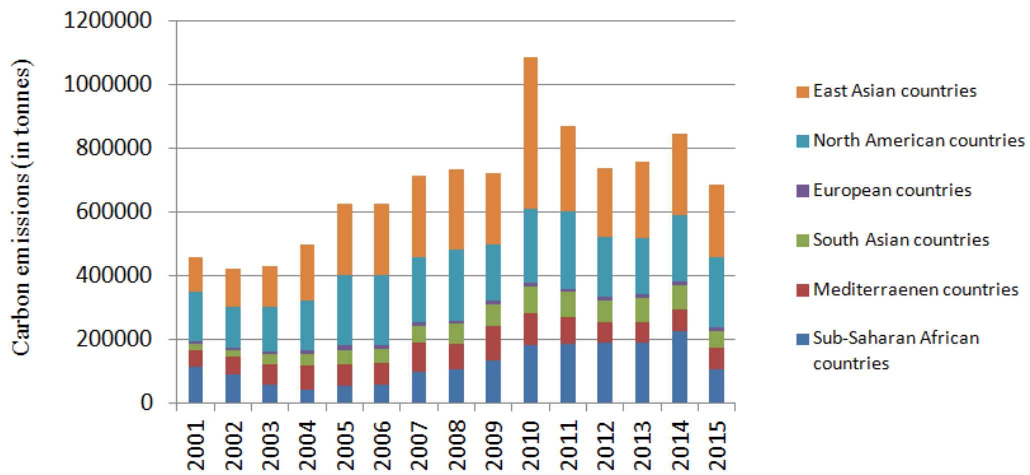
Figure 2: Evolution of total CO2 emissions due to extra-EU air freight to Belgium



4.3 Exporting countries and world regions

The three biggest exporters of air freight to Belgium are exactly the same countries as the biggest exporters to Belgium in general. These are the USA followed by China and Japan (WTO, 2017). However, comparing the top 15 exporters to Belgium in general with those exporting air freight shows remarkable differences. For instance, in the general top 15 there is only one Sub-Saharan country, namely South Africa. On the other hand, when you only look at air transport, five Sub-Saharan African countries (i.e. Ethiopia, Uganda, Kenya, Tanzania and Cameroon) appear in the top 15 air freight exporters by mass and they account for almost a sixth of the carbon emissions due to extra-EU air freight to Belgium. Chang and Ying (2008) emphasize the importance of air freight for African countries to get access to the global market. One cause might be a lack or insufficiency of (international) surface transport infrastructure (Sales, 2013, Saunders and Hayes, 2009). Furthermore, a closer look at the world region specific products - for the largest part agricultural products in the case of Sub-Saharan African countries - that are exported to Belgium by air complicates the story (see ‘Products’).

Figure 3: CO2 emissions due to extra-EU air freight to Belgium by world region



In general, all world regions see an increase in their air freight exports to Belgium in the period 2001-2015 (see 'Figure 3').[4] Most remarkable is the rise in CO2 emissions in absolute terms of the Asian countries (both South and East Asian), which is largely caused by China. Carbon emissions due to imports from China tripled between 2001 and 2008, but were put to hold by the recession. The most impressive rise in CO2 emissions occurred in exports from South Asian countries. The overall emissions increased two and a half times, but for example in the case of Bangladesh they rose tenfold between 2001 and 2015. Sub-Saharan African countries also experienced a strong rise (in the period

[4] We mapped the 25 top extra-EU importers to Belgium in six world regions: East Asia (South Korea, China, Japan, Taiwan), North America (Mexico, USA, Canada), Europe (Switzerland, Iceland), South Asia (India, Pakistan, Thailand, Bangladesh), Mediterranean countries (Turkey, Egypt, Israel, Morocco) and Sub-Saharan Africa (Ethiopia, Benin, Uganda, Cameroon, Kenya, Togo, Tanzania, Côte d'Ivoire).

2001-2014 emissions doubled). This increase was mainly caused by Ethiopia (except for 2015), but other Sub-Saharan African countries also increased their exports to Belgium. CO2 emissions due to imports from European and Mediterranean countries increased to a lesser extent, especially for the latter.

Finally, both short and long-haul flights have known a rise in the period 2001-2015, but the carbon emissions caused by long distance flights increased much more. The main reason for this is that long-haul flights have seen a stronger increase of mass transported by air.

4.4 Products

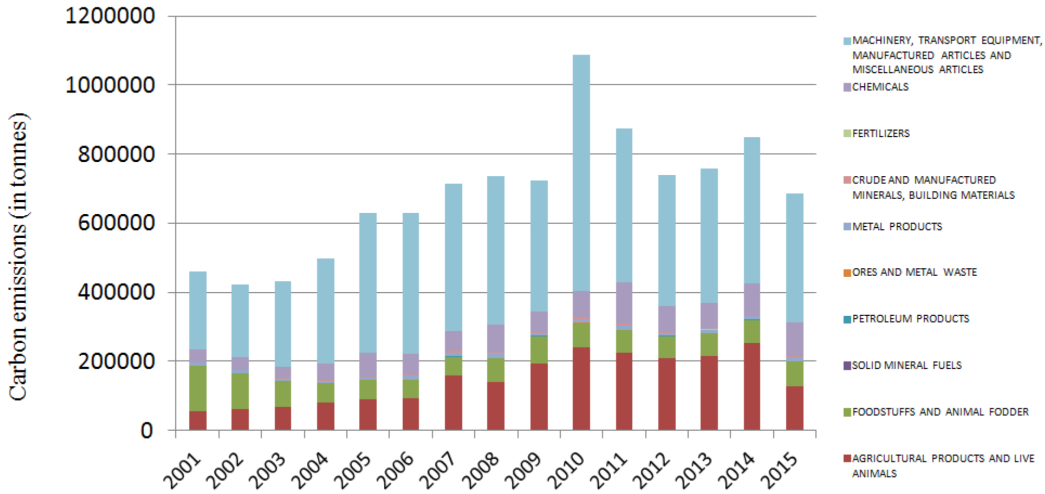
A second way to look at extra-EU air freight exports to Belgium is to distinguish between different types of products. The decision-making concerning the transport mode is a complex matter and is not only determined by the lowest cost. There are other factors that help to explain the choice for air transport. For instance speed and reliability are two strengths of aviation. Besides that, the value of the good, location of manufacture, weight, available alternative transport infrastructure and so on also influence the choice of transport mode (Sales, 2013).

The first and largest category is 'machinery, transport equipment, manufactured and miscellaneous articles', accounting for 56.1% of the overall emissions in the period 2001-2015. This includes consumer goods such as computers, smart phones, electric machinery, toys, books and so on. These kind of goods are first of all transported by air because they are high value: the unit value price was around 143,000 euro per tonne in 2015. Secondly, these goods are as well time-sensitive. They have a short market cycle which implies that the period immediately after the release of the product is crucial for making profit (Bridger, 2009). All over the world this air freight category is the most important one, both by value and mass which corresponds with the environmental impact. For instance, in the case of New Zealand air freight imports of mechanical appliances, electrical machinery, books and manuscripts account for more than 40% of total carbon emissions (Howitt et al., 2011).

Between 2001 and 2015 the top 3 countries represent 74.8% of total emissions due to air freight of machinery, transport equipment and manufactured articles, being China (31.6%) followed by the USA (26.4%) and Japan (16.9%). Most quality products come from the last two countries, while other products are produced in China and the rest of South and East Asian countries. The latter account for 18% of the emissions originating from the air transport of these goods to Belgium. We see the sharpest rise of emissions due to air freighted 'machinery, transport equipment and manufactured articles' in China. Between 2001 and 2015 they increased more than threefold and rose from 16.5% in the beginning of the period to 36.7% of the total emission at the end.

In their research about international freight transport Cristea et al. (2011) estimated that for manufactured goods, transport equipment and machinery over 75% of trade-related emissions originate from transportation, which is much higher than the 33% on average. One of the main reasons for this high proportion of transport emissions for this kind of goods is the heavy use of air transport.

Figure 4: CO2 emissions due to extra-EU air freight to Belgium by product category



The second category we analyze are agricultural products. The main reason why these products are transported by air is because the industry aims to maximize their shelf life. For agricultural products time-sensitivity outweighs their low monetary value - on average the unit value price of agricultural products was only 4000 euro per tonne in our research. Agricultural products are the biggest part of a broader group of air freighted products known as perishables. These goods are carried in refrigerated containers or dedicated freighters sometimes called 'flying fridges'. Besides food products (such as vegetables, fruit, meat and fish), this includes chemicals and pharmaceuticals that are in risk of rot. This category of perishables is seen as the largest (by volume) and most rapidly developing air freight sector (Bridger, 2009). For instance the carbon emissions due to air freighted agricultural products to Belgium rose from 11% in 2001 to 30% of the total in 2014.[5]

Between 2001 and 2015 94.6% of the carbon emissions as a result of overall agricultural imports to Belgium originate from Sub-Saharan African (53.2%) or Mediterranean countries (41.4%). The two biggest agricultural importers to Belgium are Ethiopia and Israel, respectively accounting for 31.8% and 27.2% of the carbon emissions in the covered period. This corresponds with the global picture that 40% of all air freighted agricultural exports into the EU are cultivated in Sub-Saharan African countries (Saunders and Hayes, 2009). Despite the high environmental impact, the economic importance of these countries in air freight to Belgium is much lower. In general, agricultural products have a low monetary value per unit: the large share in CO2 emissions due to extra-EU freight is caused by the large amount of mass.

Third, chemicals are part of a broader category of hazardous products which for example also includes fertilizers and pesticides. In short, these materials could be toxic, corrosive, radioactive or explosive. If we only look at imported chemicals, the prominence of the USA is striking. In the covered period they account for 68.8% of all emissions that

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[5] We look here at the period 2001-2014 because in 2015 the percentage of CO2 emissions due to air transport of agricultural products dropped to 18% due to the drought in Ethiopia.

resulted from transporting these products by air, followed by Japan with 11.5%. Historically the chemical industry is concentrated in Western Europe, North America, and Japan, nowadays these regions still have a large part in the trade of these goods using gradually more and more air transport. Most of the chemicals are used in biotechnological applications or medicinal and pharmaceutical products (Bridger, 2009). Chemicals could be both hazardous and perishable goods, which are two reasons why these goods are transport by air.

Finally, much of the air freight is business-to-business. Bridger (2009) describes this as the 'air linked assembly line'. The main reason why certain products are transported by air is not their monetary value, but time-sensitivity.[6] The just-in-time delivery of products such as components, spare parts and other intermediate goods is necessary to keep the manufacturing process in motion. The cost of air freight - which is a reliable and fast transport mode - may be lower in this case than the cost of a late delivery interrupting the production process. Moreover, this just-in-time manufacturing process minimizes inventory costs. It is true that this 'air linked assembly line' contradicts to a certain extent with our consumer approach, but we defined all exports to Belgium as consumption goods.

4.5 Estimating SCC for air freight emissions

To provide policymakers insight, we translate the CO2 emission into a monetary value using the concept of Social Cost of Carbon (SCC). The SCC values found in table 2 have been calculated using the PAGE model. Stern used the PAGE02 model to estimate an SCC value of 85 US$/tCO2 in his report in 2006. The value was perceived as rather high at that time, but the report of the IPCC in 2007 released new scientific findings that would lead to overall higher SCC estimates. Author of the PAGE model, Chris Hope, updated the model to PAGE09 to adjust it to the findings of the IPCC report. A more recent study by Wong et al. (2016) that investigated the SCC with respect to finding the optimal carbon tax for Malaysia found a value of 106.4 US$/tCO2. However, they altered the equity-weighted marginal damage cost estimates standard PAGE09 model to account for the fact that Malaysia is a developing country. Due to the fact that Belgium is not a developing country, we decide to stick with the value of 100 US$/tCO2 proposed by Hope (2011) for a BAU scenario. This is still a quite conservative value given that van den Bergh and Botzen (2014) stipulate that endorsing a low discount rate and taking into account potential high impact and unquantified damages, leads to a reasonable lower bound SCC estimate of 125 US$.

To be able to monetize the 2015 CO2 emissions calculated for Belgian air freight, we corrected the value of 100 in 2005US$ for inflation and the average exchange rate in 2015. We obtain a value of 109.43 euros/tCO2. Multiplied by the 684 thousand tonnes of CO2 emitted we obtain a total amount of 74,850,250.4 Euros.

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[6] Of course the monetary value should be above a certain minimum to assure that the use of air transport is profitable.

Table 2: A selection of mean SSC values from PAGE in literature

Source	SCC value
Stern (2007)	85 (2000 US$)
Hope (2011)	100 (2005 US$)
Wong et al. (2016)	106.4 (2005 US$)

5 Discussion

Most people, including policymakers, often do not understand the magnitude of carbon emissions. To put the evolution of carbon emissions due to imports by air in a broader perspective, we compare these numbers with total production based carbon emissions emitted in the covered period. First of all, opposed to air freight emissions, the carbon emissions caused by all source sectors in Belgium decreased from 145,815 thousand tonnes in 2001 to 109,847 thousand tonnes in 2014 (EUROSTAT, Greenhouse gas emissions by source sector). If we look at the ratio of emissions due to extra-EU air freight to the production based emissions, we see a rise from 0.31% in 2001 to 0.77% in 2014. At first sight this percentage looks quite small compared to the overall emissions. Nevertheless, there will be a rapid increase in relative terms of carbon emissions due to air freight because most other sectors are reducing their emissions. Moreover, this number covers only the top 25 extra-EU importers to Belgium. The magnitude of intra-EU air transport to Belgium - a part of air freight that should not be underestimated - is not included. If we look at the imports by air to Belgium in 2015, more air freight by mass originates from EU countries than from outside the EU.[7] Nevertheless, the environmental impact of this intra-EU transport is lower in absolute terms because flights are shorter.

Next, we make the magnitude of the carbon emissions more comprehensible for policymakers by translating them into a monetary value. The valorization using the ‘Social Cost of Carbon’ is described earlier on and led to an estimate of 109.43 euros/tCO2. One could say that imports by air to Belgium in 2015 produced a cost to society of little under 75 million euros that is not compensated for. To put this number into some perspective we express this value as a percentage of the total value of imports to Belgium by air in the year 2015 and we obtain 0.35%. Although the effect of the emissions is certainly not to be neglected since it means a real cost to society, it remains rather small compared to the total value of imported goods. Awaiting a further extension of the EU Emission Trading System, a relatively small carbon tax on products imported by air might be able to solve the externality. More specifically, we would suggest a tax on fuel because it corresponds with the environmental impact of air freight. Hereby, economic actors are forced to consider the total social cost of transporting their goods by air. Moreover, it provides an incentive to develop higher fuel efficiency in new aircrafts. Plotting the total value of imports by air against the CO2 emissions shows that they rise in a similar manner. There is almost no decoupling between the economic value creation and the environmental impact of air freight over the covered period. This is an alarming evolution if we both want to maintain economic growth of the aviation sector and at the same time reduce its environmental impact.

Finally, for the sake of completeness we come back to a remark that was made in the literature part on aviation emissions. Aviation emissions consist of more than CO2 alone. For instance, carbon taxation would be a strong signal, a good step in the direction of internalizing environmental damage caused. However, there are non-CO2 emissions such as CH4 and N2O that, if monetized, would lead to much higher costs per tonne due to their larger impact on radiative forcing (Botzen, 2014).

[7] Between 2001 and 2015 air imports by mass originating from EU countries were at least 10% higher than extra-EU air freight to Belgium throughout the whole period.

Conclusion

We have shown that, in contrast to production output emissions, the Belgian CO2 emissions due to international air transport of goods are not declining, but almost doubled between 2001 and 2015. On average, emissions increased every year with 4.6%. Moreover, the impact of these emissions is rapidly growing in relative terms because most other source sectors reduced their emissions in the covered period. To address their environmental impact, we assumed that international transport for imports has to be incorporated when analyzing the evolution of a country's carbon emissions.

Following literature, we adopted the 'broad consumer responsibility' principle which states that consumers within a country are responsible for the demand for foreign goods. This means that the accountability of international transport emissions will be given to the importing countries. Otherwise it is not clear who is responsible for the additional emissions due to international trade. This 'vacuum of responsibility' is reflected in the absence of the aviation sector in international climate agreements such as the ones of Kyoto and Paris. Based on the abovementioned principle, international transport of goods can be incorporated in the climate agreements on a national or supranational level such as the EU. It will help to reduce carbon emissions in what is up to now the no man's land of international transport emissions.

To translate the calculated CO2 emissions into usable information for policy, we monetized them using an estimate of the Social Cost of Carbon derived from literature and adapted to our research. We obtained the value of 109.43 euros/tCO2 which leads to a total value of 74.9 million euros for the emissions in 2015.

This mapping and valuating approach enables to ask other interesting questions such as: 'how much would a certain product cost if the CO2 caused by transport had to be compensated for?', and 'What can the Belgian government undertake to make either producers or consumers internalize this external cost?'. These further questions are worth investigating, and might spark further research. We focused on measuring and monetizing CO2 emissions due to air freight. The next question will be how to deal with these emissions, bearing in mind that in the case of aviation dealing with CO2 emissions only captures part of the externality caused.

We conclude that a regulative framework for carbon emissions due to air freight is necessary. A further development and implementation of market-based measures - such as carbon taxation or cap-and-trade - must take place. It is the best way to provide an incentive to limit emissions and foster less (emission intensive) transport modes. Although aviation emissions are until now only a small part of the global greenhouse gas emissions, the impact of the aviation sector is on the rise. If these emissions will not be included in any climate agreement or regulative framework, the aviation sector will become a major stumbling block on the way to building up a sustainable world economy in the near future. Fortunately, recent agreements between the ICAO and the European Commission seem to lead to emission policy including the aviation sector within the next decade.

List of tables

List of figures

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