MASTERARBEIT

Titel der Masterarbeit

„The influencing factors on carbon leakage rates of unilateral climate policy – a meta-analysis"

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angestrebter akademischer Grad

Master of Science (MSc)

Wien, 2015

Studienkennzahl lt. Studienblatt:	A 066 915
Studienrichtung lt. Studienblatt:	Masterstudium Betriebswirtschaft
Betreuer:	Univ.-Prof. Dr. Franz Wirl

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Wien, im Februar 2015

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1 Introduction

The purpose of this thesis is to provide specific insights into the current scientific findings regarding to the field of carbon leakage.
Due to the failure of setting global CO_2 emission standards, unilateral climate policies, only covering small parts of the world will be the only instrument for emission reductions in the upcoming years.
Unilateral climate policies implemented by certain regions as for example the European emission trading system (ETS) in 2005 are exemplary. For those regions, however unilateral policies bring certain side effects. The side effect, which is probably among the intensely discussed topics when talking about climate policies, is the problem of carbon leakage.

Building on the assumption that a global agreement is far from being implemented, the aim of the thesis is to analyze the problem of carbon leakage. First, the explanation of carbon leakage including its channels as well as the influencing factors is given and second, recent research papers dealing with carbon leakage are discussed and analyzed.

The remainder of the thesis is structured as follows. In section 2, carbon leakage and its channels and influencing factors are discussed. This is followed by a narrative literature review in section 3, which provides the first overview about current research on this field. In section 4 a meta-analysis to statistically analyze the leakage rates is performed. Chapter 5 provides some conclusions and gives an outlook onto future research.

2 Carbon Leakage

This section intends to provide a general idea of the carbon leakage problem in preparation for the findings of the narrative literature review and the meta-analysis. First, the Carbon Leakage Rate is further defined, as well as the Carbon Leakage Channels. Two main channels will be illustrated and further discussed according to Gerlagh and Kuik (2007). In the last section, factors, which determine carbon leakage rates, are described.

2.1 Carbon Leakage Rate

Several institutions like the Intergovernmental Panel on Climate Change or the European Commission try to explain carbon leakage. According to the Intergovernmental Panel on Climate Change, the definition of Carbon leakage is the following:

"Carbon leakage is defined as the increase in CO_2 *emissions outside the countries taking domestic mitigation action divided by the reduction in the emissions of these countries. It has been demonstrated that an increase in local fossil fuel prices resulting, for example, from mitigation policies may lead to the re-allocation of production to regions with less stringent mitigation rules (or with no rules at all), leading to higher emissions in those regions and therefore to carbon leakage. Furthermore, a decrease in global fossil fuel demand and resulting lower fossil fuel prices may lead to increased fossil fuel consumption in non-mitigating countries and therefore to carbon leakage as well. However, the investment climate in many developing countries may be such that they are not ready yet to take advantage of such leakage. Different emission constraints in different regions may also affect the technology choice and emission profiles in regions with fewer or no constraints because of the spillover of learning.* (IPCC).

Whereas the Intergovernmental Panel on Climate Change provides a broader picture of all results that might occur due to unilateral climate action, the European Commission Climate Action defines carbon leakage in a narrower way. They mostly focus on leakage risk sectors that need protection within the European Union.

"Carbon leakage is the term often used to describe the situation that may occur if, for reasons of costs related to climate policies, businesses were to transfer production to other countries which have laxer constraints on greenhouse gas emissions. This could lead to an increase in their total emissions. The risk of carbon leakage may be higher in certain energy-intensive industries." (European Commission)

When these two definitions are placed next to each other for closer observation, it shows how different certain assumptions around carbon leakage might be. Due to this reason, it is important to define carbon leakage in a way, which will then be used throughout the thesis when referring to carbon leakage.

According to Barker, et al. (2007) the leakage ratio can be defined as the increase in CO_2 emissions outside the countries taking domestic mitigation action divided by the absolute reduction in the emissions of these countries (Barker, et al., 2007).

The following formula describes the changes of CO_2 emissions in abating countries in relationship to non-abating countries (Chen, 2009).

$$CO2\ Leakage = \frac{\Delta CO2_{non\ abating\ countries}}{\Delta CO2_{abating\ countries}} * 100 \tag{1}$$

Therefore, a leakage rate of 40% indicates that a decrease in CO_2 emissions by the abating countries by 100 million tons would lead to an additional CO_2 emission increase of 40 million tons outside the region. This factor means the abatement efforts only amount to 60% of the reduced emissions in the abating countries. A leakage rate close to 100% means that the reduction of carbon emissions in one country is completely offset by the emission increase in other countries (Paltsev, 2001).

One general definition therefore says that depending on the leakage percentage, some parts of the mitigation efforts of abating countries will be reduced by increasing emissions in non-abating countries (Eichner, et al., 2009). Climate change is a global problem and therefore some measurements about the effectiveness of counteractions are essential. The two most important channels through which leakage could occur will be discussed in the next section.

2.2 Two main Carbon Leakage Channels

When certain countries and regions implement unilateral abatement policies, certain transmission channels for carbon leakage evolve. In the context of the thesis and the following meta-analysis, two main channels will be important. The following section therefore explains those two channels and they will provide the basis for the main part of the thesis.

The focus of this thesis will mainly lie on the distinction of two channels according to Gerlagh, et al. (2007), Boeters, et al. (2012) and Burniaux, et al. (2012). Gerlagh, et al. (2007) calls them the pollution haven hypothesis and the energy market model. Boeters, et al. (2012) refers to leakage through the trade in emission-intensive goods (T-leakage) and leakage through adjustment of fossil-fuel prices (F-leakage). In the paper, I will further name the channels according to Gerlagh, et al. (2007).

In the pollution haven hypothesis the increasing production costs for energy intensive goods compared to non-abating countries is the main driver for leakage. The energy market model explains leakage through changes in global fossil fuel prices resulting from demand changes in abating regions.

Figure 1 gives a brief summary about the two channels together with their influencing factors. The representation is mostly based on the work of Burniaux, et al. (2012).

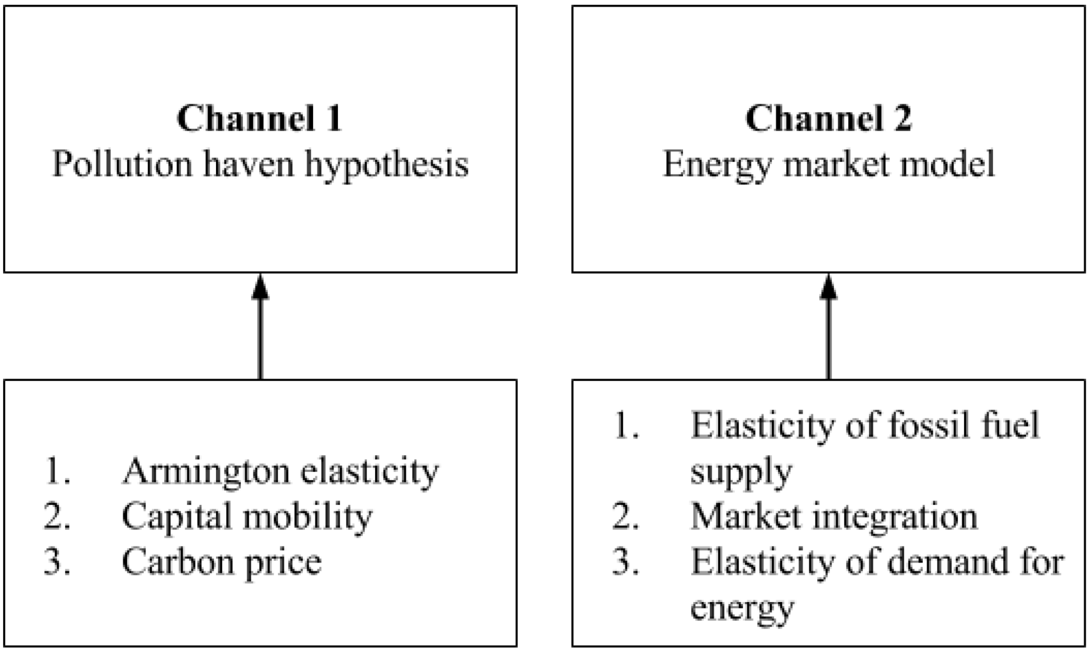

Figure 1 Two main channels and the influencing factors
Source: based on (Burniaux, et al., 2012)

The above displayed factors, which influence and determine carbon leakage rates will be further discussed in the next section. Based on those two leakage channels, as well as the identification of their influencing factors the meta-analysis and the literature review will be conducted.

2.3 Factors which determine carbon leakage rates

The leakage rate depends on different factors. In order to set up a general equilibrium model to analyze leakage rates those factors have to be assumed. Due to lack of consent about the elevation of the parameters, mostly sensitivity analyses are performed (Paltsev, 2001). The most significant factors are the Armington elasticity, the Supply elasticity of fossil fuels and the size of the abating region. With this method, the different outputs resulting from variations in the parameter set-ups can be shown.

All factors that will be included in the meta-analysis will be shortly described in this section.

2.3.1 Armington elasticity

The Armington elasticity refers to the degree of substitution between imported and domestic goods (McDaniel, et al., 2002). Armington, P. (1969) first defined the assumption that internationally traded products are differentiated by country of origin in his essay "A Theory of Demand for Products Distinguished by Place of Production" (Glossary). In cases where the Armington elasticity is high, the consumers are easily substituting between imported and domestic goods. This factor makes it very relevant in the context of carbon leakage because when energy-intensive products in the abating country become more expensive, consumers would immediately switch to cheaper imported goods, which result in a larger relocation effect and a high leakage rate.

2.3.2 Elasticity of Fossil Fuel Supply

The elasticity of fossil fuel supply refers to the reaction of energy markets due to a reduction in energy consumption within the abating countries. The lower these elasticities of oil and coal, the smaller the adjustment of the energy market are; which results in a price decrease. Therefore, the fossil fuel demand outside the abating countries increases and results in carbon leakage (Boeters, et al., 2012). In the extreme case of zero supply elasticity and price adjustments, the leakage rate increases to 100%. Therefore, on a global scale the fossil fuel use remains the same as without climate policies (Boeters, et al., 2012).

2.3.3 Size of abating region

The size of abating regions indicates how many countries participate in climate actions. Several studies show that this factor is among the most influential on leakage rates. Eichner, et al. (2009) provide the best proof for this assumption. They show that the larger the abating region, the lower the leakage rate which is intuitively speaking for itself. In cases where abatement efforts are anticipated on a global scale, the leakage rate has to be zero. In this study, countries with the highest CO_2 emissions have the highest influence.

2.3.4 Carbon price

The creation of a carbon price increases the production costs of companies and the extent decides how severe the influence is going to be. This cost shock affects the firms' output depending on the magnitude of the carbon price, the elasticity of demand, the degree of competition and the market share of each individual company. How severe the influence on each sector turns out to be, also largely depends on the sector in which the firm is operating. Carbon intensive industries are certainly more affected (Vivid Economics with Ecofys, 2013).

2.4 Models

In order to show leakage effects and calculate the leakage rates, mostly large scale general equilibrium analyses or partial equilibrium models are used. The model types within this framework differ regarding to the factors that are taken into account (Eichner, et al., 2009). In general, the literature suggests fairly substantial leakage rates that differ among the models that are used. The meta-regression analysis in section 4 will further analyze the factors among the different models in a regression model. This section intends to give a short overview about the two most used model types, namely the general equilibrium model and the partial equilibrium model.

2.4.1 Computable general Equilibrium models

CGE models are broadly used for empirical analysis to show the impacts of certain policies, which have influences on various fields (Wing, 2004). Therefore, it is also the most common method for analyzing the impacts of environmental taxes or trading systems. Most of the studies that are used for the meta-analysis use computable general equilibrium models. Wing (2004) defines the general equilibrium model as a description of an economy, using a system of simultaneous equations. It therefore implies that all the markets, sectors and industries are modeled together with corresponding inter-linkages. However, certain criticisms need to be pointed out when talking about CGE. Probably the most important critic is the so-called “black box” problem. This means that only the authors or the CGE communities have the abilities to gain further insights into all variables and parameters used for modeling (Wing, 2004). Throughout the conduction of the meta-analysis, including the collection of all parameters needed, this fact was quite obvious. Certainly, there are many studies containing all information. Be that as it may, a substantial number of studies referred to other sources for variables or simply do not mention them at all. This made it really challenging to gather all information.

2.4.2 Partial Equilibrium Models

Partial equilibrium models have certain advantages over CGE models. First, as the name already indicates they have smaller data requirements, because the only data for the analyzed sectors is needed (Bacchetta, et al., 2012). Second, there are already numerous ready-made models available and their usage and interpretation are easy to apply due to a narrow number of equations used (Bacchetta, et al., 2012). Only 6 studies among all analyzed ones in the meta-analysis use PE models (Demailly, et al., 2005), (Meunier, et al., 2014), (Monjon, et al., 2011)a,b, (Otto, et al., 2014) and (Mathiesen, et al., 2004). A reason for that number might be that all the above-mentioned benefits could also be seen as weakness due to its limitation in the models (Bacchetta, et al., 2012).

3 Narrative Literature Review

In this section, a narrative literature review is conducted. 54 scientific papers will be briefly summarized regarding their core statements and their estimation of leakage rates. Furthermore, the analyzed studies are grouped into certain factors, which determine leakage rates for a better overview and discussion.

By systematically reviewing a large amount of journal articles published in the period of 2004 to 2014 touching on the subject of carbon leakage and giving a numerical estimation of carbon leakage rates, 54 articles will be further analyzed in this section. The method uses is called narrative literature review and simply has the goal of providing an overview about a scientific field. Due to time constraints, it is not always possible to individually read all specific studies dealing with this certain topic. For those cases, a narrative literature highlights the most important findings of each individual study (Glass, M. (1981) from Rustenbach (2003)). Some scientists however criticize this method of traditional narrative reviews and refer to the statistical approach of meta-analysis or meta-regression (Rustenbach, 2003). This method will be further applied in section 4.

3.1 Classification

The papers are clustered according to the following characteristics due to their main focus of research:

- Technology spillovers[1]
- Sectorial aggregation
- Design of carbon permits
- Energy supply side
- Market structure
- Elasticity or other parameters

[1] Fullerton, D. et al. (2011) find the definition "abatement resource effect" which is essentially the same as technology spillovers. The taxed sector substitutes away from carbon into clean inputs.

- Emission reduction target
- Others[2]

The paper of Paroussos, et al., (2014) established some ideas and naming for the clusters.

Five studies analyzed technology spillover, which is, besides the abatement resource effect (Fullerton, et al., 2011), the only kind of negative emission leakage found among all studies. Nine studies deal with specific sectors, namely the cement sector (Ponssard, 2008) (Demailly, et al., 2005)), the steel industry (Ritz, 2009) (Mathiesen, et al., 2004) and others. Four different studies deal with the design of carbon permits and the same number of studies focuses on the energy supply side. Only one paper has its main focus on the market structure and its influence on carbon leakage (Babiker, 2005). Sensitivity analysis about factors influencing leakage rates like elasticities or other parameters are the subject of many studies. 18 studies were in total clustered according to this characteristic, providing a wide variety of different analysis. Three papers in the last cluster deal with reduction targets.

3.2 Review

The following table highlights the main opinions and studies published in the research area carbon leakage. Since the whole thesis deals with analysis of leakage rates it is noteworthy to point out that only studies which explicitly provide numerical leakage rate estimates were included into the narrative literature review. Additionally the summary and core statement also only describes the parts of the papers where leakage is discussed. It therefore does not provide a guarantee that all aspects of all papers are pointed out.

[2] Under "Others" the following characteristics are clustered: "Analysis of studies, Border carbon adjustments, Stochastic approach" or it was not possible to classify them.

Main focus	Title	Author & Date	Journal	Leakage Rate	Core Statement and Conclusion
Technology spillovers	Unilateral climate change mitigation, carbon leakage and competitiveness: an application to the European Union	Barker, T., Scrieciu, S. 2009	International Journal of Global Warming	-120 to -98%	With the E3MG model, they incorporate induced technological change into their model. They show that unilateral mitigation actions do not necessarily need to result in carbon leakage. Moreover, they conclude that mitigation efforts should be seen in a more positive way, namely in combination with export promotion opportunities and through international transfer and imitation effects.
Technology spillovers	Carbon leakage from unilateral Environmental Tax Reforms in Europe, 1995–2005	Barker,T. et al. 2007	Energy Policy	-2 to 2%	Analyze the Environmental Tax Reform (ETR) from 1995-2005 and cover only carbon leakage within EU member states that did not implement the ETR. Conclude that in this setting carbon leakage only takes place in a highly competitive, export-driven market. However, it is important to point out that the implemented taxes are relatively small which could be the reason for a low leakage rate.
Technology spillovers	Carbon leakage revisited: unilateral climate policy with directed technical changes	Di Maria, C., Werf, E. 2006	Environmental and Resource Economic	-30 to 40%	Include directed and undirected technical change in their model. Additionally, they show that the leakage rates generally decrease with an increase of the elasticity of relative demand for energy. They conclude that current economic analyses of climate policies mostly do not include induced technological change into their analysis and therefore overestimate carbon leakage.
Technology spillovers	Carbon Leakage With International Technology Spillovers	Gerlagh, R., Kuik, O. 2007	Fondazione Eni Enrico Mattei	-16% to 17%	In their model, they show the strength of endogenous technical change and how this factor reduces the leakage rate. Also, include the size of abating regions. Conclude that technology spillovers can even lead to negative leakage rates. Furthermore, they provide an overview of estimated leakage rates in the CGE literature.
Technology spillovers	Negative Leakage	Fullerton, D. et al. 2011	NBER WORKING PAPER	-4 to 4%	Uses a standard analytical general equilibrium model with two competitive sectors in which one introduces a carbon tax to show how negative leakage might occur. Three assumptions have to be made beforehand to show the abatement resource effect (products are not perfect substitutes; firm can substitute carbon with another input; clean input is mobile between sectors). Shows that the positive leakage rates in previous papers are overestimated. The abatement resource effect leads to negative leakage.

Sectorial aggregation	The value-added of sectoral disaggregation: Implications on competitive consequences of climate change policies	Alexeeva-Talebi, V. et al. 2012	Energy Economics	13 to 18%	Provides a model of EU ETS reduction targets and analyze sectorial disaggregation. Additionally, a sensitivity analysis with variations in the Armington elasticities and technological specifications is provided. They show that the highest influence on the increase of leakage rates shows an increase in the Armington elasticity. Their conclusion is that unilateral policies will result in carbon leakage.
Sectorial aggregation	Estimating carbon leakage and the efficiency of border adjustments in general equilibrium—does sectoral aggregation matter?	Caron, J. 2012	Energy Economics	15 to 17%	Shows the influences of carbon policies on different sectors through sectorial aggregates.
Sectorial aggregation	The Competitiveness Impacts of CO2 Emissions Reductions in the Cement Industry	Demailly, D., Quirion, P. 2005	Technical report, OECD	25%	Provides a model and shows the leakage rate of the European cement sector under the ETS. Points out that the leakage rate is very sensitive to assumptions about allocation and auctioning.
Sectorial aggregation	European emission trading scheme and competitiveness: a case study on the iron and steel industry	Demailly, D., Quirion, P. 2007	Energy Economics	1 to 25%	Focus of the paper lies on the iron and steel industry and give further variations across a range of parameters.
Sectorial aggregation	Comparing policies to combat emissions leakage: border carbon adjustments versus rebates	Fischer, C., Fox, A. 2012	Environmental Economics	5 to 58%	Different leakage rates according to sector (pulp paper; electricity; refined petroleum products; chemicals; nonmetallic minerals; nonferrous metals; iron and steel). The iron and steel sectors have the highest rate.
Sectorial aggregation	Border adjustment for European emissions trading: competitiveness and carbon leakage	Kuik, O., Hofkes, M. 2010	Energy Policy	11 to 35%	Shows the increase of leakage rates depending on the sectors included within the European trading system (10, 8% on the macro level and 35% steel sector, 19%mineral products sector 19% on the sectorial level). Furthermore, they analyze which implications have to be made for border adjustment measures.

Sectorial aggregation	Climate policy and the steel industry: achieving global emission reductions by an incomplete climate agreement	Mathiesen, L., Maestad, O. 2004	The Energy Journal	0 to 27%	The focus of this paper lies on the analysis of the steel industry sector and shows that the steel production would be lowered to half of the emission reduction if climate policies are implemented.
Sectorial aggregation	Carbon Leakage Under Incomplete Environmental Regulation: An Industry-level Approach,"	Ritz, R. 2009	University of Oxford Department of Economics Discussion Paper Series	9 to 75%	The conclusion of the steel industry model is that the two key metrics (emission intensity and trade exposure) to identify leakage risk are not sufficient. As example, which is not covered within the two metrics, he points out differences in the competitive conduct.
Sectorial aggregation	EU Emissions Trading and the Cement Sector: a Spatial Competition Analysis	Ponssard, J., Walker, N. 2008	Climate Policy	70 to 73%	Shows variations of the CO2price (20-50€/ton) for the cement sector.
Design of carbon permits	Assessing alternative solutions to carbon leakage	Antimiani, A. et al. 2012	Energy Economics	13%	Assess the economic and carbon emission effects of the Kyoto targets.
Design of carbon permits	A border adjustment for the EU ETS: reconciling WTO rules and capacity to tackle carbon leakage	Monjon, S., Quirion, P. 2011	Climate Policy	8 to 10%	Provides two different carbon permit designs: free allocation and auction. The leakage rates only differs slightly between them.
Design of carbon permits	On the Scope for Output-Based Rebating in Climate Policy	Fischer, C., Fox, A. 2010	Discussion paper, Resources for the future	6 to 9%	They find that output based rebating for energy-intensive sectors, as it is applied for example in Australia and New Zealand for energy-intensive manufacturing is the less costly solution. Additionally, it also reduces the leakage rate.
Design of carbon permits	ETCLIP -The Challenge of the European Carbon Market: Emission Trading, Carbon Leakage and Instruments to	Bednar-Friedl, B. et.al. 2011	WIFO, Wegener Center	50 to 79%	Two policy scenarios are analyzed and compared to a business as usual approach. They find that it is essential that carbon markets are not limited to firms but cover also households. Concludes that grandfathering is not a solution to mitigate carbon leakage.

	Stabilise the CO_2 Price				
Energy supply side	Carbon leakage in a fragmented climate regime: The dynamic response of global energy markets	Arroyo-Currás, T. et al. 2013	Technological Forecasting and Social Change	5 to 16%	Energy markets and the size of abating regions are investigated. Induce that pioneering regions adopt climate actions early and conclude that carbon leakage is not a strong counter-argument against early actions because the energy market is mainly responsible for reallocation of emissions.
Energy supply side	Unilateral climate policy: Can OPEC resolve the leakage problem?	Böhringer, C. et al. 2013	CREE	6 to 25%	OPEC's behavior has a big influence on leakage rates. They model different scenarios: OPEC exploits their market power to maximize its profits, OPEC rations crude oil supply, behaves as competitive producer, holds crude oil supply constant. The lowest leakage rate occurs when OPEC acts as a dominant producer.
Energy supply side	Making or breaking climate targets: The AMPERE study on staged accession scenarios for climate policy	Kriegler, E., et al. 2014	Technological Forecasting & Social Change	21 to 49%	This paper consolidates the findings of 11 different models and scenarios. The high leakage rate in one model results from higher coal and oil use in the rest of the world through the energy channel and the resulting low prices. Most of the studies included in the AMPERE study are further discussed on their own.
Energy supply side	Impact of fragmented emission reduction regimes on the energy market and on CO_2 emissions related to land use: A case study with China and the European Union as first movers	Otto et al. 2014	Technological Forecasting & Social Change	5%	Shows that the majority of emission leakage occurs via the energy market channel. They further conclude that leakage impacts are strongest in the power and transport sectors. Highlights that reduced oil prices are the main drive for carbon leakage.
Market structure	Climate change policy, market structure, and carbon leakage	Babiker, M. 2005	Journal of International Economics	25 to 130%	Different trade structures are modeled. He predicts significant relocation of energy intensive industries away from the OECD depending on the market structure. Perfect competition results in low leakage rates whereas oligopolistic competition with perfectly homogenous goods results in extremely high leakage rates. Market structure therefore plays a very important role in climate policies.

Elasticity or other parameters	Alternative designs for tariffs on embodied carbon: a global cost-effectiveness analysis	Böhringer, C. et al. 2012	Energy Economics	4 to 17%	The focus of the paper lies on the investigation of the efficiency and economic impact of different tariff design. However, some simulations regarding the size of the abating regions are also done, to find that the leakage rate decreases with the increase of the size of abating region (only 4% when China also joins the coalition).
Elasticity or other parameters	Unilateral climate policy design: efficiency and equity implications of alternative instruments to reduce carbon leakage	Böhringer, C. et al. 2012	Energy Economics	4 to 21%	Models different unilateral abatement policies in their size of abating regions and in the abatement target (10-30% reduction). The larger the reduction target the larger the leakage rate. They show which strong influence parameters like abatement target and abating regions have on the leakage rate. Additionally, it is shown that in cases where China joins the coalition the leakage rate can be reduced substantially.
Elasticity or other parameters	Embodied carbon tariffs	Böhringer, C. et.al. 2013	NBER Working Papers	16 to 28%	Simulate carbon leakage scenarios in order to analyze the effectiveness of carbon tariffs. Through variations of the Armington and the Supply elasticity, they show how the leakage rates respond (the higher the Armington elasticity the higher the leakage rate and the lower the supply elasticity the higher the leakage rate). Concludes that tariffs do reduce leakage rates however only to a certain extent even with optimistic assumptions like coverage of all sectors. Furthermore, there are important topics like possible tariff wars, which one has to bear in mind.
Elasticity or other parameters	Does a regional greenhouse gas policy make sense? A case study of carbon leakage and emissions spillover	Chen, Y. 2009	Energy Economics	75 to 90%	Reaches very high leakages rate through variations in demand elasticity (price-responsive demand (elasticity=0.2) or fixed demand) and different allowances prices above or less than \$7/t. The paper covers the Regional Greenhouse Gas Initiative (RGGI) which covers ten northeast states in the U.S. to control CO2 emissions from the electric sector. The highest leakage rates results from a demand elasticity of zero for energy goods. In cases where price-responsive demand elasticity of 0, 2 the rates are still around 70%.
Elasticity or other parameters	Climate policy and fiscal constraints: Do tax interactions outweigh carbon leakage?	Fischer, C., Fox, A. 2012	Energy Economics	28 to 52%	Shows that the size of the abating coalition reduces the leakage rate.
Elasticity or other parameters	Border tax adjustments in the climate policy context: CO2 versus broad-based GHG	Ghosh, M. et al. 2012	Energy Economics	5 to 26%	The leakage rate decreases with the size of abating coalition. In this context BTAs only, bring small efficiency gains.

	emission targeting				
Elasticity or other parameters	Addressing leakage in the EU ETS: border adjustment or output-based allocation?	Monjon, S., Quirion, P. 2011	Ecological Economics	5 to 11%	Models the leakage rates with high (11% leakage rate) and low Armington elasticity (5% leakage rate). The most efficient way for preventing leakage is with auctioning and border adjustments. This would even lead to negative leakage. Therefore, they conclude that output-based allocation should be seen as a transitory solution whereas auctioning is the best solutions in the end.
Elasticity or other parameters	Assessment of carbon leakage through the industry channel: The EU perspective	Paroussos, L. et al. 2014	Technological Forecasting and Social Change	2 to 35%	Models leakage rates through the competitiveness channel due to the inclusion of sufficiently elastic supply of fossil fuels. Variation in Armington elasticity. The higher the Armington elasticity the higher the leakage rate. Additionally, they also show the leakage rates according to sectors where they show energy intensive industries chemicals and metals that show high rates. Another simulation shows that the leakage rates are also highly dependent on the size of the region abating. In cases where China also joins the coalition, very small rates are calculated.
Elasticity or other parameters	A look inwards: carbon tariffs versus internal improvements in emissions-trading systems	Springmann, M. 2012	Energy Economics	14 to 15%	Models different abating scenarios from international emission trading to individual emission trading systems.
Elasticity or other parameters	A Numerical Investigation of the Potential for Negative Emissions Leakage	Winchester, N., Rausch, S. 2013	American Economic Review	-4 to 60%	Shows the potential for negative leakage rates by means of variations in mobility of capital and labor across regions. Fossil fuel supply elasticity and elasticity of substitution between aggregate energy and capital labor in production. The highest leakage rates are with zero supply elasticity, full mobility of capital and labor across regions and zero elasticity of substitution between aggregate energy and capital labor in production.
Elasticity or other parameters	The economic effects of border measures in subglobal climate agreements	Babiker, M., Rutherford, T. 2005	The Energy Journal	24 to 39%	The focus of the paper is comparing BCA measures to find that none of it has a substantial effect on reducing carbon leakage. Additionally, they show that with a decreasing Armington elasticity and an increasing supply elasticity of oil the leakage rate decreases (24%).

Elasticity or other parameters	Subglobal carbon policy and the competitive selection of heterogeneous firms	Balistreri, E., Rutherford, T. 2012	Energy Economics	12 to 33%	Different Armington elasticities are modeled. The highest leakage rate results from the melitz trade structure which is explained as monopolistic competition and comparable to very high Armington elasticity.
Elasticity or other parameters	Assessment of European Union transition scenarios with a special focus on the issue of carbon leakage	Bernard, A., Vielle, M. 2009	Energy Economics	0 to 10%	They find that carbon leakage might affect specific sectors however it is not of real concern at an aggregate level. The sensitivity analysis shows that Armington elasticity plays a crucial role.
Elasticity or other parameters	Optimal emission pricing in the presence of international spillovers: Decomposing leakage and terms-of-trade motives	Böhringer, C. et al. 2014	Public Economics	7 to 37%	Comes to the conclusion that it is preferable to implement uniform emission pricing which is shown by conducting a sensitivity analysis including certain parameters.
Elasticity or other parameters	Is there a case for carbon-based border tax adjustment? An applied general equilibrium analysis	Burniaux, J. et al. 2012	Applied Economics	4 to 14%	Questions the economic effects of BTAs and find that they can reduce carbon leakage if the size of the abating region is small. The more the abating region increases the impact through trade competitiveness losses decreases and the impact of fossil fuel prices increase. Concludes that BTAs have a small welfare impact and they do not necessarily prevent output losses of heavy industry.
Elasticity or other parameters	Carbon leakages: a general equilibrium view	Burniaux, J., Martins, J. 2010	Economic Theory	2 to 100%	The study is currently the most detailed analysis of modeling assumptions that are influencing the leakage rate estimates. The conclusions are that Armington elasticity does not have a high influence on leakage rates as well as capital mobility. Pre contra, the supply elasticity of coal plays the most crucial role. (Below one LR=40%, inelastic LR=100%). Additionally, the shape of the production function plays a crucial role. In cases where the inter-factor and inter-fuel substitution elasticities are high even an elastic supply elasticity of coal would generate high leakage rates.
Elasticity or other parameters	Linking Numerical and Analytical Models of Carbon Leakage	Carbone, J. 2013	American Economic Review	-9 to 28%	Shows how different parameters influence the leakage rates. The influencing parameters are sector, substitution elasticity between electricity inputs and bundle of fossil energy inputs and substitution elasticity between the value-added bundle and the energy bundle. The highest leakage rate results from a low fuel supply elasticity

					in the electricity sector.
Elasticity or other parameters	Unilateral Carbon Taxes, Border Tax Adjustments and Carbon Leakage	Elliott, J. et al. 2013	Theoretical Inquiries in Law	7 to 23%	A sensitivity analysis is conducted in order to analyze the structure of the leakage issue. It is found that the price elasticity of energy supply is the key driver for carbon leakage. A high leakage rate is the result of an inelastic energy supply. In such cases regional carbon taxes have little effect. Also, taking that finding into account is recommended for further emission trading system designs.
Emission reduction target	Climate Policy and Competitiveness: An Economic Impact Assessment of EU Leadership in Emission Regulation	Alexeeva-Talebi, V. et al. 2012	ZEW	30-35%	Shows that the leakage rates are relatively robust with respect to the level of the emission reduction target. A small decline of the leakage-rate is caused by tax discrimination of carbon and export-intensive industries.
Emission reduction target	Fossil fuel supply, leakage and the effectiveness of border measures in climate policy	Boeters, S., Bollen, J. 2012	Energy Economics	10 to 33%	Models different reduction targets from 10 to 40%, different sizes of abating regions and different fuel supply elasticities (fuel supply as fixed factor and constant elasticity of supply). Concludes that the leakage rates increase sharply with stricter reduction targets.
Emission reduction target	Alternative approaches for levelling carbon prices in a world with fragmented carbon markets	Lanzi, E. et.al. 2012	Energy Economics	3 to 10%	A detailed sensitivity analysis regarding different assumptions is conducted. One conclusion of the paper is that the best way to prevent carbon leakage is the move forward to a global carbon market that prices all sources, regardless of sector or region are combined.
Other	Reconciling climate change and trade policy	Mattoo, A. et al. 2009	World Bank Policy Research Working Paper	11%	With the Latin Hypercube Sampling (LHS), which is a restricted form of the Monte Carlo simulation, they show that unilateral emissions that are cut by the industrial countries will have minimal carbon leakage effects. They only affect the output and the exports of energy-intensive manufactures which are expected to decline substantially.

Other	The relevance of process emissions for carbon leakage: a comparison of unilateral climate policy options with and without border carbon adjustment	Bednar-Friedl, B. et al. 2012	Energy Economics	8 to 38%	Analyzes a unilateral 20% carbon dioxide reduction in terms of leakage and the effectiveness of border carbon adjustments. Concludes that leakage is heavily underestimated because leakage even tends to be higher when process emissions are correctly accounted (38% instead of 29% for combustion emissions only).
Other	Will border carbon adjustments work?	Winchester, N. et al. 2010	Journal of Economic Analysis & Policy	10%	Analyzes the effectiveness of Border carbon adjustments to reduce leakage in 2025. The main statement is that BCAs might reduce leakage with small emission impacts however larger welfare effect. Overall, they do not recommend BCAs to reduce leakage problems because those instruments are too imprecise and would cause collateral damage.
Other	The Strategic Value of Carbon Tariffs	Böhringer, C. et al. 2013	Center for Transnational Studies	9%	Analyzes the use of carbon tariffs.
Other	Switching to carbon-free production processes: Implications for carbon leakage and border carbon adjustment	Schinko, T. et al. 2014	Energy Policy	19 to 39%	The main goal of the paper is the introduction of another perspective into the common general equilibrium models of the iron and steel industry namely the electro winning production process. They introduce the switch to a carbon free economy into the model and find that BCAs could affect that transition in a negative way. Furthermore, they conclude that a switch to carbon free technologies might be even more effective than BCAs. Electro winning reduces the leakage rate from 19, 1 to 1, 4% in 2020 and unilateral EU policy. In the tariff scenario it only is reduced to 2, 6%. In contrast to the benchmark year of 2004 where tariffs reduce the leakage rate from 38, 5 to 23, 4% (electro winning 29%).
Other	Fair, optimal or detrimental? environmental vs. strategic use of border carbon adjustment	Weitzel, M. et al. 2012	Energy Economics	20%	In their analysis of border carbon adjustments, they find that there is a strong incentive to misuse them for manipulations of terms of trade rather than environment protection namely reducing carbon leakage. Furthermore, they find that there is an upper limit for reducing carbon leakage of carbon measures (marginal leakage reduction declines with higher adjustments. Another important finding of their analysis is that they confirm the fossil fuel price channel of leakage has the most

					important influence.
Other	The role of border carbon adjustment in unilateral climate policy: overview of an energy modeling forum study	Böhringer, C. et al. 2012	Energy Economics	7 to 24%	Provides a model comparison of all 12 studies, which were published in accordance to the energy-modeling forum in which different research institutions deal with the topic of carbon leakage. All of the 12 included papers are also described in the literature review. The leakage rate varies according to the model set up. Bohringer, C. et al. identifies the benefits and costs of BCAs in order to inform decision makers.
Other	Would border carbon adjustments prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies	Branger, F., Quirion, P. 2013	Ecological Economics	5 to 25%	Conducts a meta-analysis including 25 studies in order to test the efficiency of border carbon adjustments. They find that with border adjustments to the mean leakage rate among all 25 studies is reduced from 14% to 6%.
Other	The Carbon Content of Austrian Trade Flows in the European and International Trade Context	Bednar-Friedl, B. et al. 2010	FIW Research Reports, Wegener Center, BMWF	15 to 49%	A detailed analysis of different Post-Kyoto scenarios according to different factors is provided. Shows the economic impacts of carbon dioxide emission constraints with variations in the size of abating regions and a focus on international trade effects. Concludes that it is important to view carbon emissions from a consumption perspective.
Other	Capacity decisions with demand fluctuations and carbon leakage	Meunier, G., Ponssard, J. 2014	Resource and Energy Economics	0 to 71%	Variations in demand variability and CO2 price are modeled. A low CO2 price intuitively also results in low leakage rates. This finding refers to the current situation of the European Emission Trading systems which was designed in 2007 without taking the European crisis into account. Additionally, they show that leakage only occurs in the long-term (with capacity adjustment) and the impacts grew larger the higher the uncertainty of the domestic demand conditions.

Table 1 Study description of narrative literature review

3.3 Discussion

According to the studies, the potential of leakage rates ranges from -120% to 130%.

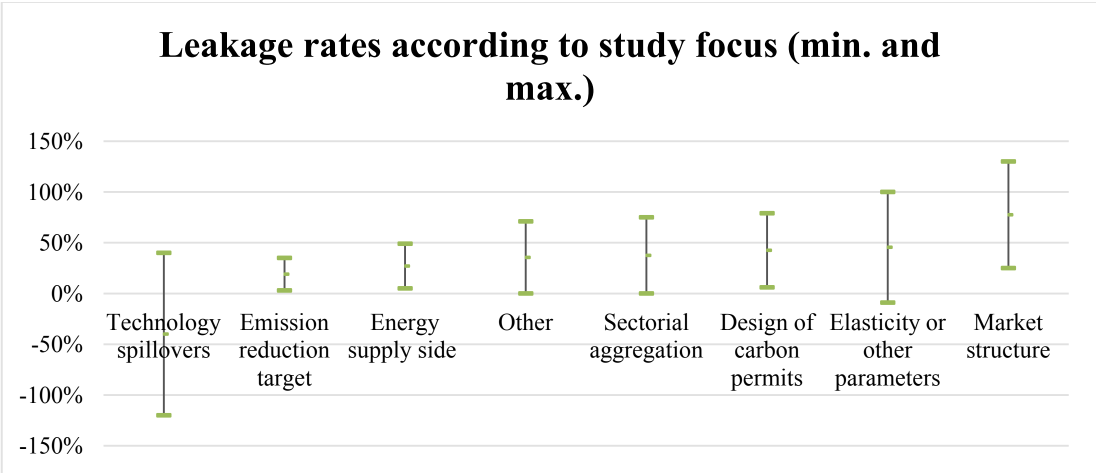

Figure 2 Leakage rates according to study focus

Figure 2 shows the dependence of leakage rate estimates on the main focus of the authors. This can be seen clearly due to the certain clusters. Technology spillovers show negative leakage rates as already mentioned before. Interestingly, the higher rates are often associated with variations in market characteristics. Elasticity parameters provides the biggest leakage rate span from -6% to 100%.

The following discussion highlights the key findings of the narrative literature review according to the clusters:

Technology spillovers:

Among all five studies, the possibility of negative leakage rates induced by technology spillovers is discussed. Di Maria, et al. (2008) point out that the overall leakage rate predictions are overestimated. By including undirected technological change into the model, the leakage rates can become zero or even negative. Gerlagh, et al. (2007) argues that including endogenous energy-saving technical change and international spillovers in the GE model might decrease the leakage rates substantially.

Sectorial aggregation:

On the sectorial level, it can be seen that the highest leakage rates are predicted in the cement sector (Ponssard, 2008) and in the steel industry (Ritz, 2009). Fischer, et al. (2012) and Caron (2012) provide a detailed analysis of different sectors. Mathiesen, et al. (2004) analyze the steel industry and predicts a production cut of 50% when climate policies are implemented.

Design of carbon permits:

Monjon, et al. (2011) explore the effects of different carbon permit designs. As a result, it can be seen that the leakage rate only differs sightly between free allocation and auction. Fischer, et al. (2010) recommend output based rebating for energy-intensive sectors as the most efficient and less costly option.

Energy supply side:

The study of Böhringer, et al. (2013) provide some insights on possible OPEC behaviours and their impact on leakage rates. It can be seen how influental OPEC's reaction to climate policies on leakage rates could be. Otto, et al. (2014) predict the energy channel to be the main driver for carbon leakage. The lower the oil price the higher carbon leakage. It is essential to point out that only a few studies focus on the energy supply side or even include the energy factor in their model.

Market structure:

Babiker (2005) predicts the highest leakage rates among all studies. The leakage rate of 130% is the result of oligopolistic competition and homogenous goods in energy-intensive industries.

Elasticity or other parameters:

The largest leakage rate variations are modelled by varying elasticity parameters in sensitivity analysis. Among all reviewed studies the most detailed and therefore also the most valuable study for our purpose is conducted by Burniaux, et al. (2012).

In their first sensitivity analysis they investigate the first channel of carbon leakage. They find in their sensitivity analysis that neither Armington elasticity, nor the migration elasticity of capital, has a strong influence on leakage rates. The percentage only changes from 2% with low Armington elasticity to 4% with high Armington elasticity.

The rest of their study analyses the second channel of carbon leakage. Due to the differences among fossil fuels they divide them into coal, oil and another less CO_2 intensive fuel (like natural gas). In this sensitivity analysis the impact of the supply elasticity of fossil fuels, the degree of market integrations as well as the demand elasticity is investigated.

One of their main findings is that the supply response of coal producers on the world level has the highest impact on leakage rates. With an elastic supply of coal the leakage rates would be very small in their model. The supply elasticity of oil and other fuels as well as the demand elasticity do not have a high impact.

To sum it up, it can be said that the supply elasticity of coal has the highest influence on leakage rates in their model. Additionally a highly integrated coal market could increase this effect even further. Together with an inelastic supply of coal and a highly integrated coal market, the leakage rates are pushed above 60% in their model (Burniaux, et al., 2012).

Emission reduction target:

Alexeeva-Talebi, et al. (2012) show that the response of leakage rates to variations in the reduction targets is relatively modest. On the contrary, Boeters, et al. (2012) model different reduction target scenarios (from 10-40%) and find that the leakage rate increases sharply with higher reduction targets.

Due to the fact that through analysis of various studies according to core statements, leakage rates and certain characteristics a certain bias could exist, I additionally perform a meta-regression analysis. The expected leakage rate estimates will therefore be further discussed using a statistical approach.

4 Meta-analysis and Data

In the previous section, 54 empirical articles and reviews are analyzed according to certain factors and the leakage rates. In order to further investigate those studies in a more objective way a meta-regression is performed. Therefore, the following section explains the statistical method of meta-analysis, which is described by Glass in 1976. Additionally, the meta-regression model to identify factors that influence carbon leakage rates in unilateral climate policy will be explained and the regression output will be discussed.

4.1 Theory of meta-analysis

The expression meta-analysis of research was first introduced by Gene V. Glass in 1976 as "***The analysis of analyses**."* (Glass, et al., 1981)
Under "analysis of analyses", Glass means a systematic quantitative summary of evidence across empirical studies (Nelson, et al., 2009). Meta-analysis first occurred in medicine, clinical psychology (Smith, et al., 1977), social psychology (Rosenthal, et al., 1978) and education. However, it is becoming more and more essential in all scientific fields, which is also due to its widened range of applicability (Hedges, et al., 1985). Nelson, et al. (2009) find in their systematic review that several hundred meta-analyses were conducted in economics. About one third of them are dealing with environmental topics. Other commonly used synonyms for meta-analysis are research synthesis, research review and systematic review (Cooper, 2009). In this study, I adopt the naming of Cooper Harris and refer to meta-analysis as the statistical method of combining the results from already conducted studies, which will be further explained in the next section (Cooper, 2009).

4.1.1 Approach

According to Cooper (2009), several steps have to be proceeded for conducting the meta-regression. Those steps are displayed in table 2 (Stanley, et al., 2013).

Step	Process of research synthesis
1	Formulating the problem
2	Searching the literature
3	Gathering information from studies
4	Evaluating the quality of studies
5	Analyzing and integrating the outcomes of studies
6	Interpreting the evidence
7	Presenting the results

Table 2 Steps for conducting a meta-analysis
Source (Cooper, 2009)

Many more authors are providing certain guidelines for conducting meta-analysis, which only differ slightly (Nelson, et al., 2009), (Stanley, 2001), (Schulze, 2004). Becker (1998) reviews about fourteen different books devoted entirely to meta-analysis, which indicates a large variety of guidance books about this topic.

4.1.2 Reporting Guidelines

Stanley, et al. (2013) published reporting guidelines of his economic research for meta-analysis. The purpose of the guidelines is to improve transparency and raise the quality of meta-regression analysis. In order to conduct the following meta-analysis I strictly follow their rules that can be divided into three topics:

- Research questions and effect size
- Research literature searching, compilation and coding
- Meta-regression modeling issues.

Further details including explanations about the statistical methods used will be explained in the following sections, together with the meta-regression results.

4.2 Database Description

There is a broad range of literature about carbon leakage. For this reason, I have collected 150 scientific papers and articles that deal with the topic. I have conducted a search under the keyword "carbon leakage" using standard search engines on the internet, scientific papers as well as in the Google Scholar search engine and it was completed in August 2014.

4.2.1 Inclusion criteria

In order to be included in the meta-analysis, studies have to satisfy certain inclusion criteria.

The first criterion to include a paper in the analysis is to give numerical estimates within a model about the carbon leakage rate. The definition of the rate has been discussed in section 2. The leakage rate in this context is very important for two reasons. First, it provides the effect size for the meta-regression analysis and second, it narrows the paper collection to those that deal with analyzing the leakage effect as such.
Therefore, only studies providing carbon leakage rates are included in the meta-sample. This criterion diminished the sample to 56 empirical studies. All of them were giving numerical results. However, not all of them could be included in the analysis due to the further criteria. Nevertheless, all 54 are included in the literature survey in section 3.
Since the study examines the influence of independent variables on carbon leakage rates, this selection process does not imply bias for the results.

The second criteria is to limit the investigated period to ten years, since the purpose of the meta-analysis is mainly to analyze the amount of carbon leakage under current environmental targets and actions. Therefore, the time span of papers that are used for the analysis lies between 2004 and 2014. Figure 1 shows how they are distributed over the years.

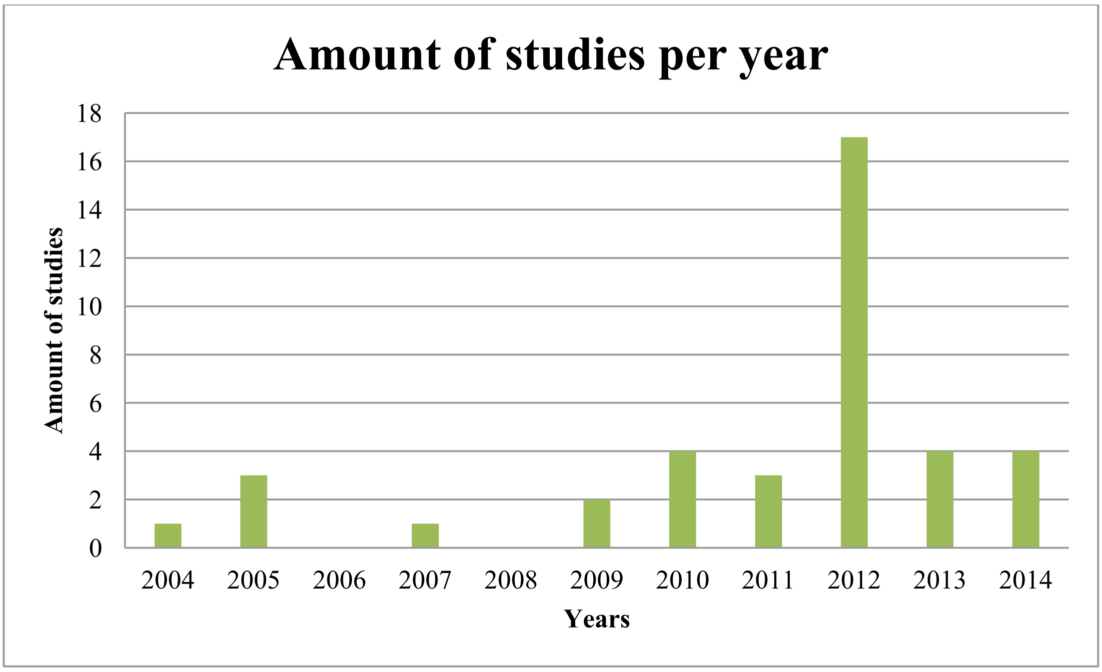

Figure 3: Amount of studies per year

Thirdly, the studies have to provide the numerical data for some of the six regression variables, which are explained below. All studies with the minimum of three out of six variables are included.

4.2.2 Sample description

Considering all the above criteria, the meta-regression is performed using data from 39 empirical studies from different authors, which are displayed in table 3. Figure 2 shows the amount of contributions per author. In order to calculate the numbers, all authors of each contribution are gathered and all of which that have contributed to more than one paper are included in the chart. Therefore, authors that are author or co-author to one paper only do not appear in the chart. In total 79 different authors contributed to the 39 studies.

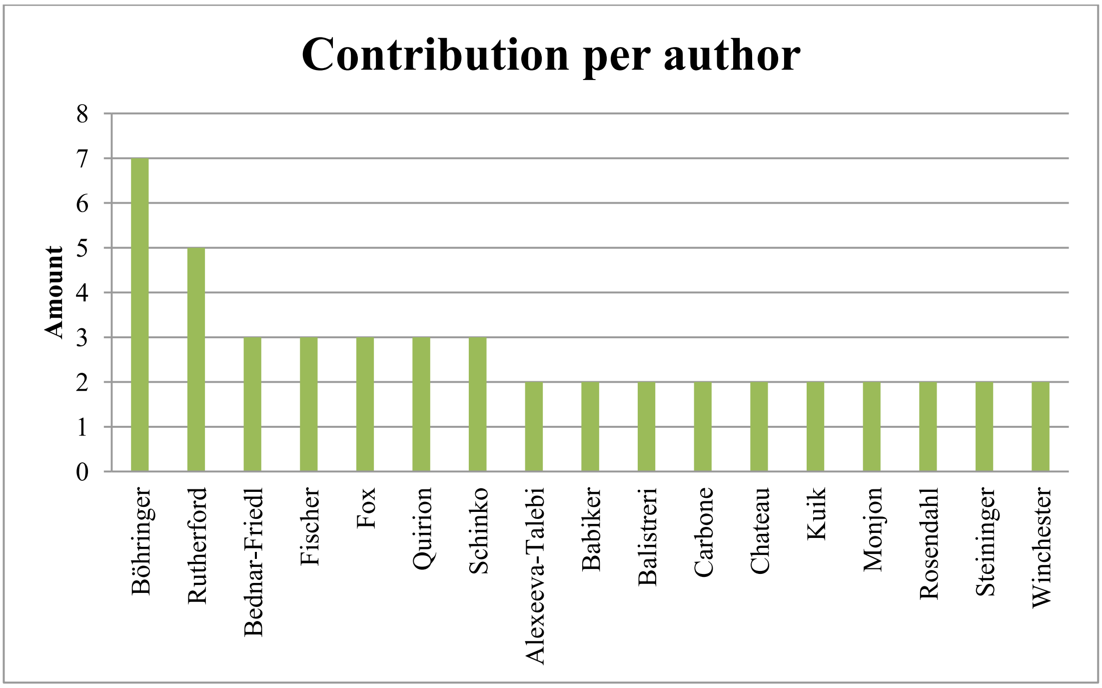

Figure 4 Contribution per author

List of primary studies used	
PACE (Alexeeva-Talebi et.al. 2012a)	CIM-EARTH (Elliott et.al. 2013)
PACE (Alexeeva-Talebi et.al. 2012b)	GTAP-EG (Fischer/Fox 2012)
GTAP-E (Antimiani et.al. 2012)	GTAP in GAMS (Fischer/Fox 2012)
CGE (Babiker/Rutherford 2005)	GTAP-E (Gerlagh/Kuik 2007)
MIT-EPPA (Babiker 2005)	EC-MS-MR (Ghosh et.al. 2012)
MINES (Balistreri/Rutherford 2012)	GTAP-E (Kuik/Hofkes 2010)
CGE (Bednar-Friedl et.al. 2010)	ENV-LINKAGES (Lanzi et.al. 2012)
CGE (Bednar-Friedl et.al. 2012)	LHS (Mattoo et.al. 2009)
GTAP-E (Bednar-Friedl et.al. 2011)	(Meunier/Ponssard 2014)
GEM-E3 (Bernard/Vielle 2009)	CASE2 (Monjon/Quirion 2011a)
WorldScan (Boeters/Bollen 2012)	CASE2 (Monjon/Quirion 2011b)
SNoW (Böhringer et.al. 2012)	IMAGE (Otto et.al. 2014)
CGE (Böhringer et.al. 2014)	GEM-E3 (Paroussos et.al. 2014)
CGE (Böhringer et.al. 2013)	CVO (Springmann 2012)
CGE (Böhringer et.al. 2012)	DART (Weitzel et.al. 2012)
MRIO (Böhringer et.al. 2012)	EPPA (Winchester et.al. 2010)
ENV-LINKAGES (Burniaux et.al. 2012)	USREP (Winchester/Rausch 2013)
FKB (Carbone 2013)	SIM (Mathiesen/Maestad 2004)
GTAP-EG (Caron 2012)	GTAP (Fischer/Fox 2010)
CEMSIM-GEO (Demailly/Quirion 2005)	

Table 3 Primary studies

Most of the primary studies have been published in the journal “Energy Economics”. Figure 3 shows the amount of papers per journal.[3]

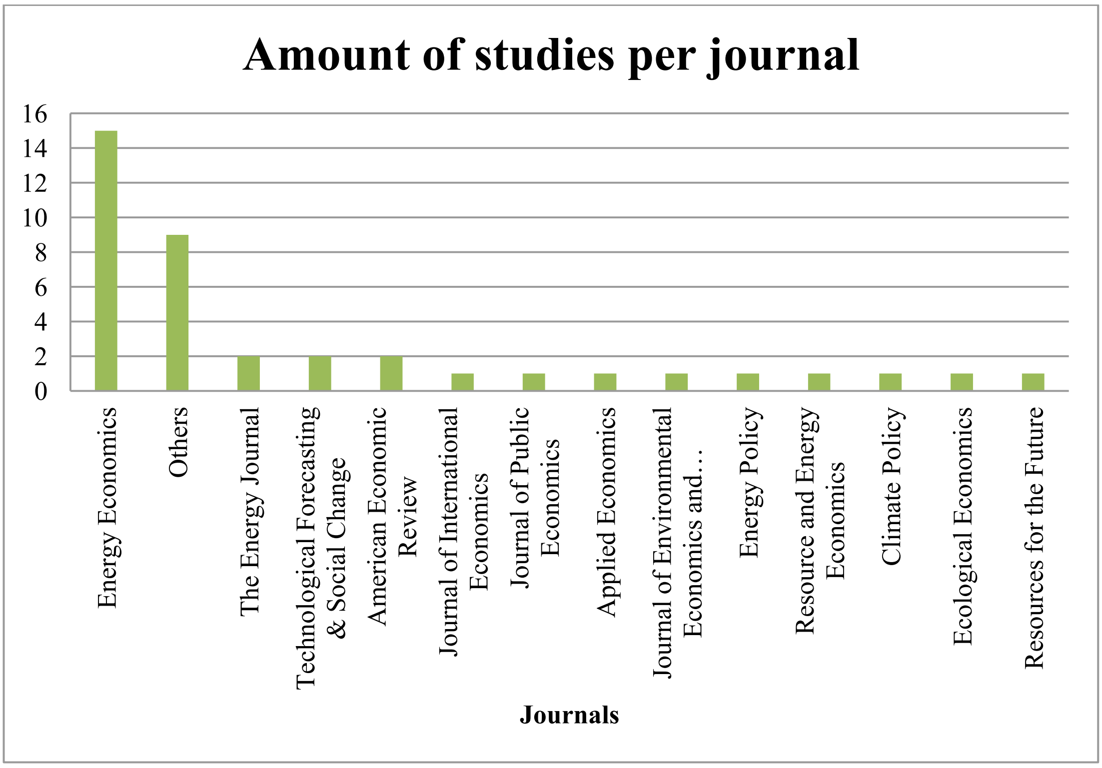

Figure 5 Amount of studies per journal

It can be seen in figure 4 that the scientific papers give more than one leakage-rate estimate in each study. Those leakage rate estimates are either displayed within the study, available on tables or included in graphs. In order to avoid publication biases, I try to include all estimates in the study. Since it was not possible to include each possible combination that could be withdrawn from graphs, those estimates are limited to the most significant ones, mostly three estimates per scenario.

[3] Under “ Others” the following publishing institutions were summarized:
ZEW, FIW Research Reports, Wegener Center, WIFO, CREE, OECD, Fondazione Eni Enrico Mattei, World Bank,Journal of Economic Analysis & Policy

The amount of leakage-rate estimates vary from one estimate up to 24 estimates in Böhringer, et al. (2014), each estimate depending on different model estimates. In total 178 observations from 39 studies are included into the meta-data.

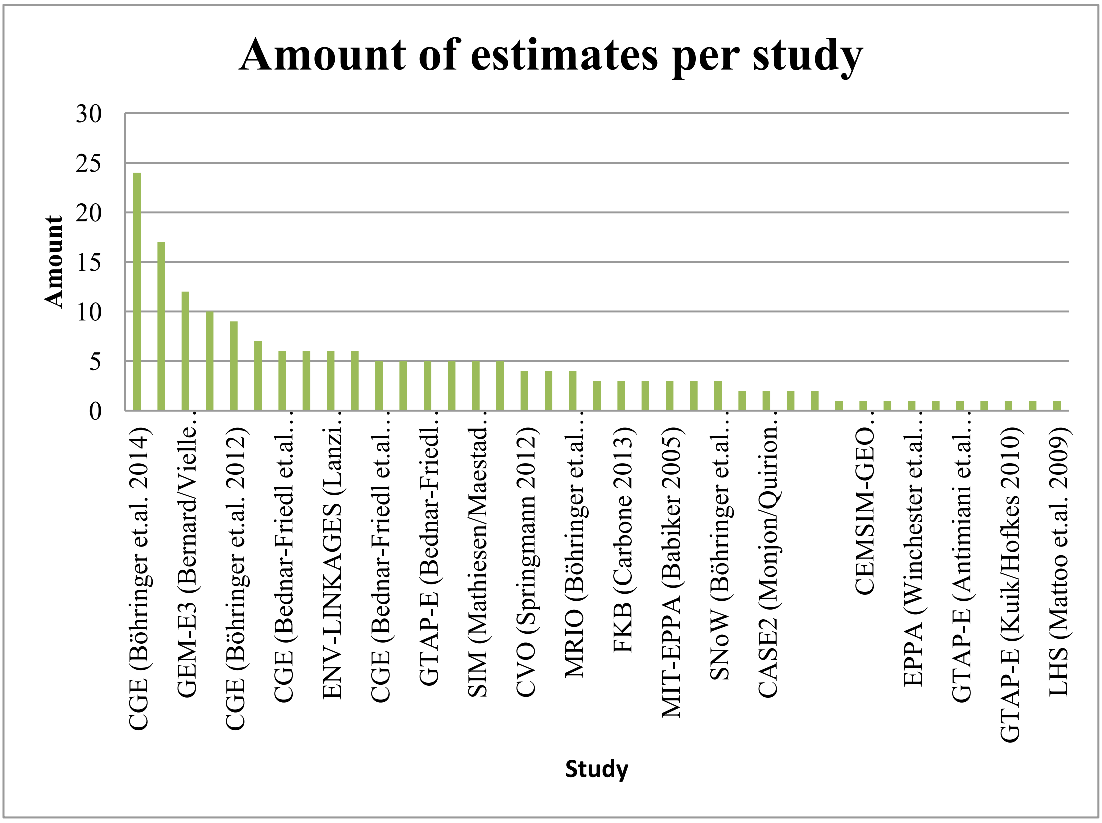

Figure 6: Amount of estimates per study

Among 140 meta-analyses conducted in environmental economics between 1989 and 2008, which are analyzed by Nelson, et al. (2009), those numbers are fairly normal. The median number of primary studies included in the 140 analysis amounts for 33 with a median number of primary observations of 92 estimates.

4.3 Descriptive statistics

Figure 7 clusters all models together and shows the amount of studies per model. In total, 25 different models are used.

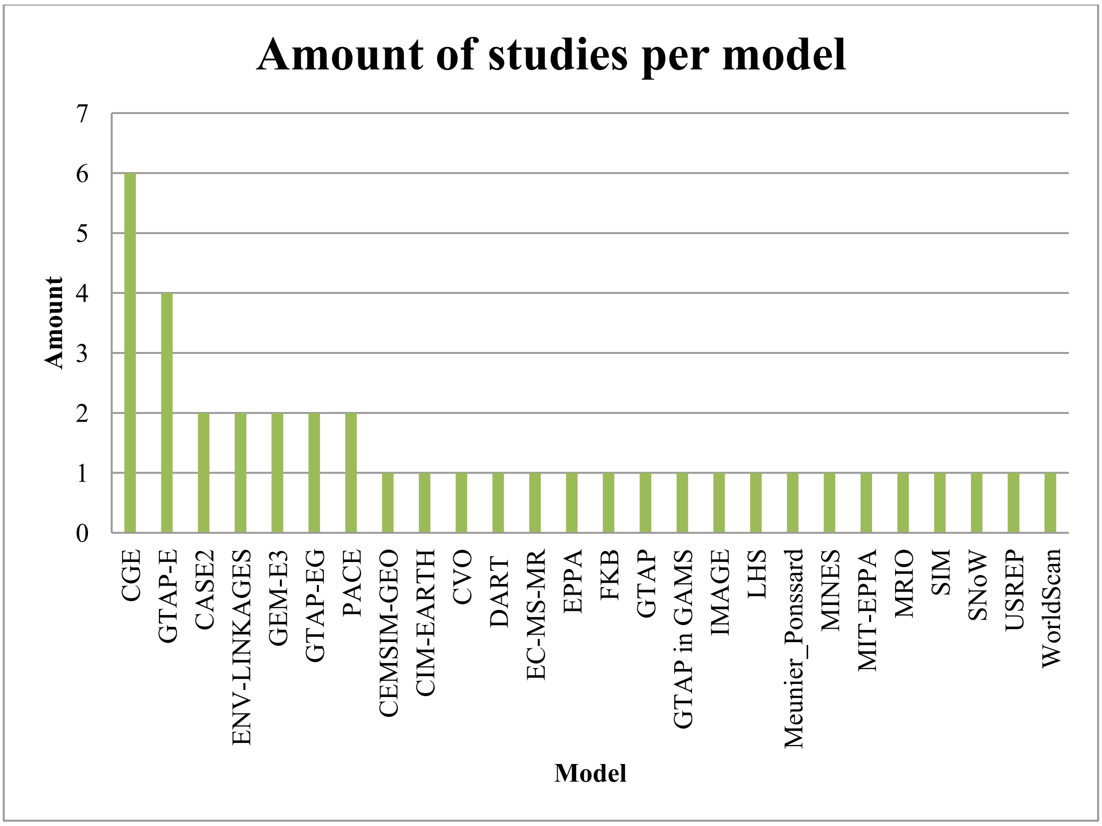

Figure 7 Amount of studies per model

The models are mostly computable general equilibrium models, only 6 papers use 5 different partial equilibrium models CEMSIM-GEO (Demailly, et al., 2005), (Meunier, et al., 2014), CASE2 (Monjon, et al., 2011)a,b, IMAGE (Otto, et al., 2014) and SIM (Mathiesen, et al., 2004) and one paper, LHS (Mattoo, et al., 2009), uses a statistical approach.

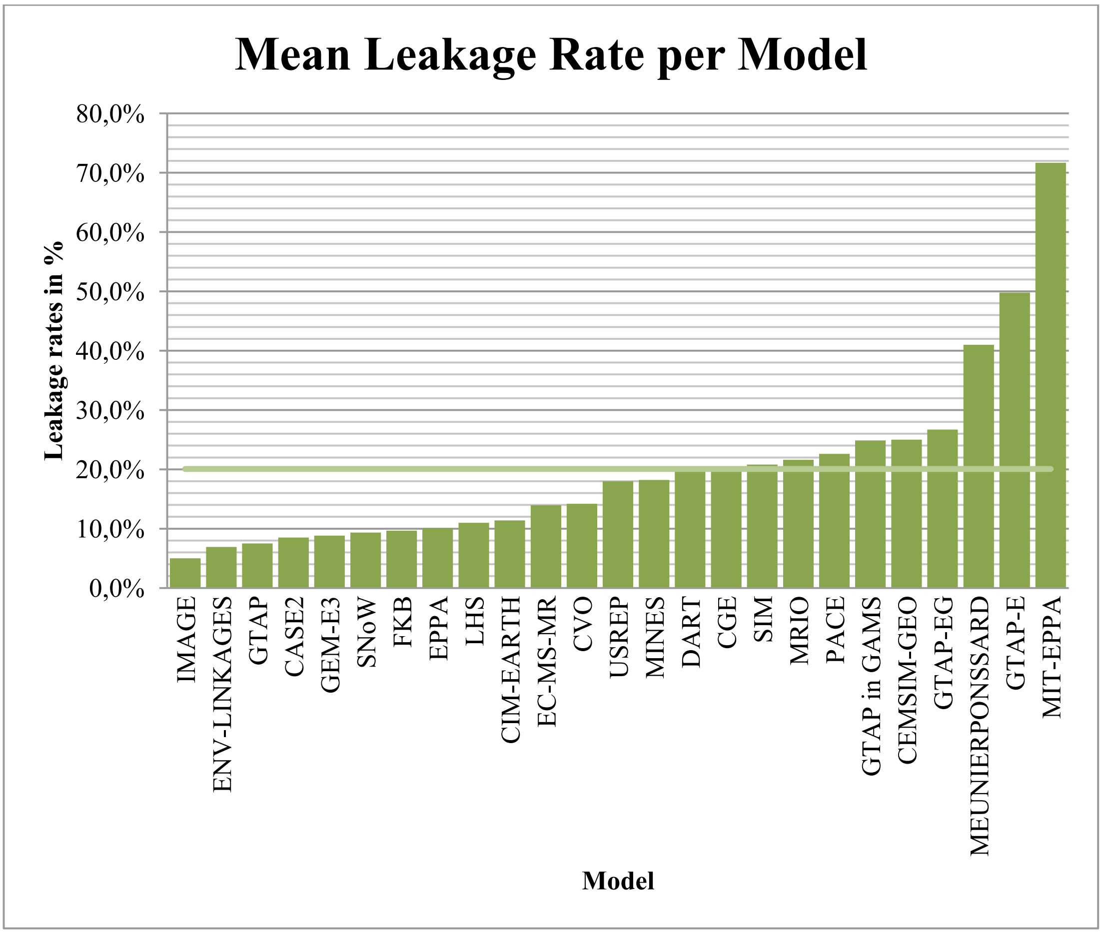

Figure 8 Mean Leakage Rate per Model

The leakage rate varies from 0% in Bernard, et al. (2009) and Mathiesen, et al. (2004) to 130% in Babiker (2005), with a mean of circa 20%. The amount of 130% is an outlier. This can be seen in figure 9. According to Nelson, et al. (2009), graphs are a useful tool to detect outliers, which will be seen as such throughout this paper.

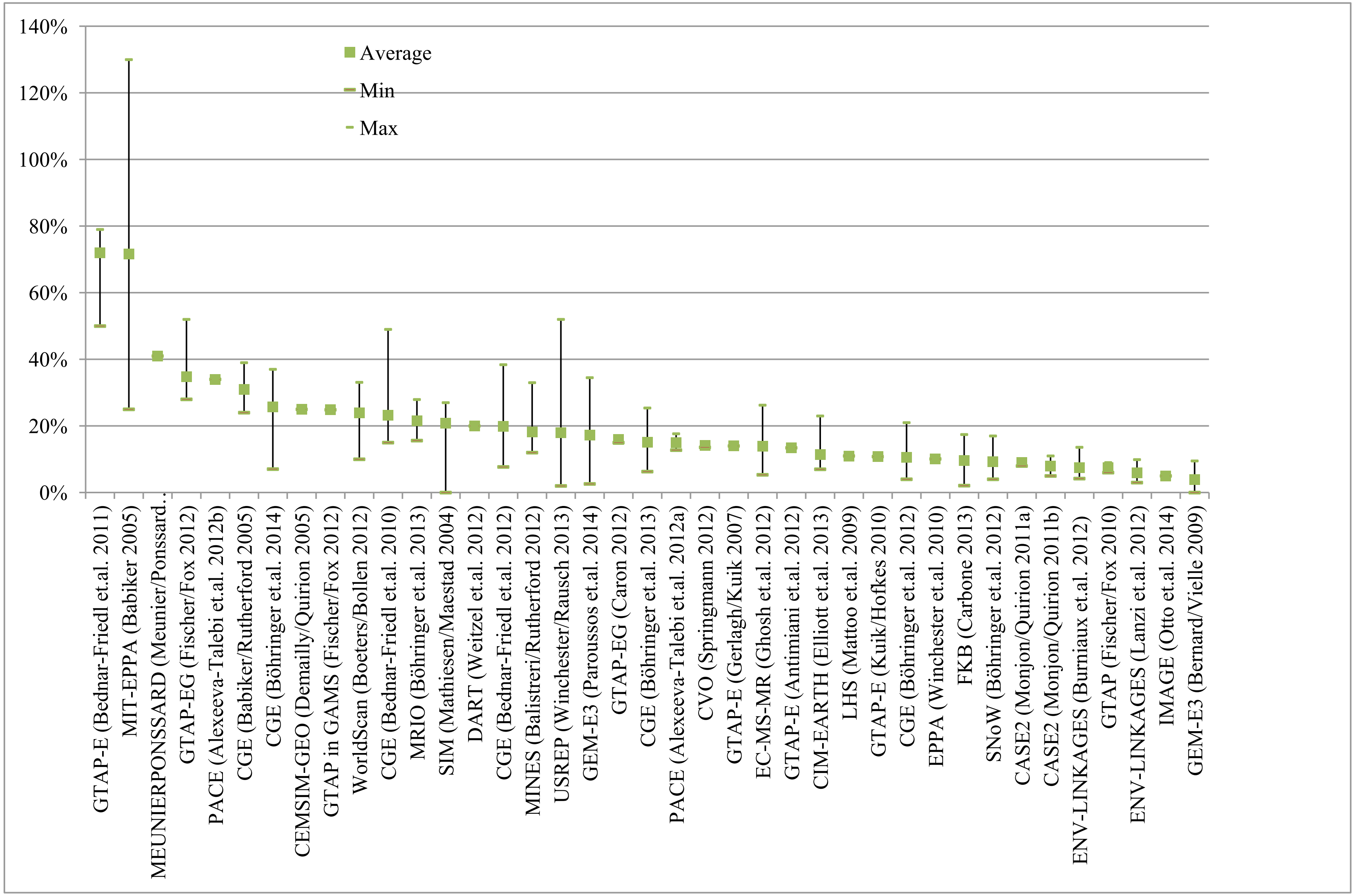

Figure 9 Leakage Ratio studies from the meta-data (mean, minimum and maximal values) ranked by mean value

Table 4 further displays the leakage ratios from the previous graph.

Study	Average	Min	Max
GTAP-E (Bednar-Friedl et.al. 2011)	72%	50%	79%
MIT-EPPA (Babiker 2005)	72%	25%	130%
MEUNIERPONSSARD (Meunier/Ponssard 2014)	41%	41%	41%
GTAP-EG (Fischer/Fox 2012)	35%	28%	52%
PACE (Alexeeva-Talebi et.al. 2012b)	34%	34%	34%
CGE (Babiker/Rutherford 2005)	31%	24%	39%
CGE (Böhringer et.al. 2014)	26%	7%	37%
CEMSIM-GEO (Demailly/Quirion 2005)	25%	25%	25%
GTAP in GAMS (Fischer/Fox 2012)	25%	25%	25%
WorldScan (Boeters/Bollen 2012)	24%	10%	33%
CGE (Bednar-Friedl et.al. 2010)	23%	15%	49%
MRIO (Böhringer et.al. 2013)	22%	16%	28%
SIM (Mathiesen/Maestad 2004)	21%	0%	27%
DART (Weitzel et.al. 2012)	20%	20%	20%
CGE (Bednar-Friedl et.al. 2012)	20%	8%	38%
MINES (Balistreri/Rutherford 2012)	18%	12%	33%
USREP (Winchester/Rausch 2013)	18%	2%	52%
GEM-E3 (Paroussos et.al. 2014)	17%	3%	35%
GTAP-EG (Caron 2012)	16%	15%	17%
CGE (Böhringer et.al. 2013)	15%	6%	25%
PACE (Alexeeva-Talebi et.al. 2012a)	15%	13%	18%
CVO (Springmann 2012)	14%	14%	15%
GTAP-E (Gerlagh/Kuik 2007)	14%	14%	14%
EC-MS-MR (Ghosh et.al. 2012)	14%	5%	26%
GTAP-E (Antimiani et.al. 2012)	13%	13%	13%
CIM-EARTH (Elliott et.al. 2013)	11%	7%	23%
LHS (Mattoo et.al. 2009)	11%	11%	11%
GTAP-E (Kuik/Hofkes 2010)	11%	11%	11%
CGE (Böhringer et.al. 2012)	11%	4%	21%
EPPA (Winchester et.al. 2010)	10%	10%	10%
FKB (Carbone 2013)	10%	2%	17%
SNoW (Böhringer et.al. 2012)	9%	4%	17%
CASE2 (Monjon/Quirion 2011a)	9%	8%	10%
CASE2 (Monjon/Quirion 2011b)	8%	5%	11%
ENV-LINKAGES (Burniaux et.al. 2012)	8%	4%	14%
GTAP (Fischer/Fox 2010)	8%	6%	9%
ENV-LINKAGES (Lanzi et.al. 2012)	6%	3%	10%
IMAGE (Otto et.al. 2014)	5%	5%	5%
GEM-E3 (Bernard/Vielle 2009)	4%	0%	10%

Table 4 Summary statistics for studies (leakage ratio)

Two papers find average leakage rates that are above 70% (Bednar-Friedl, et al., 2011) and (Babiker, 2005), furthermore, four studies report leakage rates above 30% (Meunier, et al., 2014), (Fischer, et al., 2012), (Alexeeva-Talebi, et al., 2012) and (Babiker, et al., 2005). Table 4 shows a wide variation among leakage rates within studies as well as across studies. Those with very high variations within the studies are Babiker (2005) and Bednar-Friedl, et al. (2011).

For further investigations of the density of the effect size, the kernel density estimates are computed. Due to the different amounts of estimates among all studies, two different techniques are used.

The first figure shows the scenario equality method. This method uses 178 estimates and treats each estimate individually. Therefore, an article providing more estimates has more weight in the final distribution.

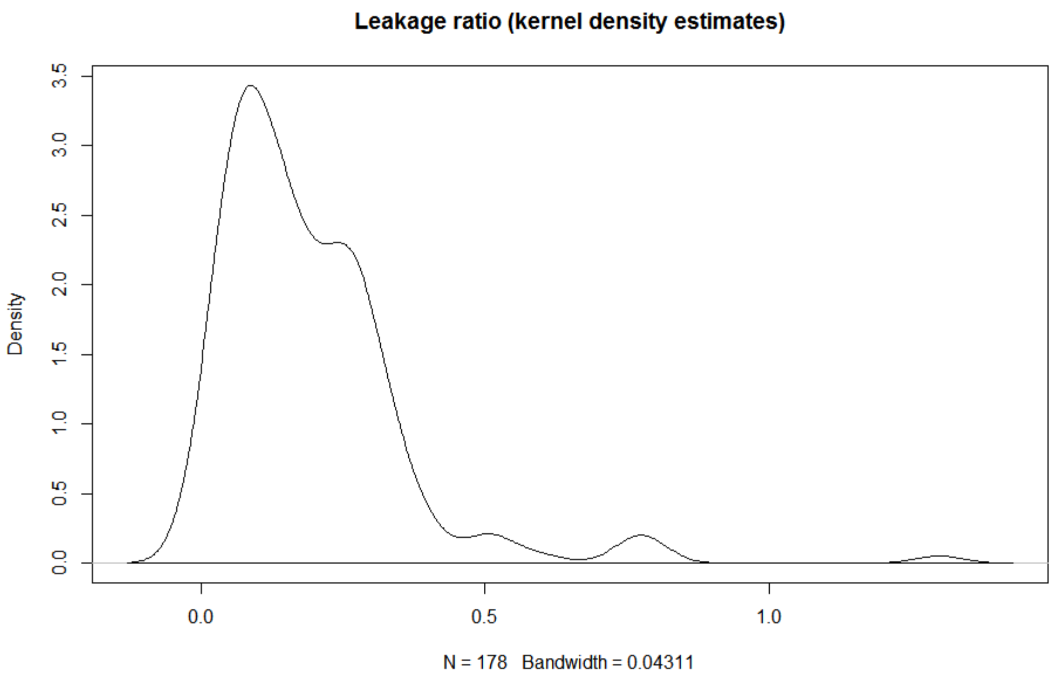

Figure 10 Kernel density estimates with scenario equality method

The other method is the equality method, which measures the estimates according to studies. This method will also be used in the further regression analysis conducted in the statistical program R.

Obviously, certain distribution differences can be identified between the two approaches. However, the overall density is similar, and this could be an indicator for the robustness of the results (Branger, et al., 2014).

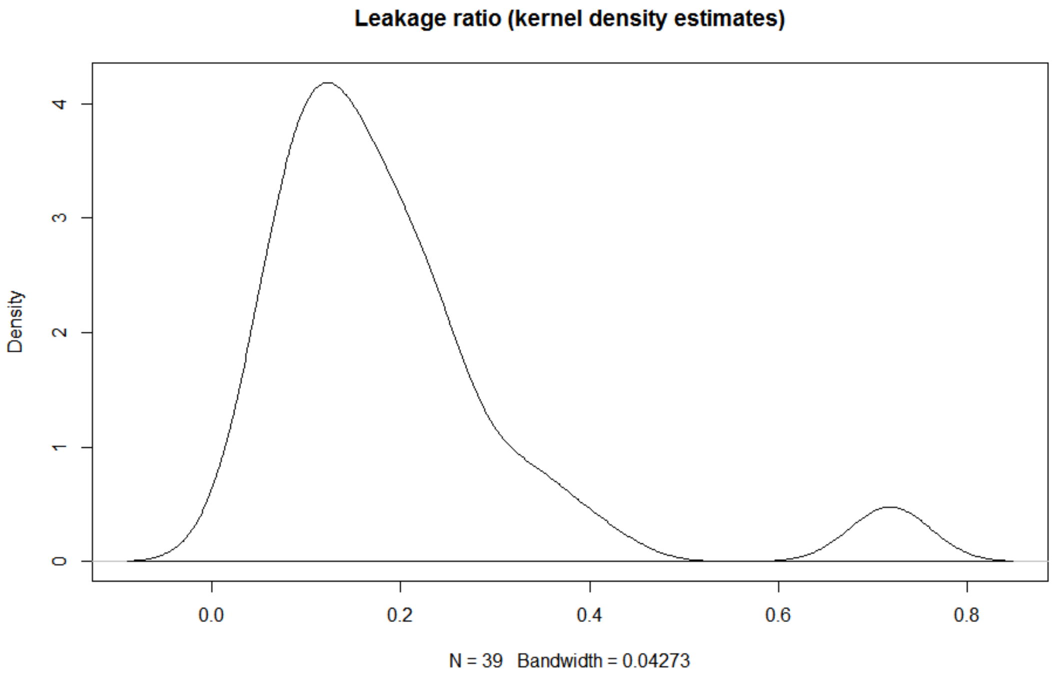

Figure 11 Kernel density estimates with article equality method

On both distributions the high estimate of 130% in (Babiker, 2005) is evident. The literature suggests using Huber weights for outlier observations, which are unrepresentative or overly influential (Branger, et al., 2014). This means only including estimates in the final regression analysis with final weights above a certain threshold. Due to the time constraints of a master thesis and the insights gained from the meta-analysis by Branger et al. (2014) who found out that "the exclusion of outliers only slightly improves the statistical significance for some coefficients without substantially affecting the results of the meta-regression analysis", the following regression analysis is performed without excluding outlier observations.

4.4 Meta-regression Analysis

Meta-regression as an approach of combining effect sizes in a statistical manner is shortly introduced in the beginning of this chapter. This chapter points out the important characteristics that have to be added according to the guidelines by Stanley (2013) and discusses certain problems, which could occur by conducting meta-regression analysis. Furthermore, it provides the regression model, the parameters used and the results. The results will be further discussed at the end of this chapter.

4.4.1 Definition of Problems

"Within the regression model, all empirical results from different studies that are synthesized in a common framework" (Benos, et al., 2013).
Due to the large amount of studies and observations; in our case 39 studies and 178 estimations, certain problems might occur.

The primary studies all use a different model to explain and predict leakage rates. In order to combine the results from all of the studies, fixed or random effect models are used. The main difference is that the fixed-effect model implies that all studies have the same true effect. Under the random-effects the true effect is assumed to vary (Borenstein, et al., 2009). Since the studies included in the meta-database do not exactly use the same models and assumptions, heterogeneity among true effects is expected in this case. One possibility to include this variability using the random effect model is to treat it as completely random (Hedges, et al., 1985). In cases were one or more moderators are included in the model, those may account for parts of the heterogeneity in the true effects. This model is called mixed-effects model (Hedges, et al., 1985).

Stanley (2001) recommends choosing one estimate that the author believes is the best per study to avoid giving unequal importance to certain studies or fields. However, this method would reduce the size of estimates substantially from 178 to 39. Due to this reason, a Random Effect Multi-Level (REML) model is used for this study. The advantage hereby is that the pool of estimates would not be reduced because REML avoids downward biased estimates of the between study variance, underestimated standard errors as well as anticonservative inference. Benos et al. (2013) study identifiers to control the dependence of estimates within a study are included (Doucouliagos, et al., 2008).
The exact model set up will be explained in the next section.

Publication bias plays an important role in meta-regression. Therefore, many statistical methods for considering this bias exist. One method is a visual examination of a funnel plot. In cases without publication bias the shape is an inverted funnel (Benos, et al., 2013). Since the graphical methods are on subjective tests there are other possibilities like the rank correlation test (Begg, et al., 1994), the linear regression test (Egger, et al., 1997), arcsin test (Ruecker, et al., 2008) and the file drawer method (Rosenthal, 1979). However, all of those methods require standard errors (Nelson, et al., 2009).
In the case of mathematical models without standard errors, no such models could have been found. For this reason, as many studies as possible, published in academic journals as well as in working papers, were included in the analysis in order to prevent publication bias.

Although Stanley, et al. (2013) recommends coding the data with more than two persons, in this meta-analysis the complete data was only coded by the author.

4.4.2 Critics of meta-regression analysis

According to (DeCoster, 2004) the main critics regarding meta-analysis are the following:

- Garbage-in, Garbage-out problem: This refers to the fact that poor quality studies that might be included in the meta-analysis lead to poor meta-regression output. Nevertheless, DeCoster (2004) points out that this problem can be avoided when the specific content of the analysis is presented which makes it easier to identify poor meta-analyses than it would be to detect poor literature reviews.

- Apples and oranges problems: It occurs when primary research which does not actually fit together is combined in the meta-analysis

- File drawer problem: Sharpe (1997) names the third problem "file drawer problem". It occurs when studies with a significant effect are more likely to be published than studies without. In our case, it might be that more papers predicting relatively high or low leakage rates are more often published.

Although three main problems of meta-analysis could be identified, meta- analysis is a very powerful tool in all fields of research. According to Lipsey, et al. (2009) the main benefits are the following:
A meta-analysis provides a structural summary of all research findings. Through the documentation of the meta-analysis, the output of all included studies can be easily retraced. Additionally this research format is more objective than other formats like the narrative literature review which has been conducted in the previous section.

4.4.3 Model

Stanley et al. (2005) suggests the following meta-regression model:

$$b_j = \beta + \sum_{k=1}^{K} \alpha_k Z_{jk} + e_j \quad (j = 1, 2, \ldots, L) \tag{2}$$

Formula 1 Meta-regression model
Source (Stanley, et al., 2005)

Based on the above formula and on the paper of Gerlagh, et al. (2007), the defined meta-regression model is formulated as follows:

$$LR_j = \beta + \alpha_1 GE + \alpha_2 Policy + \alpha_3 Coalition.size + \alpha_4 Supply.elasticity + \alpha_5 Armington + \alpha_6 CO2.price + e_j$$

(3)

4.4.4 Meta regression variables

Besides the leakage ratio, which is the parameter to be analyzed in the meta-regression analysis, six other parameters are included in order to test their influence on the leakage ratio. All of them were already explained in section 2. The following table lists the meta-regression variables.

Meta regression variables		
Name	**Variable Type**	**Explanation**
GE	Dummy	Model type (1 if the model is a general equilibrium model;0 otherwise)
Policy	Dummy	Policy regime (1 if international emission trading; 0 otherwise)
Coalition.size	Percentage	Global CO_2 emissions share of abating countries
Supply.elasticity	Values	Elasticity of supply of carbon-energy
Armington	Values	Armington trade elasticity
CO2.price	Values	Price of carbon in $

Table 5 Meta regression variables

The following explanations give further insights into how certain meta-regression variables are collected. Those that are not mentioned are fully displayed in the primary studies.

Coalition size

First, most of the authors only mention the abating countries without giving any specific information about the share of carbon emissions in those countries. However, the percentage in the sense of carbon emission in that region to the global carbon emissions is needed. For this reason, this number is computed with the data displayed in table 6 from Oliver et al. (2013). This makes it easier to compare the size of abating regions among the 39 studies.

Region/Country	CO_2 emissions in billion tones, 2012
United States	5.19
EU27	3.74
EU15	3.00
-Germany	0.81
-France	0.37
-Italy	0.39

-United Kingdom	0.49
-Spain	0.29
-Netherlands	0.16
EU12 (new Member States)	0.74
-Poland	0.32
Japan	1.32
Other Annex II	1.12
-Australia	0.43
-Canada	0.56
Russian Federation	1.77
Other Annex I-EIT*	1.04
-Ukraine	0.32
China	9.86
- cement production in China	0.89
Other large DC***	4.11
-India	1.97
-Brazil	0.46
-Mexico	0.49
-Iran	0.41
-Saudi Arabia	0.46
-South Africa	0.33
Other non-Annex I ****	5.22
-Asian tigers**	1.91
-South Korea**	0.64
-Indonesia**	0.49
-Taiwan**	0.28
-Thailand**	0.26
International transport	1.06
Total	34.5

* EIT = economies in transition. Including all other countries of the former Soviet Union (excl. the Russian Federation) and including Turkey.

** Asian tigers here are: Indonesia, Singapore, Malaysia, Thailand, South Korea and Taiwan.

*** DCs = developing countries. Other large developing countries are: Brazil, Mexico, South Africa, Saudi Arabia, India and Iran.

**** Remaining developing countries.

Table 6 CO_2 emissions per region/country 2012

Source: (Oliver, et al., 2013)

The calculated percentages are as follows. Please refer to appendix A.2 for detailed calculations.

Region	Abbreviation	Abating Region/Total Carbon Emissions
Annex 1 countries	A1	41%
Annex 1 countries, excluding Russia	A1xR	36%
Annex 1 countries, excluding Russia, including China	A1xR_C	65%
Annex 1 countries, including China	A1_C	70%
Annex 1 countries, excluding United States of America, excluding Australia	A1xUSxAUS	25%
European Union	EUR	11%
United States of America	US	15%
European Union, including China	EUR_C	39%
European Union, including United States of America	EUR_US	26%
European Union, including Australia	EUR_AUS	12%
United States of America, including Australia, including new EU member states	US_AUS_oEUA1	18%

Table 7 Carbon Emissions per Abating Region in %

Armington

Most of the authors display the exact numbers from their models which could be directly included in the meta-analysis. However, some referred to the GTAP7 database documented in (Hertel, et al., 2008). In those cases the number of 3.5 is included in the analysis.

In some cases the authors display the Armington elasticity as high or low to the reference scenario. In cases with “high” the reference elasticity is doubled and in the cases for “low” half of the reference elasticity is taken. The same proceeding is also used for the supply elasticity.

CO_2 price
In studies where the CO_2 price is displayed in Euro, the exchange rate 1.31977 (27.8.2014) has been used.

Not all authors use or display all regression variables. For this reason, the missing values are generated using SPSS, which will be further explained in the next chapter.

4.4.5 Statistical instruments

4.4.5.1 Missing Data

The technique I use in order to generate the missing data points in the meta-database are called multiple imputations and this process is performed by using the statistical program SPSS. It fills in missing data with plausible values and has been first addressed by Rubin in 1987, which is explained in more detail in the paper of Schafer (1999). According to Schafer (1999), "Multiple imputation is a Monte Carlo technique in which the missing values are replaced by $m > 1$ simulated versions, where m is small with values around 3 to 10."
An overall summary of missing values, as well as the variable summary and the imputation models are displayed below.

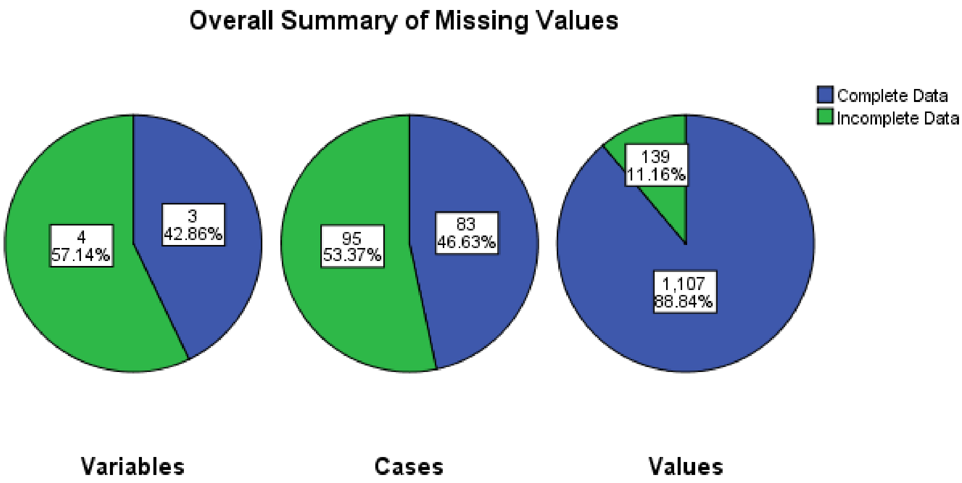

Figure 12 Overall Summary of Missing Values

Variable Summary[a,b]

	Missing				Std.
	N	Percent	Valid N	Mean	Deviation
Supply.elasticity	67	37.6%	111	4.8036	13.17319
Armington	39	21.9%	139		
CO2price	29	16.3%	149		
Coalition.size	4	2.2%	174	.2503	.17329

a. Maximum number of variables shown: 25

b. Minimum percentage of missing values for variable to be included: ,0%

Table 8 Variable Summary

	Model		Missing Value
	Type	Effects	
Coalition.size	Linear Regression	LR, Ge2, Policy	4
CO2price	Linear Regression	LR, Ge2, Policy	29
Armington	Linear Regression	LR, Ge2, Policy	39
Supply.elasticity	Linear Regression	LR, Ge2, Policy	67

Table 9 Imputation Models

4.4.5.2 Meta-regression R

There is a wide variety of standalone software for conduction of meta-analysis. Viechtbauer (2010) gives a good overview about possible software solutions: The commercial packages are Meta Win from Rosenberg et al. (2000) and comprehensive meta-analysis from Borenstein et al. (2005). Others are freely available like R. Packages available in R are for example meta by Schwarzer (2010) or rmeta by Lumley (2009). (Viechtbauer, 2010)

For this meta-regression the following package is used:
Bates D, Maechler M, Bolker B and Walker S (2014). lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-7, http://CRAN.R-project.org/package=lme4.

4.4.6 Results

Table 10 shows the results from the estimation of the meta-regression equation (3). The simulation is conducted with the regression variable GE and without GE as a moderator variable.

	With GE	Without GE
GE	0.0288 (0.50)	
Policy	0.0470 (1.70)*	0.0469 (1.71) *
Coalition.Size	-0.3028 (-6.05) †	-0.3017 (-6.04) †
Supply.elasticity	-0.0015 (-2.71)***	-0.0015 (-2.71) ***
Armington	0.0075 (8.65) †	0.0075 (8.67) †
CO2.price	0.0004 (0.016)**	0.0004 (2.52) **
N	178	178
Wald X^2 Type - II	134.61†	133.33 †
LR Test	119.34 †	119.13 †
DW Test	0.8894 †	0.8915 †
R^2	0.8294	0.8293

†: P = 0.0000, *: P<0.1, **: P<0.05, ***: P<0.01.

Table 10 Results of meta-regression

The parameter GE is excluded in the second equation. The reason for it is the lack of statistical significance. Most of the studies apply general equilibrium models. Only 13 out of the 39 studies do not apply general equilibrium models. Therefore the statistical variability of parameters is not given which could be the reason for the insignificance of GE.

The meta-regression explains respectively 82,94% of the variance in the leakage rate of the first equation and 82,93% of the equation excluding GE.

Additionally, the LR Test and the Wald X^2 Test prove that the quality of the estimations is given. The LR test furthermore indicates that the model used for the regression is suitable.

4.4.7 Discussion of Results

In the first equation five of the six variables listed in table 5 have a significant effect on the LR. GE is not significant, as already indicated above. Policy is found to be weakly significant at the 10% level in both equations, indicating that wheather there is international emission trading among abating countries is influencing the leakage rate on a smaller level than one would expected. However this result could also occur due to the lack of variation among the studies.

The most significant parameters are coalition.size and Armington, which was already predicted in previous literature.

Carbon leakage is negatively related to coalition size, meaning that the more countries are taking abating measures the smaller the potential amount of leakage rates. Increasing the size of the European Emission trading system (EU 11% of CO_2 emissions) only to EU and China (39% of CO_2 emissions) would decrease the leakage rate by around 8% in the model. The expansion to Annex 1 countries including China (70% of CO_2 emissions) would make the leakage problem nearly negligible due to the leakage rate reduction of around 18%.[4] Additionally, it is important to remark that only small increases in the size of the coalition already lead to significant leakage reductions. The exact amount is certainly depending on the emission intensity of the joining economy.

Carbon leakage is positively related to the Armington elasticity, indicating that the larger the substitution elasticities of trade the larger the leakage rates. A high Armington elasticity indicates that minor price changes of domestically produced goods immediately shift the demand to imported goods. This leads to production shifts at world level.

The variable CO2.price is significant in both equations at the 5 % level.

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[4] The mean leakage rate of all models amounts for 20%.

The parameters coalition size and Armington are already widely discussed in current literature. There is a broad consent about the importance of those two influencing factors. A new important aspect however shows the significance of supply elasticity.

Supply elasticity is found to be statistically significant in both equations at the 1% level, indicating that the higher the supply elasticity of fossil fuels the lower the leakage rate. In cases of low supply elasticity, CO_2 reductions in one region increase the demand of fossil fuel in non-abating countries. The increase of demand is also depending on the structure of energy markets.

Due to the unavailability of separate elasticity data of coal, oil and other fossil fuels in the most of the studies, the distinction between them is missing in this analysis. According to Burniaux, et al. (2012) this distinction is essential due to their different characteristics. In comparison of oil and coal, the later is much less integrated in the world market (Burniaux, et al., 2012).

Although clearly further research is needed regarding the influences of different types of fossil fuels, the gained result supports the Energy market model. It highlights the importance of equally taking both channels, the pollution heaven hypothesis and the energy market model into account. Current attempts for decreasing the carbon leakage potential mostly focus on the pollution heaven hypothesis.

Additionally, it is noteworthy that although meta-regression is a very important tool in analyzing certain effects, it can never provide perfect solutions due to its dependence on variability of output from primary studies.

5 Conclusion

By means of a narrative literature review and a meta-analysis, the problem of carbon leakage has been assessed. The main focus lies on the identification of factors that influence the amount of leakage induced by unilateral climate policies. In this thesis, it can be seen that a large body of scientific literature has focused on the prediction of leakage rates.
Assessing the drivers for carbon leakage however is a very complex task, due to the different interactions of different parameters and channels. That is the reason for the variety of controversial outcomes among all studies.

Specifically, 39 empirical studies have been analyzed and meta-regression has been applied using 6 estimators. The impact of the parameters has been investigated and it could be shown that both of the two identified channels influence leakage rates.
The significance of the size of abating countries is an already widely discussed argument, which supports both channels. The strong recommendation of a big coalition of abating countries is hereby proved to be among the most important points.

Regarding the first channel the pollution heaven hypothesis the high influence of Armington elasticity could have been proved. The high significance of the Armington elasticity of trade supports the implementation of boarder measured or other policies to combat leakage.

However, the third significant estimate, the supply elasticity of fossil fuels is widely underestimated in the current political debate. Only a few studies included in the meta-analysis have put their focus on the influence of supply elasticity on leakage rates. Furthermore, it can also be revealed that further research on this topic is recommended. Although the meta-regression has provided some useful insights into the problem of carbon leakage, the influence of different fossil fuel supply elasticities remains unclear. It would be interesting to distinguish and provide a further analysis.

However, showing that not only the size of abating countries has an influence on leakage rates could already provide a positive signal for committing to unilateral climate policies by the European Union or other countries around the world.

Summarizing, one can say that combining a large amount of studies on the field of carbon leakage all studies together predict a substantial rate of carbon leakage. However, bearing the extreme variation of modelled leakage rate estimates, it becomes clear how uncertain this problem occurs to be. This uncertainty factor is most certainly a really important driver of postponing climate policy actions.

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Appendix A

Appendix A.1 Leakage Rates

Narrative Literature Review

Focus	**Min**	**Max**
Energy supply side	6%	25%
Energy supply side	21%	49%
Energy supply side	5%	5%
Energy supply side	5%	16%
Design of carbon permits	13%	13%
Design of carbon permits	8%	10%
Design of carbon permits	6%	9%
Design of carbon permits	50%	79%
Elasticity or other parameters	4%	17%
Elasticity or other parameters	4%	21%
Elasticity or other parameters	16%	28%
Elasticity or other parameters	75%	90%
Elasticity or other parameters	28%	52%
Elasticity or other parameters	5%	26%
Elasticity or other parameters	5%	11%
Elasticity or other parameters	2%	35%
Elasticity or other parameters	14%	15%
Elasticity or other parameters	-4%	60%
Elasticity or other parameters	24%	39%
Elasticity or other parameters	12%	33%
Elasticity or other parameters	0%	10%
Elasticity or other parameters	7%	37%
Elasticity or other parameters	4%	14%
Elasticity or other parameters	2%	100%
Elasticity or other parameters	-9%	28%
Elasticity or other parameters	7%	23%
Emission reduction target	30%	35%
Emission reduction target	10%	33%
Emission reduction target	3%	10%
Market structure	25%	130%
Other	5%	25%
Other	7%	24%
Other	19%	39%
Other	20%	20%
Other	15%	49%
Other	0%	71%
Other	11%	11%

Other	10%	10%
Other	9%	9%
Other	8%	38%
Sectorial aggregation	13%	18%
Sectorial aggregation	15%	17%
Sectorial aggregation	25%	25%
Sectorial aggregation	1%	25%
Sectorial aggregation	5%	58%
Sectorial aggregation	11%	35%
Sectorial aggregation	0%	27%
Sectorial aggregation	9%	75%
Sectorial aggregation	70%	73%
Technology spillovers	-4%	4%
Technology spillovers	-120%	-98%
Technology spillovers	-2%	2%
Technology spillovers	-30%	40%
Technology spillovers	-16%	17%

Appendix A.2 Calculations

The following data and calculations were used for the output displayed in table 7:[5]

Annex 1 countries	A1
-US	5,19
-EU27	3,74
-Japan	1,32
-Other A2 (AUS, CAN)	1,12
-Russia	1,77
-Other A1	1,04
Region	14,18
Global	34,50
	41%

	A1xR
-US	5,19
-EU27	3,74
-Japan	1,32
-Other A2 (AUS, CAN)	1,12
-Russia	
-Other A1	1,04
Region	12,41
Global	34,50
	36%

	A1xR_C
-US	5,19
-EU27	3,74
-Japan	1,32
-Other A2 (AUS, CAN)	1,12
- Other A1	1,04
China	9,86
Region	22,27
Global	34,50

[5] All numbers are CO_2 emissions in billion tones

	65%

	A1_C
-US	5,19
-EU27	3,74
-Japan	1,32
-Other A2 (AUS, CAN)	1,12
-Russia	1,77
- Other A1	1,04
China	9,86
Region	24,04
Global	34,50
	70%

	A1xUSxAUS
-EU27	3,74
-Japan	1,32
-Other A2 (AUS, CAN)	0,69
-Russia	1,77
- Other A1	1,04
Region	8,56
Global	34,50
	25%

	EUR
-EU27	3,74
Region	3,74
Global	34,50
	11%

	US
-US	5,19
Region	5,19
Global	34,50
	15%

	EUR_C
-EU27	3,74
China	9,86
Region	13,60
Global	34,50
	39%

	EUR_US
-US	5,19
-EU27	3,74
Region	8,93
Global	34,50
	26%

	EUR_AUS
-EU27	3,74
Australia	0,43
Region	4,17
Global	34,50
	12%

	US_AUS_RoEUA1
-US	5,19
-ROEU (new Memeber states)	0,74
Australia	0,43
Region	6,36
Global	34,50
	18%

Appendix A.3 Database

Database according to authors including explanations:

Model and paper	**Leakage Rate**	**GE**	**Policy**	**Coalition size**	**Coalition size in %**	**Supply elasticity**	**Armington**	**CO2 price***
PACE (Alexeeva-Talebi et.al. 2012a)	13%	1	0	EUR	11%	n.a.	1,43	$67,24/t
PACE (Alexeeva-Talebi et.al. 2012a)	15%	1	0	EUR	11%	n.a.	2,86	$69,82/t
PACE (Alexeeva-Talebi et.al. 2012a)	18%	1	0	EUR	11%	n.a.	5,72	$74,64/t
PACE (Alexeeva-Talebi et.al. 2012b)	34%	1	0	EUR	11%	n.a.	1***	n.a.
PACE (Alexeeva-Talebi et.al. 2012b)	34%	1	0	EUR	11%	n.a.	1***	n.a.
GTAP-E (Antimiani et.al. 2012)	13%	1	1	A1	41%	n.a.	3,5	$22,92/t
CGE (Babiker/Rutherford 2005)	24%	1	0	A1	41%	1 (h)	1,5 (l)	$76/t [2]
CGE (Babiker/Rutherford 2005)	30%	1	0	A1	41%	0,5 (ref) [2]	3 (ref) [2]	$76/t [2]
CGE (Babiker/Rutherford 2005)	39%	1	0	A1	41%	0,25 (l)	6 (h)	$76/t [2]
MIT-EPPA (Babiker 2005)	25%	1	1	OECD ***	51%	0,83[2]	8	n.a.
MIT-EPPA (Babiker 2005)	60%	1	1	OECD ***	51%	0,83[2]	∞	n.a.
MIT-EPPA (Babiker 2005)	130%	1	1	OECD ***	51%	0,83[2]	∞	n.a.
MINES (Balistreri/Rutherford 2012)	12%	1	0	A1xR_C	65%	n.a.	5,9	$25/t
MINES (Balistreri/Rutherford 2012)	13%	1	0	A1xR	36%	n.a.	3,8	$43/t
MINES (Balistreri/Rutherford 2012)	14%	1	0	A1xR	36%	n.a.	5,6	$43/t
MINES (Balistreri/Rutherford 2012)	19%	1	0	A1xR	36%	n.a.	5,9	$49/t
MINES (Balistreri/Rutherford 2012)	33%	1	0	EUR	11%	n.a.	5,9	$85/t
CGE (Bednar-Friedl et.al. 2010)	15%	1	0	A1**	31%	n.a.	3,7	$330/t
CGE (Bednar-Friedl et.al. 2010)	16%	1	0	A1**	35%	n.a.	3,7	$176/t
CGE (Bednar-Friedl et.al. 2010)	18%	1	0	A1**	31%	n.a.	3,7	$121/t

CGE (Bednar-Friedl et.al. 2010)	18%	1	0	A1**	31%	n.a.	3,7	$159/t
CGE (Bednar-Friedl et.al. 2010)	49%	1	1	EUR**	10%	n.a.	3,7	$181/t
CGE (Bednar-Friedl et.al. 2012)	8%	1	0	A1xR_C	65%	n.a.	3,2	n.a.
CGE (Bednar-Friedl et.al. 2012)	10%	1	0	A1xR_C	65%	n.a.	3,2	n.a.
CGE (Bednar-Friedl et.al. 2012)	14%	1	0	A1xR	36%	n.a.	3,2	n.a.
CGE (Bednar-Friedl et.al. 2012)	19%	1	0	A1xR	36%	n.a.	3,2	n.a.
CGE (Bednar-Friedl et.al. 2012)	29%	1	1	EUR	11%	n.a.	3,2	n.a.
CGE (Bednar-Friedl et.al. 2012)	38%	1	1	EUR	11%	n.a.	3,2	n.a.
GTAP-E (Bednar-Friedl et.al. 2011)	50%	1	0	A1	41%	n.a.	3,4²	n.a.
GTAP-E (Bednar-Friedl et.al. 2011)	76%	1	1	EUR	11%	n.a.	3,4²	n.a.
GTAP-E (Bednar-Friedl et.al. 2011)	77%	1	1	EUR	11%	n.a.	3,4²	n.a.
GTAP-E (Bednar-Friedl et.al. 2011)	78%	1	1	EUR	11%	n.a.	3,4²	n.a.
GTAP-E (Bednar-Friedl et.al. 2011)	79%	1	1	EUR	11%	n.a.	3,4²	n.a.
GEM-E3 (Bernard/Vielle 2009)	0%	1	1	EUR	11%	n.a.	0	€7/t ($9,24/t)
GEM-E3 (Bernard/Vielle 2009)	0%	1	1	EUR	11%	n.a.	0	€28/t ($36,95/t)
GEM-E3 (Bernard/Vielle 2009)	0%	1	1	EUR	11%	n.a.	0	€72/t ($95,02/t)
GEM-E3 (Bernard/Vielle 2009)	2%	1	1	EUR	11%	n.a.	3	€7/t ($9,24/t)
GEM-E3 (Bernard/Vielle 2009)	3%	1	1	EUR	11%	n.a.	3	€28/t ($36,95/t)
GEM-E3 (Bernard/Vielle 2009)	4%	1	1	EUR	11%	n.a.	6	€7/t ($9,24/t)
GEM-E3 (Bernard/Vielle 2009)	5%	1	1	EUR	11%	n.a.	3	€72/t ($95,02/t)
GEM-E3 (Bernard/Vielle 2009)	5%	1	1	EUR	11%	n.a.	6	€28/t ($36,95/t)
GEM-E3 (Bernard/Vielle 2009)	6%	1	1	EUR	11%	n.a.	9	€7/t ($9,24/t)
GEM-E3 (Bernard/Vielle 2009)	6%	1	1	EUR	11%	n.a.	6	€72/t ($95,02/t)
GEM-E3 (Bernard/Vielle 2009)	8%	1	1	EUR	11%	n.a.	9	€28/t ($36,95/t)
GEM-E3 (Bernard/Vielle 2009)	10%	1	1	EUR	11%	n.a.	9	€72/t ($95,02/t)
WorldScan (Boeters/Bollen 2012)	10%	1	0	A1xR_C	65%	5,72*	n.a.	$22/t
WorldScan (Boeters/Bollen 2012)	18%	1	0	A1xR	36%	5,73*	n.a.	$19,3/t

WorldScan (Boeters/Bollen 2012)	24%	1	0	A1xR	36%	5,73*	n.a.	$23,4/t
WorldScan (Boeters/Bollen 2012)	28%	1	0	A1xR_C	65%	5,72*	n.a.	$39,9/t
WorldScan (Boeters/Bollen 2012)	31%	1	0	EUR	11%	5,22*	n.a.	$25,8/t
WorldScan (Boeters/Bollen 2012)	33%	1	0	EUR	11%	5,22*	n.a.	$29/t *
SNoW (Böhringer et.al. 2012)	4%	1	1	A1xR_C	65%	3	3,5*	$47/t
SNoW (Böhringer et.al. 2012)	7%	1	1	A1xR	36%	3	3,5*	$47/t
SNoW (Böhringer et.al. 2012)	17%	1	1	EUR	11%	3	3,5*	$57/t
CGE (Böhringer et.al. 2014)	7%	1	1	US	15%	3**	3,5*	$56/t²
CGE (Böhringer et.al. 2014)	8%	1	1	US	15%	3**	3,5*	$64/t²
CGE (Böhringer et.al. 2014)	8%	1	1	US	15%	3**	3,5*	$69,5/t²
CGE (Böhringer et.al. 2014)	21%	1	1	EUR	11%	6**	3,5*	$102/t²
CGE (Böhringer et.al. 2014)	23%	1	1	EUR	11%	6**	3,5*	$135,5/t²
CGE (Böhringer et.al. 2014)	23%	1	1	EUR	11%	3**	1,75*	$102/t²
CGE (Böhringer et.al. 2014)	24%	1	1	EUR	11%	3**	3,5*	$102/t²
CGE (Böhringer et.al. 2014)	24%	1	1	EUR	11%	6**	3,5*	$155,5/t²
CGE (Böhringer et.al. 2014)	25%	1	1	EUR	11%	3**	1,75*	$135,5/t²
CGE (Böhringer et.al. 2014)	26%	1	1	EUR	11%	3**	1,75*	$155,5/t²
CGE (Böhringer et.al. 2014)	26%	1	1	EUR	11%	3**	3,5*	$102/t²
CGE (Böhringer et.al. 2014)	28%	1	1	EUR	11%	3**	3,5*	$135,5/t²
CGE (Böhringer et.al. 2014)	28%	1	1	EUR	11%	3**	3,5*	$102/t²
CGE (Böhringer et.al. 2014)	28%	1	1	EUR	11%	3**	3,5*	$155,5/t²
CGE (Böhringer et.al. 2014)	28%	1	1	EUR	11%	3**	3,5*	$135,5/t²
CGE (Böhringer et.al. 2014)	28%	1	1	EUR	11%	3**	7*	$102/t²
CGE (Böhringer et.al. 2014)	29%	1	1	EUR	11%	3**	3,5*	$135,5/t²
CGE (Böhringer et.al. 2014)	30%	1	1	EUR	11%	3**	3,5*	$155,5/t²
CGE (Böhringer et.al. 2014)	31%	1	1	EUR	11%	3**	3,5*	$135,5/t²
CGE (Böhringer et.al. 2014)	31%	1	1	EUR	11%	3**	3,5*	$155,5/t²

CGE (Böhringer et.al. 2014)	33%	1	1	EUR	11%	3**	7*	$155,5/t²
CGE (Böhringer et.al. 2014)	34%	1	1	EUR	11%	1,5**	3,5*	$102/t²
CGE (Böhringer et.al. 2014)	36%	1	1	EUR	11%	1,5**	3,5*	$135,5/t²
CGE (Böhringer et.al. 2014)	37%	1	1	EUR	11%	1,5**	3,5*	$155,5/t²
CGE (Böhringer et.al. 2013)	6%	1	0	EUR	11%	3**	3,5*	$44/t
CGE (Böhringer et.al. 2013)	7%	1	0	EUR	11%	3**	1,75*	$44/t
CGE (Böhringer et.al. 2013)	9%	1	0	EUR	11%	3**	3,5*	$44/t
CGE (Böhringer et.al. 2013)	9%	1	0	EUR	11%	1,5**	3,5*	$44/t
CGE (Böhringer et.al. 2013)	12%	1	0	EUR	11%	3**	3,5*	$44/t
CGE (Böhringer et.al. 2013)	12%	1	0	EUR	11%	6**	3,5*	$44/t
CGE (Böhringer et.al. 2013)	13%	1	0	EUR	11%	3**	7*	$44/t
CGE (Böhringer et.al. 2013)	14%	1	0	EUR	11%	6**	3,5*	$55/t
CGE (Böhringer et.al. 2013)	15%	1	0	EUR	11%	3**	3,5*	$55/t
CGE (Böhringer et.al. 2013)	16%	1	0	EUR	11%	3**	3,5*	$51/t
CGE (Böhringer et.al. 2013)	17%	1	0	EUR	11%	3**	1,75*	$55/t
CGE (Böhringer et.al. 2013)	18%	1	0	EUR	11%	3**	3,5*	$55/t
CGE (Böhringer et.al. 2013)	19%	1	0	EUR	11%	3**	3,5*	$56/t
CGE (Böhringer et.al. 2013)	21%	1	0	EUR	11%	3**	7*	$55/t
CGE (Böhringer et.al. 2013)	22%	1	0	EUR	11%	3**	3,5*	$55/t
CGE (Böhringer et.al. 2013)	22%	1	0	EUR	11%	3**	3,5*	$61/t
CGE (Böhringer et.al. 2013)	25%	1	0	EUR	11%	1,5**	3,5*	$55/t
CGE (Böhringer et.al. 2012)	4%	1	1	A1_C	70%	n.a.	n.a.	$7,5/t
CGE (Böhringer et.al. 2012)	5%	1	1	A1_C	70%	n.a.	n.a.	$20,5/t
CGE (Böhringer et.al. 2012)	6%	1	1	A1_C	70%	n.a.	n.a.	$43,5/t
CGE (Böhringer et.al. 2012)	7%	1	1	A1	41%	n.a.	n.a.	$11,1/t
CGE (Böhringer et.al. 2012)	9%	1	1	A1	41%	n.a.	n.a.	$30,6/t
CGE (Böhringer et.al. 2012)	10%	1	1	A1	41%	n.a.	n.a.	$64/t

CGE (Böhringer et.al. 2012)	15%	1	1	EUR	11%	n.a.	n.a.	$13,9/t
CGE (Böhringer et.al. 2012)	18%	1	1	EUR	11%	n.a.	n.a.	$38,8/t
CGE (Böhringer et.al. 2012)	21%	1	1	EUR	11%	n.a.	n.a.	$82/t
MRIO (Böhringer et.al. 2013)	16%	1	1	A1xR	36%	2,85 (ref) ***	3,2	n.a.
MRIO (Böhringer et.al. 2013)	19%	1	1	A1xR	36%	1,43 (l) ***	3,2	n.a.
MRIO (Böhringer et.al. 2013)	24%	1	1	A1xR	36%	2,85 (ref) ***	6,4	n.a.
MRIO (Böhringer et.al. 2013)	28%	1	1	A1xR	36%	1,43 (l) ***	6,4	n.a.
ENV-LINKAGES (Burniaux et.al. 2012)	4%	1	0	A1	41%	5,7 (h) ***	3,5 (ref)*	$70/t
ENV-LINKAGES (Burniaux et.al. 2012)	5%	1	0	EUR	11%	5,7 (h) ***	3,5 (ref)*	$59/t
ENV-LINKAGES (Burniaux et.al. 2012)	5%	1	0	A1	41%	2,85 (ref) ***	1,75 (l)*	$74/t
ENV-LINKAGES (Burniaux et.al. 2012)	6%	1	0	A1	41%	2,85 (ref) ***	3,5 (ref)*	$74/t
ENV-LINKAGES (Burniaux et.al. 2012)	7%	1	0	A1	41%	2,85 (ref) ***	7 (h) *	$73/t
ENV-LINKAGES (Burniaux et.al. 2012)	8%	1	0	EUR	11%	2,85 (ref) ***	1,75 (l)*	$62/t
ENV-LINKAGES (Burniaux et.al. 2012)	8%	1	0	EUR	11%	2,85 (ref) ***	3,5 (ref)*	$61/t
ENV-LINKAGES (Burniaux et.al. 2012)	9%	1	0	EUR	11%	2,85 (ref) ***	7 (h) *	$61/t
ENV-LINKAGES (Burniaux et.al. 2012)	10%	1	0	A1	41%	1,43 (l) ***	3,5 (ref)*	$80/t
ENV-LINKAGES (Burniaux et.al. 2012)	14%	1	0	EUR	11%	1,43 (l) ***	3,5 (ref)*	$66/t

FKB (Carbone 2013)	2%	1	0	n.a.	n.a.	∞	n.a.	n.a.
FKB (Carbone 2013)	9%	1	0	n.a.	n.a.	0,58	n.a.	n.a.
FKB (Carbone 2013)	17%	1	0	n.a.	n.a.	0	n.a.	n.a.
GTAP-EG (Caron 2012)	15%	1	0	A1xR	36%	0,58	3,5*	n.a.
GTAP-EG (Caron 2012)	16%	1	0	A1xR	36%	0,58	3,5*	n.a.
GTAP-EG (Caron 2012)	17%	1	0	A1xR	36%	0,58	3,5*	n.a.
CEMSIM-GEO (Demailly/Quirion 2005)	25%	0	1	A1xUSxAUS	25%	n.a.	n.a.	€15/t ($19,8/t)
CIM-EARTH (Elliott et.al. 2013)	7%	1	0	A1	41%	8	3,7	$29/t
CIM-EARTH (Elliott et.al. 2013)	7%	1	0	A1	41%	6	3,7	$29/t
CIM-EARTH (Elliott et.al. 2013)	8%	1	0	A1	41%	4	3,7	$29/t
CIM-EARTH (Elliott et.al. 2013)	12%	1	0	A1	41%	2	3,7	$29/t
CIM-EARTH (Elliott et.al. 2013)	23%	1	0	A1	41%	0	3,7	$29/t
GTAP-EG (Fischer/Fox 2012)	28%	1	0	A1	41%	1,77	n.a.	€50/t ($65,99/t)
GTAP-EG (Fischer/Fox 2012)	29%	1	0	EUR_US	26%	1,77	n.a.	€35/t ($46,19/t)
GTAP-EG (Fischer/Fox 2012)	30%	1	0	A1_C	70%	1,77	n.a.	€270/t ($356,34/t)
GTAP-EG (Fischer/Fox 2012)	52%	1	0	EUR	11%	1,77	n.a.	€80/t ($105,58/t)
GTAP in GAMS (Fischer/Fox 2012)	25%	1	1	US	15%	1,77²	n.a.	$14/t
GTAP-E (Gerlagh/Kuik 2007)	14%	1	1	0,62	62%	0,6	3,5	n.a.
EC-MS-MR (Ghosh et.al. 2012)	5%	1	1	A1_C *	61%	n.a.	3,5	$51,26/t
EC-MS-MR (Ghosh et.al. 2012)	10%	1	1	A1x R *	44%	n.a.	3,5	$81,28/t
EC-MS-MR (Ghosh et.al. 2012)	26%	1	1	EUR *	5%	n.a.	3,5	$151,26/t
GTAP-E (Kuik/Hofkes 2010)	11%	1	1	EUR	11%	n.a.	n.a.	€20/t ($26,4/t)
ENV-LINKAGES (Lanzi et.al. 2012)	3%	1	1	A1	41%	n.a.	n.a.	$39/t
ENV-LINKAGES (Lanzi et.al. 2012)	4%	1	0	A1	41%	n.a.	n.a.	$72/t
ENV-LINKAGES (Lanzi et.al. 2012)	6%	1	0	US_AUS_oEUA1	18%	n.a.	n.a.	$39/t

ENV-LINKAGES (Lanzi et.al. 2012)	6%	1	1	US_AUS_oEUA2	18%	n.a.	n.a.	$39/t
ENV-LINKAGES (Lanzi et.al. 2012)	8%	1	1	EUR_AUS	12%	n.a.	n.a.	$39/t
ENV-LINKAGES (Lanzi et.al. 2012)	10%	1	0	EUR_AUS	12%	n.a.	n.a.	$37/t
LHS (Mattoo et.al. 2009)	11%	0	0	OECD	41%	2,67²	4,33²	n.a.
(Meunier/Ponssard 2014)	41%	0	0	n.a.	n.a.	n.a.	n.a.	€40/t ($52,79/t)
CASE2 (Monjon/Quirion 2011a)	8%	0	1	EUR	11%	n.a.	n.a.	$21/t
CASE2 (Monjon/Quirion 2011a)	10%	0	1	EUR	11%	n.a.	n.a.	$18/t
CASE2 (Monjon/Quirion 2011b)	5%	0	1	EUR	11%	n.a.	1,83²	€24/t ($31,67/t)
CASE2 (Monjon/Quirion 2011b)	11%	0	1	EUR	11%	n.a.	3,83²	€24/t ($31,67/t)
IMAGE (Otto et.al. 2014)	5%	0	0	EUR_C	39%	n.a.	n.a.	n.a.
GEM-E3 (Paroussos et.al. 2014)	3%	1	0	EUR_C	39%	5,7 (h) ***	2,25²	$18,5/t
GEM-E3 (Paroussos et.al. 2014)	3%	1	0	EUR_C	39%	5,7 (h) ***	4,3²	$18,5/t
GEM-E3 (Paroussos et.al. 2014)	4%	1	0	EUR_C	39%	5,7 (h) ***	8,6²	$18,5/t
GEM-E3 (Paroussos et.al. 2014)	24%	1	0	EUR	11%	5,7 (h) ***	2,25²	$18,5/t
GEM-E3 (Paroussos et.al. 2014)	25%	1	0	EUR_US	26%	5,7 (h) ***	4,3²	$18,5/t
GEM-E3 (Paroussos et.al. 2014)	28%	1	0	EUR	11%	5,7 (h) ***	4,3²	$18,5/t
GEM-E3 (Paroussos et.al. 2014)	35%	1	0	EUR	11%	5,7 (h) ***	8,6²	$18,5/t
CVO (Springmann 2012)	14%	1	1	A1	41%	0,58	3,2	$40,9/t
CVO (Springmann 2012)	14%	1	1	A1	41%	0,58	3,2	$50,3/t
CVO (Springmann 2012)	14%	1	0	A1	41%	0,58	3,2	$42/t
CVO (Springmann 2012)	15%	1	0	A1	41%	0,58	3,2	$60,44/t
DART (Weitzel et.al. 2012)	20%	1	1	A1xR	36%	n.a.	n.a.	$75/t
EPPA (Winchester et.al. 2010)	10%	1	0	US	15%	n.a.	n.a.	$86.6/t
USREP (Winchester/Rausch 2013)	2%	1	0	US	15%	∞	3,2	$30/t
USREP (Winchester/Rausch 2013)	2%	1	0	US	15%	20	3,2	$30/t
USREP (Winchester/Rausch 2013)	9%	1	0	US	15%	5	3,2	$30/t
USREP (Winchester/Rausch 2013)	25%	1	0	US	15%	1	3,2	$30/t

USREP (Winchester/Rausch 2013)	52%	1	0	US	15%	0	3,2	$30/t
SIM (Mathiesen/Maestad 2004)	0%	0	0	A1	41%	2*	0	$25/t
SIM (Mathiesen/Maestad 2004)	24%	0	0	A1	41%	2*	4	$25/t
SIM (Mathiesen/Maestad 2004)	26%	0	0	A1	41%	2*	8	$25/t
SIM (Mathiesen/Maestad 2004)	27%	0	0	A1	41%	2*	16	$25/t
SIM (Mathiesen/Maestad 2004)	27%	0	0	A1	41%	2*	32	$25/t
GTAP (Fischer/Fox 2010)	6%	1	1	US	15%	1,77[2]	n.a.	$17,68/t
GTAP (Fischer/Fox 2010)	9%	1	1	US	15%	1,77[2]	n.a.	$17,24/t

n.a. is not available, meaning that I could not find the estimate in the model descriptions

Comments:

Coalition size

_ = including
x = excluding

with a * papers are marked where the % of abating regions was displayed in the study; therefore the calcuated numbers where not taken

** % of each region was displayed in the study; therefore the average was calculated for each scenario

*** from Gerlagh, R., Kuik, O. 2007

Supply elasticity

[2] in studies where the supply elasticity of of carbon energy was not directly displayed as a number the avarage supply elasticity of coal, crude oil and gas was taken

(h) only high was displayed in the study therefore the ref scenario was doubled (ref*2)
(l) only low was displayed in the study therefore the ref scenario was halved (ref/2)
*coal only
** from Graham et.al. 1999
*** the average of all supply elasticities included in the meta-analysis was taken

Armington

[2] average
(h) only high was displayed in the study therefore the ref scenario was doubled (ref*2)
(l) only low was displayed in the study therefore the ref scenario was halved (ref/2)
* GTAP database
** HIGH means Melitz transfered into Armington according to Dixon et.al. 2013
*** (0-2) =1

CO2 price*

*exchange rate 1,31977 (27.8.2014)
**in 2004

Appendix A.4 Abstract

The purpose of this thesis is to provide specific insights into the current scientific findings regarding to the field of carbon leakage by means of a narrative literature review and a meta-analysis.

Central points of this investigation are the climate targets of the European Union. The EU committed to a greenhouse gas reduction by at least 40% by 2030 compared to 1990 levels. One main factor for achieving this goal will be the reformation of the current European Emission Trading Scheme (ETS) in order to most effectively achieve the targets.

Due to the failure of setting global CO_2 emission standards, unilateral climate policies, only covering small parts of the world will be the only instrument for emission reductions in the upcoming years. A major argument in the debate against unilateral climate policies is the leakage effect.

There are many uncertainties about carbon leakage. Therefore, this thesis investigates the height of the carbon leakage rate as well as its influencing factors by analyzing scientific studies conducted on the carbon leakage topic.

39 studies are examined in the meta-analysis using a regression model with the parameters like size of the countries abating, Armington elasticity or supply elasticity of fossil fuels.

The regression analysis shows that the factors with the greatest impact on leakage rates are the size of the abating countries and the Armington elasticity. An extension of the EU ETS (EU 11% of global CO_2 emissions) on EU and China (39% of global CO_2 emissions) would reduce the leakage rates in the model by about 8%. An extension to Annex 1 and China (70% of global CO_2 emissions) would almost solve the leakage problem. A reduction of about 18% could be achieved in the model. The average leakage rate of 39 studies is about 20%.

Those factors are already widely discussed in the literature. However, a whole new aspect provides the significance of the elasticity of supply of fossil fuels. The elasticity of supply of fossil fuels behaves negatively to the leakage rate which means that a CO_2 reduction in the abating region induces a higher demand of fossil fuels in other regions.

The analysis shows that all studies predict a relatively high proportion of leakage rates (average 20%). However, it is also shown that many different factors could influence the leakage rates.

Appendix A.5 Abstract German

Ziel dieser Masterarbeit ist es, die Einflussfaktoren auf Carbon Leakage Raten bei unilateraler Klimapolitik anhand einer Literaturstudie und Metaanalyse zu untersuchen.
Zentraler Hintergrund dieser Analyse ist die Verpflichtung seitens der Europäischen Union zu einer Treibhausgasreduktion von mindestens 40% bis zum Jahr 2030 im Vergleich zum Basisjahr 1990. Einer der Hauptfaktoren dieser Ziele wird es sein, den EU-Emissionshandel (ETS) zu reformieren, um mit Hilfe von diesem das Ziel möglichst effektiv und kostengünstig erreichen zu können.

Da die Europäische Union mit ihrer zumeist ambitionierten Klimapolitik weltweit geringe Unterstützung findet stellt sich die Frage, welche Auswirkungen eine Form der einseitigen Klimapolitik auf die weltweiten Emissionen haben. Annahmen bestehen, dass ein substantieller Teil der Emissionsreduktionen innerhalb der Regionen mit strenger Klimapolitik in Regionen ohne Reduktionsmaßnahmen zu erhöhtem CO_2 Ausstoß führen.

Ein Hauptargument in der Debatte gegen eine unilaterale Klimapolitik der Europäischen Union ist der Leakage-Effekt. Davon ausgehend, dass ein globales Abkommen zur Emissionsreduktion in der nächsten Zeit nicht umsetzbar ist, werden die Höhe sowie die Einflussfaktoren des Leakage Effekts anhand zweier wichtiger Leakage Kanäle, der„pollution heaven hypothesis“ (Investitionsabwanderung) und dem Markt für fossile Brennstoffe, in der vorliegenden Arbeit analysiert.

39 Studien werden in der Metaanalyse mithilfe einer Regressionsanalyse nach Parametern, wie zum Beispiel die Größe der Regionen innerhalb der Klimapolitik, Armington Elastizität, Höhe des CO_2 Preises und Angebotselastizität fossiler Brennstoffe untersucht.

Die Regressionsanalyse zeigt, dass fünf der sechs Parameter einen signifikanten Effekt auf die Leakage Raten haben. Die Faktoren mit dem meisten Einfluss auf Leakage Raten sind die Größe der Regionen mit Klimapolitik und die Armington Elastizität. Eine Erweiterung des EU ETS (EU 11% der weltweiten CO_2 Emissionen) auf EU und China (39% der weltweiten CO_2 Emissionen) würde die Leakage Raten im Modell um circa 8% reduzieren. Eine Erweiterung auf Annex 1 und China (70% der weltweiten CO_2 Emissionen) würde das Leakage Problem nahezu lösen, da eine Reduktion von circa 18% im Modell erreicht werden kann. (Die durchschnittlichen Leakage-Raten der 39 Studien betragen 20%.) Dies wurde bereits vielfach in der Literatur diskutiert.

Einen ganz neuen Aspekt erweist jedoch die Signifikanz der Angebotselastizität für fossile Brennstoffe. Die Angebotselastizität der fossilen Brennstoffe verhält sich negativ zur Leakage-Rate. Das heißt, eine CO_2 Reduktion bestimmter Regionen lässt die Nachfrage nach fossilen Brennstoffen in anderen Regionen steigen. Wie stark dieser Effekt ist, hängt stark vom jeweiligen Markt für fossile Brennstoffe ab. Kohle unterscheidet sich hier sehr stark von den restlichen Energieträgern.

Die Analyse zeigt, dass alle Studien einen relativ hohen Anteil an Leakage Raten vorhersagen (Durchschnitt 20%). Allerdings wird auch gezeigt, dass viele unterschiedliche Faktoren Einfluss auf die tatsächliche Höhe von Leakage Raten haben.

Curriculum Vitae

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