AALBORG UNIVERSITET

Introducing the Porter Hypothesis when Analyzing Carbon Leakage through International Trade for a Small Open Economy

A New Way of Thinking About Carbon Leakage through International Trade

ABSTRACT

This paper aims at introducing a new view on carbon leakage through international trade, by providing evidence that the negation of the Porter Hypothesis creates an upwards bias in the current calculation of carbon leakage rates. The Porter Hypothesis introduces the idea that environmental regulations might increase firms' competitiveness as a result of technological development. We begin by Looking at the current empirical evidence investigating the Porter Hypothesis, to see whether using this framework when calculating carbon leakage through international trade should be justified. As we find the effects of the Porter Hypothesis to be justified, we build a two-area ecological Stock-Flow-Consistent model including Denmark and the rest of the world, also introducing different degrees of the Porter Hypothesis framework. Using this model, we find that accepting different degrees of the Porter Hypothesis, changes how the implementation of an environmental regulation in Denmark affect emission in both Denmark and the rest of the world. Calculating leakage rates based on these results, we find that including more effects (a higher degree) of the Porter Hypothesis lowers the leakage rates, thereby providing evidence of an upwards bias when negating the Porter Hypothesis. Furthermore, we find the upwards bias to be higher as we increase the timespan of the analysis. This upwards bias implies that the Porter Hypothesis should be accounted for when calculating carbon leakage through international trade. Therefore, the Porter Hypothesis should be taken into account when providing political recommendations for reaching the Danish climate goals, whereas we present two focus areas for future political recommendations enhancing the effects of the PH framework.

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AALBORG UNIVERSITET
STUDENTERRAPPORT

Title:
Introducing the Porter Hypothesis when Analyzing Carbon Leakage through International Trade for a Small Open Economy

Theme:
Master's thesis

Period:
Spring semester 2023

Group: 1

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Standard pages:
53 (character count is 126.048)

Hand in date:
Monday, May 1, 2023

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Preface

The research presented in this master's thesis has been conducted within the period of December 1, 2022 to May 1, 2023 within the economics program at Aalborg Business School. This thesis is based on macroeconomic modeling, a topic in which I have developed a strong interest during my studies. Macroeconomic modeling seems to be superior within the area of carbon leakage rates, whereas my previous experience with building SFC models has been a valuable asset when writing this master's thesis. In this thesis I have further pushed my boundaries for macroeconomic modeling with plenty of struggles throughout the process. Therefore, this thesis has taught me valuable lessons both professionally and personally.

I have been extremely happy to have my supervisor Mikael Randrup Byrialsen available for discussions about my work throughout this process. Mikael has provided excellent guidance and has a significant share in the final outcome of this thesis. On this basis, I would like to thank Mikael for his help and guidance.

In general, the focus of this thesis is on the green side of the economy, for this reason only variables like green R&D spending, and export/import of green capital are included in the analysis. Therefore, when using terms like "improving technological efficiency" or "technological development", it is a way of describing that technology becomes more climate friendly, most often used when the renewability share of production is increased.

All the material used for replicating the results of this paper can be found on GitHub following this link: https://github.com/simonmig10/Material-for-Master-s-Thesis

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Section 1 Introduction

Looking at the current state of the climate crisis, actions capable of reducing world emission are in high demand. An important aspect being that a reduction in emission at any place in the world will have the same effect within an area as if the reduction happened in the area itself. For this reason, unilateral climate policies should be effective in minimizing an increase in emission outside an environmental regulated area, or even maximize a reduction of emission outside this area. The increasing focus on measuring how unilateral climate policies affect emission outside a regulated area has led to the calculation of carbon leakages, even though the effects of carbon leakages are found to be important these are still not incorporated within national climate goals.

In this paper, we will focus on the Danish economy with a reputation of being one of the most ambitious countries in the world when it comes to reducing climate damages. This is typically based on the climate goals imposed by the Danish parliament in 2020, restricting Denmark to reduce its emission of carbon with 70% in 2030 compared to the level in 1990, as well as a goal of making Denmark carbon neutral in 2050 (Danish Parliament, 2020). As mentioned, these climate goals are considered highly ambitious, however, a key challenge with these goals is that they only use territorial emission in their calculations, therefore neglecting the effect of carbon leakages by keeping world emission fixed[1]. The importance of analyzing how unilateral climate policies affect emission outside the regulated area seems especially important for small open economies like Denmark, as they through international trade can have a relatively large effect on world emission due to their openness, compared to the small effect a reduction in their territorial emission can have, due to their (on a world scale) small size.

Today, most studies analyze carbon leakage issues for a coalition of countries (Antimiani et al., 2013; Böhringer et al., 2018) or a large country like the US (Fischer & Fox, 2012) typically finding leakage rates between 10-30% (Carbone & Rivers, 2017). There are only a limited number of studies dealing with carbon leakage issues for small open economies, typically building on single-country partial or general equilibrium models (Copenhagen economics, 2011; DØRS, 2019; Kjær Kruse-Andersen et al., 2022). These studies typically find quite large leakage rates in the range of 40-90%, indicating the importance of further investigating carbon leakage for small open economies.

[1] Thereby unilateral climate policies are only evaluated based on their effect to reduce emission within the borders of the Danish economy.

In this paper, we will focus on leakage through international trade, which is often argued to be one of the most important channels for a small open economy[2]. In current leakage rate literature, the framework of the Pollution Haven Hypothesis dominates within this channel, where the implementation of an environmental regulation will affect relative prices, by increasing production costs within the regulated country. The overall effect being a reduction in demand of produced goods in the regulated country, while increasing demand of similar goods produced elsewhere. This might force firms who are faced by environmental regulation to move their production to less environmentally restricted areas thereby moving emission outside the regulated area (DØRS, 2019; Kjær Kruse-Andersen et al., 2022).

Leakage through this channel therefore always affects emission outside the regulated area negatively (by increasing emission) and plays a large role in the magnitude of the leakage rates calculated, especially for small open economies. Looking at the literature investigating the effect of environmental regulations on competitiveness, the Pollution Haven Hypothesis framework stood alone until the early 1990's where the popular framework was challenged by Porter & Van Der Linde (1995) arguing that econometric studies showing that environmental regulation raises costs and harms competitiveness are subject to bias, as net compliance costs are overestimated by assuming away innovation benefits. Porter & Van Der Linde (1995) therefore asked the rhetorical question: "*By largely assuming away innovation effects, how could economic studies reach any other conclusion than they do?* ".
According to Porter & Van Der Linde (1995) the debate has been framed incorrectly, coming from a static view on environmental regulation, where technology, products, processes and customer needs are all fixed. Arguing for the adaptation of a new paradigm in which competitiveness is defined as dynamic and based on innovation. They even argue that firms might actually benefit from properly crafted environmental regulations that are more stringent than competitors within other countries, the primary goal being to stimulate innovation. Jaffe & Palmer (1997) support the idea that a country adopting a stricter environmental regulation compared to its competitors will experience an increase in innovation and enable the country to become an exporter of newly developed green technology, describing it as the Porter Hypothesis (PH).

If the PH framework holds, environmental regulation might enhance innovation leading to green technological development thereby increasing country-level competitiveness and export within the green side of the economy, or even in some cases the total economy as some evidence points towards (Costantini & Mazzanti, 2012), the negation of this framework should therefore lead to an upwards bias in the leakage

[2] DØRS (2019) argue that a larger degree of openness in the economy increase the effect of leakage through international trade, whereas this channel is argued to be the main channel for a small open economy.

rates calculated in the current literature. Negating the effects that the PH framework might have on carbon leakage through international trade seem even more problematic when looking at the potential of green exports presented by the Danish government and Danish firms, where a focus on developing new green technology, specifically wind technology, has increased the share of green export since 2010 (The Danish Energy Agency, 2021, 2022a). In 2021, Denmark exported 65 billion DKK of green energy technology, estimated to reduce global emission by 5–8-million-ton Co2 in 2021 alone. But with a long life span of green technology the long run effects are even more interesting, where the reduction in global emission associated with the green export in 2021 alone is estimated to be 215 million tons Co2[3] (The Danish Energy Agency, 2022a). Furthermore, the Danish government has initiated a climate partnership with several Danish companies, including specific goals for accelerating exports of green technology. Interviews with leading companies within the green sector suggests that utilizing the full potential of Danish green technology will result in a total reduction potential of 1.500 million tons Co2 in 2030 within the EU-borders alone[4]. Through a larger focus from the government on improving green technology within Denmark, the goal is to double the Danish exports of green technology from 2017 till 2030, thereby exporting for 140 billion DKK green technology (Regeringen, 2020). This further emphasizes the importance of the current leakage rate literature being able to account for the effects presented by the PH framework, incorporating a relationship between environmental regulations and exports of Danish green technology.

In this paper, we find evidence that the PH framework through spurring innovation and green technological development might be successful in increasing the country-level competitiveness both increasing the share of green exports, and in the more controversial case also increasing the level of total exports allowing Danish green technology to reduce emission in the rest of the world through the export of green technology. We therefore argue that the exclusion of the PH framework leads to an upwards bias in the current calculation of leakages through the channel of international trade, where empirical evidence points towards an even higher upwards bias in the case of small open economies like Denmark due to a high degree of openness. To illustrate the importance of including the PH framework when calculating carbon leakages through international trade, we add three contributions: First, we develop an ecological two-area Stock Flow Consistent model representing Denmark and the rest of the world, enabling us to calculate how implementing a unilateral climate policy in Denmark not only reduce Danish emission but also affects emission in the rest of the world. Second, we incorporate different degrees of the PH framework into the model[5], to analyze whether accepting different degrees of this framework changes how implementing a

[3] Estimated to be 2-3 times Denmark's consumption based emission.
[4] Which is 10 times higher than what the current export of Danish green technology has been able to reduce emission by.
[5] Where a higher degree of the PH framework refers to including more effects of this framework, these effects will be introduced in Section 2.

unilateral climate policy in Denmark affects emission in both Denmark and the rest of the world. To the best of our knowledge, we are the first to incorporate the effects of the PH framework within a macroeconomic model, and thereby analyze how this framework might affect emission. Third, we calculate the leakage rate under different degrees of the PH framework to see whether the leakage rate changes as a higher degree of this framework is introduced. By doing this, we investigate whether negating the PH framework results in an upwards bias in the current calculations. Thereby, the main goal of this paper will be to introduce a new view on carbon leakage through international trade, when evaluating the effects of a unilateral climate policies in a small open economy like Denmark.

The remainder of this paper is organized as follows. Section 2 will present a literature review of the three versions of the PH framework used in this paper, as well as the empirical evidence for each version. Section 3 examines what type of environmental regulation is preferred within the PH framework. Section 4 will present the two-area ecological SFC model used for the analysis of this paper, with a focus on introducing the different versions of the PH framework. In section 5, we analyze the effect of introducing a policy-mix within the two-area ecological SFC model, focusing on whether the results change under different degrees of the PH framework. Section 6 will use the results of Section 5 to investigate whether an upwards bias exists when negating the effects of the PH framework. Lastly, we conclude the main results in Section 7.

Section 2 Literature review

In the introduction we presented two opposing frameworks analyzing environmental regulations and how these regulations affect country-level competitiveness, the two frameworks being the Pollution Haven Hypothesis and the Porter Hypothesis. In the Pollution Haven Hypothesis environmental regulations are viewed as a constraint to the production possibility set requiring less pollution from a firm that is otherwise profit maximizing which can only reduce profitability (Palmer et al., 1995) resulting in firms allocating their production to areas with less strict environmental regulations. In contrast the framework of the Porter Hypothesis (Porter, 1991; Porter & Van Der Linde, 1995) introduced a more dynamic view, where properly designed environmental regulations with a focus on firms' green innovations could potentially enhance firm-level productivity and country-level competitiveness.

In this section, we will focus specifically on the empirical evidence for the Porter Hypothesis and examine whether we can justify using this framework when calculating carbon leakage through international trade. We begin by splitting the PH framework into three versions which will be used in this paper, following the work of Jaffe & Palmer (1997). They split up the PH framework into the Weak PH, Narrowly Strong PH, and the Strong PH which we have visualized in the figure below interpreted from left to right, starting with the implementation of an environmental regulation[6]. The first arrow represents the Weak PH implying that environmental regulations lead to an increase in firms' green R&D spending. The second arrow (upper) represents the Narrowly Strong PH stating that green firms, through higher green R&D spending, improve competitiveness through the first mover effect. Lastly, the third arrow (lower) represents the Strong PH suggesting that an increase in green R&D spending can lead to greater competitiveness for the entire economy.

We will now provide a short description for each of the three versions of the PH framework, along with the existing empirical evidence associated with each of the three versions. This will allow us to investigate whether we can justify the use of these hypotheses in the context of carbon leakage through international trade.

[6] They also present the Narrowly PH, this version states that only certain types of environmental regulations stimulate innovation. Here the focus of environmental regulations should be on the outcomes and not the process (Jaffe & Palmer, 1997).

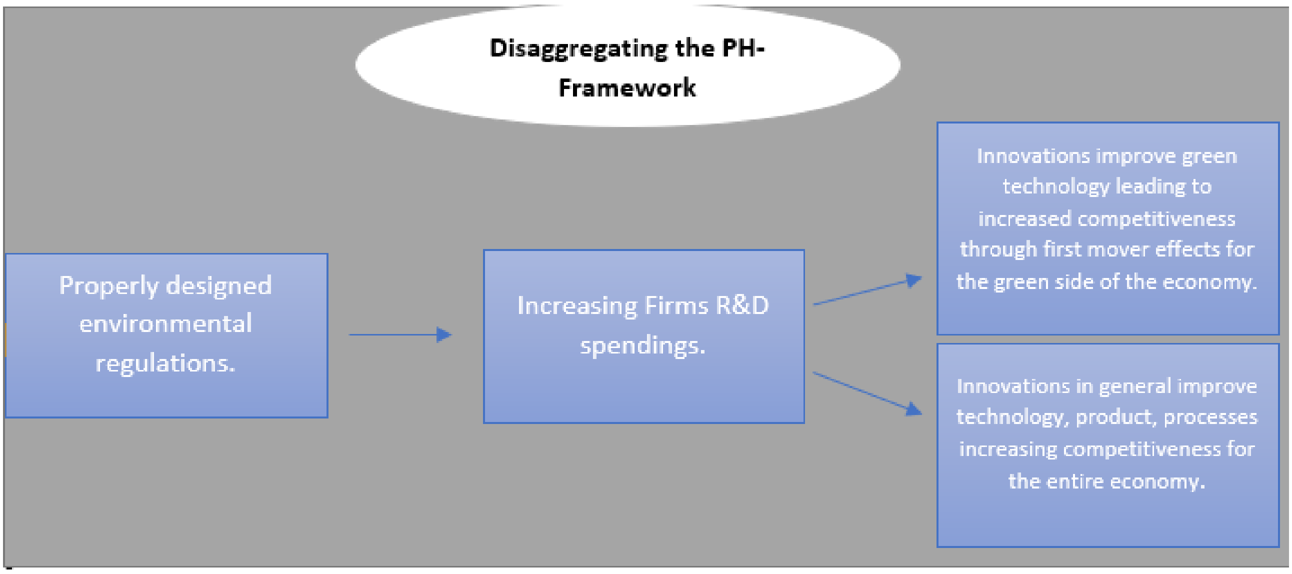

Figure 2-1 Disaggregating the PH Framework

2.1 Environmental regulations on innovation and technological development (Weak PH)

Starting with the **Weak PH** this hypothesis implies that environmental regulations will introduce an extra constraint in firms' maximization problem. When firms maximize profits under these new constraints they will do a variety of things differently, most likely leading to investments in ways to meet the new constraints at a lower cost. For this reason, the weak version of the Porter Hypothesis should only be interpreted as the capability of properly designed environmental regulations to improve innovations and technological development (Ambec et al., 2013; Jaffe & Palmer, 1997)[7].

2.1.1 Empirical evidence of the Weak PH

Empirical evidence seems to confirm that environmental regulations enhance firms' innovation, usually using R&D expenses or patents data. Jaffe & Palmer (1997) use environmental compliance cost data, to find a positive coefficient of 0.15 when looking at the relationship between pollution abatement costs associated with environmental regulations and total R&D expenditures, implying that a 1% increase in firms costs associated with environmental regulations increase R&D expenditures by 0.15%.
Looking at environmentally related patent applications, Lanjouw & Mody (1996), Brunnermeier & Cohen

[7] Since additional constraints to a maximizing problem cannot improve the outcome, the weak PH implies that opportunity costs should be associated with the new innovations (Jaffe & Palmer, 1997).

(2003), Popp (2003, 2006), Arimura et al. (2007), Lanoie et al. (2011), and J. Lee et al. (2011) all show a positive relationship between environmental regulations and green patents. Thereby, we do find a large amount of evidence for the existence of the Weak PH in previous literature. A few newer studies further narrow it down by looking at the effect of environmental regulations on innovation of renewable energy technology (using patent and R&D expenditure data) also finding a positive relationship (Böhringer et al., 2017; Hille et al., 2020; Johnstone et al., 2010; Kim et al., 2017).

As argued by Klassen & McLaughlin (1996) firms increase environmental innovations to improve technological development therefore minimizing costs from material waste and inefficient processes and lowering emission. Therefore, the Weak PH directly implies that environmental R&D spending will have an effect on green technological development. Evidence that a higher level of green innovation leads to new green technological development is provided by studies looking at the effect of green R&D spending on emission reduction measures like Co2 intensity of production (K. H. Lee & Min, 2015; Többelmann & Wendler, 2019).

2.2 Environmental regulations on firms' competitiveness (the Strong- and Narrowly Strong PH)

The Weak PH explained how environmental regulations lead to increments in green R&D spending and green technological development. In the **Narrowly Strong PH** the focus on competitiveness is introduced as a result of the government inducing innovation in green technology through certain types of environmental regulations leading to technological advancements within the green side of the economy, thereby gaining a comparative advantage for the domestic environmental technology industry. Using the description of the Narrowly Strong PH made by Costantini & Mazzanti (2012) it implies that a stricter environmental regulation might positively impact only the green side of the economy, as inducement of early innovation in environmental fields will result in domestic environmental industries to gain competitiveness through a higher technological development (also known as the "first mover advantage")[8].

The Narrowly Strong PH is often seen as a sub version of the **Strong PH,** which starts from a rejection of the profit-maximizing paradigm, meaning that firms will not always pursue all profitable opportunities for new products or processes. A newly introduced environmental regulation might therefore induce firms to

[8] Jaffe et al. (1995) argue that the Narrowly Strong PH implies that some regulated firms probably within the green sector will benefit at the expense of other regulated firms within the conventional sector, when an environmental regulation is implemented.

broaden their thinking to include new technologies, products, or processes, complying with both the newly environmental regulations but also increasing firms' competitiveness. For this reason, the Strong PH can be seen as offering firms a free lunch, as the environmental regulations induce innovation and technological development whose benefits exceed its costs, increasing competitiveness for the economy overall.

In the following section, we will introduce the empirical evidence for the Narrowly Strong and Strong PH, where the empirical evidence have diverged into two subcategories using either firm-level measures or country-level measures[9].

2.2.1 Empirical evidence of the Strong- and Narrowly Strong PH

Up until today, the literature still seems relatively split when it comes to the Strong PH, having difficulties in proving a positive relationship between environmental regulations and the overall competitiveness. A meta-analysis by Cohen & Tubb (2017) uses 107 studies to investigate the empirical results of the Strong PH; they show that over half of the studies are finding insignificant results. Interestingly, the studies finding significant results seem to be equally divided between finding negative and positive relationships. Additionally, they find the empirical evidence to be split up into two categories: I) Using firm- or industry-level performance as a measure for competitiveness. II.) Using country-level competitiveness measures such as exports as a measure for competitiveness. We will now provide the empirical evidence for each of these two categories, also including empirical evidence for the Narrowly Strong PH as we turn towards the country-level competitiveness.

Firm-level measures

Starting with the firm-level competitiveness Cohen & Tubb (2017) find that most significant relationships between environmental regulations and competitiveness are negative, this is also the conclusion of the literature review performed by Ambec et al. (2013) when looking at the empirical evidence for the Strong PH using firm-level measures. However, several studies also find positive results using firm-level productivity measures, for example Berman & Bui (2001) find that refineries located in the Los Angeles area experienced significantly higher productivity compared to other US refineries despite more stringent air pollution regulations. Similarly, Alpay et al. (2002) find that productivity of the Mexican food-processing industry is increasing with the pressure of environmental regulations, leading them to conclude that more stringent regulations are not always detrimental to productivity.

[9] For now, only a few studies provide empirical evidence for the Narrowly Strong PH and are only using measures of country-level competitiveness, whereas most of the empirical results will have a focus on the Strong PH.

So far, only the direct effect of environmental regulations on firm performance has been presented, but a study by Lanoie et al. (2011) is able to isolate the effect of environmental innovation on business performance. They estimate a positive relationship implying that environmental regulations spur innovation and increase business performance, providing evidence of the causal link suggested by the Strong PH. At the same time, they also find that environmental regulations have an overall negative effect on business performance, indicating that the positive effect associated with the Strong PH does not outweigh the direct negative effect of the regulation. The key take away from their analysis is that not taking into account the effect of the Strong PH will result in an overshooting of the negative effect on business performance associated with environmental regulations.

The studies presented so far, only analyze the static effects of environmental regulations on productivity measures, thereby not allowing time for the innovation process to occur. Including a more dynamic approach Lanoie et al. (2008) find that stricter regulations lead to modest long-term gains in productivity looking at a sample of 17 Quebec manufacturing sectors, showing that this effect is more important in industries being highly exposed to outside competition.

Country-level measures

In the earliest of the two papers presented by Michael E. Porter (1991), he examines competition among nations, investigating whether environmental regulations will positively affect the country-level competitiveness. Contrary to the strand of literature focusing on the firm-level measures, Cohen & Tubb (2017) find that the studies looking at country-level competitiveness are most likely to show positive significant relationships for the Strong PH.
When looking at country-level competitiveness, most often the two opposing frameworks in the form of the Porter Hypothesis and the Pollution Haven Hypothesis are analyzed. A share of the empirical literature looking at country-level competitiveness turns the Porter Hypothesis on its head by instead examining the Pollution Haven Hypothesis, typically evaluated under two categories. The first concept tries to determine if environmental regulations weaken trade, where the second concept tests whether firms choose to relocate their investments based upon environmental regulations. Over the years, many empirical studies have debated these effects (Ederington et al., 2005; Eskeland & Harrison, 2003; Grossman & Krueger, 1991; Jug & Mirza, 2005). Some studies find evidence that environmental regulation will increase firms' production costs, increasing product prices, thereby weakening trade (Brock & Taylor, 2005; Copeland & Taylor, 2004). This might in the long run lead to delocalization of dirty industries towards countries with a relatively lower burden of environmental regulation, as implied by the Pollution Haven Hypothesis, thereby providing

evidence against the Strong PH (Ben-David et al., 2018; Letchumanan & Kodama, 2000; Levinson & Taylor, 2008).

Still, earlier literature presented in a literature review performed by Grossman & Krueger (1995) as well as literature presented in the meta-analysis made by Cohen & Tubb (2017), find relatively little evidence supporting the Pollution Haven Hypothesis that environmental regulations should have a large adverse effect on country-level competitiveness.

In the later years, more studies have investigated the Porter Hypothesis directly, both looking at the Strong PH and the Narrowly Strong PH using country-level competitiveness in the form of export and green export growth. A study by Becker & Shadbegian (2008) find that environmental regulations have a positive influence on total export performance which is far greater than on productivity performance. Also, Costantini & Mazzanti (2012) use the total export and green export to test both the Strong and Narrowly Strong PH, looking at the competitive advantage for the total domestic industry (Strong PH), as well as the domestic environmental industry (Narrowly Strong PH) for countries within the European Union. They find significant and persistent impacts on export related to technological improvements within the high- and medium- technology sectors, thereby supporting the Strong PH. Furthermore, they find that environmental regulations have a significant relationship with green exports through technological development using different explanatory variables, thereby supporting the Narrowly Strong PH. A newer study by Hwang & Kim (2017) finds an overall negative relationship between environmental regulations and trade performance which is contrary to the results of Costantini & Mazzanti (2012), while at the same time finding a negative relationship between environmental friendly activities, measured by CO_2 intensity and trade performance, indicating that environmental friendly activities encourage exports, therefore providing evidence that firms with higher environmental management increase competitiveness leading to higher green exports thereby supporting the Narrowly Strong PH.

Summarizing this section, we first provided a short introduction of the PH framework, disaggregating the effects into three versions as provided by Jaffe & Palmer (1997). The Weak PH provided a relationship between the pollution abatement costs associated with environmental regulations and firms R&D spending, resulting in technological development. Empirical results showed a high degree of support for this hypothesis using R&D expenditures or green patent data, thereby justifying the use of the Weak PH. We then turned to the introduction of the Narrowly Strong and Strong PH arguing that environmental regulations might have a positive relationship with green- or total exports. A meta-analysis by Cohen & Tubb (2017) found that even more than 20 years after the introduction of the Porter Hypothesis empirical results are still split, with a large share of the papers finding non-significant results when investigating environmental regulations on competitiveness. Interestingly, they showed that for papers finding significant results, the relationship is often found to be negative when using firm-level measures of competitiveness such as productivity or business performance, while on the other hand country-level measures provided evidence that the Porter Hypothesis might be superior to the framework of the Pollution Haven Hypothesis, finding a positive relationship between environmental regulations and competitiveness. Therefore, we argue that the empirical evidence presented in this section, justifies the use of the Strong PH when using country-level competitiveness measures which will be the case in this paper. Lastly, we also provided empirical evidence for the Narrowly Strong PH, finding that environmental regulations through green technological development showed significant positive effects on green exports, keeping in mind that the number of papers investigating the Narrowly Strong PH is very low we still argue that this justifies the use of the Narrowly Strong PH within this paper.

In the next section, we will further look into what type of environmental regulation is typically preferred by the PH framework, as it should be successful in improving innovation and competitiveness.

Section 3 Policies enhancing the effects presented by the Porter Hypothesis framework

In the previous section, we provided a description of the three disaggregated versions of the Porter Hypothesis presented by Jaffe & Palmer (1997) being the Weak-, Narrowly Strong-, and Strong PH. We found empirical evidence that environmental regulations increase firms' incentives to innovate indicated by the Weak PH. We also found empirical evidence that the higher focus on innovation and technological development could result in an overall positive effect on country-level competitiveness for the green side of the economy, indicated by the Narrowly Strong PH. Lastly, the empirical evidence regarding the Strong PH was less conclusive, with a large proportion of non-significant results. However, looking at the studies finding significant results, a majority of the positive relationships used country-level competitiveness measures. For this reason, we argue that using the framework of the Strong PH is justified when using this type of measure.

In this section, we will comment on what type of environmental regulation is preferred by the PH framework, where the regulation should have a focus on green innovation, green technological development, and competitiveness, thereby enhancing the effects of the PH framework.

The original contribution of Porter (1991) and Porter & Van Der Linde (1995) clearly indicate that not all environmental regulations result in the effects suggested by the PH framework, but that the effect on innovation and competitiveness is highly dependent on what type of environmental policy is implemented, where a green transition of economic performance and exports needs to be supported by coevolving innovation and environmental policy instruments (Geels & Schot, 2007).

As argued by Ambec et al. (2013), the PH framework suggests that a preferred environmental regulation should be flexible and market-based referring to regulations such as carbon taxes, tradable allowances, or performance standards, as these will leave more freedom for firms to find their own technological solutions that minimizes the compliance costs. In the table below, we provide a short explanation of the three environmental regulations suggested: Carbon taxes, tradeable allowances, and performance standards.

Table 1 Policy measures preferred by the PH framework

Policy	Carbon Tax	Tradeable allowances	Performance standards
Description	The government sets a price that emitters must pay for each ton of Co2 they emit.	The government fixes a ceiling for the total amount of Co2 that manufactures are allowed to emit. The government then divides this total value of Co2 into portions which can be sold and traded between firms.	Performance standards limit a firm to obtain a given environmental outcome. For example, limiting firms to emit no more than 100 tons of Co2.
Possibility of obtaining revenue	This creates a revenue for the government through the increased tax income.	If the distribution of allowances goes through an auction system, this will create revenue for the government.	Performance standards will in most cases not lead to any revenue obtained by the government.

The focus towards flexible and market-based regulations are in the words of Jaffe & Palmer (1997) called the Narrow PH, implying that the focus of environmental regulations should be on the outcomes and not the process. As described by Lehmann (2012), the pollution control strategies employed by governments up until the introduction of carbon taxes, were mainly command-and-control policies[10]. The more flexible and market-based instruments like carbon taxes were mainly introduced throughout the 1990's coinciding with the introduction of the PH framework. The higher degree of market-based regulations introduced since the early 1990's, as advocated by Porter, seems to provide an explanation for the higher degree of empirical support for the PH framework since then. This implies that the idea presented by the Narrowly PH, introducing a higher focus towards the final outcome of an environmental regulation instead of the process, seems to enhance the effect of the PH framework (Ambec et al., 2013).

Moreover, if market-based instruments generate revenues (e.g., from taxes or permit auctioning), the efficient recycling of those revenues can improve competitiveness outcomes[11] (Ambec et al., 2013). As presented by Porter & Van Der Linde (1995) environmental regulations should be implemented with a goal of spurring innovation and technological development therefore calling for a policy-mix which is made possible by using the revenue of a carbon tax[12]. This view is also supported by the IMF (2020) arguing that optimal environmental regulations should consist of a policy-mix including policy-tools capable of raising

[10] Providing a certain type of technology or solution that the firm was forced to implement to reduce emission.
[11] A study analyzing such a set-up is presented by Andersen et al. (2007) who analyze the effect of a policy-mix where environmental tax revenues in seven EU countries are recycled into other tax cuts (labor or income). They find a neutral or slightly positive net impact on gross domestic product.
[12] The term policy-mix is often used when implementing several policies addressing the same problem (Johnstone, 2003).

the price of carbon, as well as policy-tools that spur innovation. A literature review made by Lehmann (2012) analyzes the use of multiple policies (a policy-mix), in contrast to the performance of single policies when looking at environmental regulations. He finds that the existence of different market failures such as pollution externalities, technological spillovers, and asymmetric information makes it essential to combine policies creating a policy-mix.

Apart from envrionmental regulations, Ambec et al. (2013) emphasize how general government policies capable of improving the relationship between environmental policies and innovation/competitiveness could further enhance the effects of the PH framework, specifically looking at the effects of industrial and patent policies, where well defined property rights can help reduce R&D spillovers thereby increasing the incentives for firms to invest in R&D[13].

In this section, we found the freedom provided by flexible market-based policies (for example a carbon tax) to be preferred by the PH framework, as firms can provide their own solutions to comply with the new regulations through innovation. We also found that recycling the revenue of a carbon tax, to support innovation and competitiveness, would enhance the effects provided by the PH framework, whereas we will use this type of policy-mix as we in Section 5 introduce an environmental regulation in the Danish economy.

But first, we will use the upcoming section to describe the model in which this regulation will be introduced, with a goal of implementing the effects of the PH framework within this model.

[13] They also mention policies providing training for firm managers to help them reach low hanging fruits, both helping them comply with environmental regulations and implement new technologies.

Section 4 A two-area ecological Stock-Flow-Consistent model

Up until this point, we have provided empirical evidence for the three versions of the Porter Hypothesis justifying the use of these hypotheses within the analysis of this paper. Furthermore, we looked at what type of environmental regulation is preferred within the PH framework finding that a move towards carbon taxes should enhance the effects, optimally recycling the tax revenue creating a policy-mix. These findings will be useful in this section as we will introduce the two-area ecological Stock-Flow-Consistent model, including different degrees of the PH framework[14].

The model used in this paper is an extended version of the two-area ecological SFC model developed by Carnevali et al. (2021). Their model belongs to the class of SFC dynamic macroeconomic models (e.g. Godley & Lavoie (2016); Nikiforos & Zezza (2017); Carnevali et al. (2019)). By using this type of model for examining leakage rates, we move away from the tradition of using CGE models. The use of SFC models provide us with a simpler set-up compared to the CGE models. Since SFC models do not require optimization, it is possible to include a higher level of complexity when establishing relationships, useful when measuring different levels of technological efficiency for different stocks and flows of capital. Since we focus on a small open economy, we divide the world economy into a small open economy (represented by Denmark), and the rest of the world (ROW). This is in contrast to Carnevali et al. (2021) who divide the world economy into two equally-sized economies.

This section will first provide a model description introducing the most important equations for the two economies as well as the ecological sector, with a specific focus on the implementation of the PH framework. We then turn to the calibration of the model, covering the calibration of already existing variables, with a main goal of adjusting the two economies to match the size of Denmark and the rest of the world. We also cover the calibration of new parameters focusing on the parameters included to incorporate the effects of the PH framework. As we want to analyze the effect of having different degrees of the PH framework active in the model, we end up calibrating four different baseline models, each including different degrees of this framework[15]. Lastly, we validate these four baseline models to ensure that key variables follow the overall trends of real data.

[14] Where a higher degree of the PH framework implies that we introduce another of the three underlying hypotheses (the Weak-, Narrowly Strong-, or Strong PH)

[15] All four baseline models will have similar equations, but with different parameter values. The exact difference between the four baseline models can be seen in Appendix -B, but will also be made clear as we present the calibration of the models.

4.1 Model description

In this section, we will present the most central equations used for the analysis of this paper, with a specific focus on the additions made to the model of Carnevali et al. (2021)[16]. Almost all equations will be presented from the perspective of the Danish economy, whereas an identical equation (if not stated otherwise) is included for the rest of the world. Just like Carnevali et al. (2021), we use constant prices but diverge from the floating exchange regime as Denmark in 1982 implemented a fixed exchange rate against the DEM and later the EUR[17]. Therefore, one unit of output will always be worth the same in both economies. The equations and parameter values necessary for replicating the model is presented in Appendix -A and Appendix -B respectively.

The model description will be split into three parts: I.) Equations describing the two economies, II.) Equations describing the ecological sector, and how this is linked with the rest of the economy, III.) Equations introducing the different versions of the PH framework in the model.

4.1.1 Equations describing the two economies

To highlight our contributions to the model of Carnevali et al. (2021), we present a directed acyclic graph (DAG) in the figure below, representing the most important relations within the economies themselves, but also the interactions between the two economies. The filled circles denote new variables and therefore new equations added to the model of Carnevali et al. (2021), we will also modify already existing equations of the variables connected with these new additions. It should be noted that the figure below only shows the relations within the Danish economy and how it affects the rest of the world, whereas a similar figure could be made for the rest of the world.

[16] The full set of equations for the model will be presented in Appendix -A. Here it will be made clear which equations have been added to the model of Carnevali et al. (2021).
[17] As Germany later changed its currency from the German D-mark (DEM) to the Euro (EUR).

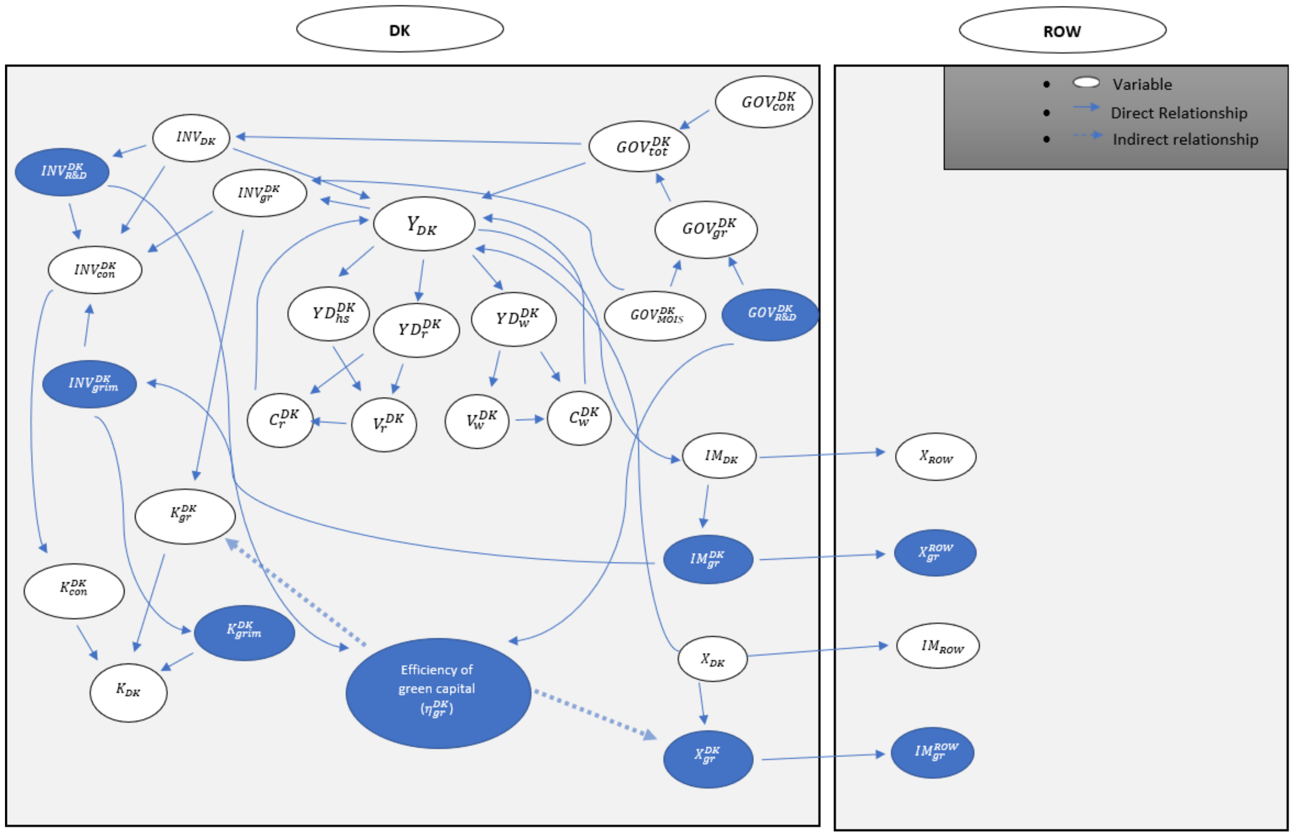

Figure 4-1 DAG presenting the Danish economy and the relations to ROW

The main goal of this section will be to describe the relationships between the variables shown in the figure above. We begin by presenting the equation determining the total production of the Danish economy below:

$$Y_{DK} = C_r^{DK} + C_w^{DK} + GOV_{tot}^{DK} + X_{DK} - IM_{DK} + INV_{DK}$$

Here we observe that output is driven by aggregate demand, which overall implies that the economies are demand-led in both the short-, and long-run with the only supply constraints being the availability of resources and climate related damages. We will now present the equations describing the components of the total production function, for now excluding the equations determining international trade, as these are introduced later when implementing the PH framework. For this reason, the focus will be on the government's total expenditures, investments, and consumption.

One of the main drivers of the economy is government spending where, just like Carnevali et al. (2021), this is divided into conventional and green government spending as presented below:

$$GOV_{tot}^{DK} = GOV_{con}^{DK} + GOV_{gr}^{DK}$$

Starting with the second term in the form of green government spending (GOV_{gr}^{DK}), we introduce a new type of green government spending being government spending in green R&D ($GOV_{R\&D}^{DK}$). The introduction of this variable allows the government to enhance green technological development within the economy.

$$GOV_{gr}^{DK} = GOV_{Mois}^{DK} + GOV_{R\&D}^{DK}$$

Besides from government spending towards green R&D, the government can also attribute its expenditures towards green MOIS (mission-oriented government spending) providing the government with an option to enhance green investment plans of firms, which we will touch on later.

The last type of government spending is conventional government spending determined using an AR (1) process, as shown below[18]:

$$GOV_{con}^{DK} = \gamma_{GOV0}^{DK} + \gamma_{GOV1}^{DK} * GOV_{con_{t-1}}^{DK}$$

Just like in Carnevali et al. (2021) (and also indicated by the DAG above) government spending is the main driver of investments within the two economies[19], looking at the equation for total investments (INV_{DK}) below, we see that government spending is included argued to have an investment-enhancing effect through provision of infrastructure[20]. Besides from the effect of government spending, the total investments are given by an autonomous part, an autoregressive part, and lastly it is affected by climate change related damages[21].

$$INV_{DK} = \left(\gamma_0^{DK} + \gamma_1^{DK} * INV_{DK_{t-1}} + \gamma_2^{DK} * GOV_{totinv_{t-1}}^{DK}\right) * \left(1 - d_{T_{t-1}}^{DK}\right)$$

Looking at green investments (INV_{gr}^{DK}) in the equation below, the main effects are the same as in Carnevali et al. (2021). Again government spending is playing a large role as the green investments are determined by government spending in green MOIS which is argued by Mazzucato (2018) to reduce the risk taken by firms when undertaking green investments. Furthermore, green investments are also positively affected by GDP, and climate change related damages. As an addition to the equation used by Carnevali et al. (2021), we

[18] For now, we will not comment on the parameter values, as we in the calibration section provide an explanation for the calibration of the most important parameters.

[19] Carnevali et al. (2021) argue that government interventions affect firms investments through provision of infrastructure and investment-enhancing programs.

[20] Here we do not include the government spending used for green R&D spending, whereas $GOV_{totinv}^{DK} = GOV_{tot}^{DK} - GOV_{R\&D}^{DK}$.

[21] Climate change related damages are given by the function $d_T^{DK} = 1 - \left(1 + d_1^{DK} * T_{AT} + d_2^{DK} * T_{AT}^2 + d_3^{DK} * T_{AT}^{x_{DK}}\right)^{-1}$ where the damage is increasing as atmospheric temperature increases (T_{AT}). As can be observed in Appendix -A the atmospheric temperature is affected by the atmospheric Co2 concentration and therefore emission (for a visual representation of this see Figure 4-2).

include an exogenously determined growth in the green investments determined by g_{GrInv}^{DK} to demonstrate an increasing willingness within firms to adopt green investments.

$$INV_{gr}^{DK} = \left(\left(\chi_1^{\mathrm{DK}} * GOV_{grinv}^{DK} + \chi_2^{DK} * Y_{DK} + \chi_3^{DK} * d_T^{DK}\right) * \left(1 - d_{T_{t-1}}^{DK}\right)\right) * \left(1 + g_{GrInv}^{DK}\right)^{Trend}$$

In contrast to Carnevali et al. (2021) we introduce two new types of investments undertaken by firms, being investments in imported green capital, and firms' investments in green R&D. Starting with investments in imported green capital (INV_{grim}^{DK}), this has a direct link with the green imports and is therefore given by the identity below:

$$INV_{grim}^{DK} = IM_{gr}^{DK}$$

Now looking at firms' investments in green R&D ($INV_{R\&D}^{DK}$), this is given as a share of total investments in the baseline model, observed in the equation below[22]:

$$INV_{R\&D}^{DK} = \exp\left(\Gamma_0^{DK} + \Gamma_1^{DK} * Log(INV_{DK})\right)$$

Lastly, we introduce the same mechanic as Carnevali et al. (2021) using conventional investments as a residual. As we do not want conventional investments to be negative, we use a constraint not allowing green investments to be higher than total investments subtracted by imported green investments and investments in green R&D, ensuring that conventional investments will always be zero or above.

$$INV_{con}^{DK} = INV_{DK} - INV_{gr}^{DK} - INV_{grim}^{DK} - INV_{R\&D}^{DK}$$

$$INV_{gr}^{DK} \leq INV_{DK} - INV_{grim}^{DK} - INV_{R\&D}^{DK}$$

Firms are able to fund their investments through retained earnings (F_u^{DK}) or by issuing new equities ($\Delta E_S^{ROW,DK}$ and $\Delta E_S^{DK,DK}$). If this is not sufficient in financing firms' investments, the rest will be financed by loans, whereas we use loans as the residual leading to the change in loans demanded by firms being defined as follows:

$$L_f^{DK} = L_{f_{t-1}}^{DK} + INV_{DK} - AF_{DK} - F_u^{DK} - \Delta E_S^{ROW,DK} - \Delta E_S^{DK,DK}$$

This concludes the dynamics of investments within the model, besides from the equations introduced by Carnevali et al. (2021) we introduced two new types of investments being investments in green R&D ($INV_{R\&D}^{DK}$) as well as investments in green imported capital (INV_{grim}^{DK}).

[22] As we will later include the effects of the Weak PH, this equation will be slightly modified.

We will now comment on the different capital stocks within the model, determined as an accumulation of the investments over time, as seen in the equations below[23]:

$$K_{gr}^{DK} = K_{gr_{t-1}}^{DK} + INV_{gr}^{DK} - DA_{gr}^{DK}$$

$$K_{con}^{DK} = K_{con_{t-1}}^{DK} + INV_{con}^{DK} - DA_{con}^{DK}$$

$$K_{grim}^{DK} = K_{grim_{t-1}}^{DK} + INV_{grim}^{DK} - DA_{grim}^{DK}$$

With the total capital stock being defined as a sum of the capital components.

$$K_{DK} = K_{gr}^{DK} + K_{con}^{DK} + K_{grim}^{DK}$$

The reader should note that firms' investments in green R&D is not accumulated into a capital component, instead investment in green R&D should be seen as investments in improving the efficiency of the green capital component (K_{gr}^{DK}) [24], as shown by the DAG above.

Lastly, we will provide the equations describing income and consumption within the model, as seen in the DAG above, no additional changes are made to these equations, compared to the ones presented in Carnevali et al. (2021).

Starting with consumption, this is divided into two components being consumption of capitalists (C_r^{DK}) and workers (C_w^{DK}) where α_{1r}^{DK} and α_{1w}^{DK} are the propensities to consume out of income, while α_{2r}^{DK} and α_{2w}^{DK} are the propensity to consume out of retained income respectively for capitalists and workers. The last term captures climate related damages.

$$C_r^{DK} = \left(\alpha_{1r}^{DK} * YD_r^{DK} + \alpha_{2r}^{DK} * V_{r_{t-1}}^{DK}\right) * (1 - d_{T_{t-1}}^{DK})$$

$$C_w^{DK} = \left(\alpha_{1w}^{DK} * YD_w^{DK} + \alpha_{2w}^{DK} * V_{w_{t-1}}^{DK}\right) * (1 - d_{T_{t-1}}^{DK})$$

The equations for disposable income are modeled as total income by capitalists or workers minus taxes:

$$YD_r^{DK} = Y_r^{DK} * (1 - \theta_{DK})$$

$$YD_w^{DK} = Y_w^{DK} * (1 - \theta_{DK})$$

Capital gains are assumed to be tax-free, whereas we also introduce the Haig-Simons disposable income for capitalists adding in the gains from financial assets ($CG_b^{DK} + CG_e^{DK}$):

[23] The last component in each of the three capital stocks represents depreciation of the capital stock.
[24] And through the effects of international trade introduced later also improving the efficiency of K_{grim}^{ROW}.

$$YD_{hs,r}^{DK} = YD_r^{DK} + CG_b^{DK} + CG_e^{DK}$$

The stock of retained income (wealth) is calculated below, using the disposable income minus consumption to calculate the amount added to the already existing stock.

$$V_r^{DK} = V_{r_{t-1}}^{DK} + YD_{hs,r}^{DK} - C_r^{DK}$$

$$V_w^{DK} = V_{w_{t-1}}^{DK} + YD_w^{DK} - C_w^{DK}$$

The total income of workers is simply determined by a share (ω_{DK}) of total output, as shown below:

$$Y_w^{DK} = \omega_{DK} * Y_{DK}$$

As capitalists obtain their earnings through domestic firms, we present the equation for firms' profits below. Subtracting workers total income (Y_w^{DK}), the total depreciation of the capital stock (DA_{DK}), and firms interest payments for loans ($r_{l_{t-1}}^{DK} * L_{f_{t-1}}^{DK}$) from total output ($Y_{DK}$).

$$F_f^{DK} = Y_{DK} - Y_w^{DK} - DA_{DK} - r_{l_{t-1}}^{DK} * L_{f_{t-1}}^{DK}$$

Firms then retain an exogenously determined percentage of the total profits:

$$F_u^{DK} = F_f^{DK} * ret_{DK}$$

And also use the profits to pay dividends to shareholders (F_d^{DK}) both in Denmark ($r_{e_{t-1}}^{DK} * E_{S_{t-1}}^{DK,DK}$) and the rest of the world ($r_{e_{t-1}}^{DK} * E_{S_{t-1}}^{ROW,DK}$):

$$F_d^{DK} = r_{e_{t-1}}^{DK} * (E_{S_{t-1}}^{DK,DK} + E_{St-1}^{ROW,DK})$$

In the end, the residual component is modeled as compensation of managers in Denmark:

$$F_m^{DK} = F_f^{DK} - F_u^{B} - F_d^{DK}$$

In contrasts to workers, capitalists are also holders of financial assets (both bonds and equities) which leads us to the total income of capitalists being:

$$Y_r^{DK} = F_m^{DK} + F_b^{DK} + r_{b_{t-1}}^{DK} * B_{S_{t-1}}^{DK,DK} + r_{b_{t-1}}^{ROW} * B_{S_{t-1}}^{DK,ROW} + F_{d_{t-1}}^{DK,DK} + F_{d-1}^{DK,ROW}$$

The first term (F_m^{DK}) we introduced as compensation for managers in Denmark. Second, (F_b^{DK}) describing the profits made by banks. Third, ($r_{b_{t-1}}^{DK} * B_{S_{t-1}}^{DK,DK}$) determining the flow of income coming from Danish issued bonds. Fourth, ($r_{b_{t-1}}^{ROW} * B_{S_{t-1}}^{DK,ROW}$) determining the flow of income coming from bonds issued in the rest of the world. Fifth, the two terms ($F_{d_{t-1}}^{DK,DK} + F_{d-1}^{DK,ROW}$) describing the flow of income coming from equities in Danish and international firms.

This concludes the equations describing the two economies, whereas we now turn towards the eco-system and its relation to the two economies.

4.1.2 Equations describing the eco-system and its link to the economy

To provide the reader with an overview of the eco-system and its relation to the two economies, we have visualized the set-up described by Carnevali et al. (2021) in the figure below. Again, it is within the filled areas that we include new additions to their model. Introducing the eco-system, our focus will be towards these new equations.

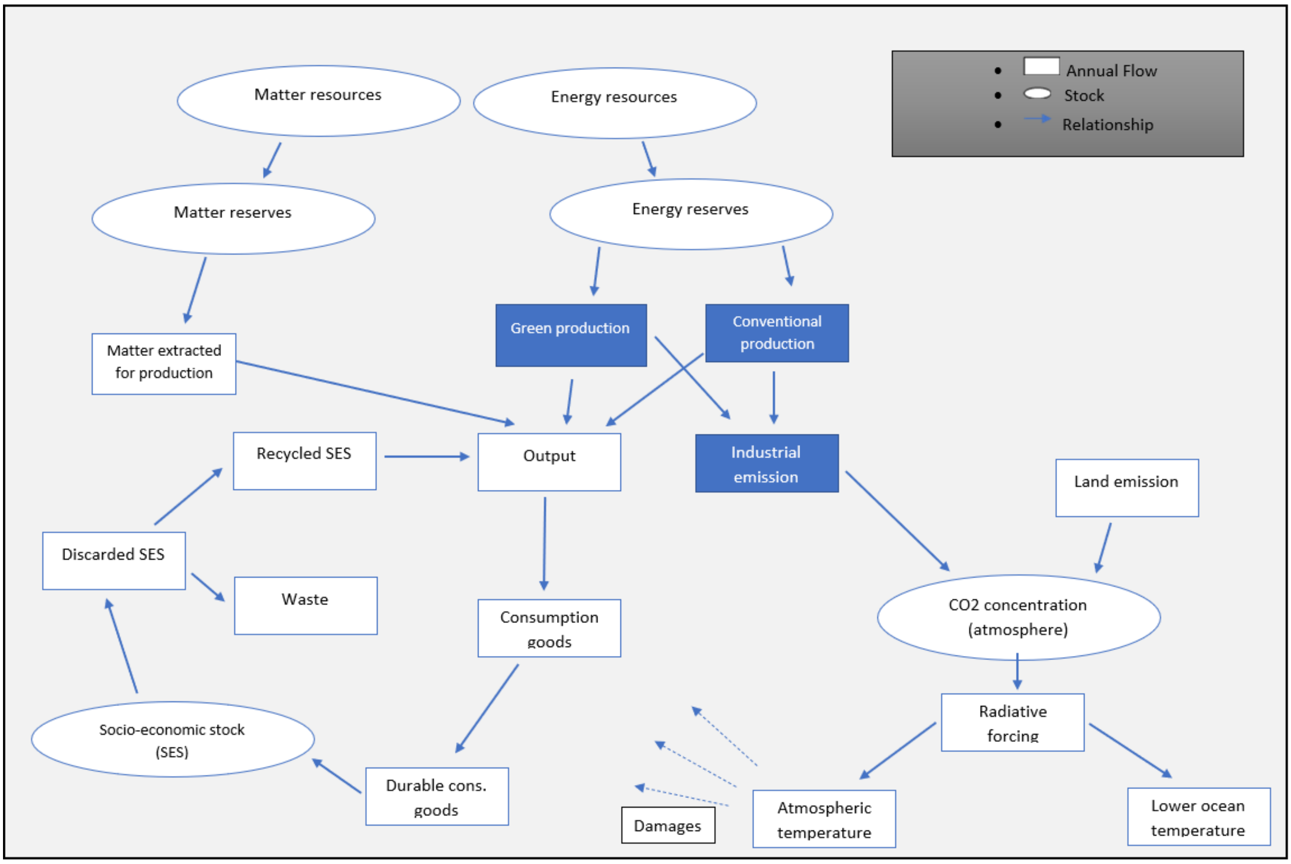

Figure 4-2 DAG of the eco-system

We begin by presenting the measures used to determine the ecological efficiency of the capital stock, being the matter-intensity (μ_{DK}), energy-intensity (ϵ_{DK}), Co2-intensity (β_{DK}), and the renewability share (η_{DK})[25].

As indicated by the DAG above, two types of production can occur within the two economies, green and conventional production. To produce within the green production sector green capital is used in the form of domestically produced green capital or imported green capital, whereas only conventional capital is used within the conventional production sector. The efficiency of green capital, measured using the four efficiency measures described above, is more efficient relative to the conventional capital, whereas the use of conventional capital will lead to a higher matter-, energy-, Co2-intensity, and a lower share of renewability. For this reason, when presenting the efficiency of the capital stock (associated with the total production), we need to take an average based on the share of each capital components used for the total production, being the share of green capital (K_{gr}^{DK}), imported green capital (K_{grim}^{DK}), and conventional capital (K_{con}^{DK}). The parameter multiplied on each of the capital shares is the measure of efficiency for this specific type of capital, thereby describing the matter intensity, Co2 intensity, energy intensity, and renewability share of respectively the green capital (μ_{gr}^{DK}, β_{gr}^{DK}, ϵ_{gr}^{DK}, and η_{gr}^{DK}), imported green capital (μ_{grim}^{DK}, β_{grim}^{DK}, ϵ_{grim}^{DK}, and η_{grim}^{DK}), and conventional capital (μ_{con}^{DK}, β_{con}^{DK}, ϵ_{con}^{DK}, and η_{con}^{DK})[26].

$$\mu_{DK} = \mu_{gr}^{DK} * \frac{K_{gr}^{DK}}{K_{DK}} + \mu_{grim}^{DK} * \frac{K_{grim}^{DK}}{K_{DK}} + \mu_{con}^{DK} * \frac{K_{con}^{DK}}{K_{DK}}$$

$$\beta_{DK} = \beta_{gr}^{DK} * \frac{K_{gr}^{DK}}{K_{DK}} + \beta_{grim}^{DK} * \frac{K_{grim}^{DK}}{K_{DK}} + \beta_{con}^{DK} * \frac{K_{con}^{DK}}{K_{DK}}$$

$$\epsilon_{DK} = \epsilon_{gr}^{DK} * \frac{K_{gr}^{DK}}{K_{DK}} + \epsilon_{grim}^{DK} * \frac{K_{grim}^{DK}}{K_{DK}} + \epsilon\,_{con}^{DK} * \frac{K_{con}^{DK}}{K_{DK}}$$

$$\eta_{DK} = \eta_{gr}^{DK} * \frac{K_{gr}^{DK}}{K_{DK}} + \eta_{grim}^{DK} * \frac{K_{grim}^{DK}}{K_{DK}} + \eta_{con}^{DK} * \frac{K_{con}^{DK}}{K_{DK}}$$

Imported green capital is a new addition to the model of Carnevali et al. (2021), whereas the second term in the equations above is now introduced.

[25] When we in the future use the term technological efficiency, this will mainly refer to these measures, and more specifically the different measures of renewability share as our focus will be towards endogenizing the renewability share of green capital (η_{gr}^{DK}).
[26] Later, we will endogenize the renewability share of green capital ($\eta_{gr}^{DK}, \eta_{gr}^{ROW}$) whereas the equation for the renewability share will be modified further.

As we have now introduced the efficiency of the capital stock measured by matter-, energy-, Co2-intensity, and the renewability share, we will now describe how these measures affect the industrial emission through production.

First, the energy intensity (ϵ_{DK}) is used for calculating the energy needed in total production (e_{DK}) to produce the output (Y_{DK}) shown in the equation below:

$$e_{DK} = \epsilon_{DK} * Y_{DK}$$

Second, the renewability share (η_{DK}) is used for calculating the share of energy being renewable energy (er_{DK}) which can then be used for calculating the share of energy being non-renewable energy (en_{DK}) as shown below:

$$er_{DK} = \eta_{DK} * e_{DK}$$

$$en_{DK} = e_{DK} - er_{DK}$$

Third, we use the measure of Co2 intensity (β_{DK}) to calculate the total emission within Denmark ($emis_{DK}$), together with an autonomous level of emission (β_o^{DK})[27]. Here we see that only the non-renewable energy is associated with emission:

$$emis_{DK} = \beta_o^{DK} + \beta_{DK} * en_{DK}$$

This concludes the presentation of the central equations within the eco-system. In the next section, we will take a closer look at the equations describing international trade within the model and how the PH framework is implemented within these equations.

4.1.3 Equations introducing the Porter Hypothesis framework

In this section, the main goal will be to present the equations used for incorporating the PH framework within the model. As this framework is not included by Carnevali et al. (2021), all equations in this section will be new or modified equations compared to the ones used in their model. In the figure below, we visualize how the implementation of the Porter Hypothesis is carried out. We have introduced a few more variables as well as relationships compared to Figure 4-1 introduced earlier. Three main effects should be considered when looking at the DAG below represented by the red colored arrows:

[27] The autonomous level of emission which in the model of (Carnevali et al., 2021) is falling over time using an exogenous determined rate, we instead keep it fixed. Instead, we argue that it is the Co2 intensity of the green capital (β_{gr}^{DK}) which should be falling over time, whereas we include an exogenously determined degrowth rate (g_{grbeta}^{DK}) within the equation of Co2 intensity of green capital as shown in Appendix -A.

I.) As will be further described in Section 5 a carbon tax is introduced to the model, which through the effects of the Weak PH should affect firms spending towards green R&D, improving efficiency of green capital.

II.) As green capital becomes more efficient, the effects of the Narrowly Strong and Strong PH should be at play, increasing green exports when only the Narrowly Strong PH is active and increasing green and total exports when both the Narrowly Strong and Strong PH is active thereby improving the country-level competitiveness.

III.) As our goal is not only to include the effects of the Porter Hypothesis, but also to calculate how the implementation of this framework enables a small open economy like Denmark to affect emission in ROW. There should be a mechanism improving the efficiency of the capital stock in ROW, as they import a higher level of green capital from Denmark, as well as when Denmark improves its efficiency of green capital.

By including these effects, we combine two areas of research, the first being the PH literature implementing a relationship between environmental regulations and firms' R&D spending, affecting competitiveness measured by export and green export through technological developments. So far, these relationships are shown to exist through empirical evidence of the PH framework. But unlike studies looking at its opposing hypothesis (the Pollution Haven Hypothesis), no one seems to analyze the larger perspective of how the effects of the PH framework might provide channels in which a small open economy can affect emission in the rest of the world through the implementation of an environmental regulation. This last area of research is mostly associated with the literature on carbon leakage rates, still only relying on the Pollution Haven Hypothesis framework when it comes to carbon leakage through international trade, even though we in Section 2 showed how the empirical evidence in some cases find the PH framework to have even stronger effects than the Pollution Haven Hypothesis framework.

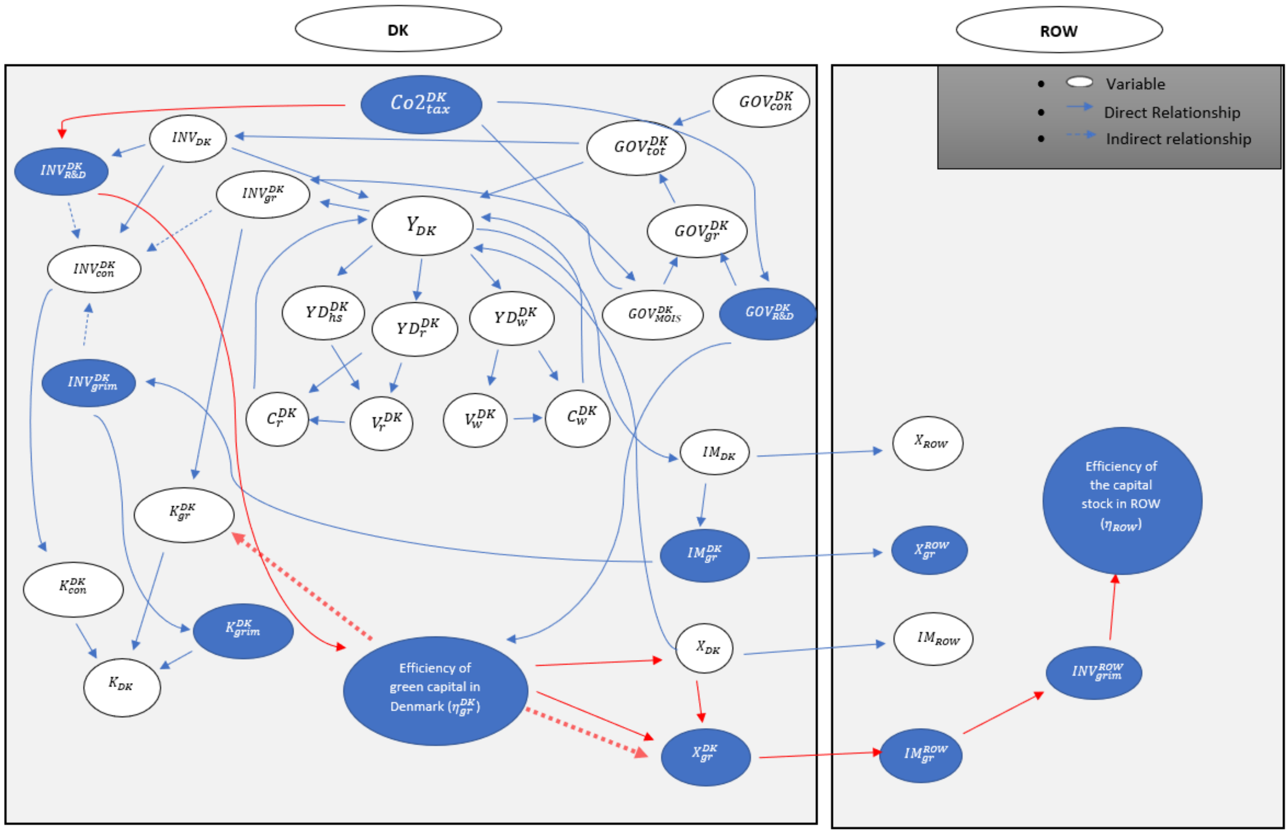

Figure 4-3 DAG implementing the PH framework

Implementing the Weak PH

Previously, we introduced two forms of green R&D spending (also shown in the figure above) the first being government spending towards green R&D, which together with green MOIS resulted in the total green government spending. Besides from the government being able to invest in green R&D, we also introduced green R&D investments by the firms, as being a fixed share of investments. As we indicate by the red arrow going from $Co2_{tax}^{DK}$ to $INV_{R\&D}^{DK}$ in the DAG above, we now include a second term in the equation as we include a link between firms' costs associated with the carbon tax and firms' investments in green R&D, shown by the equation below:

$$INV_{R\&D}^{DK} = \exp\left(\Gamma_0^{DK} + \Gamma_1^{DK} * \ Log(INV_{DK}) + \Gamma_2^{DK} * Log(Co2_{tax}^{DK})\right)$$

Thereby an increase in firms' costs associated with environmental regulations (a carbon tax) will increase the incentive for firms to invest in green R&D, as suggested by the Weak PH.

We should now focus on how green R&D improves the effectiveness of green capital within the model. As mentioned in the introduction, Denmark's largest source of green technology is within renewable energy (The Danish Energy Agency, 2022b), whereas we endogenize the renewability share of green capital (η_{gr}^{DK})

presented in the previous section[28]. We do so by modeling the improvements of the renewability share of green capital (η_{impv}^{DK}) as a function of total R&D expenditures in the economy ($GOV_{R\&D}^{DK} + INV_{R\&D}^{DK}$)[29].

$$\eta_{impv}^{DK} = \exp\left(impv_0^{DK} + impv_1^{DK} * log\left(GOV_{R\&D}^{DK} + INV_{R\&D}^{DK}\right)\right)$$

This allow us to calculate the renewability share of green capital presented below:

$$\eta_{gr}^{DK} = \eta_{gr_{t-1}}^{DK} + \eta_{impv}^{DK}$$

As a change in the renewability share of new green capital does not mean that already produced green capital will be automatically updated, only the newly produced green capital should be associated with the renewability share at the time of production. To estimate the average renewability share of green capital we create a moving average equation, here we allow for the assumption that parts of the already existing green capital can be updated to the new renewability share shown by the parameter $(1 - imp_{DK})$. Looking at the first term in the equation below, we observe how new green capital (K_{NEWgr}^{DK}) is updated using the renewability share today (η_{gr}^{DK})[30]. In the second term, the share of already existing green capital that will not be updated will have the average renewability of the previous period ($\eta_{AVGgr_{t-1}}^{DK}$). Lastly, the share of already existing capital, that we assume will be updated, has the renewability share today (η_{gr}^{DK}). From this equation, we obtain a new average renewability share for the total stock of green capital (η_{AVGgr}^{DK}).

$$\eta_{AVGgr}^{DK} = (\frac{K_{NEWgr}^{DK}}{K_{gr}^{DK}}) * \eta_{gr}^{DK} + imp_{DK} * \left(\frac{K_{gr}^{DK} - K_{NEWgr}^{DK}}{K_{gr}^{DK}}\right) * \eta_{AVGgr_{t-1}}^{DK} + (1 - imp_{DK}) * \left(\frac{K_{gr}^{DK} - K_{NEWgr}^{DK}}{K_{gr}^{DK}}\right) * \eta_{gr}^{DK}$$

A similar moving average equation is made for the imported green capital in Denmark. However, we do not allow for already existing imported green capital to be updated when the producing country improves the renewability share[31]. The equation for the renewability share of imported green capital ($\eta_{AVGgrim}^{DK}$) can be seen below[32].

[28] As shown in Appendix -C Figure 6, the renewability share of green capital can exceed 100%, whereas we assume that the additional energy will be used for conventional production. As also seen the renewability share of the total capital stock never exceeds 100%.

[29] We add together the governments and firms' R&D spending as we assume these to have the same effect on technological efficiency. Another reason for adding them together when introducing this relationship is that using an amount of firms R&D spending to" invent" technology X means that using the same amount of government R&D spending cannot lead to inventing the same technology X.

[30] New green capital (K_{NEWgr}^{DK}) is calculated using the following equation: $K_{NEWgr}^{DK} = K_{gr}^{DK} - K_{gr_{t-1}}^{DK}$ and new imported green capital ($K_{NEWgrim}^{DK}$) introduced later is calculated using the equation: $K_{NEWgrim}^{DK} = K_{grim}^{DK} - K_{grim_{t-1}}^{DK}$.

[31] This assumption implies that the efficiency of Danish exported green capital will not automatically be updated as Denmark improves efficiency of green capital. We find this case to be the most realistic, but as presented in Appendix -D (page 120), relaxing this assumption does not change the conclusions of this paper.

[32] The reader should note that it is the current renewability share of green capital in the exporting country (in Denmark's case (η_{gr}^{ROW})) used for updating the moving average.

$$\eta^{DK}_{AVGgrim} = \left(\frac{K^{DK}_{NEWgrim}}{K^{DK}_{grim}}\right) * \eta^{ROW}_{gr} + \left(\frac{K^{DK}_{grim} - K^{DK}_{NEWgrim}}{K^{DK}_{grim}}\right) \eta^{DK}_{AVGgrim}$$

The reader should keep in mind that the interesting equation for the analysis in this paper, is the renewability share of imported green capital in ROW ($\eta^{ROW}_{AVGgrim}$), implying that when the renewability share of green capital increase in Denmark (η^{DK}_{gr}), this will lead to an increase in the efficiency of green capital imported by ROW[33].

As we have now introduced the average renewability share of domestic green capital (η^{DK}_{AVGgr}) and imported green capital ($\eta^{DK}_{AVGgrim}$). These measures are now used for calculating the average renewability share of the total capital stock (also referred to as the renewability share of total production), thereby updating the equation introduced in the previous section[34]:

$$\eta_{DK} = \eta^{DK}_{AVGgr} * \frac{K^{DK}_{gr}}{K_{DK}} + \eta^{DK}_{AVGgrim} * \frac{K^{DK}_{grim}}{K_{DK}} + \eta^{DK}_{con} * \frac{K^{DK}_{con}}{K_{DK}}$$

Thereby, the implementation of the Weak PH is complete, showing how an increase in the carbon tax increase firms' investments in green R&D (indicated by the red arrow going from $Co2^{DK}_{tax}$ to $INV^{DK}_{R\&D}$), then increasing the efficiency of green technology in Denmark (indicated by the red arrow from $INV^{DK}_{R\&D}$ to η^{DK}_{gr}), which then has two indirect effects, first increasing the average efficiency of green capital in Denmark (indicated by the arrow going from η^{DK}_{gr} to K^{DK}_{gr}), and second, increasing the efficiency of the exported green capital by Denmark (indicated by the dashed red arrow going from η^{DK}_{gr} to X^{DK}_{gr})[35].

Implementing the Narrowly Strong and Strong PH

In the implementation of the Weak PH, the introduction of a carbon tax in Denmark increased technological development, improving efficiency of green capital in Denmark, and imported green capital in ROW. As we turn towards the second of the three effects presented above, we will start the implementation of the Narrowly Strong and the Strong PH, thereby allowing green technological development to improve the country-level competitiveness for Denmark measured by exports. Starting with the Narrowly Strong PH, stating that the green technological development should only affect the green side of the economy and

[33] Where instead of η^{ROW}_{gr} the renewability share of green capital in Denmark will be used (η^{DK}_{gr}).
[34] Not using these moving average equations will lead to an overshooting of the effects associated with improving the efficiency of green capital.
[35] Which is the same as improving the efficiency of imported green capital by ROW.

thereby only green exports, we introduce a link between green exports and the efficiency of green capital as shown below[36]:

$$X_{gr}^{DK} = \exp\left(\Omega_0^X + \Omega_1^X * log(X_{DK}) + \Omega_2^X * log\left(\eta_{gr}^{DK}\right)\right)$$

From the second term, we see that green exports are also dependent on total exports as we assume that a fixed share of new exports is green capital.

With only the Weak PH active, the introduction of a carbon tax increases the efficiency of green imported capital by ROW. With the introduction of the Narrowly Strong PH, not only will the efficiency of green imported capital for ROW improve, but ROW will also import a larger stock as the efficiency improves, thereby increasing the level of imported green capital by ROW (indicated by the red arrow going from η_{gr}^{DK} to X_{gr}^{DK} in the DAG shown above in Figure 4-3).

Turning to the Strong PH, which indicates that overall competitiveness improves as green technological efficiency improves, the story is almost the same. As we introduce a link between the efficiency of green capital and total exports (indicated by the red arrow going from η_{gr}^{DK} to X_{DK}), as shown below[37]:

$$X_{DK} = \exp\left(\varepsilon_0 + \varepsilon_1 * log(Y_{ROW}) + \varepsilon_2 * log\left(\eta_{gr}^{DK}\right)\right)$$

Introducing the efficiency of green capital in the equation for total exports thereby has an indirect effect on the green export as we assumed that a fixed share of new exports will consist of green capital. Thereby the inclusion of the Strong PH should not only increase total exports, but also increase the level of green exports (indicated by the red arrow going from X_{DK} to X_{gr}^{DK})[38].

Lastly, we should comment on how the PH framework is capable of affecting the renewability share of the capital stock in ROW (η_{ROW}), thereby affecting emission in ROW.

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[36] We assume that the Narrowly Strong PH is only active for Denmark, as the main argument for a country experiencing the effects of the Narrowly Strong PH is due to First mover effects, where we assume the first mover effect to be only active in Denmark especially within the renewability sector. Similar assumptions are used when estimating spillover effects when experiencing technological development (e.g. Bosetti et al. (2008)).

[37] In Appendix -A we include the exchange rate within this equation (and others) but as we model a fixed exchange regime the exchange rate is just set to 1. This enables a replication of this model for a floating exchange rate.

[38] In Appendix -D (page 123) , we provide the final results when removing this assumption, whereas the increase in total exports is only associated with an increase in "normal" exports as the effect on the green side of the economy is captured by the Narrowly Strong PH as presented by Jaffe & Palmer (1997).

The effect of the PH framework on efficiency in ROW

The equations allowing the PH framework to affect the efficiency of green capital in ROW should not be new for the reader, as most of these equations has already been introduced throughout the model presentation and will follow the red arrows going from X_{gr}^{DK} to IM_{gr}^{ROW}, from IM_{gr}^{ROW} to INV_{grim}^{ROW}, and lastly from INV_{grim}^{ROW} to the efficiency of the capital stock in ROW (η_{ROW}).

First, the increase in Danish exports of green capital is by identity equal to an increase in imports of green capital by ROW:

$$IM_{gr}^{ROW} = X_{gr}^{DK}$$

As only firms are capable of importing green capital, the entire stock of imported green capital by ROW is directly associated with firms' investments in imported green capital.

$$INV_{grim}^{ROW} = IM_{gr}^{ROW}$$

As we indicate by the dashed red arrow going from η_{gr}^{DK} to X_{gr}^{DK}, these investments are associated with the renewability share of green capital in Denmark, whereas they improve the efficiency of the capital stock in ROW (η_{ROW}).

Thereby, all three versions of the PH framework have now been implemented within the two-area ecological SFC model used in this paper, allowing them to affect the efficiency of the capital stock in ROW through international trade. We have so far added several new equations and therefore also parameters to the model compared with the model presented by Carnevali et al. (2021)[39]. Additionally, the size of the two economies should be adjusted to analyze a small open economy like Denmark in relation to the rest of the world. Therefore, the next section will introduce a calibration of the model parameters to ensure both a realistic implementation of the PH framework as well as a realistic relationship between a small open economy like Denmark and the rest of the world.

[39] In Appendix -C (Figure 1) we show that there are no leakages in the baseline models, as the two redundant equations are fulfilled.

4.2 Calibration of the model

In this section, we will describe the calibration of the model commenting on both the calibration of new parameters, associated with the implementation of the PH framework, and already existing parameters as we calibrate key variables such as GDP, government spending, consumption to match the observed data for Denmark and ROW[40]. As we wish to analyze the effect of having different degrees of the PH framework active in the model, we create four different baseline models with different versions of the PH framework active and therefore also including slightly different parameter values. In the end, we will perform a validation of these baseline models obtained, with a goal of fitting all four baseline models to match the levels and trends of real data as good as possible[41].

4.2.1 Calibration of existing parameters

To obtain as realistic results as possible, we calibrate key variables within the economy of Denmark and ROW to follow real data. For this reason, we create a small data bank containing data for the world and Danish economy in the period of 1960-2017[42]. We use this data to calculate the shares of the Danish economy relatively to the world economy for the key variables, whereas we can use these shares to adjust the existing parameters and starting values presented by Carnevali et al. (2021) [43], thereby creating realistic parameters for both the Danish economy and the rest of the world. Additionally, we also include differences in parameters like the tax rate, rate of consumption, Co2 intensity, energy intensity, and others between the two economies to make the model as realistic as possible. To create a realistic starting point for the model, we use the same strategy as Carnevali et al. (2021), using the obtained data to hold a few key variables fixed (for example total consumption and government spending) up until 2017 whereafter these variables are endogenized[44].

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[40] All parameter values will be presented in Appendix -B.

[41] When we start including different channels using log relationships, the starting values of some variables change therefore we adjust the autonomous level in these variables to be as close to each other as possible, still this might create small differences across the four baseline models.

[42] Using data from the World Bank, IMF, and Ritchie and Roser 2017. The small data bank is available on GitHub following the link presented in the Preface.

[43] By taking one minus the share of the Danish economy relative to the world economy.

[44] For example, conventional government spending is set equal to the observed data up until 2017, whereafter it is determined by the AR (1) process presented earlier. These methods are also used by (Carnevali et al., 2021).

4.2.2 Calibration of new parameters

When calibrating new parameters, we will have a specific focus on making the implementation of the PH framework as realistic as possible, whereas we mostly base these parameter values on empirical findings, using the evidence presented in the literature review from Section 2.

Starting with the parameters for the Weak PH we introduced a relationship between a carbon tax (this carbon tax will later be introduced) and firms investments in green R&D (Γ_2^{DK})[45], to set this parameter, we use the empirical evidence presented by Jaffe & Palmer (1997) finding a coefficient value of 0.15[46]. Thereby, a 1% increase in firms costs associated with environmental regulations increase firms R&D expenses by 0.15%.

Another important aspect for the Weak PH is the initial size of R&D spending, for this reason, we should both look at the determination of government spending towards green R&D as well as firms' investments in green R&D.

Starting with government spending in green R&D, this is calculated to be 5% of total green government spending using data from Denmark's statistics to set this ratio[47]. Firms' investments in green R&D spending is set to be 10% of total investments mainly to match the observed growth rate in real data for the renewability share, which we will comment on later. In the graph below, we see the level of government spending towards both green MOIS and green R&D. We also observe that green government spending is introduced in 1990[48], meaning that up until this point, the government has only been able to stimulate the economy through conventional government spending.

[45] The Weak PH is also active in the rest of the world through the parameter Γ_2^{ROW}, but will have no effect as no carbon tax is introduced here.

[46] This estimate of 0.15 is also used by Bosetti et al. (2008) when analyzing international spillovers of technological development. We do also perform a sensitivity analysis lowering this estimate to 0.1 which does not seem to change the results, this analysis can be seen in Appendix -D on page 127.

[47] Whereas we set green MOIS to be the remaining 95%.

[48] This is also the case for firms' investments in green R&D, whereas green technological development will only happen after 1990.

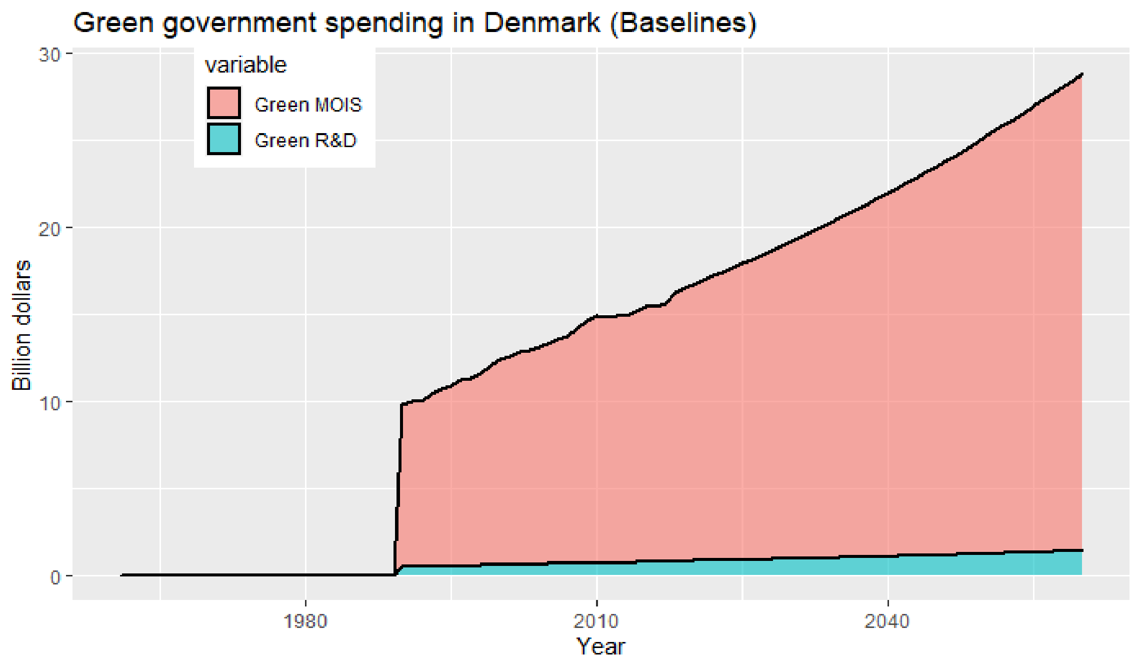


Figure 4-4 Danish green government spending in the four baseline models

As the Weak PH also implies changes to green technological efficiency, several parameters are set to obtain a realistic development for the renewability share of the capital stock in Denmark (η_{DK}). The main goal being to calibrate parameters to match the growth rate observed from real data, calculated to be approximately 4.5%[49]. This includes both determining the size of government and firms green R&D spending as argued above, but also setting the parameters for how R&D spending affects the renewability share of green capital in Denmark. The main parameter explaining this relationship was introduced in the equation describing the improvements of green capital in Denmark (η_{impv}^{DK}) being the parameter $impv_1^{DK}$[50].

We will now turn towards the calibration of parameters for implementing the relationship between technological development and country-level competitiveness associated with the Narrowly Strong and Strong PH. Starting with the Narrowly Strong PH and therefore green exports, we set the parameter determining how the efficiency of green capital affects green exports (Ω_2^X) equal to 0.5 implying that a 1% increase in the renewability share of green capital increase green exports by 0.5%. This coefficient is set according to the empirical evidence found by Hwang & Kim (2017) who find that reducing the Co2 intensity

[49] Using data on the renewability share for Denmark from Eurostat starting from 2004 up until 2021.
[50] Where a positive relationship is found by the literature looking at technological development within renewable energy (Schmidt-ehmcke et al., 2010).

by 1% increases green exports by 0.46%. Costantini & Mazzanti (2012) also find a coefficient of similar magnitude regressing patent data on green exports[51]. The size of green exports is calibrated to hit approximately 8% of total exports in 2021 thus matching the findings of The Danish Energy Agency (2022b).

Turning to the Strong PH, we include a relationship between technological development, again measured by the renewability share of green capital, and total exports determined by (ε_2)[52]. Here we use the empirical evidence presented by Costantini & Mazzanti (2012), who find empirical evidence for the Strong PH using R&D expenditure and green patent data as a proxy for green technological improvements. Their estimates for the relationship between green technological improvements and total exports lie in the range of 0.05-0.14. As we earlier found the Strong PH to be the most controversial, with a large share of non-significant results, we go with the lower value of 0.05[53].
The additional coefficients included in the equations for Danish exports and imports are set to match real data in the start of the simulation (1960)[54].

Besides from the parameter values presented above, the remaining parameter values are given realistic and reasonable values (see Appendix -B for an overview of the parameter values), enabling us to reproduce the trends observed for the Danish economy as we will present in the upcoming section when validating the four baseline models. Before presenting the validation, we will provide an overview of the four different baseline models including different degrees of the PH framework. We include the different versions of the PH framework (Weak PH, Narrowly Strong PH, and Strong PH) based on their empirical evidence discussed in Section 2. The specification of each baseline model is presented in the table below:

Table 2: Specifications of the four baseline models.

Coefficient\Baseline	Baseline 1	Baseline 2	Baseline 3	Baseline 4
Γ_2^{DK} & Γ_2^{ROW}	0	0.15	0.15	0.15
Ω_2^X	0	0	0.5	0.5
ε_2 & μ_2	0	0	0	0.05

[51] Costantini & Mazzanti (2012) estimates a significant coefficient to lie within a range of 0.1-0.55 using different measures, while Hwang & Kim (2017) finds two significant estimates of this coefficient being 0.46 as presented above, but also 0.22. As the first is found to be significant on a higher significance level we use this coefficient in the main analysis, still we perform a sensitivity analysis shown in Appendix -D (page 121) setting the parameter to 0.22 which also matches the range found by Costantini & Mazzanti (2012).
[52] The Strong PH is also introduced for the rest of the world through the parameter μ_2.
[53] We also perform a sensitivity analysis of this parameter, increasing it to 0.1 shown in Appendix -D on page 122.
[54] We do this to obtain realistic starting values for other key variables such as GDP, consumption, and investments. This leads to a small deviation from the observed trade balance at the time the carbon tax is introduced. Changing the coefficients for the export and import equation to match the observed trade balance in 2017 does not change any of the conclusions of this paper (see Appendix -D on page 126 and 127).

Baseline 1 does not include any of the three versions of the PH framework and will be providing a basis of comparison as we start implementing this framework. *Baseline 2* introduces the coefficient of $\Gamma_2^{DK} = \Gamma_2^{ROW} = 0.15$ and thereby includes the most empirically justified version of the PH framework being the Weak PH where unilateral carbon policies affect firms spending towards green R&D. In *Baseline 3* we set $\Omega_2^X = 0.5$ thereby introducing the Narrowly Strong PH, creating a relationship between the efficiency of green capital and green exports within Denmark. Lastly in *Baseline 4,* we set $\varepsilon_2 = \mu_2 = 0.05$ introducing the Strong PH creating a link between the efficiency of green capital and total exports, this relationship seems to be the most controversial of the three versions as the literature is still relatively split. However, significant results seem to find a positive relationship between unilateral carbon policies and country-level competitiveness in the form of exports, as presented in Section 2.

4.2.3 Validation of the model

So far, we have introduced the calibration of the four baseline models, and how the four baseline models include different degrees of the PH framework, whereas we now turn to the validation of these models using the figures presented below. Here we plot the simulated values of GDP and emission in Denmark and ROW, together with the observed data[55]. We observe that the simulated values of GDP overall fits the trend of the data both before and after 2017 for both Denmark and ROW. Looking at emission, the model seems to be able to match the data up till 2017 for the rest of the world, while we observe an overshoot in the Danish emission especially from 2000-2017, with the main reason being that all other measures than the renewability share and Co2 intensity are held fixed over time[56]. After 2017, we see that the overall trend of emission starts falling in both economies mainly as a result of a higher green capital to total capital ratio as well as the efficiency of the capital stock improving[57]. Overall, we are able to validate the four baseline models as we observe that they are capable of matching the trends observed in the data[58].

[55] In Appendix -C (Figure 2, Figure 3, and Figure 4), we include additional variables in the validation, all capable of matching the trend observed in real data.
[56] Measures like energy intensity and matter intensity for both green and conventional capital is unchanged over the entire simulation (just as in Carnevali et al. (2021)). As we do not want to overcomplicate the model we accept this overshooting, as this should not change the overall effects relative to each other.
[57] The increasing share of green capital is a result of the exogenously set growth rate of firm's green investments ($INV_{gr}^{DK}, INV_{gr}^{ROW}$). Whereas the increase in green technological efficiency is a result of the endogenization of the renewability share of green capital ($\eta_{gr}^{DK}, \eta_{gr}^{ROW}$), and the exogenously determined degrowth of the Co2 intensity of green capital ($\beta_{gr}^{DK}, \beta_{gr}^{ROW}$).
[58] As there is almost no difference between the four baseline models, the lines representing each model lays on top of each other.

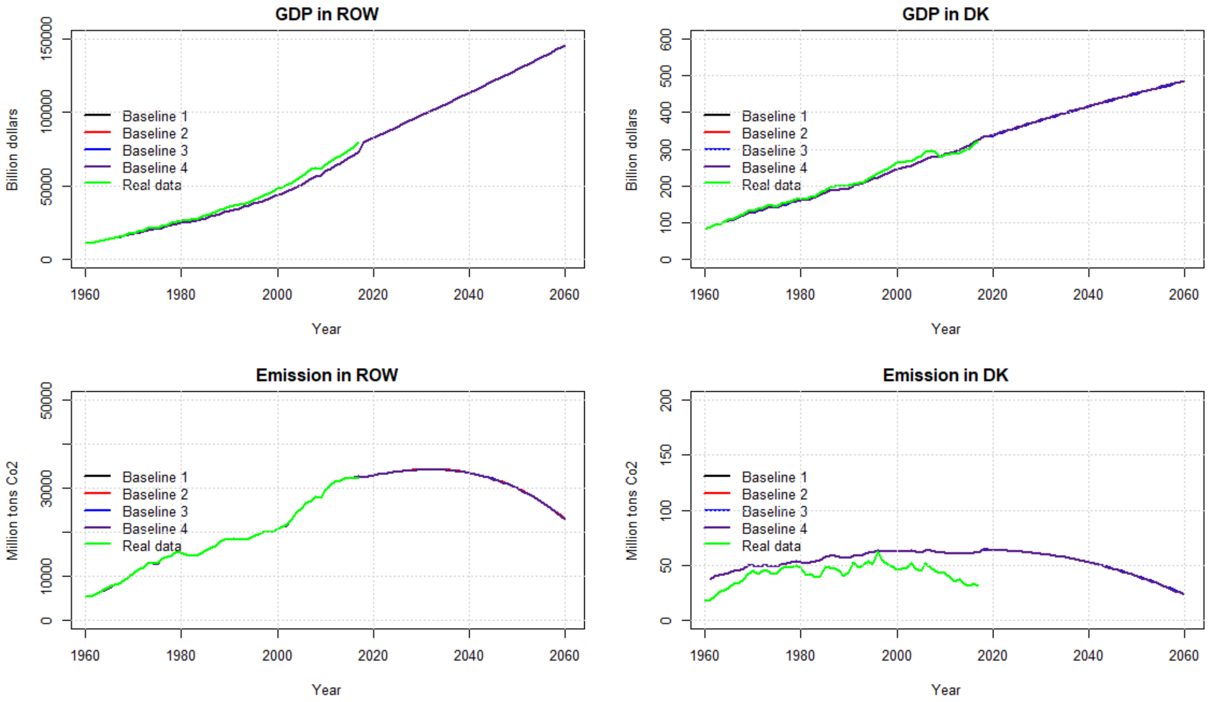


Figure 4-5 Validation of the four baselines (GDP and Emission)

We have now presented the most important dynamics within the two-area ecological SFC model used for the analysis of this paper. Besides describing the most central equations, we also commented on the equations incorporating the different versions of the PH framework. We then touched on the calibration of the model both looking at existing and new parameters, leaving us with four different baseline models including different degrees of the PH framework. Lastly, we compared the simulated values of the four baseline models with real data, thereby providing a validation of each of the four models.

In the upcoming section, we will analyze whether activating different degrees of the PH framework changes the way in which a small open economy like Denmark can affect emission in the rest of the world, by implementing the type of policy-mix described in Section 3.

Section 5 Introducing a policy-mix in the Danish economy

In the previous section, we introduced the two-area ecological SFC model for Denmark and ROW, resulting in four different baseline models each including different degrees of the PH framework. The scope of this section will be to use these four baseline models to analyze the effect on emission in Denmark and ROW, when implementing an environmental regulation in Denmark, having different degrees of the PH framework active. We start this section by providing a description of the environmental regulation introduced as a shock to the four baseline models. Next, we will present each scenario individually with a focus on showing what channels are activated as we have different degrees of the PH framework active when implementing the environmental regulation. Lastly, we analyze the effect on emission, comparing the results of each scenario relative to each other, thereby investigating whether accepting different degrees of the PH framework will increase or decrease the effect on emission in Denmark and ROW, useful when discussing the negation of the PH framework in the current calculation of leakage rates in Section 6.

5.1 Introducing the policy-mix

As mentioned, we start this section by presenting the design of the environmental regulation which we will introduce as a shock to the Danish economy. Most often the leakage rate literature base their calculations on the implementation of a carbon tax, we take a similar approach as this type of flexible and market based regulation was also found to be preferred by the PH framework in Section 3. Additionally, we found that using the revenue of this carbon tax could further stimulate innovation enhancing the effects of the PH framework. Therefore, we argue that implementing a policy-mix, introducing a carbon tax and allowing the government to use the revenue of this tax towards green government spending, is the best way of testing the different degrees of the PH framework. We will start out by introducing the equations used for implementing the carbon tax within the model, whereafter we show how the government can use the obtained tax revenue.

We begin the implementation of the carbon tax by determining the size of the tax measured by the cost per ton of Co2 emitted ($Co2_{rate}^{DK}$), we use the political agreement recently presented by the Danish parliament (2022) setting the carbon tax to 50 USD in 2025, with increments of 12 USD each year until 2030; thereafter it is held fixed at 110 USD[59]. From the tax rate, we can calculate the total sum of the carbon tax ($Co2_{Tax}^{DK}$) as follows[60]:

$$Co2_{Tax}^{DK} = (emis_{DK} * Co2_{rate}^{DK})/100$$

As the carbon tax is paid by the firms, we subtract the total amount of the carbon tax from the firm's profit function, as seen below. The carbon tax is then also included within the government's tax incomes, and thereby public finances.

$$f^{DK} = y^{DK} - y_w^{DK} - da^{DK} - r_{l_{t-1}}^{DK} * l_{firm_{t-1}}^{DK} - Co2_{Tax}^{DK}$$

$$T_{DK} = (y_r^{DK} + y_w^{DK}) * \theta_{DK} + Co2_{Tax}^{DK}$$

The government can spend the carbon tax revenue on the two types of green government spending (green MOIS and green R&D) presented in Section 4. The government will be able to divide the tax income towards these two types of green government spending indicated by ($Co2_{MOIS}^{DK}$), and ($Co2_{R\&D}^{DK}$) in the equation below[61]. Additionally, the government spend an exogenously determined level of government spending (GOV_{GrOb}^{DK}) each year, which we previously argued to be split between government spending towards green MOIS and government spending for green R&D[62].

$$GOV_{MOIS}^{DK} = GOV_{GrOb}^{DK} * S_{MOIS}^{DK} + \ Co2_{MOIS}^{DK}$$
$$GOV_{R\&D}^{DK} = GOV_{GrOb}^{DK} * S_{R\&D}^{DK} + Co2_{R\&D}^{DK}$$

This concludes the implementation of the policy-mix with a goal of: I.) Increasing firms costs associated with emission through a carbon tax, spurring firms green R&D spending. II.) Increasing government spending towards green MOIS, spurring firms' green investments. III.) Increasing government spending towards green R&D, spurring green innovation in the economy. In the next section, we will provide a short introduction of the four scenarios, before presenting the results.

[59] The carbon tax will only be implemented for the industries outside the European quota system. We will in section 6 provide a more detailed description of this quota system.
[60] To keep the same level of units we divide by 100.
[61] The share of tax income going to green MOIS, and green R&D is split 50/50.
[62] Based on data from Denmark's statistics, we set green government spending to be 20% of total government spending starting from 1990. This share is set relatively high compared to what is found in real data (Denmark's statistics) of 5%. We use the 20% as this enables us to hit the observed level and growth rate of the renewability share in Denmark. In Appendix -D on page 125 we perform a sensitivity analysis setting green government spending to 5% of total government spending still starting from 1990. Doing this leaves us with the same conclusion as in the main analysis (see also Appendix -D page 128).

5.2 Introducing the four scenarios

In Section 4.2.3 we introduced the four baseline models each including different degrees of the PH framework based on the empirical evidence found in Section 2[63]. We will now introduce four scenarios, implementing the policy-mix just described within each of the four baseline models. We should then be able to analyze how accepting different degrees of the Porter Hypothesis affect emission in a small open economy like Denmark, but more importantly, how Denmark as a small open economy will be able to affect world emission through international trade. Below we present a short overview of the four scenarios performed in this paper:

Scenario 1: In this scenario we go against the empirical evidence found previously by excluding the framework of the Porter Hypothesis when implementing the policy-mix. Thereby, this scenario is mainly providing a basis of comparison with the other scenarios enabling us to isolate the effects of including different degrees of the PH framework[64].

Scenario 2: In this scenario we introduce the same policy-mix as in Scenario 1, but now in the baseline model including the effects of the Weak PH, thereby having a link between the costs associated with the carbon tax and firms' green R&D spending, using the estimate found by Jaffe & Palmer (1997) that a 1% increase in firms pollution abatement costs increases R&D spending by 0.15%.

Scenario 3: In this scenario we again introduce the policy-mix, now in the baseline model including both the Narrowly Strong PH and the Weak PH. The introduction of the Narrowly strong PH allows technological development to affect green export, using the empirical evidence found by Hwang & Kim (2017) that a fall in Co2 intensity of 1% increases green export by 0.5%.

Scenario 4: Like in the previous scenarios we again introduce the same policy-mix, now within the baseline model including both the Strong, Narrowly strong, and Weak PH. Introducing the Strong PH lets technological development affect both the total level of export and green export at the same time, using the empirical evidence found by Costantini & Mazzanti (2012) that an increase in technological efficiency of 1% (measured using patent data) increases total exports by 0.05%.

[63] We found the empirical evidence for the Weak PH to be the strongest, as well as the Strong PH being the most controversial, whereas we introduce the Weak PH in all three scenarios where the PH framework is active, while only having the Strong PH active in Scenario 4.

[64] Even though the PH framework is not included, technological development is held endogenous in this scenario, whereas we should still expect a small effect on emission in ROW.

In the following section, we will demonstrate how accepting different versions of the PH framework, as we implement the policy-mix in Denmark, creates new channels for the policy-mix to affect the two economies, thereby creating differences between the four scenarios.

5.3 How the policy-mix affects the Danish economy through different channels

As our analysis is based on performing the exact same shock (introducing the policy-mix described in Section 5.1 in Denmark) within each of the four baseline models, the effects of implementing this shock will be different for each scenario, whereas we can attribute these differences to the three versions of the PH framework. In this section, we will look at what channels are associated with activating the Weak PH, Narrowly Strong PH, and Strong PH when implementing the shock[65]. But we should also comment on some of the general channels activated within all four scenarios as the shock is introduced.

To analyze the general channels activated when introducing the policy-mix, we begin by looking at the components of the policy-mix being the carbon tax itself and the recycling of the carbon tax revenue towards green government spending. As the Weak-, Narrowly Strong-, and Strong PH does not affect these variables we should expect the same effect across all four scenarios.

Looking at the carbon tax revenue shown in the appendix (Figure 5), we see that the revenue is approximately 3000 million USD in 2025 increasing to approximately 6500 million USD in 2030 within all four scenarios[66]. The revenue is then recycled into two types of government spending being government spending in green MOIS and green R&D shown below[67].

[65] These channels should be expected to match the three effects presented in Section 4.1.3, represented by the red arrows in the DAG presented in Figure 4-3.

[66] The small differences between the four scenarios are associated with the small differences in emission, as some of the effects of the PH framework results in a higher reduction of Danish emission, which will be discussed later.

[67] To compare the green government spending before and after introducing the policy-mix one should look at Figure 4-4.

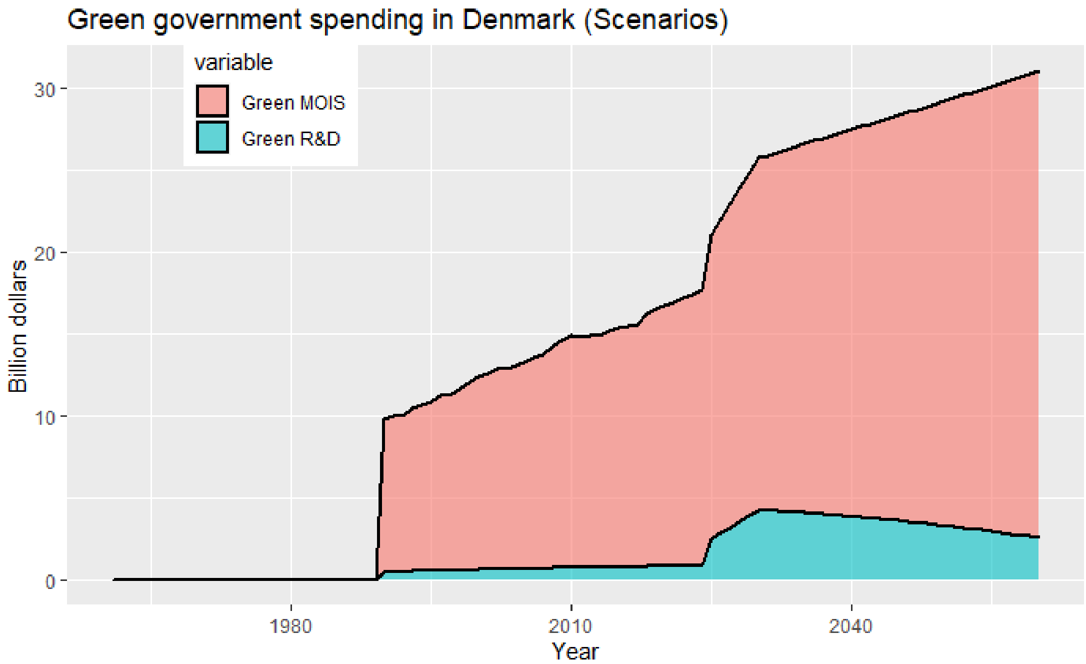


Figure 5-1 Green government spending in Denmark (Scenario 1-4)

As expected, we observe that the government increases their spending towards green MOIS and green R&D as the carbon tax is introduced in 2025[68].

Now that we have demonstrated the channels through which the policy-mix impacts the economy identically for all four scenarios, we will present how the introduction of the policy-mix can lead to different economic impacts, depending on what versions of the PH framework are activated. When looking at these channels, we will use three measures: I.) Efficiency of Danish green capital measured by the renewability share of green capital in Denmark II.) Green Danish export, III.) Total Danish exports.

Scenario 1:

As mentioned, Scenario 1 is mainly providing a basis of comparison by omitting the PH framework. Still, Scenario 1 will introduce a new aspect to the current literature by having technological change endogenous within the model. Therefore, as the government recycles the carbon tax revenue into green R&D spending, we should expect an improvement in the efficiency of Danish green capital[69], observed in the plot below:

[68]After 2030 we see that green R&D spending starts falling meanwhile green MOIS keeps rising, as the carbon tax is equally split and green R&D is a smaller share of green government spending, then the fall in the carbon tax which happens over time after 2030 as a result of lower emission will outweigh the overall increase in government spending.

[69] Even though green technological efficiency (measured by the renewability share of green capital) is also endogenized in ROW, there will be no change in this measure as there is not introduced any carbon tax in ROW. The level of the different measures of renewability share for both Denmark and ROW can be seen in the appendix (Figure 6 and Figure 7).

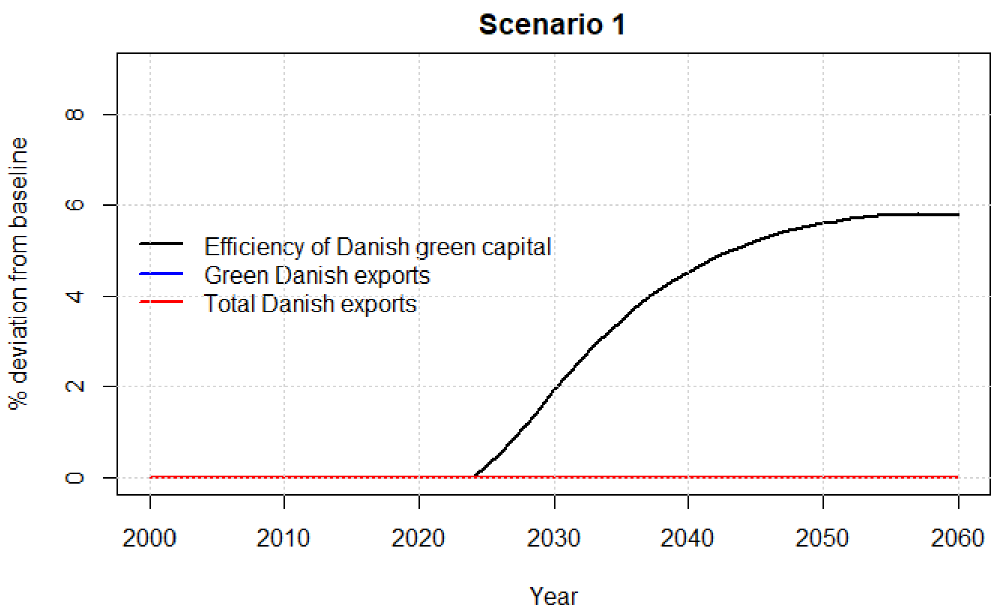


Figure 5-2 Implementing the PH framework: Scenario 1

As the Weak PH is not active in this scenario, the increase in green technological development should only be associated with the increase in green government R&D spending[70]. We do not observe any changes in green exports or total exports for Denmark, which should also be expected, as the Narrowly Strong and Strong PH is not active.

Scenario 2:

In Scenario 2, we perform the same shock as in Scenario 1 now using the baseline including the Weak PH, allowing firms' costs associated with the carbon tax to affect firms' investments towards green R&D. As shown in the appendix (Figure 5) the costs associated with the carbon tax increase, whereas we should expect an increase in firms' investments towards green R&D in Denmark[71]. To see the effect on firms' investments in green R&D, we have plotted this variable before and after introducing the policy-mix below[72].

[70] In appendix (Figure 8) we plot the level change in firms' green R&D spending, where one should note a small increase in Scenario 1, this is associated with the increase in total government spending as a result of the increasing green government spending, thereby increasing total investments.
[71] The Weak PH is also active in ROW, but as no carbon tax is introduced, it plays no effect.
[72] We assume that the introduction of a carbon tax does not have a level effect on firms' green R&D spending, we have simulated all scenarios changing this assumption allowing for a level effect on firms' green investments as a carbon tax is introduced. This still leads to the same overall differences between the scenarios just with a larger magnitude. The main results are shown in the sensitivity analysis provided in Appendix -D (page 124).

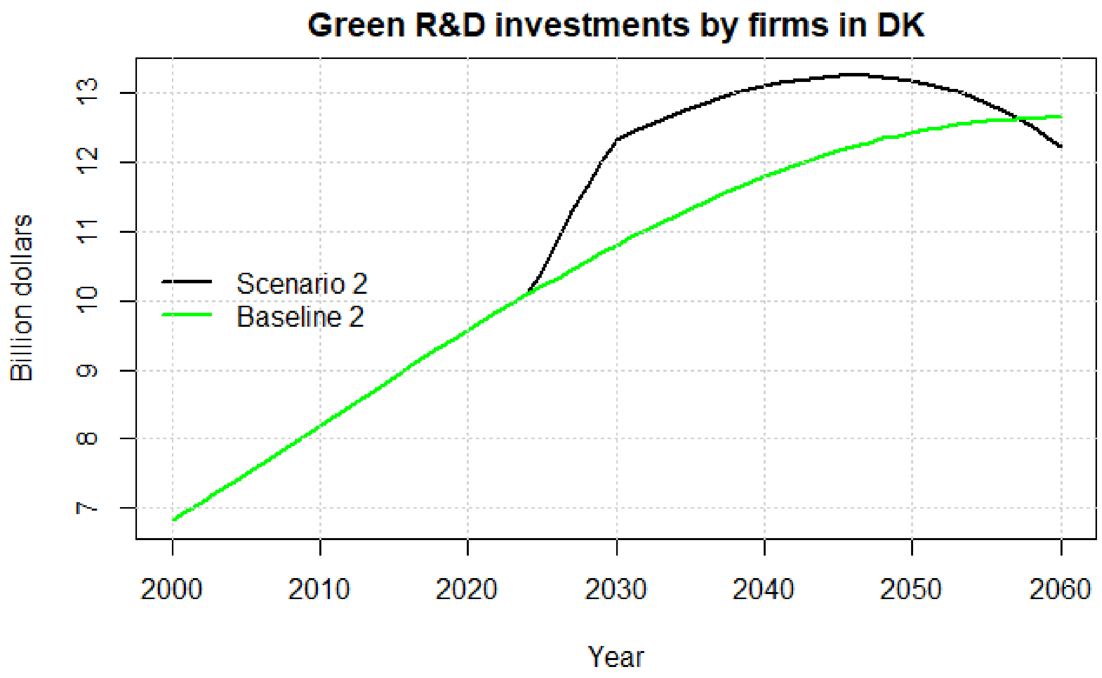


Figure 5-3 Danish firms green R&D spending

After implementing the policy-mix (Scenario 2), we observe a higher growth rate of firms' green R&D investments in the period of 2025-2030 relative to the baseline, as the total amount of the carbon tax increases within this period. But looking at the growth rate after 2030, we see that the growth in firms' investments in green R&D is actually lower in the scenario relative to the baseline[73]. Overall, we observe that firms' green R&D spending is higher in the period of 2025-2055 relative to the baseline, when introducing the policy-mix, whereas the efficiency of green capital will become relatively better within this period.

This is also observed when looking at the change in the efficiency of Danish green capital, where we now observe an increase of approximately 8% in the end of the period, compared to approximately 6% in Scenario 1.

[73] This happens as the tax rate is held fixed at 110 USD, while total emission is falling faster in the scenario compared to the baseline, whereas firms' costs associated with the carbon tax start falling (see Figure 5).

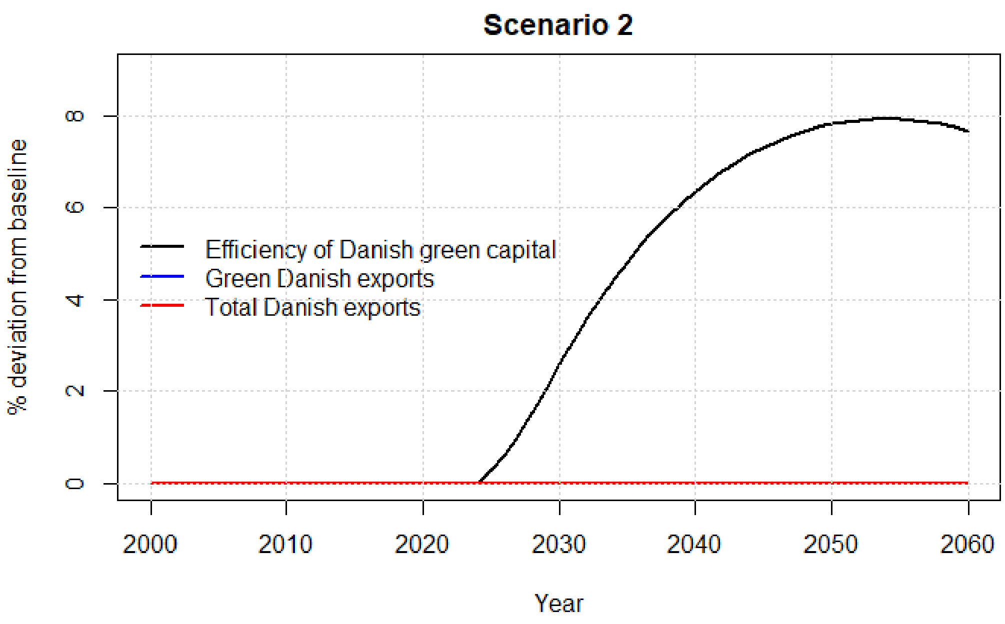


Figure 5-4 Implementing the PH framework: Scenario 2

As we do not include the effects of the Narrowly Strong and Strong PH, we observe no effect on green exports or total exports in Denmark.

Scenario 3:

We now introduce the policy-mix in the baseline model including both the Weak PH and the Narrowly Strong PH, thereby allowing for the efficiency of Danish green capital to affect country-level competitiveness of green firms (green export), using the empirical evidence found earlier (Costantini & Mazzanti, 2012; Hwang & Kim, 2017). As expected, we now observe an increase in the Danish green exports when implementing the policy-mix, as firms green R&D investments and governments green R&D spending increase, thereby improving the efficiency of Danish green capital[74]:

[74] As mentioned earlier, the Narrowly Strong PH is not active in ROW, as technological developments should only be associated with green exports as a result of first mover advantage, which we assume is not active in ROW.

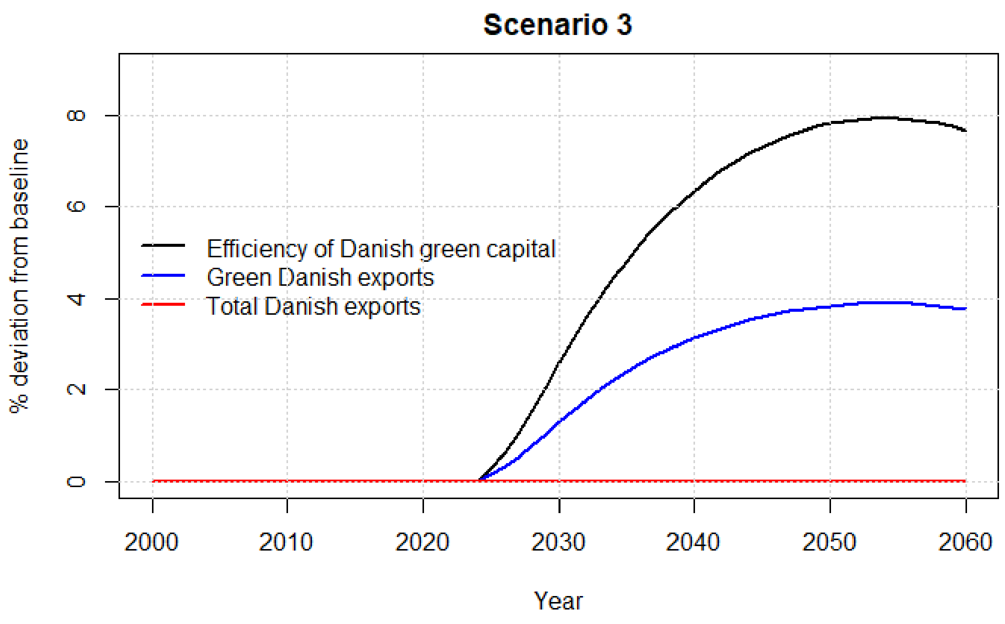


Figure 5-5 Implementing the PH framework: Scenario 3

As Danish green exports by identity are set equal to the green imports for the rest of the world, the later should increase with the exact same magnitude as seen in the appendix (Figure 9).

As only firms in ROW are capable of importing Danish green capital, the increase in green imports by ROW is directly associated with an increase in firms' investments of imported green capital in ROW (see appendix Figure 10), which then increases the capital stock of imported green capital over time, as shown in the plot below:

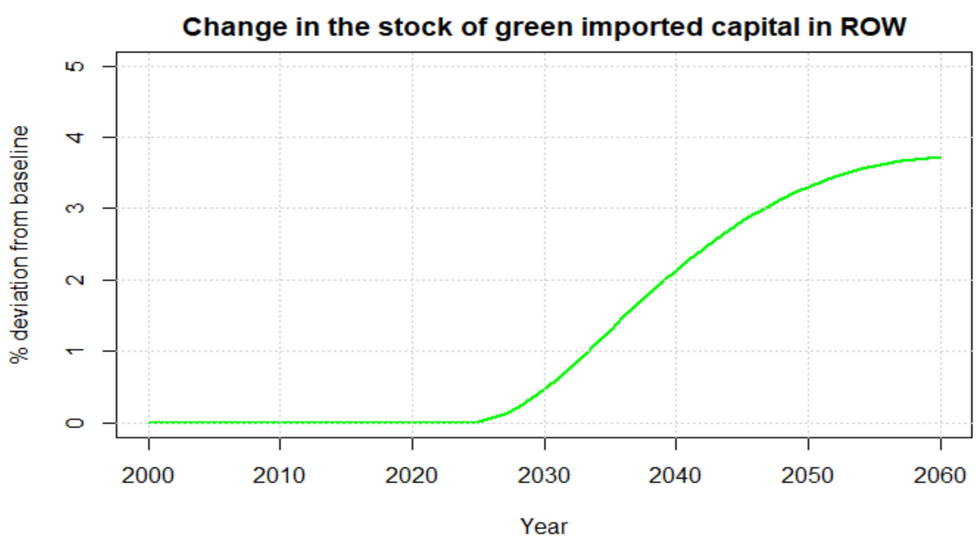


Figure 5-6 Change in green imported capital in ROW

As conventional capital in ROW is directly substituted with the new imported green capital, meanwhile Denmark also improves its efficiency of green capital, this increase in imported green capital by ROW should have an effect on emission in the rest of the world which we will comment on in the upcoming section.

Scenario 4:

In this last scenario, we introduce the policy-mix in the baseline model including both the Weak-, Narrowly Strong-, and the Strong PH. The introduction of the Strong PH, like the Narrowly Strong PH, also affects the level of Danish green exports but is doing it indirectly through increasing the total exports in Denmark. Therefore, we observe a further increase in the Danish green exports compared to Scenario 3[75], while also seeing an increase in total Danish exports shown in the plot below:

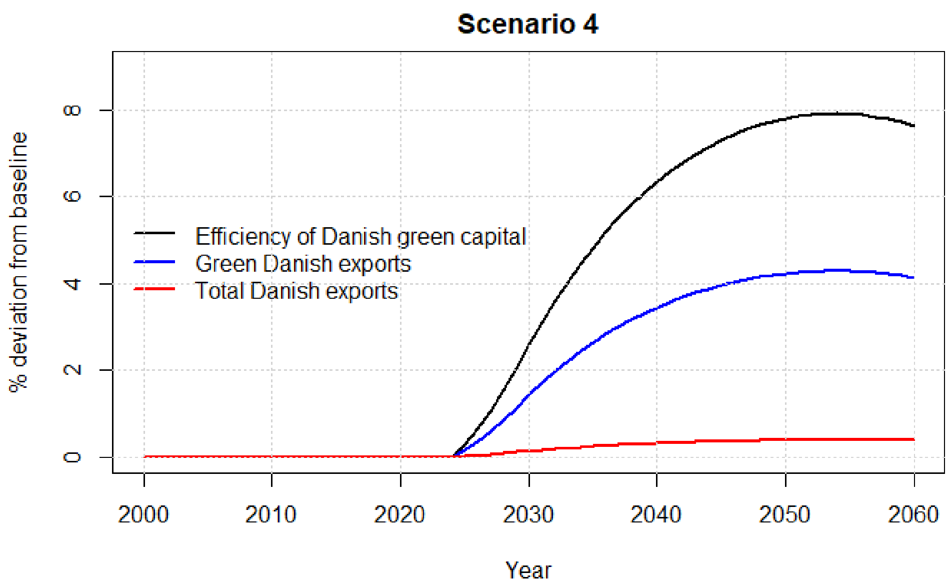


Figure 5-7 Implementing the PH framework: Scenario 4

In contrast to the previous scenario the total Danish exports are now affected, whereas we should also expect an effect on the trade balance for Denmark and ROW. In the plot below we have plotted the Danish trade balance together with its components (Danish imports and exports)[76].

[75] In some literature providing the theoretical basis of the Strong PH, this second channel will not be active as they argue that the Narrowly Strong PH already accounts for the effect on the green exports, whereas the new export associated with the Strong PH is only associated with conventional export. The results of adopting this view can be seen in appendix (page 123) and does not seem to impact the overall findings of this paper.

[76] As mentioned in section 4.2 we calibrated the model to match Danish export and import from 1960 leading to a slight deficit on the Danish trade balance. As mentioned, this do not change the main conclusions (see appendix page 126 and 127)

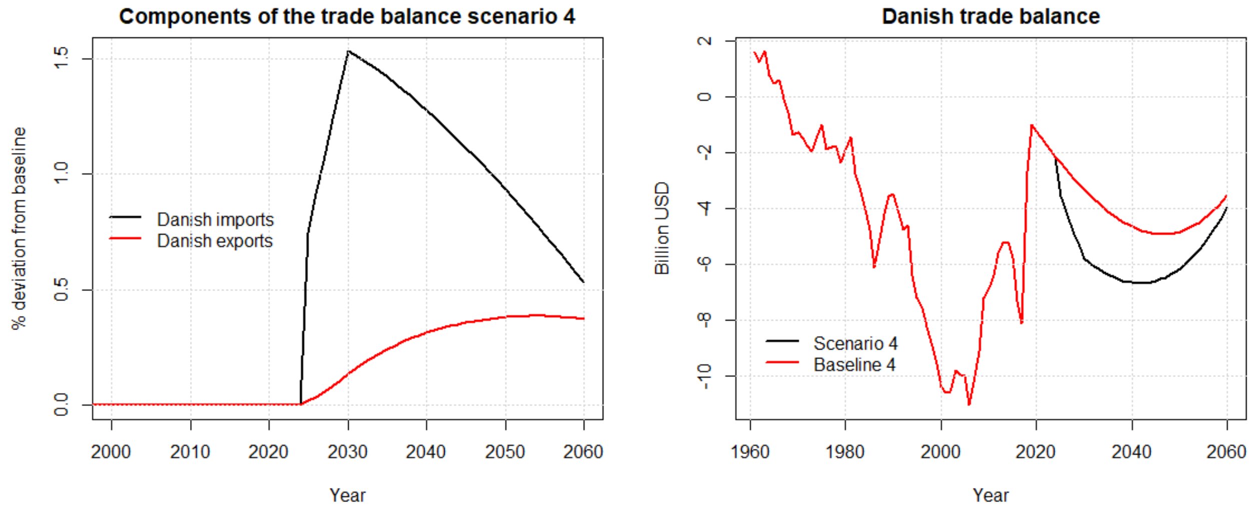


Figure 5-8 The effect on the Danish trade balance in Scenario 4 and the underlying components

Here we observe an increase in total Danish exports as a result of higher level of competitiveness for domestic firms associated with the improved efficiency of Danish green capital. More surprisingly, we observe an increase in Danish imports larger than the increase in exports. The higher imports can be associated with an increase in Danish GDP (which we will comment on later) increasing the Danish demand for international goods. As the increase in imports exceed the increase in exports, we will observe a drop in the Danish trade balance as a result of implementing the policy-mix. But the drop in the Danish trade balance would have been of a higher magnitude if there would not have been an increase in total Danish exports associated with the Strong PH[77].

This concludes the presentation of the main channels activated when implementing the policy-mix within Denmark, including different degrees of the PH framework. In the next section, we will turn our focus towards changes in emission within Denmark and ROW as a result of implementing the policy-mix.

5.4 Analyzing the effect on emission within the four scenarios

In the previous section, we presented how implementing the policy-mix in Denmark, impacted mainly the Danish economy through different channels, with a main goal of showing that including different versions of the PH framework activates new but expected channels. Still, we have not discussed how the implementation of the policy-mix affect emission within Denmark and ROW, which will be the focus of this section. As we are not using a fully empirical model the exact magnitude of a change in emission should be interpreted carefully. The focus should instead be towards the relative differences between the four

[77] In the next section, we will see that the effects of the Strong PH increasing total exports results in a lower deficit on the trade balance compared to the other scenarios not including the Strong PH.

scenarios using Scenario 1 as a basis of comparison. When looking at the change in emission associated with the implementation of the PH framework, two overall channels should be analyzed for both Denmark and ROW. To help the reader follow along, we have provided a DAG in the appendix (Figure 11) showing the relationships between the three measures presented in the previous section (efficiency of Danish green capital (η_{Gr}^{DK}), Danish green exports (X_{GR}^{DK}), and Danish total exports (X_{DK})) and the two channels directly associated with emission in Denmark and ROW.

I.) The first channel goes through output, as a change in output within Denmark or ROW increases the need for energy towards production, thereby increasing emission.

II.) The second channel goes through the efficiency of the capital stock, measured by the average renewability share of total capital (η_{DK}, η_{ROW}). Here there will also be two underlying effects: a.) improvements in the efficiency of the different capital components (green capital, imported green capital, and conventional capital), b.) changes in the "capital-mix" as the share of each capital component to the total capital changes[78].

Before looking at the change in emission, we should therefore first compare the effect on output and the efficiency of the capital stock within the four scenarios.

5.4.1 Comparing the effect on output

In the plot below, we show the percentage deviation from the baseline looking at GDP in Denmark and ROW[79]. Across the four scenarios, we observe an increase in GDP for both Denmark and ROW with GDP increasing by approximately 1% in Denmark, meanwhile observing a much smaller increase of 0.006% in ROW. The increase in Danish GDP is associated with the increase in government spending shown in the appendix (Figure 12), where the revenue of the carbon tax is used for green government spending. As mentioned in the previous section, the increase in Danish GDP increases domestic demand for international goods, thereby increasing the Danish imports explaining the increase in GDP for the rest of the world[80].

[78] The term "capital-mix" should therefore be understood as how the underlying components of the total capital change over time (green capital, imported green capital, and conventional capital).
[79] Note that the blue line covers the green line in the case of Danish GDP and also later when plotting the trade balance of Denmark, whereas the green line is not observable.
[80] In the appendix (Figure 13), we show the development of Danish imports, matching the increase in output for ROW.

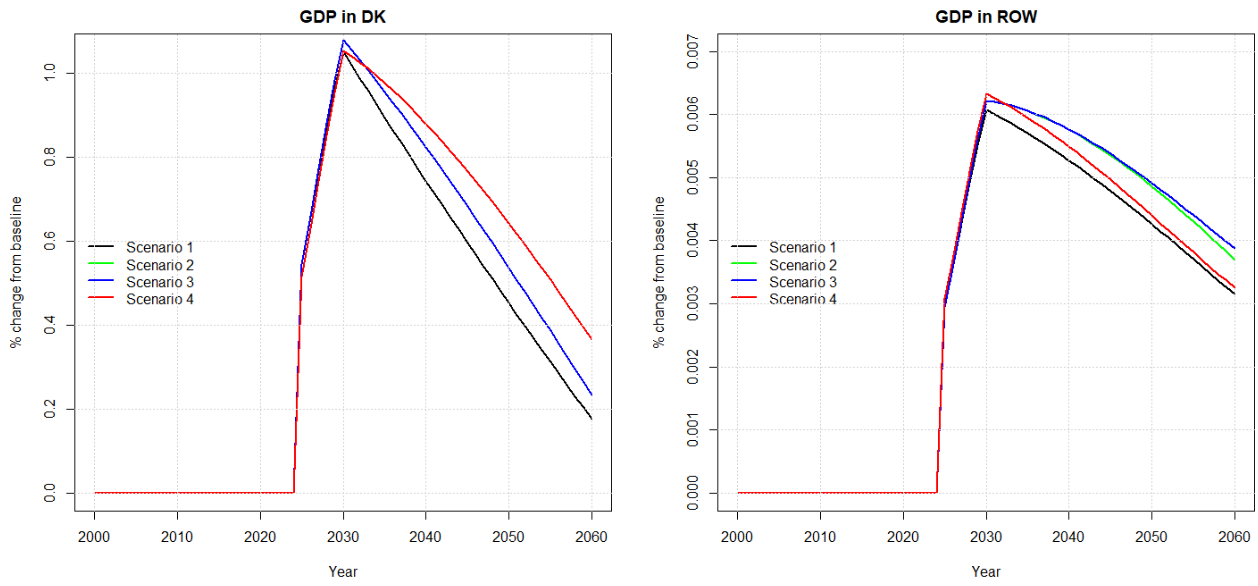


Figure 5-9 Change in GDP for Denmark and the rest of the world

Looking at the results relative to each other, using Scenario 1 as a basis of comparison, we find only small differences when including the effects of the PH framework, where the effects seem to increase output in both Denmark and ROW by a small amount. This minor increase should mainly be associated with the Weak PH increasing green R&D investments[81]. Besides from the effect of the Weak PH, the minor differences between Scenario 2, 3 & 4 should mainly be associated with changes in the trade balance shown in the plot below. We find the Danish trade balance to be negatively affected in all four scenarios, the main reason being the rise in Danish imports associated with the increasing GDP. But as we in Scenario 4 introduce the Strong PH, increasing Danish exports, this will lower the drop in the Danish trade balance by a small amount, thereby improving output in Denmark while reducing output in ROW over time as observed above.

[81] As this is a substitute for conventional investments and will therefore lower the total capital stock, meaning lower level of depreciation.

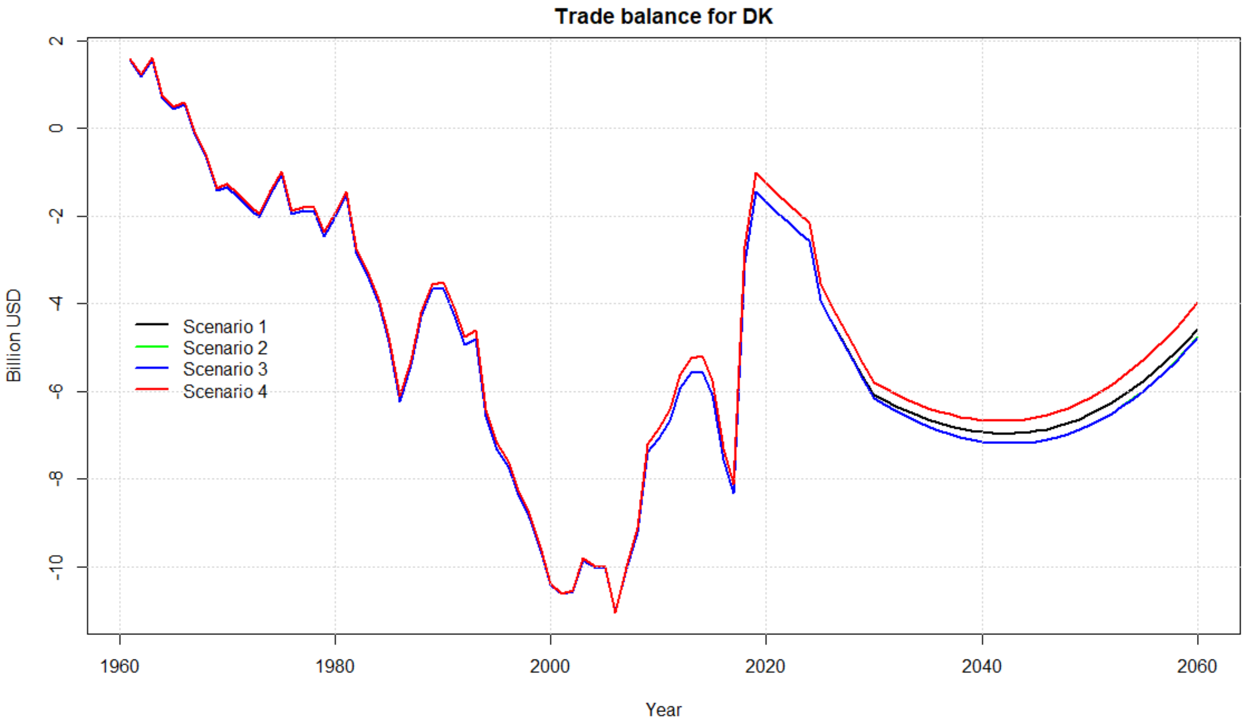


Figure 5-10 Trade balance for Denmark

Concluding the first of the two channels affecting emission, we only find small differences in GDP for both Denmark and ROW across the four scenarios. We will now turn towards the second channel affecting emission being changes in the efficiency of the capital stock.

5.4.2 Comparing the effect on efficiency of the capital stock

Looking at GDP, we found only small differences in the percentage deviation from the baseline across the four scenarios, whereas differences for the change in emission should most likely not be associated with this channel. Now, we turn towards the second channel going through the efficiency of the capital stock[82], measured by the average renewability share of the total capital stock (η_{DK}, η_{ROW}). As there are multiple channels affecting the average renewability share of total capital, we provide a visualization of these channels below:

[82] In the plots describing this channel for Denmark, we do not observe the green line as it lies directly under the blue line. Therefore, the effects in Scenarios 2 & 3 are exactly the same within this channel when looking at the Danish economy.

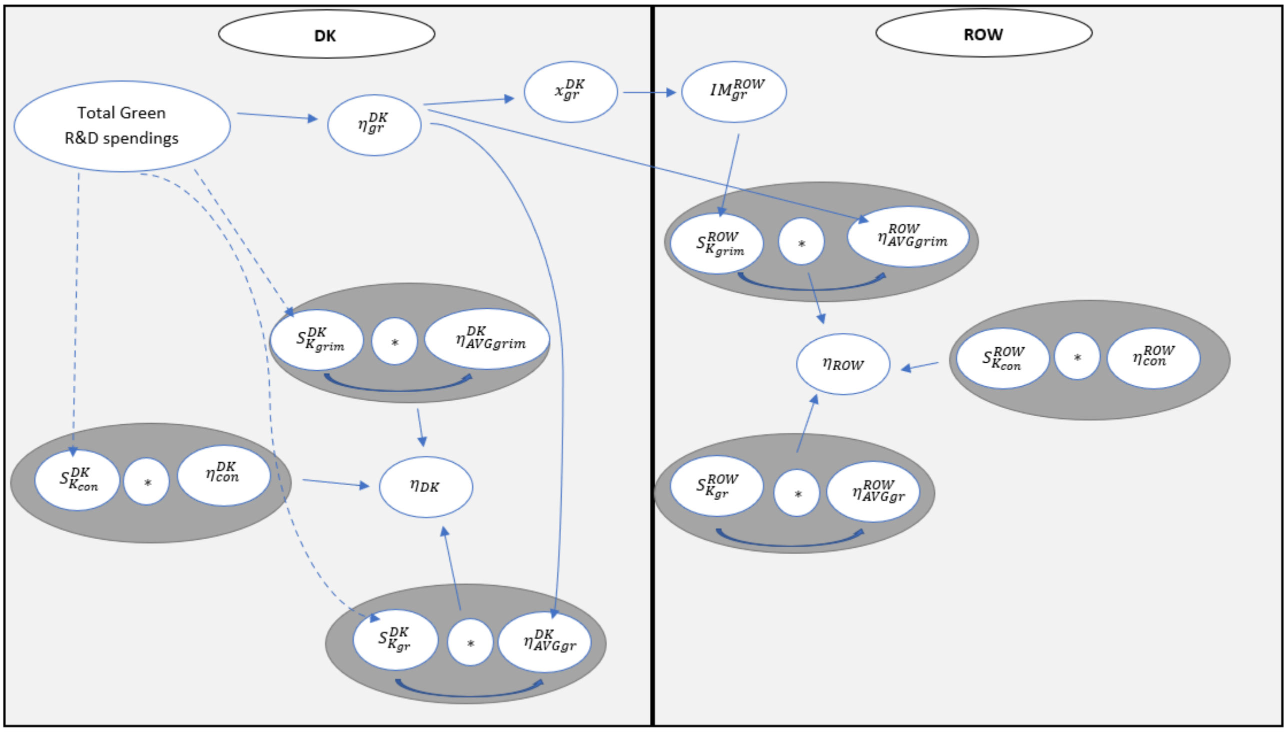


Figure 5-11 DAG for the effects on the average renewability share of total capital

As shown in the DAG presented in the appendix (Figure 11), changes in the renewability share of green capital in Denmark (in the rest of this section noted as η_{gr}^{DK}) affects both the average renewability share of total capital in Denmark and ROW (in the rest of this section noted as η_{DK} and η_{ROW}) given by the relationships shown in the DAG above (Figure 5-11). Furthermore, the introduction of the carbon tax while activating the Weak-, Narrowly Strong-, and Strong PH also have an indirect effect on η_{DK} and η_{ROW} through changes to the "capital-mix", whereas the presentation of this channel will be divided into two areas:

I.) The first area being changes in efficiency of the different capital components, specifically looking at changes in the average renewability share of green capital (in the rest of this section noted as η_{AVGgr}^{DK} and η_{AVGgr}^{ROW}), as well as the average renewability share of imported green capital for the importing country (in the rest of this section noted as $\eta_{AVGgrim}^{DK}$ and $\eta_{AVGgrim}^{ROW}$)[83].

[83] We do not look at changes in the renewability share of conventional capital, as this is just a fixed parameter.

II.) The second area being changes to the "capital-mix", thereby looking at the share of conventional-, green-, and imported green capital to total capital in both Denmark and ROW (in the rest of this section noted as $S_{K_{gr}}^{DK}, S_{K_{gr}}^{ROW}, S_{K_{grim}}^{DK}, S_{K_{grim}}^{ROW}, S_{K_{con}}^{DK}, S_{K_{con}}^{ROW}$).

Changes in efficiency of the different capital components

We start with the first of the two areas, looking at the efficiency of the capital components. In Section 5.3 we found that η_{gr}^{DK} increased within all four scenarios when looking at each scenario in isolation, but to compare the effects relative to each other, we now plot the results together in one plot also plotting the same measure for ROW (η_{gr}^{ROW}). As expected, we only observe a change in Denmark as green R&D spending in ROW is not affected as no policy-mix is introduced[84].

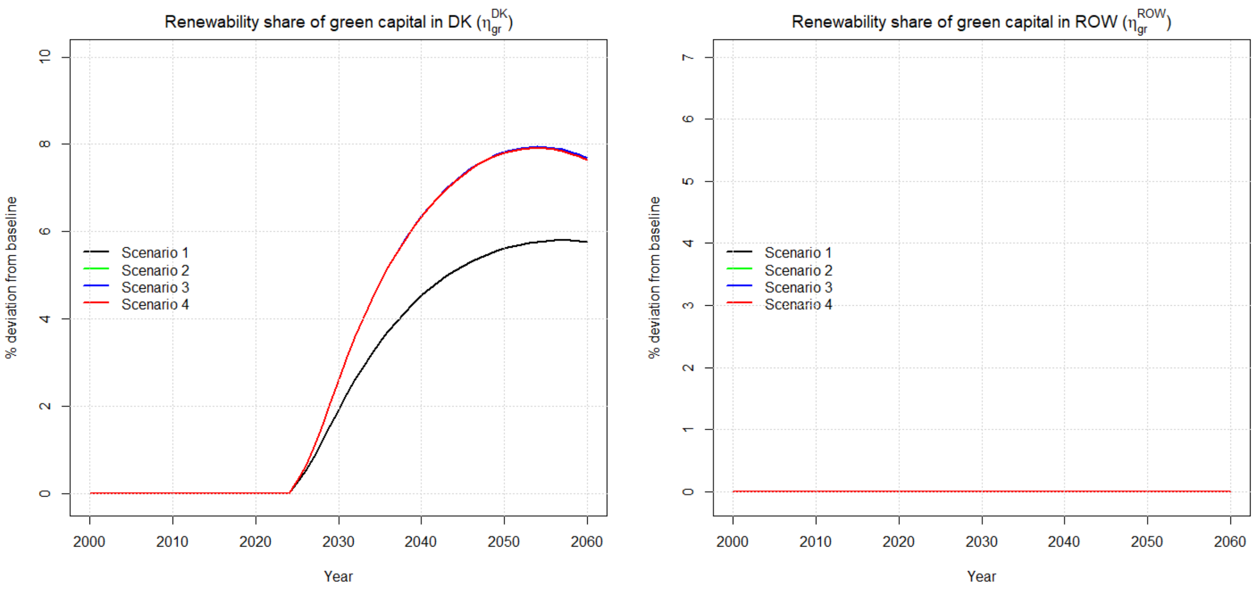


Figure 5-12 Change in the renewability share of green capital in Denmark and ROW

Looking at the change in η_{gr}^{DK}, we observe a similar increase for Scenario 2, 3 & 4, which should be expected as the Narrowly Strong and Strong PH only changes the dynamics of competitiveness. The lower effect observed in Scenario 1, can be associated with the Weak PH not being activate, whereas the implementation of a carbon tax does not affect firms green R&D investments, thereby the total effect in Scenario 1 can be attributed to the increase in government spending towards green R&D.

Looking at the DAG in Figure 5-11 , we see that the change in η_{gr}^{DK} will affect both η_{AVGgr}^{DK} and $\eta_{AVGgrim}^{ROW}$, whereas we show the development in both these measures in the plot below:

[84] Thereby not affecting green technological development in ROW, as visualized in the plot.

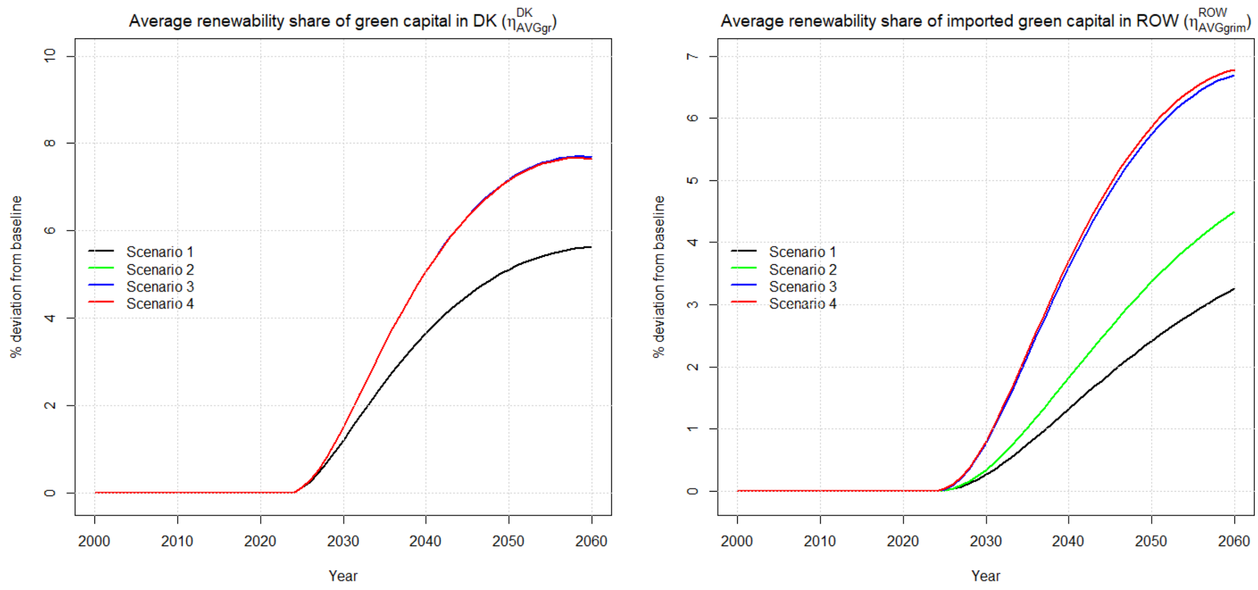


Figure 5-13 Change in average renewability share of Danish green capital and imported green capital by ROW

Unsurprisingly, we observe a similar pattern of η^{DK}_{AVGgr} as shown in the previous plot showing η^{DK}_{gr}. More interestingly, we see that the change in Scenarios 3 & 4 is larger than Scenario 2 when looking at $\eta^{ROW}_{AVGgrim}$ compared to the pattern of η^{DK}_{gr}. The main reason being that $S^{ROW}_{K_{grim}}$ increase in the later periods when η^{DK}_{gr} is high, this will increase the overall moving average calculated for the stock of green imported capital. This effect is especially large for Scenario 3 & 4, whereas we observe a larger effect within these scenarios when looking at $\eta^{ROW}_{AVGgrim}$[85].

To conclude the first of the two areas, we should compare Figure 5-13 showing η^{DK}_{AVGgr} and $\eta^{ROW}_{AVGgrim}$, with the left side plot in Figure 5-12 showing η^{DK}_{gr}. If the different shares of the capital components were fixed over time, these three plots should look similar (still with different magnitudes), which we can see is not the case. Therefore, we should look at the development of these shares ($S^{DK}_{K_{gr}}$, $S^{ROW}_{K_{gr}}$, $S^{DK}_{K_{grim}}$, $S^{ROW}_{K_{grim}}$, $S^{DK}_{K_{con}}$, $S^{ROW}_{K_{con}}$), thereby analyzing changes in the "capital mix".

Changes in the "capital-mix"

Looking at the left side plot below, we see that $S^{DK}_{K_{gr}}$ increase in all scenarios mainly due to the increase in green MOIS associated with the recycling of the carbon tax revenue. However, we observe that the magnitude of this increase is higher in Scenarios 2, 3 & 4 where the main difference seems to lie in changes of the total capital stock shown in appendix (Figure 14). Here the total capital in Scenarios 2, 3 & 4 does not

[85] This effect is also shown in the DAG in Figure 5-11, described by the arrow going from $S^{ROW}_{K_{grim}}$ to $\eta^{ROW}_{AVGgrim}$.

increase as much as in Scenario 1 thereby increasing $S_{K_{gr}}^{DK}$ even more in these three scenarios[86].

The increase in $S_{K_{grim}}^{DK}$ shown to the right in the plot below should mainly be associated with the increase in total imports of Denmark, whereas a fixed share of total imports are associated with imports of green capital[87]. The difference between the scenarios should again be associated with the development of the total capital stock. The reader should keep in mind that even though we observe differences in $S_{K_{grim}}^{DK}$ we previously saw that no changes occurred for η_{gr}^{ROW} whereas the changes in $S_{K_{grim}}^{DK}$ should not be of great importance[88].

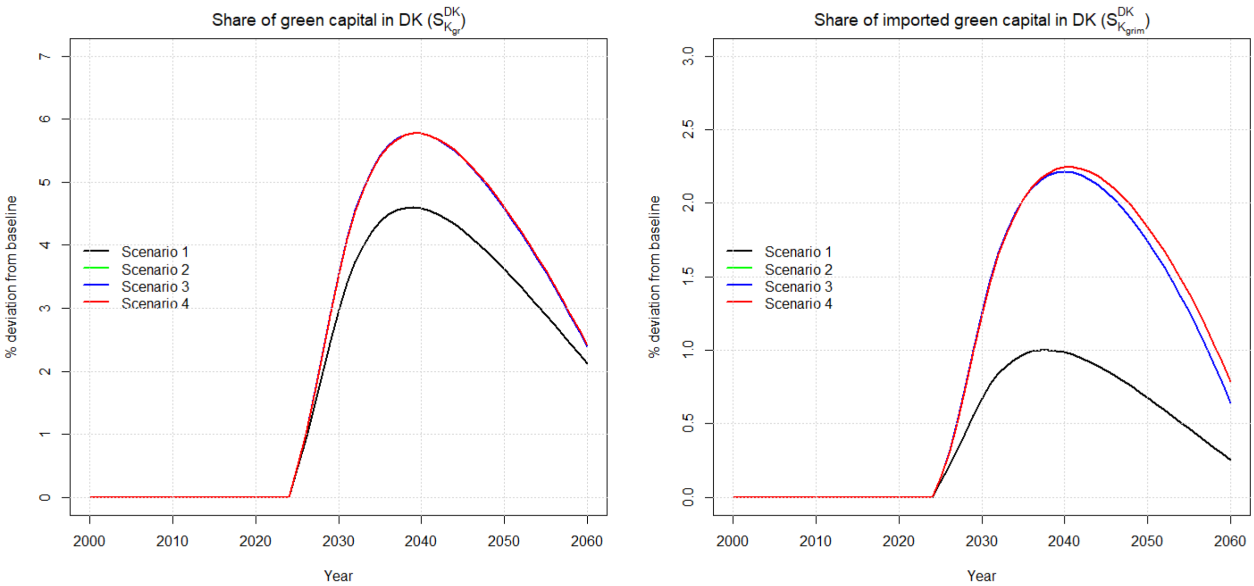


Figure 5-14 Change in the share of green and imported green capital Denmark

We should now turn towards $S_{K_{gr}}^{ROW}$ and $S_{K_{grim}}^{ROW}$ within the four scenarios. Starting to the left in the plot below, we observe no changes in $S_{K_{gr}}^{ROW}$, as the implementation of a policy-mix within Denmark does not affect the government spending towards green MOIS in the rest of the world[89]. On the other hand, when looking at the right side of the plot, we see that $S_{K_{grim}}^{ROW}$ increases in both Scenario 3 & 4, which should be expected as these two scenarios include the Narrowly Strong or Strong PH, thereby increasing the export of

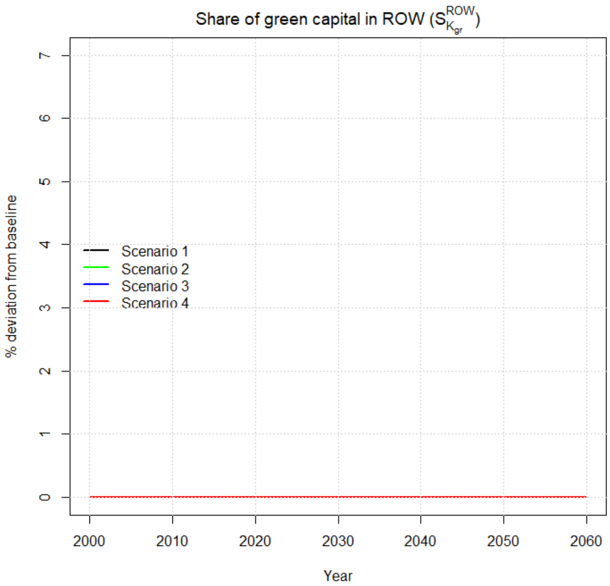
86 The reason why capital falls in Scenario 2, 3 & 4 is given by the change in firms' investments in green R&D which is higher in these scenarios as the Weak PH is introduced. The higher level of firms' green R&D investments reduce the stock of conventional capital thereby lowering the total capital stock.

87 We do not look at the development of conventional capital as this will just be the residual of the two effects shown, as the sum of the shares cannot diverge from 100%.

88 One small effect of the increasing green capital both domestic and imported, is that this is a substitute for conventional capital, therefore improving efficiency through other parameters than renewability, even though renewability by far plays the largest effect. The change in the different efficiency measures can be observed in the appendix (Figure 15, and Figure 16)

89 As a carbon tax is not introduced in ROW, there will be no increased spending in green MOIS.

green capital in Denmark[90]. As expected, we observe the largest increase in scenario four as both the Narrowly Strong and Strong PH is included, with the Strong PH introducing an additional increase in the green exports through an increase in total exports.



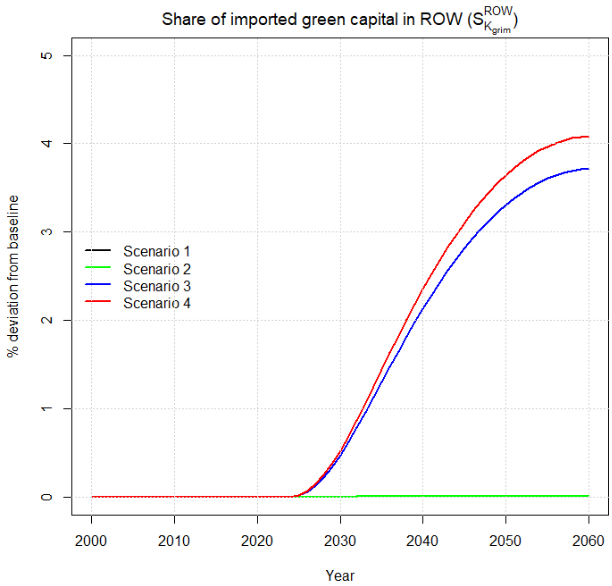


Figure 5-15 Changes in the share of green and imported green capital ROW.

This concludes the two areas being changes in the efficiency of the three capital components, and changes in the "capital-mix", whereas we can now conclude this second channel affecting emission through the implementation of the policy-mix, by looking at the change in η_{DK} and η_{ROW}.

[90] This is shown in the DAG in Figure 5-11 going through the channel of green exports affecting the share of green imported capital in ROW, this channel was further described in Section 5.3.

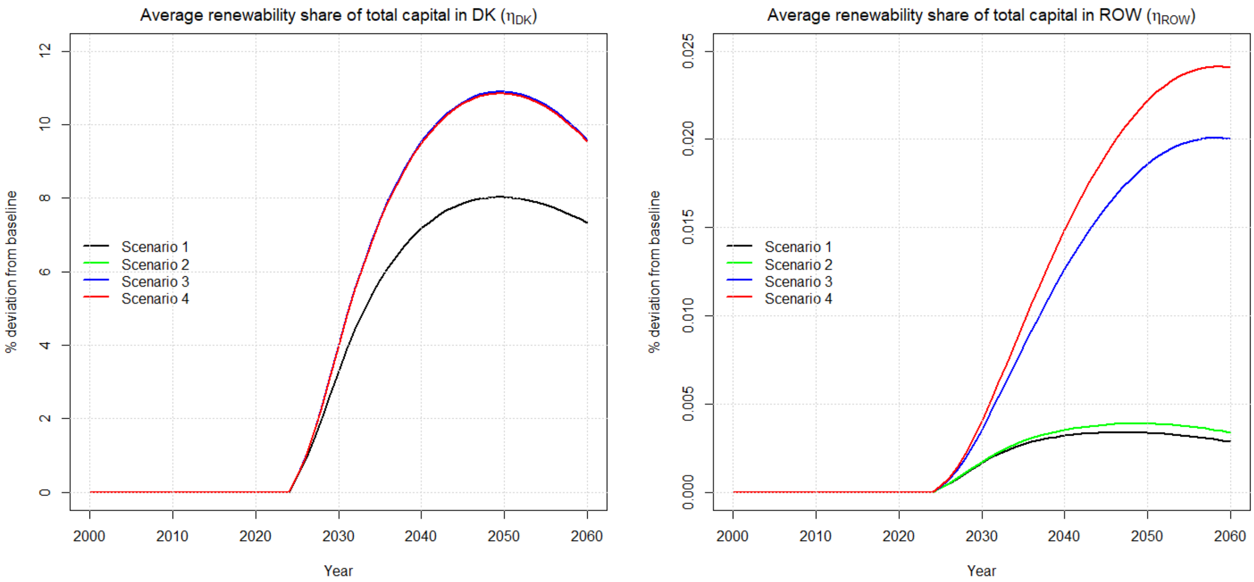


Figure 5-16 Changes in the average renewability share of total capital for Denmark and ROW

Starting with Denmark shown to the left in the plot above, we see that the change in η_{DK} is almost similar for Scenario 2, 3 & 4, but with a lower change in Scenario 1. This is mainly because of the relative differences shown in both $\eta^{DK}_{AVG_{gr}}$ (see left side plot in Figure 5-13), and $S^{DK}_{K_{gr}}$ (see left side plot in Figure 5-14) for Scenario 2, 3 & 4 again relative to scenario 1. The main reason for this relative difference can be attributed to the inclusion of the Weak PH, as the higher level of firms R&D spending both increase η^{DK}_{gr} and $S^{DK}_{K_{gr}}$. Furthermore, the effect of the Narrowly Strong and Strong PH seems to have no effect on emission through η_{DK}.

Looking at the rest of the world, the effect seems to be more diverged between the four scenarios, still increasing η_{ROW} in all four scenarios. The largest increase is found in Scenario 4 as we saw a slightly higher increase in $\eta^{ROW}_{AVGgrim}$ compared to Scenario 3 (see right site plot in Figure 5-13)[91]. Furthermore, we also observed the largest increase in $S^{ROW}_{K_{grim}}$ for Scenario 4 as a result of including both the Narrowly strong, and Strong PH (right site plot in Figure 5-15)[92]. In the end, we see that relative to Scenario 1, the inclusion of the PH framework in Scenarios 2, 3 & 4 increase the effect on η_{ROW}, where the largest effect in isolation seems to come from the introduction of the Narrowly Strong PH[93]. As we now turn towards the change in emission within Denmark and ROW, the two channels just analyzed should be kept in mind, being the

[91] Associated with ROW increasing its import of green technology when the efficiency of Danish green capital is higher.
[92] As these two effects increase green exports for Denmark, thereby increasing the stock of imported green capital in ROW.
[93] In the appendix (page 119) this can also be observed when looking at the effect of the Weak, Narrowly Strong, and Strong PH in isolation.

channel looking at changes in GDP shown by Figure 5-9, and the channel looking at changes in η_{DK} and η_{ROW} shown by Figure 5-16.

5.4.3 Comparing the effect on Emission

For now, we have focused on the two primary channels that affect changes in emission – changes in the efficiency of the capital stock and output. With this knowledge, we can now analyze the changes in emission, shown in the plot below:

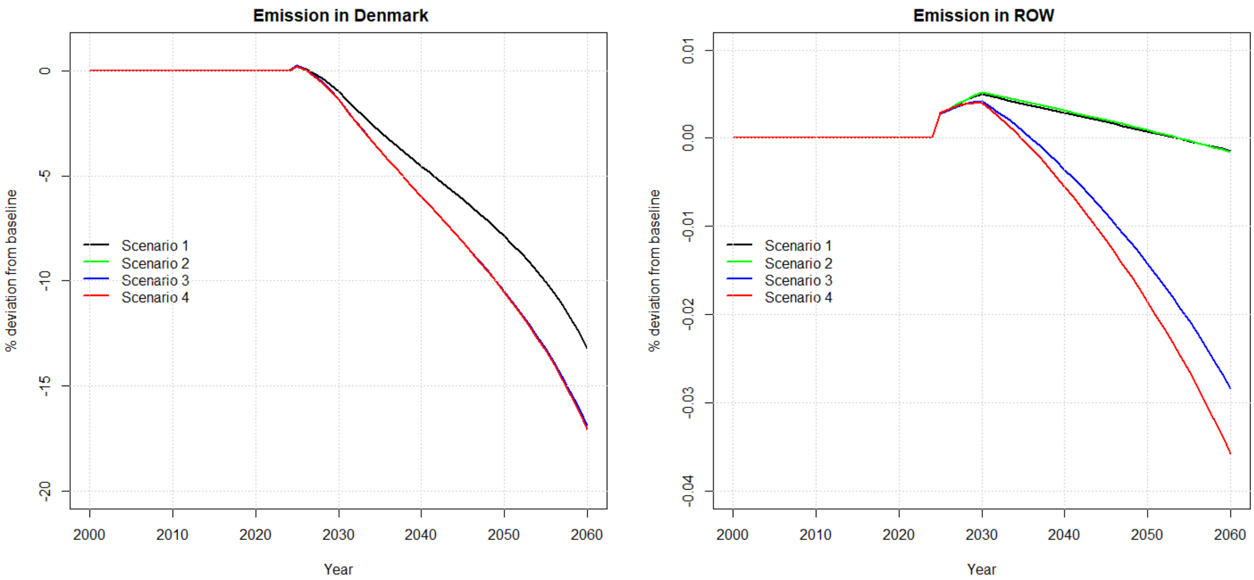


Figure 5-17 Change in emission for Denmark and ROW

Starting with emission in Denmark (left side plot above), no major differences can be observed between Scenario 2, 3 & 4, consistent with our analysis of the two underlying channels. However, we do observe that all scenarios including the Weak PH, further reduce emission relative to scenario 1. This is primarily due to the higher level of R&D spending associated with the Weak PH, which results in a greater increase in η_{DK} observed in the previous scenario.

It gets more interesting as we turn towards the change in emission outside Denmark, the main goal of this paper being to calculate how accepting different degrees of the PH framework changes the effects on emission in the rest of the world as an environmental regulation is implemented in the Danish economy. We find the effect on emission in the rest of the world to be almost similar for Scenario 1 & 2. The main reason being that the two underlying channels have offsetting effects, as we in Scenario 2 both see a higher level of GDP, reducing the magnitude of the fall in emission, but at the same time observe a larger increase in η_{ROW} relative to Scenario 1. For this reason, the introduction of the Weak PH alone appears to have little or no effect on emission outside Denmark[94].

Looking at the introduction of the Narrowly Strong PH and the Strong PH in Scenario 3 & 4, the relative difference to Scenario 1 is much larger, with the main reason being the increments in η_{ROW}, with the largest effect observed in Scenario 4 as the Strong PH introduces an extra effect on Danish green exports, further increasing the share of imported green capital in ROW ($S_{K_{grim}}^{ROW}$) leading to a higher η_{ROW}. These results clearly emphasize that the more effects of the PH framework are being accepted the larger is the magnitude of the fall in emission for the rest of the world. These results also emphasize the importance of the Narrowly strong PH, as this version seems to be contributing with the largest relative effect when going from Scenario 2 till Scenario 3, mainly through the higher level of green exports[95].

Finally, we can look at how the total world emission and temperature changes as a result of implementing the policy-mix in Denmark. Unsurprisingly, we observe that world emission falls in every scenario as we observe a fall in emission both within Denmark and ROW for all four scenarios. We see the importance of Denmark being able to affect emission in the rest of the world as the effect on world emission more than doubles in Scenario 3 & 4. So even though the percentage decrease in ROW emission is small, as seen in the plot above, the reduction contributes a lot more to the world emission compared to a high percentage drop in emission within a small open economy like Denmark.

[94] In the sensitivity analysis we perform the shock isolating the effect of the Narrowly Strong and Strong PH, where we see that the exclusion of the Weak PH when introducing the Narrowly Strong PH or Strong PH lowers the effect on ROW emission, whereas the Weak PH in combination with the Narrowly Strong and Strong PH seems to have an effect on emission in ROW (see appendix page 119).

[95] To see the isolated effect of each version of the PH framework (Weak PH, Narrowly strong PHH, and Strong PH) see appendix (page 119).

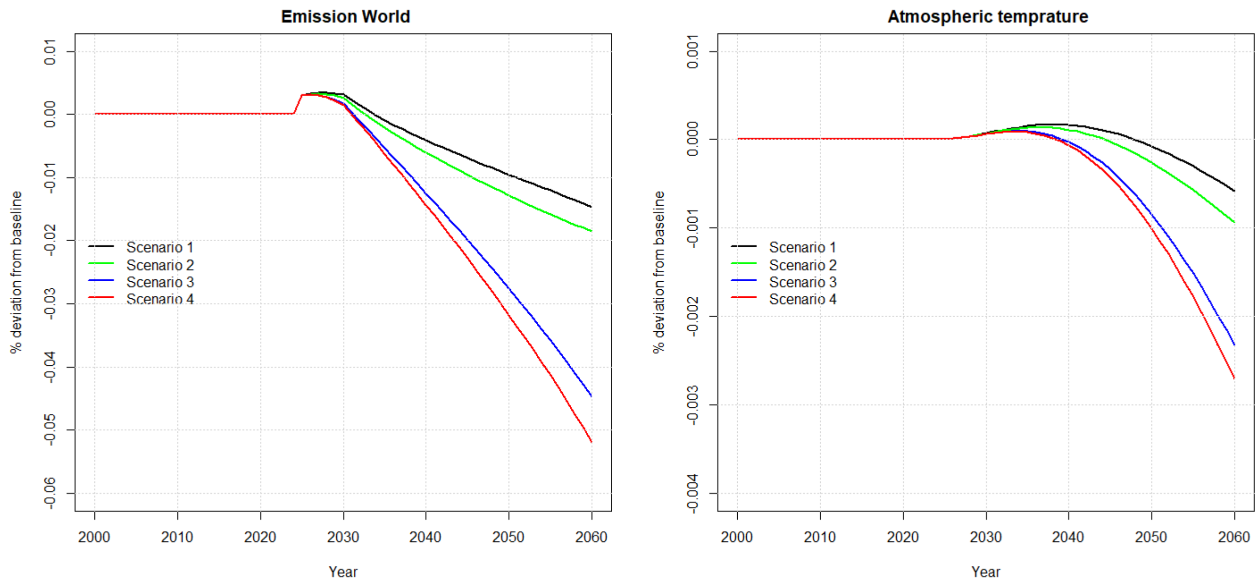


Figure 5-18 Change in world emission and atmospheric temperature

This concludes the effects of implementing the policy-mix within the two-area SFC model presented in Section 4. In the next section, we will use the obtained results to calculate the leakage rate within each of the four scenarios, thereby investigating whether negating the effects of the PH framework can result in an upwards bias in the current calculations of the leakage rate. Lastly, we will discuss whether the introduction of the PH framework within the leakage rate set-up changes which political measures should be put in focus when looking at the green transition of the Danish economy.

Section 6 Discussion

In the previous section, we provided a comparison of the four scenarios looking at the change in emission within Denmark and ROW as a result of implementing the policy-mix described earlier in Denmark. We found that the introduction of the Weak PH enhanced the effect on emission within Denmark but had no real effect on emission in ROW. Second, we found that the introduction of the Narrowly Strong PH did not change anything in regards of emission within Denmark but showed a further reduction of emission in ROW[96]. Lastly, the introduction of the Strong PH showed similar effects to the Narrowly Strong PH, having no effect on Danish emission while further increasing the fall in emission for the rest of the world. As the PH framework seems to introduce a way in which a small open economy like Denmark can affect emission in the rest of the world through international trade, when implementing a policy-mix within Denmark, this highlights a problem of the current literature on leakage rates where the PH framework for now has been negated, whereas we argue that this is most likely creating an upwards bias within the current literature.

We begin this section by providing a short description of the main channels in which carbon leakage can occur and discuss the importance of these channels for a small open economy like Denmark. Next, we will use the results from the previous section to calculate the leakage rates associated with each of the four scenarios. Finally, we will use the results to discuss whether the effects provided by the PH framework should change the focus of political recommendations with a goal of reaching the Danish climate goals.

6.1 Estimation of the leakage rate

We start by presenting the five main channels of leakage included by the current literature, also discussing the importance of each channel for a small open economy like Denmark. The five channels are presented by DØRS (2019) when providing an overview of the current leakage rate literature, the channels are: I.) Leakage through the fossil fuel market, II.) Leakage through the European quota system (ETS), III.) Leakage through political incentives, IV.) Leakage through technological development, V.) Leakage through international trade.

Leakage through the fossil fuel market:

This channel highlights that a unilateral climate policy implemented in Denmark increases Danish firms' costs associated with consuming fossil fuels in their production. As a result, firms reduce their consumption

[96] As a result of a higher share of green imported capital to total capital in ROW, but also because the average renewability share of imported green capital in ROW is increased.

of fossil fuels, leading to a lower national demand. This will cause the international price on fossil fuels to drop, increasing the demand of fossil fuels outside Denmark thereby increasing emission as well.

Evidence typically based on macroeconomic models (CGE) find that this effect in general is a large contributor to the leakage rate (Kuik & Hofkes, 2010). For a small open economy like Denmark, this should only have small price effects, but as these effects occur on a large global market, they can still be substantial for a small open economy like Denmark (Kjær Kruse-Andersen et al., 2022).

Leakage through the European quota system (ETS):

The EU has established a quota system, limiting the amount of Co2 emission to a fixed amount within certain sectors. Companies operating in these sectors need to purchase additional quotas if they wish to increase emission. Until 2018, the number of quotas were fixed meaning that if Denmark lowered its demand for quotas this would reduce the price level but not cause any change in supply, implying a leakage rate of 100%. A reform was then imposed in 2018, lowering the supply of quotas as demand falls. But even with the implementation of this new reform the supply is not affected 1- to- 1 by a fall in demand whereas the leakage rate is still positive within these sectors.

A study by Kjær Kruse-Andersen et al. (2022) finds that political agreements and systems are crucial in the calculations of leakage rates for a small open economy, for instance, a small EU country will be substantially affected by the climate policy of the EU.

Leakage through political incentives:

Here two opposing effects are at play: First, as an environmental regulation implemented in Denmark also lowers global emission, this might increase other nations incentive to increase their own emission and thereby obtain a status quo in world emission.
On the other hand, Denmark might also be able to put pressure on other countries, by showing which political initiatives might be useful in lowering world emission, often referred to as the "demonstration effect". Other countries might then find inspiration from these solutions and if already shown to be effective in lowering emission within Denmark these countries might be more inclined to adopt these solutions.

There seems to be no real empirical evidence for how this channel affects leakage rates, as most literature finds it hard to quantify these effects. But as argued by Hoel (2012) the greatest impact a small economy can have on the climate is to be an example to follow, arguing that the demonstration effect should be put as a policy goal. When looking at the different goals and political initiatives presented by the Danish government, affecting emission through the demonstration effect seems to be a highly prioritized goal (The Danish Energy Agency, 2021, 2022b).

Leakage through technological development:

This channel starts from the same underlying idea as the Weak PH, emphasizing that the implementation of an environmental regulation should improve green technological development through increased R&D spending, as a result of higher pollution abatement costs. When firms within the regulated country discover new technologies, this creates an opportunity for other areas to use them as a base for further R&D, this effect is also known as the knowledge spillover effect.

DØRS (2019) argues that for a small open economy like Denmark, this channel should be modest as it depends on the diffusion of these new technologies, where they argue that the market shares of Danish firms are too small[97]. Looking a the empirical evidence, we earlier found the effects of the Weak PH to be empirically justified, suggesting that environmental regulations affect technological development through increased R&D spending (see section 2.1.1), but when looking at the evidence whether this might lead to knowledge spillovers, evidence provided by Schmidt-ehmcke et al. (2010) finds no significant international spill-over effects when looking at the Danish Wind industry, whereas this type of leakage might be small in the case of Denmark.

Leakage through international trade:

This channel has been the main focus throughout this paper, where the two opposing frameworks in the form of the Porter Hypothesis and the Pollution Haven Hypothesis have been introduced. Even though we find empirical evidence for the PH framework, the effects within this framework are totally negated when looking at the leakage rate literature, while on the other hand, the Pollution Haven Hypothesis seems to be unquestioned. Leakage through international trade is therefore seen as raising firms' costs as an environmental regulation is introduced in Denmark. These costs will to some extent affect the relative price level between firms within the regulated area and its competitors outside the area. To reduce costs there is an incentive for the company to move its production outside the country, thereby increasing the emission outside of Denmark. If the company does not move its production thereby resulting in higher prices, customers might seek towards their competitors operating outside the regulated area, thereby increasing production in the less environmentally regulated areas.

[97] We find this argument a bit controversial when looking at the industry of renewable energy, as the Danish firm Vestas is the market leader within the wind power industry with a market share of 20.3% (Fernández, 2023)

As presented by DØRS (2019) this effect seems to be larger the higher the degree of openness in the economy, whereas it in the case of Denmark is argued to be the main effect of leakage. A calculation of this channel for a small open economy is provided by Copenhagen Economics (2011) estimating carbon leakage rates for energy-intensive industries in Denmark using a partial equilibrium model. The model only accounts for leakage through international trade and finds a leakage rate of 88 percent from a particular tax reform in Denmark, thereby finding the effect to be quite large for a small open economy.

Estimating leakage rates:

In the current leakage rate literature, the GTAP-model (or versions of this model) seem to be the most frequently used type of model, an important aspect of this model type, is that it only includes two out of the five channels presented above, being the leakage through International trade and the fossil fuel market. Some studies have also integrated leakage through the European quota system into this type model (e.g. Kjær Kruse-Andersen et al. (2022)).
Using this type of model therefore implies that implementing a unilateral carbon policy should only be capable of increasing emission outside the regulated area, as all three channels are associated with an increase in emission (as only the Pollution Haven Hypothesis is used when looking at leakage through international trade). Therefore, it should not be a surprise that the leakage rate using this type of model is always found to be positive and is typically in the range of 10-30% for large economies (see Carbone & Rivers (2017) or Branger & Quirion (2014) for literature reviews), and between 40-90% for small open economies (see Kjær Kruse-Andersen et al. (2022); Copenhagen Economics (2011), DØRS (2019)).

The exclusion of the two additional channels being leakage through political incentives and leakage through technological development is therefore often argued to result in an upwards bias of the calculations[98] (Kjær Kruse-Andersen et al., 2022; Wingender & Misch, 2021), where one should expect the upwards bias to be even more severe for a small open economy[99].

In this paper, we provide evidence for another type of upwards bias in the current calculations of the leakage rate, going through the channel of international trade. As mentioned above, this channel has until now only included the framework of the Pollution Haven Hypothesis, whereas we in this paper first provided empirical evidence that the effects of the Porter Hypothesis exists, and even might outdo the opposing framework of the Pollution Haven Hypothesis, with a likely explanation being that environmental

[98] One of the few studies including the leakage through technological development is Gerlagh & Kuik (2014) finding that a combination of carbon taxes and subsidies towards research can actually lead to negative leakage rates.
[99] As especially the demonstration effect is argued to be large for a small open economy.

regulations are becoming more flexible, and market based[100]. Secondly, we also presented results showing how implementing a higher degree of the PH framework, as a policy mix is implemented in a small open economy like Denmark, further reduced emission in the rest of the world. For this reason, we find it controversial that the current literature is not accounting for this upwards bias in their calculations, especially when calculating the leakage rate of a small open economy, where the channel of international trade is argued to be the main channel of leakage (DØRS, 2019).

We will now calculate the leakage rate associated with each of the four scenarios, thereby gaining insight of the magnitude of this upwards bias associated with the different degrees of the PH framework. The leakage rate is calculated using the equation below. With L_R being the leakage rate, ΔE_{ROW} being the change in emission for ROW, and ΔE_{DK} being the change in emission for Denmark, all as a result of implementing the policy-mix within Denmark.

$$L_R = -\frac{\Delta E_{ROW}}{\Delta E_{DK}}$$

It is important to highlight, that none of the above mentioned channels associated with carbon leakage are included in the results of this paper[101]. Whereas the leakage rate estimated using the results from Section 5 should only provide us with the effects associated with the PH framework, therefore the calculation of the leakage rate in this paper should not be seen as a calculation of the total leakage rate for Denmark, but only providing evidence of an existing upwards bias if leaving out the PH framework. Furthermore, as our model is only partly empirical, using real data to calibrate starting values and parameters, the magnitude of each estimate should be interpreted carefully, instead, we should focus on the relative differences using Scenario 1 as a basis of comparison. As we use a dynamic model, some of the effects take time to play-in, for this reason, we calculate the leakage rate 10, 20, and 30 years after the last change in the carbon tax in 2030, shown in the table below. We also provide the reader with the cumulative change in emission for Denmark, ROW, and the World (measured in million tons Co2)[102].

[100] Thereby spurring green innovation and green technological development.
[101] This also implies that we only look at industries not being part of the EU quota system.
[102] Compared to Figure 5-17 where we plotted the % deviation from the baseline in each period for emission, we now look at the cumulative level difference in emission between the scenario and baseline. In the appendix (Figure 17, Figure 18, and Figure 19) we provide a further visualization of the development over time for these measures.

Table 3 Calculating the leakage rate associated with introducing an environmental regulation in Denmark

Scenario\ Measure	ΔE_{DK}	ΔE_{ROW}	ΔE_{World}	L_R
Scenario 1 10 years	-17.50	14.65	-2.83	0.84
Scenario 1 20 years	-46.44	20.18	-26.22	0.43
Scenario 1 30 years	-78.55	19.17	-59.33	0.24
Scenario 2 10 years	-23.08	15.55	-7.53	0.67
Scenario 2 20 years	-61.61	21.80	-39.81	0.35
Scenario 2 30 years	-103.76	20.80	-82.96	0.20
Scenario 3 10 years	-23.08	2.20	-20.88	0.10
Scenario 3 20 years	-61.61	-26.72	-88.33	-0.43
Scenario 3 30 years	-103.76	-82.86	-186.62	-0.80
Scenario 4 10 years	-23.24	-1.85	-25.09	-0.08
Scenario 4 20 years	-61.83	-46.81	-103.69	-0.68
Scenario 4 30 years	-103.94	-114.93	-218.87	-1.11

In the first column of Table 3, we see that introducing an environmental regulation in Denmark lowers the carbon emission within Denmark in all scenarios (ΔE_{DK}), with an increasing magnitude the longer the timespan. In the next column, we observe that the environmental regulation introduced in Denmark also lowers emission in the rest of the world (ΔE_{ROW}) for Scenario 3 & 4 but not for Scenario 1 & 2, whereas we should expect a positive leakage rate for Scenario 1 & 2, and a negative leakage rate for Scenario 3 & 4. As the increase in carbon emission for ROW is lower than the fall observed in Denmark for Scenario 1 & 2, the leakage rate should still be lower than 1, also implying that the change in emission for the world economy (ΔE_{World}) should be negative as seen in the third column. Lastly in column four, we calculate the leakage rate associated with the change in emission for Denmark and ROW using the results in column one and two (ΔE_{DK} and ΔE_{ROW}). These calculations clearly indicate two important aspects[103]: I.) That including more effects of the PH framework will reduce the leakage rate substantial compared to the leakage rates calculated in Scenario 1, where especially the implementation of the Narrowly Strong PH (going from Scenario 2 till Scenario 3), seems to play a large role[104]. This confirms the existence of an upwards bias

[103] In Table 4 Appendix -D we show how the calculations of the leakage rate changes under different assumptions analyzed in the sensitivity analysis. The main conclusion that the implementation of the PH framework lowers the leakage rate relative to scenario 1 does not change with these results.

[104] In the sensitivity analysis in the appendix (page 119), we look at the effect of the Narrowly Strong PH in isolation, also finding it to have the largest effect of the three versions.

when not including the effects of the PH framework. II.) Just like Lanoie et al. (2008) who tests the PH framework using a dynamic set-up, we find that the effects of the Porter Hypothesis increase as the timespan is extended, thereby indicating that the upwards bias is increasing as the improvements in Danish green technology is allowed time to diffuse[105].

In this section we provided evidence that leaving out the PH framework when calculating leakage rates for a small open economy like Denmark should result in an upwards bias through the channel of international trade. Because of the increasing amount of literature looking at leakage rates, a larger focus is put on reducing emission through unilateral climate policies without just moving the emission elsewhere. For this reason, we will use the upcoming section to discuss whether including the effects implied by the PH framework into the leakage rate literature, could provide new focus areas for political recommendations when taking into account leakage rates.

6.2 Political aspects

In the previous section, we provided evidence for the existence of an upwards bias through the channel of international trade, when negating the effects of the PH framework, whereas the effects of this framework in the future should be taken into account. In this section will discuss whether accepting the PH framework when analyzing leakage through international trade, should result in new focus areas when making political recommendations for reaching the Danish climate goals. First, we will comment on the general political recommendations made to reach the Danish climate goals, and how taking into account carbon leakages change these recommendations. Lastly, we will present two new focus areas for political recommendations capable of increasing the effects of the PH framework.

In the introduction we argued that reaching the Danish climate goals should also include a plan of minimizing/maximizing an increase/decrease in emission outside Denmark, which at the moment is not the case. If the idea is only to meet the Danish climate goals, thereby not considering carbon leakage, the most cost efficient policy is argued to be a uniform carbon tax across all industries[106] (DØRS, 2018; Kjær Kruse-Andersen & Birch Sørensen, 2021).

When introducing the effects of carbon leakages, several new political measures are taking into use mainly with a goal of minimizing the counter-effect on international competitiveness argued by the Pollution Haven Hypothesis where firms relocate investments from one country to another with a goal of reducing costs associated with emission (Fischer & Fox, 2012; Kjær Kruse-Andersen & Birch Sørensen, 2021). For this

[105] To see the development of the leakage rate, see Figure 17 in the appendix.
[106] Besides industries included in the ETS.

reason, taking into account leakage rates, the most optimal type of policy is argued to be a system of border carbon adjustments, imposing a tax on the estimated carbon content of imported goods and offering a rebate for some of the domestic carbon tax on the production of exported goods. This type of regulation is argued to reverse the negative effects on competitiveness implied by the Pollution Haven Hypothesis framework (Böhringer et al., 2012; Fischer & Fox, 2012; Hoel, 1996). However, as argued by Cosbey et al. (2019) border carbon adjustments will most likely be challenged under the current WTO rules, as they involve a risk of starting a trade war. This has led to different alternatives like: I.) Differentiating carbon tax rates across sectors to mitigate leakage (Hoel, 1996), II.) Including different types of subsidies of green production, III.) Introducing consumption taxes on internationally traded goods (Kruse-Andersen & Sørensen, 2019).

As mentioned above, all these initiatives assume that competitiveness can only be negatively affected by the introduction of an environmental regulation. However, the results provided in this paper suggests that the PH framework might introduce new aspects to this discussion. Therefore, we will now present two focus areas for political initiatives with a goal of maximizing the decrease in ROW emission through the effects of the PH framework[107].

I.) According to DØRS (2019) the impact of technological development on carbon leakage in a small open economy is argued to be minimal as diffusion of new technologies are dependent on the innovator's world market share, which for companies in a small open economy is considered to be low. But as presented earlier, some Danish companies especially within the green sector seem to have large world market shares, with a company like Vestas having more than one fifth of the world market share within the wind power industry (Fernández, 2023). For this reason, a focus area could be to differentiate the rate of a carbon tax based on world market shares, or the potential for firms to obtain a large share of the world market, thereby introducing a higher rate for firms with larger world market shares, while at the same time providing them with a higher rate of subsidies towards green R&D. This could enhance the diffusion of new green technology through green exports, as these companies already have strong international relationships.

II.) Through a climate partnership between the parliament and several green Danish companies, a questionnaire showed that Danish green technology has an estimated potential of reducing

[107] These ideas should not be seen as policy recommendations but are meant to start a debate whether these effects should have a focus in the future when making recommendations based on lowering carbon leakage.

emission within Europe with up to 1500 million tons of CO_2 (Regeringen, 2020). One of the main obstacles being to create international relationships thereby creating opportunities for green firms to export their green technologies. Even with those relationships Munch & Schaur (2018) argue that the main challenge is that exporters initially are uncertain about the foreign partner's reliability. These obstacles provide a strong rationale for governmental policies that encourage the diffusion of environmental technologies (Jaffe et al., 2005), by for example offering guidance and protection when engaging in exports. Therefore, a focus on governmental promotion and protection of Danish green exports should also provide a basis for increasing the effect on emission in ROW through the effects of the PH framework[108].

This concludes the two focus areas presented in this paper looking at how political initiatives might further enhance the effects presented by the PH framework. In the next section, we will present the main conclusions of this paper.

[108] In Denmark, all governmental trade-promotion activities are organized under one roof in the Trade Council under the Ministry of Foreign Affairs with a yearly budget of approximately USD 65 million.

Section 7 Conclusion

Throughout this paper, our main goal has been to challenge the current way of analyzing carbon leakage through international trade for small open economies, as only the negative effects on competitiveness suggested by the Pollution Haven Hypothesis are included today. This implies that the current view on carbon leakage through international trade today negates the way in which competitiveness can also be positively affected by an environmental regulation, as a regulation might enhance innovation and technological development. Such a view is presented by Porter & Van Der Linde (1995) in the form of the Porter Hypothesis framework, whereas we sought to provide evidence that negating the effects of this framework should result in an upwards bias in the current calculation of carbon leakage through international trade, with a specific focus on this upwards bias for a small open economy like Denmark. As the framework presented by Porter & Van Der Linde (1995) includes several effects, we isolated the key suggestions introducing the three disaggregated versions of the PH framework presented by Jaffe & Palmer (1997) being the Weak-, Narrowly Strong-, and Strong PH. As we looked at the current empirical evidence for these three versions of the PH framework, we found the existing evidence to justify the inclusion of these three hypotheses suggesting that environmental regulations increase both innovation and competitiveness[109]. As the effects presented by the PH framework depend on what type of environmental regulation is being introduced, we discussed how such an environmental regulation should be designed to maximize these effects, finding the shift towards flexible and market based regulations, like carbon taxes, to be optimal within the PH framework. Furthermore, we found that recycling the carbon tax revenue with a goal of supporting innovation and competitiveness through a so-called policy-mix could further enhance the effects presented by the PH framework.

To understand how this policy-mix affects emission in Denmark and ROW through the channels of the PH framework, we build a two-area ecological Stock-Flow-Consistent model including the Danish economy against the economy of the rest of the world[110], introducing the effects of the PH framework within the model. More specifically, we tested how accepting different degrees of the PH framework, using four different baseline models, would affect emission in Denmark and ROW as the policy-mix was implemented in Denmark.

Looking at the results of introducing the policy-mix within each of the four baseline models, we saw different effects on emission for both Denmark and ROW. Looking at changes in Danish emission, the Weak PH further increased the magnitude of the drop while the Narrowly Strong- and Strong PH had no effect.

[109] But with the effects of the Strong PH found to be more controversial.
[110] Inspired by the model built by (Carnevali et al., 2021).

For changes in emission within the rest of the world, the Narrowly Strong- and Strong PH further increased the magnitude of the drop in emission, while the Weak PH alone seemed to have no effect[111].

To analyze whether the negation of the PH framework could lead to a possible upwards bias in the current calculations of the leakage rates, we used these results to calculate leakage rates associated with different degrees of the PH framework. From these calculations we found that the leakage rate falls as more effects of the PH framework are being introduced, thereby providing evidence of an upwards bias. Also, the timespan of the analysis seemed to play in, increasing the upwards bias the longer the timespan of the analysis. These findings suggests that the PH framework should be taken into consideration when calculating leakage rates. For this reason, we discussed whether the introduction of the PH framework should lead to new focus areas when providing political recommendations for reaching the Danish climate goals, in a way where emission is not just moved elsewhere. We ended up presenting two new focus areas: first, suggesting that a focus should be put on spurring innovation for industries with large world market shares, and second, arguing that the government should have a large focus on protection and promotion of Danish exports of green technology.

[111] We found in the sensitivity analysis looking at the three versions of the PH framework in isolation, that the Weak PH in combinations with the two other versions seemed to have an effect on emission in ROW (see Appendix -D Figure 20).

Literature list

Alpay, E., Buccola, S., Kerkvliet, J., Alpay, E., Buccola, S., & Kerkvliet, J. O. E. (2002). Agricultural & Applied Economics Association Productivity Growth and Environmental Regulation in Mexican and U . S . Food Manufacturing. *Oxford University Press on Behalf of the Agricultural & Applied Economics Association*, *84*(4), 887–901.

Ambec, S., Cohen, M. A., Elgie, S., & Lanoie, P. (2013). The porter hypothesis at 20: Can environmental regulation enhance innovation and competitiveness? *Review of Environmental Economics and Policy*, *7*(1), 2–22. https://doi.org/10.1093/reep/res016

Antimiani, A., Costantini, V., Martini, C., Salvatici, L., & Tommasino, M. C. (2013). Assessing alternative solutions to carbon leakage. *Energy Economics*, *36*, 299–311. https://doi.org/10.1016/j.eneco.2012.08.042

Arimura, T. H., Hibiki, A., & Johnstone, N. (2007). An empirical study of environmental R&D: What encourages facilities to be environmentally innovative. *Environmental Policy and Corporate Behaviour*, *May 2020*, 142–173. https://doi.org/10.4337/9781781953020.00009

Becker, R. A., & Shadbegian, R. J. (2008). *THE GREEN INDUSTRY: AN EXAMINATION OF ENVIRONMENTAL PRODUCTS MANUFACTURING*. 1–23.

Ben-David, I., Jang, Y., Kleimeier, S., & Viehs, M. (2018). Exporting Pollution: Where Do Multinational Firms Emit CO2? *Economic Policy*, *25063*. https://doi.org/10.1093/epolic/eiab009

Berman, E., & Bui, L. T. M. (2001). Environmental Regulation and Productivity : Evidence from Oil Refineries. *The MIT Press*, *83*(3), 498–510.

Böhringer, C., Balistreri, E. J., & Rutherford, T. F. (2012). The role of border carbon adjustment in unilateral climate policy: Overview of an Energy Modeling Forum study (EMF 29). *Energy Economics*, *34*(SUPPL.2), S97–S110. https://doi.org/10.1016/j.eneco.2012.10.003

Böhringer, C., Carbone, J. C., & Rutherford, T. F. (2018). Embodied Carbon Tariffs. *Scandinavian Journal of Economics*, *120*(1), 183–210. https://doi.org/10.1111/sjoe.12211

Böhringer, C., Cuntz, A., Harhoff, D., & Asane-Otoo, E. (2017). The impact of the German feed-in tariff scheme on innovation: Evidence based on patent filings in renewable energy technologies. *Energy Economics*, *67*, 545–553. https://doi.org/10.1016/j.eneco.2017.09.001

Bosetti, V., Carraro, C., Massetti, E., & Tavoni, M. (2008). International energy R&D spillovers and the economics of greenhouse gas atmospheric stabilization. *Energy Economics*, *30*(6), 2912–2929. https://doi.org/10.1016/j.eneco.2008.04.008

Branger, F., & Quirion, P. (2014). Climate policy and the “carbon haven” effect. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(1), 53–71. https://doi.org/10.1002/wcc.245

Brock, W. A., & Taylor, M. S. (2005). Economic Growth and the Environment: A Review of Theory and Empirics. *Handbook of Economic Growth*, *1*(SUPPL. PART B), 1749–1821. https://doi.org/10.1016/S1574-0684(05)01028-2

Brunnermeier, S. B., & Cohen, M. A. (2003). Determinants of environmental innovation in US manufacturing industries. *Journal of Environmental Economics and Management*, *45*(2), 278–293. https://doi.org/10.1016/S0095-0696(02)00058-X

Carbone, J. C., & Rivers, N. (2017). The impacts of unilateral climate policy on competitiveness: Evidence from computable general equilibrium models. *Review of Environmental Economics and Policy*, *11*(1), 24–42. https://doi.org/10.1093/reep/rew025

Carnevali, E., Deleidi, M., & Pariboni, R. (2019). Frontiers of Heterodox Macroeconomics. In *Frontiers of Heterodox Macroeconomics*. Springer International Publishing. https://doi.org/10.1007/978-3-030-23929-9

Carnevali, E., Deleidi, M., Pariboni, R., & Veronese Passarella, M. (2021). Cross-border financial flows and global warming in a two-area ecological SFC model. *Socio-Economic Planning Sciences*, *75*. https://doi.org/10.1016/j.seps.2020.100819

Cohen, M. A., & Tubb, A. (2017). The Impact of Environmental Regulation on Firm and Country Competitiveness: A Meta-Analysis of the Porter Hypothesis. *Paper Knowledge . Toward a Media History of Documents*, 12–26.

Copeland, B. R., & Taylor, M. S. (2004). *Trade , Growth , and the Environment ’*. *42*(1), 7–71.

Copenhagen economics. (2011). *Carbon leakage from a Nordic perspective*. http://books.google.com/books?hl=en&lr=&id=B6UZYyUR3qIC&oi=fnd&pg=PA7&dq=Carbon+leakage+from+a+Nordic+perspective&ots=u5Q_o6r8Cd&sig=34i0JPkTu_r2l4N8dxHnxt4-oss

Cosbey, A., Droege, S., Fischer, C., & Munnings, C. (2019). Developing Guidance for Implementing Border Carbon Adjustments: Lessons, Cautions, and Research Needs from the Literature. *Review of Environmental Economics and Policy*, *13*(1), 3–22. https://doi.org/10.1093/reep/rey020

Costantini, V., & Mazzanti, M. (2012). On the green and innovative side of trade competitiveness? the impact of environmental policies and innovation on EU exports. *Research Policy*, *41*(1), 132–153. https://doi.org/10.1016/j.respol.2011.08.004

Danish parliament. (2022). *Green tax reform*.

Danish Parliament. (2020). *Climate agreeement for energy and industry (original title: Klimaaftale for energi og industri mv.)*. 1–16. https://fm.dk/media/18085/klimaaftale-for-energi-og-industri-mv-2020.pdf

DØRS. (2018). *Kapitel III Klimapolitik Frem Mod 2030*. https://dors.dk/files/media/rapporter/2018/M18/kap_3/m18_kap_iii_klimapolitik_frem_mod_2030.pdf

DØRS. (2019). *Økonomi og miljø 2019*.

Ederington, J., Levinson, A., & Minier, J. (2005). Footloose and Pollution-Free. *The Review of Economics and Statistics*, *87*(1), 92–99.

Eskeland, G. S., & Harrison, A. E. (2003). Moving to greener pastures? Multinationals and the pollution haven hypothesis. *Journal of Development Economics*, *70*(1), 1–23. https://doi.org/10.1016/S0304-3878(02)00084-6

Fernández, L. (2023). *Global market share of the world's leading wind turbine manufacturers in 2018, based on sales*. https://www.statista.com/statistics/272813/market-share-of-the-leading-wind-turbine-manufacturers-worldwide/

Fischer, C., & Fox, A. K. (2012). Comparing policies to combat emissions leakage: Border carbon adjustments versus rebates. *Journal of Environmental Economics and Management*, *64*(2), 199–216. https://doi.org/10.1016/j.jeem.2012.01.005

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, *36*(3), 399–417. https://doi.org/10.1016/j.respol.2007.01.003

Gerlagh, R., & Kuik, O. (2014). Spill or leak? Carbon leakage with international technology spillovers: A CGE analysis. *Energy Economics*, *45*, 381–388. https://doi.org/10.1016/j.eneco.2014.07.017

Godley, W., & Lavoie, M. (2016). *Monetary Economics*.

Grossman, G. M., & Krueger, A. B. (1991). *Environmental impacts of a North American free trade agreement*. *3914*.

Grossman, G. M., & Krueger, A. B. (1995). Economic Growth and the Environment. *The Quarterly Journal of Economics*, *110*(2), 353–377.

Hille, E., Althammer, W., & Diederich, H. (2020). Environmental regulation and innovation in renewable energy technologies: Does the policy instrument matter? *Technological Forecasting and Social Change*, *153*(January), 119921. https://doi.org/10.1016/j.techfore.2020.119921

Hoel, M. (1996). Should a carbon tax be differentiated across sectors? *Journal of Public Economics*, *59*(1), 17–32. https://doi.org/10.1016/0047-2727(94)01490-6

Hoel, M. (2012). *Klimatpolitik och ledarskap – vilken roll kan ett litet land spela?*

Hwang, J. A., & Kim, Y. (2017). Effects of Environmental Regulations on Trade Flow in Manufacturing Sectors: Comparison of Static and Dynamic Effects of Environmental Regulations. *Business Strategy and the Environment*, *26*(5), 688–706. https://doi.org/10.1002/bse.1965

IMF. (2020). *Mitigating Climate Change—Growth- and - Imf 2020*. *October*, 85–114.

Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2005). A tale of two market failures: Technology and environmental policy. *Ecological Economics*, *54*(2–3), 164–174. https://doi.org/10.1016/j.ecolecon.2004.12.027

Jaffe, A. B., & Palmer, K. (1997). Environmental Regulation and Innovation : A Panel Data Study. *The MIT Press*, *79*(4), 610–619.

Jaffe, A. B., Peterson, S. R., Portney, P. R., & Stavins, R. N. (1995). Environmental Regulation and the Competitiveness of U.S. Manufacturing: What does the evidence tell us? *Journal of Economic Literature*, *33*(1), 132–163. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11893638

Johnstone, N. (2003). *Efficient and Effective Use of Tradeable Permits in Combination with other Policy Instruments*. *1711*, 276–284.

Johnstone, N., Haščič, I., & Popp, D. (2010). Renewable energy policies and technological innovation: Evidence based on patent counts. *Environmental and Resource Economics*, *45*(1), 133–155. https://doi.org/10.1007/s10640-009-9309-1

Jug, J., & Mirza, D. (2005). Environmental regulations in gravity equations: Evidence from Europe. *World Economy*, *28*(11), 1591–1615. https://doi.org/10.1111/j.1467-9701.2005.00748.x

Kim, K., Heo, E., & Kim, Y. (2017). Dynamic Policy Impacts on a Technological-Change System of Renewable Energy: An Empirical Analysis. In *Environmental and Resource Economics* (Vol. 66, Issue 2). Springer Netherlands. https://doi.org/10.1007/s10640-015-9946-5

Kjær Kruse-Andersen, P., Beck, U., & Stewart, L. B. (2022). Carbon Leakage in a Small Open Economy: The Importance of International Climate Policies. *SSRN Electronic Journal*, *117*(December 2022), 106447. https://doi.org/10.2139/ssrn.3972986

Kjær Kruse-Andersen, P., & Birch Sørensen, P. (2021). Opimal Unilateral Climate Policy with Carbon Leakage at the Extensive and the Intensive Margin. *SSRN Electronic Journal*, *July*. https://doi.org/10.2139/ssrn.3887249

Klassen, R. D., & McLaughlin, C. P. (1996). The impact of environmental management on firm performance. *Management Science*, *42*(8), 1199–1214. https://doi.org/10.1287/mnsc.42.8.1199

Kruse-Andersen, P. K., & Sørensen, P. B. (2019). Optimal energy taxes and subsidies under a cost-effective unilateral climate policy: Addressing carbon leakage. *Energy Economics*, *109*(October). https://doi.org/10.1016/j.eneco.2022.105928

Kuik, O., & Hofkes, M. (2010). Border adjustment for European emissions trading: Competitiveness and carbon leakage. *Energy Policy*, *38*(4), 1741–1748. https://doi.org/10.1016/j.enpol.2009.11.048

Lanoie, P., Laurent-Lucchetti, J., Johnstone, N., & Ambec, S. (2011). Environmental policy, innovation and performance: New insights on the porter hypothesis. *Journal of Economics and Management Strategy*, *20*(3), 803–842. https://doi.org/10.1111/j.1530-9134.2011.00301.x

Lanoie, P., Patry, M., & Lajeunesse, R. (2008). Environmental regulation and productivity: Testing the porter hypothesis. *Journal of Productivity Analysis*, *30*(2), 121–128. https://doi.org/10.1007/s11123-008-0108-4

Lee, J., Veloso, F. M., & Hounshell, D. A. (2011). Linking induced technological change, and environmental regulation: Evidence from patenting in the U.S. auto industry. *Research Policy*, *40*(9), 1240–1252. https://doi.org/10.1016/j.respol.2011.06.006

Lee, K. H., & Min, B. (2015). Green R&D for eco-innovation and its impact on carbon emissions and firm performance. *Journal of Cleaner Production*, *108*, 534–542. https://doi.org/10.1016/j.jclepro.2015.05.114

Lehmann, P. (2012). Justifying a policy mix for pollution control: A review of economic literature. *Journal of*

Economic Surveys, *26*(1), 71–97. https://doi.org/10.1111/j.1467-6419.2010.00628.x

Letchumanan, R., & Kodama, F. (2000). Reconciling the conflict between the “pollution-haven” hypothesis and an emerging trajectory of international technology transfer. *Research Policy*, *29*(1), 59–79. https://doi.org/10.1016/S0048-7333(99)00033-5

Levinson, A., & Taylor, M. S. (2008). Unmasking the pollution haven effect. *International Economic Review*, *49*(1), 223–254. https://doi.org/10.1111/j.1468-2354.2008.00478.x

Mazzucato, M. (2018). Mission-oriented innovation policies: Challenges and opportunities. *Industrial and Corporate Change*, *27*(5), 803–815. https://doi.org/10.1093/icc/dty034

Mody, A., & Lanjouw, J. O. (1996). Innovation and the international diffusion of environmentally responsive technology. *Research Policy*, *25*(4), 549–571.

Munch, J., & Schaur, G. (2018). The Effect of Export Promotion on Firm-Level Performance. *Journal of Controlled Release*, *11*(2), 430–439.

Nikiforos, M., & Zezza, G. (2017). Stock-Flow Consistent Macroeconomic Models: a Survey. *Journal of Economic Surveys*, *31*(5), 1204–1239. https://doi.org/10.1111/joes.12221

Palmer, K., Oates, W. E., & Portney, P. R. (1995). Tightening environmental standards: The Benefit-Cost or the No-Cost paradigm? *Economic Costs and Consequences of Environmental Regulation*, *9*(4), 435–448. https://doi.org/10.1257/jep.9.4.119

Popp, D. (2003). Pollution Control Innovations and the Clean Air Act of 1990. *Journal of Policy Analysis and Management*, *22*(4), 641–660. https://doi.org/10.1002/pam.10159

Popp, D. (2006). International innovation and diffusion of air pollution control technologies: The effects of NOX and SO2 regulation in the US, Japan, and Germany. *Journal of Environmental Economics and Management*, *51*(1), 46–71. https://doi.org/10.1016/j.jeem.2005.04.006

Porter, M. E. (1991). Americas Green Strategy. *Sci. Am.*

Porter, M. E., & Van Der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Corporate Environmental Responsibility*, *9*(4), 61–82. https://doi.org/10.1257/jep.9.4.97

Regeringen. (2020). *Regeringens klimapartnerskaber*.

Schmidt-ehmcke, J., Braun, F. G., & Zloczysti, P. (2010). *Innovative Activity in Wind and Solar Technology: April*.

The Danish Energy Agency. (2021). *Global Afrapportering 2021*. 13–13. http://www.ens.dk

The Danish Energy Agency. (2022a). *Danmarks globale valg*.

The Danish Energy Agency. (2022b). *Global Afrapportering 2022*. 13–13. http://www.ens.dk

Töbelmann, D., & Wendler, T. (2019). The impact of environmental innovation on carbon dioxide emissions. *Journal of Cleaner Production*, *244*. https://doi.org/10.1016/j.jclepro.2019.118787

Wingender, P., & Misch, F. (2021). Revisiting Carbon Leakage. *IMF Working Papers*, *2021*(207), 1. https://doi.org/10.5089/9781513593029.001

Appendices (Overview)

In the following we will present the four appendices used in this paper:

- **Appendix -A:** Presenting the full set of equations used to run the two-area SFC model used in this paper. Also providing an overview of which equations are introduced to the model of Carnevali et al. (2021)
- **Appendix -B:** Presenting the parameter values used for calibrating the two-area SFC model used in this paper. Also presenting which parameter values are changed under the four different baseline models.
- **Appendix -C:** Presenting figures used throughout the paper.
- **Appendix -D:** Presenting the main results of the different sensitivity analyses used in this paper. The replication code for these sensitivity analyses can be found on GitHub following this link: https://github.com/simonmig10/Material-for-Master-s-Thesis

Appendix -A Model equations:

I.) Disposable income, wealth, and taxes

ROW:

$$YD_r^{ROW} = Y_r^{ROW} \cdot (1 - \theta_{ROW}) \qquad \text{(A. 1)}$$

$$YD_w^{ROW} = Y_w^{ROW} \cdot (1 - \theta_{ROW}) \qquad \text{(A. 2)}$$

$$YD_{hs,r}^{ROW} = YD_r^{ROW} + CG_b^{ROW} + CG_e^{ROW} \qquad \text{(A. 3)}$$

$$CG_b^{ROW} = d(xr_{DK}) \cdot B_{s,-1}^{ROW,DK} \qquad \text{(A. 4)}$$

$$CG_e^{ROW} = d(xr_{DK}) \cdot E_{S,-1}^{ROW,DK} \qquad \text{(A. 5)}$$

$$V_r^{ROW} = V_{r,-1}^{ROW} + YD_{hs,r}^{ROW} - C_r^{ROW} \qquad \text{(A. 6)}$$

$$V_w^{ROW} = V_{w,-1}^{ROW} + YD_w^{ROW} - C_w^{ROW} \qquad \text{(A. 7)}$$

Newly added or changed equations (ROW)

$$T_{ROW} = (Y_r^{ROW} + Y_w^{ROW}) \cdot \theta_{ROW} + co2_{tax}^{ROW} \qquad \text{(A. 8)}$$

DK:

$$YD_r^{DK} = Y_r^{DK} \cdot (1 - \theta_{DK}) \qquad \text{(A. 9)}$$

$$YD_w^{DK} = Y_w^{DK} \cdot (1 - \theta_{DK}) \qquad \text{(A. 10)}$$

$$YD_{hs,r}^{DK} = YD_r^{DK} + CG_b^{DK} + CG_e^{DK} \qquad \text{(A. 11)}$$

$$CG_b^{DK} = d(xr_{ROW}) \cdot B_{s,-1}^{DK,ROW} \qquad \text{(A. 12)}$$

$$CG_e^{DK} = d(xr_{ROW}) \cdot E_{S,-1}^{DK,ROW} \qquad \text{(A. 13)}$$

$$V_r^{DK} = V_{r,-1}^{DK} + YD_{hs,r}^{DK} - C_r^{DK} \qquad \text{(A. 14)}$$

$$V_w^{DK} = V_{w,-1}^{DK} + YD_w^{DK} - C_w^{DK} \qquad \text{(A. 15)}$$

Newly added or changed equations (DK)

$$T_{DK} = (Y_r^{DK} + Y_w^{DK}) \cdot \theta_{DK} + co2_{tax}^{DK} \qquad \text{(A. 16)}$$

II.) Consumption and income shares

ROW:

$$C_r^{ROW} = \left(\alpha_{1r}^{ROW} \cdot YD_r^{ROW} + \alpha_{2r}^{ROW} \cdot V_{r,-1}^{ROW}\right) \cdot \left(1 - d_{T,-1}^{ROW}\right) \qquad \text{(A. 17)}$$

$$C_w^{ROW} = \left(\alpha_{1w}^{ROW} \cdot YD_w^{ROW} + \alpha_{2w}^{ROW} \cdot V_{w,-1}^{ROW}\right) \cdot \left(1 - d_{T,-1}^{ROW}\right) \qquad \text{(A. 18)}$$

$$Y_{ROW} = C_r^{ROW} + C_w^{ROW} + GOV_{tot}^{ROW} + X_{ROW} - IM_{ROW} + INV_{ROW} \qquad \text{(A. 19)}$$

$$Y_W^{ROW} = \omega_{ROW} \cdot Y_{ROW} \qquad \text{(A. 20)}$$

$$F_u^{ROW} = F_f^{ROW} \cdot \mathrm{ret}_{ROW} \tag{A. 21}$$

$$F_d^{ROW} = r_{e,-1}^{ROW} \cdot \left(E_{S,-1}^{ROW,ROW} + E_{s,-1}^{DK,ROW}\right) \tag{A. 22}$$

$$F_m^{ROW} = F_f^{ROW} - F_u^{ROW} - F_d^{ROW} \tag{A. 23}$$

$$Y_r^{ROW} = F_m^{ROW} + F_b^{ROW} + r_{b,-1}^{ROW} \cdot B_{s,-1}^{ROW,ROW} + xr_{DK,-1} \cdot r_{b,-1}^{DK} \cdot B_{s,-1}^{ROW,DK} + F_{d,-1}^{ROW,DK} + F_{d,-1}^{ROW,ROW} \tag{A. 24}$$

$$F_d^{ROW,ROW} = r_e^{ROW} \cdot E_s^{ROW,ROW} \tag{A. 25}$$

$$F_d^{ROW,DK} = r_e^{DK} \cdot E_s^{ROW,DK} \tag{A. 26}$$

Newly added or changed equations (ROW)

$$F_f^{ROW} = Y_{ROW} - Y_w^{ROW} - DA_{ROW} - r_{l,-1}^{ROW} \cdot L_{f,-1}^{ROW} - co2_{tax}^{ROW} \tag{A. 27}$$

DK:

$$C_r^{DK} = \left(\alpha_{1r}^{DK} \cdot YD_r^{DK} + \alpha_{2r}^{DK} \cdot V_{r,-1}^{DK}\right) \cdot \left(1 - d_{T,-1}^{DK}\right) \tag{A. 28}$$

$$C_w^{DK} = \left(\alpha_{1w}^{DK} \cdot YD_w^{DK} + \alpha_{2w}^{DK} \cdot V_{w,-1}^{DK}\right) \cdot \left(1 - d_{T,-1}^{DK}\right) \tag{A. 29}$$

$$Y_{DK} = C_r^{DK} + C_w^{DK} + GOV_{tot}^{DK} + X_{DK} - IM_{DK} + INV_{DK} \tag{A. 30}$$

$$Y_W^{DK} = \omega_{DK} \cdot Y_{DK} \tag{A. 31}$$

$$F_u^{DK} = F_f^{DK} \cdot \mathrm{ret}_{DK} \tag{A. 32}$$

$$F_d^{DK} = r_{e,-1}^{DK} \cdot \left(E_{S,-1}^{DK,DK} + E_{S,-1}^{ROW,DK}\right) \tag{A. 33}$$

$$F_m^{DK} = F_f^{DK} - F_u^{DK} - F_d^{DK} \tag{A. 34}$$

$$Y_r^{DK} = F_m^{DK} + F_b^{DK} + r_{b,-1}^{DK} \cdot B_{s,-1}^{DK,DK} + xr_{ROW,-1} \cdot r_{b,-1}^{ROW} \cdot B_{s,-1}^{DK,ROW} + F_{d,-1}^{DK,ROW} + F_{d,-1}^{DK,DK} \tag{A. 35}$$

$$F_d^{DK,DK} = r_e^{DK} \cdot E_s^{DK,DK} \tag{A. 36}$$

$$F_d^{DK,ROW} = r_e^{ROW} \cdot E_s^{DK,ROW} \tag{A. 37}$$

Newly added or changed equations (DK)

$$F_f^{DK} = Y_{DK} - Y_w^{DK} - DA_{DK} - r_{l,-1}^{DK} \cdot L_{f,-1}^{DK} - co2_{tax}^{DK} \tag{A. 38}$$

III.) Firms' investment plans

ROW:

$$K_{gr}^{ROW} = K_{gr,-1}^{ROW} + INV_{gr}^{ROW} - DA_{gr}^{ROW} \tag{A. 39}$$

$$K_{\mathrm{con}}^{ROW} = K_{\mathrm{con},-1}^{ROW} + INV_{\mathrm{con}}^{ROW} - DA_{\mathrm{con}}^{ROW} \tag{A. 40}$$

$$DA_{gr}^{ROW} = \delta_{ROW} \cdot K_{gr,-1}^{ROW} \tag{A. 41}$$

$$DA_{\text{con}}^{ROW} = \delta_{ROW} \cdot K_{\text{con,-1}}^{ROW} \quad (A.\ 42)$$

$$AF_{ROW} = DA_{ROW} \quad (A.\ 43)$$

$$INV_{ROW} = \left(\gamma_0^{ROW} + \gamma_1^{ROW} * INV_{ROW_{t-1}} + \gamma_2^{ROW} * GOV_{totinv_{t-1}}^{ROW}\right) * \left(1 - d_{T_{t-1}}^{ROW}\right) \quad (A.\ 44)$$

$$L_f^{ROW} = L_{f,-1}^{ROW} + INV_{ROW} - AF_{ROW} - F_u^{ROW} - d\left(E_s^{DK,ROW}\right) - d\left(E_s^{ROW,ROW}\right) \quad (A.\ 45)$$

Newly added or changed equations (ROW)

$$INV_{gr}^{ROW} = \left(\left(\chi_1^{ROW} * GOV_{grinv}^{ROW} + \chi_2^{ROW} * Y_{ROW} + \chi_3^{ROW} * d_T^{ROW}\right) * \left(1 - d_{T_{t-1}}^{ROW}\right)\right) * \left(1 + g_{GrInv}^{ROW}\right)^{Trend} \quad (A.\ 46)$$

$$INV_{grim}^{ROW} = IM_{gr}^{ROW} \quad (A.\ 47)$$

$$Log\left(INV_{R\&D}^{ROW}\right) = \Gamma_0^{\text{ROW}} + \Gamma_1^{\text{ROW}} * Log(INV_{ROW}) + \Gamma_2^{\text{ROW}} * Log(Co2_{tax}^{ROW}) \quad (A.\ 48)$$

$$INV_{con}^{ROW} = INV_{ROW} - INV_{gr}^{ROW} - INV_{grim}^{ROW} - INV_{R\&D}^{ROW} \quad (A.\ 49)$$

$$INV_{gr}^{ROW} \leq INV_{ROW} - INV_{grim}^{ROW} - INV_{R\&D}^{ROW} \quad (A.\ 50)$$

$$K_{grim}^{ROW} = K_{grim_{t-1}}^{ROW} + INV_{grim}^{ROW} - DA_{grim}^{ROW} \quad (A.\ 51)$$

$$DA_{grim}^{ROW} = \delta_{ROW} \cdot K_{grim,-1}^{ROW} \quad (A.\ 52)$$

$$K_{ROW} = K_{gr}^{ROW} + K_{con}^{ROW} + K_{grim}^{ROW} \quad (A.\ 53)$$

$$DA_{ROW} = DA_{gr}^{ROW} + DA_{\text{con}}^{ROW} + DA_{grim}^{ROW} \quad (A.\ 54)$$

DK:

$$K_{gr}^{DK} = K_{gr,-1}^{DK} + INV_{gr}^{DK} - DA_{gr}^{DK} \quad (A.\ 55)$$

$$K_{\text{con}}^{DK} = K_{\text{con, -1}}^{DK} + INV_{\text{con}}^{DK} - DA_{\text{con}}^{DK} \quad (A.\ 56)$$

$$DA_{gr}^{DK} = \delta_{DK} \cdot K_{gr,-1}^{DK} \quad (A.\ 57)$$

$$DA_{\text{con}}^{DK} = \delta_{DK} \cdot K_{\text{con,-1}}^{DK} \quad (A.\ 58)$$

$$AF_{DK} = DA_{DK} \quad (A.\ 59)$$

$$INV_{DK} = \left(\gamma_0^{DK} + \gamma_1^{DK} * INV_{DK_{t-1}} + \gamma_2^{DK} * GOV_{totinv_{t-1}}^{DK}\right) * \left(1 - d_{T_{t-1}}^{DK}\right) \quad (A.\ 60)$$

$$L_f^{DK} = L_{f,-1}^{DK} + INV_{DK} - AF_{DK} - F_u^{DK} - d\left(E_s^{ROW,DK}\right) - d\left(E_s^{DK,DK}\right) \quad (A.\ 61)$$

Newly added or changed equations (DK)

$$INV_{gr}^{DK} = \left(\left(\chi_1^{\text{DK}} * GOV_{grinv}^{DK} + \chi_2^{DK} * Y_{DK} + \chi_3^{DK} * d_T^{DK}\right) * \left(1 - d_{T_{t-1}}^{DK}\right)\right) * (1 + g_{GrInv}^{DK})^{Trend} \quad (A.\ 62)$$

$$INV_{grim}^{DK} = IM_{gr}^{DK} \tag{A. 63}$$

$$Log\left(INV_{R\&D}^{DK}\right) = \Gamma_0^{\mathrm{DK}} + \Gamma_1^{\mathrm{DK}} * \ Log(INV_{DK}) + \Gamma_2^{\mathrm{DK}} * Log(Co2_{tax}^{DK}) \tag{A. 64}$$

$$INV_{con}^{DK} = INV_{DK} - INV_{gr}^{DK} - INV_{grim}^{DK} - INV_{R\&D}^{DK} \tag{A. 64}$$

$$INV_{gr}^{DK} \leq INV_{DK} - \ INV_{grim}^{DK} - INV_{R\&D}^{DK} \tag{A. 65}$$

$$K_{grim}^{DK} = K_{grim_{t-1}}^{DK} + INV_{grim}^{DK} - DA_{grim}^{DK} \tag{A. 66}$$

$$DA_{grim}^{DK} = \delta_{DK} \cdot K_{grim,-1}^{DK} \tag{A. 67}$$

$$K_{DK} = K_{gr}^{DK} + K_{con}^{DK} + K_{grim}^{DK} \tag{A. 68}$$

$$DA_{DK} = DA_{gr}^{DK} + DA_{\mathrm{con}}^{DK} + DA_{grim}^{DK} \tag{A. 69}$$

IV.) International trade

ROW:

$$X_{ROW} = IM_{DK} \tag{A. 70}$$

$$IM_{ROW} = X_{DK} \tag{A. 71}$$

Newly added or changed equations (ROW)

$$IM_{gr}^{ROW} = X_{gr}^{DK} \tag{A. 72}$$

$$X_{gr}^{ROW} = IM_{gr}^{DK} \tag{A. 73}$$

DK:

Newly added or changed equations (DK)

$$X_{gr}^{DK} = \exp\left(\Omega_0^x + \Omega_1^x * log(X_{DK}) + \Omega_2^x * log\left(\eta_{gr}^{DK}\right)\right) \tag{A. 74}$$

$$IM_{gr}^{DK} = \exp\left(\Omega_0^{IM} + \Omega_1^{IM} * log(IM_{DK}) + \Omega_2^{IM} * log\left(\eta_{gr}^{ROW}\right)\right) \tag{A. 75}$$

$$\log(X_{DK}) = \varepsilon_0 + \varepsilon_1 * \log(Y_{ROW}) + \varepsilon_2 * \log\,(\eta_{gr}^{DK}) + \varepsilon_3 * \log\left(xr_{DK_{t-1}}\right) \tag{A. 76}$$

$$\log(IM_{DK}) = \mu_0 + \mu_1 * \log(Y_{DK}) + \mu_2 * \log\,(\eta_{gr}^{ROW}) + \mu_3 * \log\left(xr_{DK_{t-1}}\right) + \tag{A. 77}$$

V.) Demand for financial assets

ROW:

$$\frac{B_d^{ROW,ROW}}{V_r^{ROW}} = \lambda_{40} - \lambda_{41} \cdot r_{b,-1}^{DK} + \lambda_{42} \cdot r_{b,-1}^{ROW} - \lambda_{43} \cdot r_{e,-1}^{DK} - \lambda_{44} \cdot r_{e,-1}^{ROW} \tag{A. 78}$$

$$\frac{B_d^{ROW,DK}}{V_r^{ROW}} = \lambda_{50} + \lambda_{51} \cdot r_{b,-1}^{DK} - \lambda_{52} \cdot r_{b,-1}^{ROW} - \lambda_{53} \cdot r_{e,-1}^{DK} - \lambda_{54} \cdot r_{e,-1}^{ROW} \quad \text{(A. 79)}$$

$$\frac{E_d^{ROW,DK}}{V_r^{ROW}} = \lambda_{80} - \lambda_{81} \cdot r_{b,-1}^{DK} - \lambda_{82} \cdot r_{b,-1}^{ROW} + \lambda_{83} \cdot r_{e,-1}^{DK} - \lambda_{84} \cdot r_{e,-1}^{ROW} \quad \text{(A. 80)}$$

$$\frac{E_d^{ROW,ROW}}{V_r^{ROW}} = \lambda_{100} - \lambda_{101} \cdot r_{b,-1}^{DK} - \lambda_{102} \cdot r_{b,-1}^{ROW} - \lambda_{103} \cdot r_{e,-1}^{DK} + \lambda_{104} \cdot r_{e,-1}^{ROW} \quad \text{(A. 81)}$$

$$M_r^{ROW} = \left(V_r^{ROW} - B_S^{ROW,ROW} - E_S^{ROW,ROW} - \left(B_S^{ROW,DK} + E_S^{ROW,DK}\right) * xr_{DK}\right) \cdot v_{ROW} \quad \text{(A. 82)}$$

$$H_r^{ROW} = V_r^{ROW} - B_S^{ROW,ROW} - E_S^{ROW,ROW} - \left(B_S^{ROW,DK} + E_S^{ROW,DK}\right) * xr_{DK} - M_r^{ROW} \quad \text{(A. 83)}$$

$$M_w^{ROW} = V_W^{ROW} \cdot v_{ROW} \quad \text{(A. 84)}$$

$$H_w^{ROW} = V_w^{ROW} - M_w^{ROW} \quad \text{(A. 85)}$$

$$H_h^{ROW} = H_w^{ROW} + H_r^{ROW} \quad \text{(A. 86)}$$

DK:

$$\frac{B_d^{DK,DK}}{V_r^{DK}} = \lambda_{40} - \lambda_{41} \cdot r_{b,-1}^{DK} + \lambda_{42} \cdot r_{b,-1}^{ROW} - \lambda_{43} \cdot r_{e,-1}^{DK} - \lambda_{44} \cdot r_{e,-1}^{ROW} \quad \text{(A. 87)}$$

$$\frac{B_d^{DK,ROW}}{V_r^{DK}} = \lambda_{50} + \lambda_{51} \cdot r_{b,-1}^{DK} - \lambda_{52} \cdot r_{b,-1}^{ROW} - \lambda_{53} \cdot r_{e,-1}^{DK} - \lambda_{54} \cdot r_{e,-1}^{ROW} \quad \text{(A. 88)}$$

$$\frac{E_d^{DK,ROW}}{V_r^{DK}} = \lambda_{80} - \lambda_{81} \cdot r_{b,-1}^{DK} - \lambda_{82} \cdot r_{b,-1}^{ROW} + \lambda_{83} \cdot r_{e,-1}^{DK} - \lambda_{84} \cdot r_{e,-1}^{ROW} \quad \text{(A. 89)}$$

$$\frac{E_d^{DK,DK}}{V_r^{DK}} = \lambda_{100} - \lambda_{101} \cdot r_{b,-1}^{DK} - \lambda_{102} \cdot r_{b,-1}^{ROW} - \lambda_{103} \cdot r_{e,-1}^{DK} + \lambda_{104} \cdot r_{e,-1}^{ROW} \quad \text{(A. 90)}$$

$$M_r^{DK} = \left(V_r^{DK} - B_S^{DK,DK} - E_S^{DK,DK} - \left(B_S^{DK,ROW} + E_S^{DK,ROW}\right) * xr_{ROW}\right) \cdot v_{DK} \quad \text{(A. 91)}$$

$$H_r^{DK} = V_r^{DK} - B_S^{DK,DK} - E_S^{DK,DK} - \left(B_S^{DK,ROW} + E_S^{DK,ROW}\right) * xr_{ROW} - M_r^{DK} \quad \text{(A. 92)}$$

$$M_w^{DK} = V_W^{DK} \cdot v_{DK} \quad \text{(A. 93)}$$

$$H_w^{DK} = V_w^{DK} - M_w^{DK} \quad \text{(A. 94)}$$

$$H_h^{DK} = H_w^{DK} + H_r^{DK} \quad \text{(A. 95)}$$

VI.) Supplies and prices of financial assets

ROW:

$$e_S^{ROW} = e_{s,-1}^{ROW} + \xi_{ROW} \cdot \frac{INV_{ROW,-1}}{p_{e,-1}^{ROW}} \quad \text{(A. 96)}$$

$$p_e^{ROW} = \frac{E_d^{ROW,ROW} + E_d^{DK,ROW}}{e_S^{ROW}} \quad \text{(A. 97)}$$

$$r_e^{ROW} = \left(1 - \pi_{dy}^{ROW}\right) \cdot r_b^{ROW} + \pi_{dy}^{ROW} \cdot r_e^{ROW,T} \tag{A. 98}$$

$$r_e^{ROW,T} = \frac{F_f^{ROW}}{e_{s,-1}^{ROW} \cdot p_{e,-1}^{ROW}} \tag{A. 99}$$

$$B_s^{ROW,ROW} = B_d^{ROW,ROW} \tag{A. 100}$$

$$B_s^{ROW,DK} \& = B_d^{ROW,DK} \tag{A. 101}$$

$$E_s^{ROW,ROW} \& = E_d^{ROW,ROW} \tag{A. 102}$$

$$E_s^{ROW,DK} \& = E_d^{ROW,DK} \tag{A. 103}$$

DK:

$$e_s^{DK} = e_{s,-1}^{DK} + \xi_{DK} \cdot \frac{INV_{DK,-1}}{p_{e,-1}^{DK}} \tag{A. 104}$$

$$p_e^{DK} = \frac{E_d^{DK,DK} + E_d^{ROW,DK}}{e_s^{DK}} \tag{A. 105}$$

$$r_e^{DK} = \left(1 - \pi_{dy}^{DK}\right) \cdot r_b^{DK} + \pi_{dy}^{DK} \cdot r_e^{DK,T} \tag{A. 106}$$

$$r_e^{DK,T} = \frac{F_f^{DK}}{e_{s,-1}^{DK} \cdot p_{e,-1}^{DK}} \tag{A. 107}$$

$$B_s^{DK,DK} = B_d^{DK,DK} \tag{A. 108}$$

$$B_s^{DK,ROW} = B_d^{DK,ROW} \tag{A. 109}$$

$$E_s^{DK,DK} = E_d^{DK,DK} \tag{A. 110}$$

$$E_s^{DK,ROW} = E_d^{DK,ROW} \tag{A. 111}$$

VII.) The banking sector

ROW:

$$M_s^{ROW} = M_w^{ROW} + M_r^{ROW} \tag{A. 112}$$

$$L_s^{ROW} = L_f^{ROW} \tag{A. 113}$$

$$B_{b,not}^{ROW} = M_s^{ROW} - L_s^{ROW} \tag{A. 114}$$

$$\zeta_{ROW} = 1 \text{ iff } B_{b,not}^{ROW} > 0; \text{ otherwise } \zeta_{ROW} = 0 \tag{A. 115}$$

$$B_b^{ROW} = B_{b,not}^{ROW} \cdot \zeta_{ROW} \tag{A. 116}$$

$$A_d^{ROW} = -B_{b,not}^{ROW} \cdot (1 - \zeta_{ROW}) \tag{A. 117}$$

$$A_s^{ROW} = A_d^{ROW} \tag{A. 118}$$

$$F_b^{ROW} = r_{b,-1}^{ROW} \cdot B_{b,-1}^{ROW} + r_l^{ROW} \cdot L_{s,-1}^{ROW} \tag{A. 119}$$

DK: (A. 120)

$$M_s^{DK} = M_w^{DK} + M_r^{DK} \quad \text{(A. 121)}$$

$$L_s^{DK} = L_f^{DK} \quad \text{(A. 122)}$$

$$B_{b,not}^{DK} = M_s^{DK} - L_s^{DK} \quad \text{(A. 123)}$$

$$\zeta_{DK} = 1 \text{ iff } B_{b,not}^{DK} > 0;\ \text{otherwise } \zeta_{DK} = 0 \quad \text{(A. 124)}$$

$$B_b^{DK} = B_{b,not}^{DK} \cdot \zeta_{DK} \quad \text{(A. 125)}$$

$$A_d^{DK} = -B_{b,not}^{DK} \cdot (1 - \zeta_{DK}) \quad \text{(A. 126)}$$

$$A_s^{DK} = A_d^{DK} \quad \text{(A. 127)}$$

$$F_b^{DK} = r_{b,-1}^{DK} \cdot B_{b,-1}^{DK} + r_l^{DK} \cdot L_{s,-1}^{DK} \quad \text{(A. 128)}$$

VIII.) The central bank and government sector

ROW:

$$B_{cb}^{ROW,ROW} = B_s^{ROW} - B_s^{ROW,ROW} - B_s^{DK,ROW} - B_b^{ROW} \quad \text{(A. 129)}$$

$$H_s^{ROW} = B_{cb}^{ROW,ROW} + A_s^{ROW} \quad \text{(A. 130)}$$

$$F_{cb}^{ROW} = r_{b,-1}^{ROW} \cdot B_{cb,-1}^{ROW,ROW} \quad \text{(A. 131)}$$

$$GOV_{\text{tot}}^{ROW} = GOV_{\text{con}}^{ROW} + GOV_{gr}^{ROW} \quad \text{(A. 132)}$$

$$GOV_{\text{Con}}^{ROW} = \gamma_{GOV0}^{ROW} + \gamma_{GOV1}^{ROW} \cdot GOV_{\text{con},-1}^{ROW} \quad \text{(A. 133)}$$

$$B_s^{ROW} = B_{s,-1}^{ROW} + GOV_{tot}^{ROW} + r_{ROW,-1} \cdot B_{s,-1}^{ROW} - T_{ROW} - F_{cb}^{ROW} \quad \text{(A. 134)}$$

Newly added or changed equations (ROW)

$$GOV_{gr}^{DK} = GOV_{Mois}^{DK} + GOV_{R\&D}^{DK} \quad \text{(A. 135)}$$

$$GOV_{MOIS}^{DK} = GOV_{GrOb}^{DK} * S_{MOIS}^{DK} + Co2_{MOIS}^{DK} \quad \text{(A. 136)}$$

$$GOV_{R\&D}^{DK} = GOV_{GrOb}^{DK} * S_{R\&D}^{DK} + Co2_{R\&D}^{DK} \quad \text{(A. 137)}$$

$$GOV_{totinv}^{DK} = GOV_{MOIS}^{DK} + GOV_{\text{Con}}^{DK} \quad \text{(A. 138)}$$

DK:

$$B_{cb}^{DK,DK} = B_s^{DK} - B_s^{DK,DK} - B_s^{ROW,DK} - B_b^{DK} \quad \text{(A. 139)}$$

$$H_s^{DK} = B_{cb}^{DK,DK} + A_s^{DK} \quad \text{(A. 140)}$$

$$F_{cb}^{DK} = r_{b,-1}^{DK} \cdot B_{cb,-1}^{DK,DK} \quad \text{(A. 141)}$$

$$GOV_{\text{tot}}^{DK} = GOV_{\text{con}}^{DK} + GOV_{gr}^{DK} \quad \text{(A. 142)}$$

$$GOV_{\text{Con}}^{DK} = \gamma_{GOV0}^{DK} + \gamma_{GOV1}^{DK} \cdot GOV_{\text{con},-1}^{DK} \quad \text{(A. 143)}$$

$$B_s^{DK} = B_{s,-1}^{DK} + GOV_{tot}^{DK} + r_{DK,-1} \cdot B_{s,-1}^{DK} - T_{DK} - F_{cb}^{DK} \quad \text{(A. 144)}$$

Newly added or changed equations (DK)

$$GOV_{gr}^{DK} = GOV_{Mois}^{DK} + GOV_{R\&D}^{DK} \quad \text{(A. 145)}$$

$$GOV_{MOIS}^{DK} = GOV_{GrOb}^{DK} * S_{MOIS}^{ROW} + Co2_{MOIS}^{DK} \quad \text{(A. 146)}$$

$$GOV_{R\&D}^{DK} = GOV_{GrOb}^{DK} * S_{R\&D}^{ROW} + Co2_{R\&D}^{DK} \quad \text{(A. 147)}$$

$$GOV_{totinv}^{DK} = GOV_{MOIS}^{DK} + GOV_{\text{Con}}^{DK} \quad \text{(A. 148)}$$

IX.) The ecosystem: material resources and reserves

ROW:

$$y_{\text{mat}}^{ROW} = \mu_{ROW} \cdot Y_{ROW} \quad \text{(A. 149)}$$

$$\text{mat}_{ROW} = y_{\text{mat}}^{ROW} - \text{rec}_{ROW} \quad \text{(A. 150)}$$

$$\text{rec}_{ROW} = \rho_{ROW} \cdot dis_{ROW} \quad \text{(A. 151)}$$

$$dis_{ROW} = \mu_{ROW} \cdot \left(DA_{ROW} + \xi_{DK} \cdot DC_{-1}^{ROW}\right) \quad \text{(A. 152)}$$

$$DC^{ROW} = DC_{-1}^{ROW} + C_{r}^{ROW} + C_{w}^{ROW} - TB_{ROW,-1} - \zeta_{ROW} \cdot DC_{-1}^{ROW} \quad \text{(A. 153)}$$

$$k_{se}^{ROW} = k_{se,-1}^{ROW} + y_{\text{mat}}^{ROW} - dis_{ROW} \quad \text{(A. 154)}$$

$$wa_{ROW} = \text{mat}_{ROW} - d(k_{se}^{ROW}) \quad \text{(A. 155)}$$

$$k_{m}^{ROW} = k_{m,-1}^{ROW} + \text{conv}_{m}^{ROW} - \text{mat}_{ROW} \quad \text{(A. 156)}$$

$$\text{conv}_{m}^{ROW} = \sigma_{m}^{ROW} \cdot \text{res}_{m,-1}^{ROW} \quad \text{(A. 157)}$$

$$\text{res}_{m}^{ROW} = \text{res}_{m,-1}^{ROW} - \text{con}_{m}^{ROW} \quad \text{(A. 158)}$$

$$\text{cen}_{ROW} = \frac{emis_{ROW}}{\text{car}} \quad \text{(A. 159)}$$

$$o2_{ROW} = emis_{ROW} - cen_{ROW} \quad \text{(A. 160)}$$

DK:

$$y_{\text{mat}}^{DK} = \mu_{DK} \cdot Y_{DK} \quad \text{(A. 161)}$$

$$\text{mat}_{DK} = y_{\text{mat}}^{DK} - \text{rec}_{DK} \quad \text{(A. 162)}$$

$$\text{rec}_{DK} = \rho_{DK} \cdot dis_{DK} \quad \text{(A. 163)}$$

$$dis_{DK} = \mu_{DK} \cdot (DA_{DK} + \xi_{ROW} \cdot DC_{-1}^{DK}) \quad \text{(A. 164)}$$

$$DC^{DK} = DC_{-1}^{DK} + C_{r}^{DK} + C_{w}^{DK} - TB_{DK,-1} - \zeta_{DK} \cdot DC_{-1}^{DK} \quad \text{(A. 165)}$$

$$k_{se}^{DK} = k_{se,-1}^{DK} + y_{\text{mat}}^{DK} - dis_{DK} \quad \text{(A. 166)}$$

$$wa_{DK} = \text{mat}_{DK} - d(k_{se}^{DK}) \quad \text{(A. 167)}$$

$$k_{m}^{DK} = k_{m,-1}^{DK} + \text{conv}_{m}^{DK} - \text{mat}_{DK} \quad \text{(A. 168)}$$

$$\text{conv}_{m}^{DK} = \sigma_{m}^{DK} \cdot \text{res}_{m,-1}^{DK} \quad \text{(A. 169)}$$

$$\mathrm{res}_m^{DK} = \mathrm{res}_{m,-1}^{DK} - \mathrm{con}_m^{DK} \tag{A. 170}$$

$$\mathrm{cen}_{DK} = \frac{emis_{DK}}{\mathrm{car}} \tag{A. 171}$$

$$o2_{DK} = emis_{DK} - cen_{DK} \tag{A. 172}$$

X.) The ecosystem: energy resources and reserves

ROW:

$$e_{ROW} = \epsilon_{ROW} \cdot Y_{ROW} \tag{A. 173}$$

$$er_{ROW} = \eta_{ROW} \cdot e_{ROW} \tag{A. 174}$$

$$en_{ROW} = e_{ROW} - er_{ROW} \tag{A. 175}$$

$$ed_{ROW} = er_{ROW} + en_{ROW} \tag{A. 176}$$

$$k_e^{ROW} = k_{e,-1}^{ROW} + \mathrm{conv}_e^{ROW} - en_{ROW} \tag{A. 177}$$

$$\mathrm{conv}_e^{ROW} = \sigma_e^{ROW} \cdot \mathrm{res}_e^{ROW} \tag{A. 178}$$

$$\mathrm{res}_e^{ROW} = res_{e,-1}^{ROW} - \mathrm{conv}_e^{ROW} \tag{A. 179}$$

DK:

$$e_{DK} = \epsilon_{DK} \cdot Y_{DK} \tag{A. 180}$$

$$er_{DK} = \eta_{DK} \cdot e_{DK} \tag{A. 181}$$

$$en_{DK} = e_{DK} - er_{DK} \tag{A. 182}$$

$$ed_{DK} = er_{DK} + en_{DK} \tag{A. 183}$$

$$k_e^{DK} = k_{e,-1}^{DK} + \mathrm{conv}_e^{DK} - en_{DK} \tag{A. 184}$$

$$\mathrm{conv}_e^{DK} = \sigma_e^{DK} \cdot \mathrm{res}_e^{DK} \tag{A. 185}$$

$$\mathrm{res}_e^{DK} = res_{e,-1}^{DK} - \mathrm{conv}_e^{DK} \tag{A. 186}$$

XI.) The ecosystem: emissions and climate change

ROW:

$$\mathrm{emis}_{ROW} = \beta_0^{ROW} + \beta_1^{ROW} \cdot en_{ROW} \tag{A. 187}$$

DK:

$$emis_{DK} = \beta_0^{DK} + \beta_1^{DK} \cdot en_{DK} \tag{A. 188}$$

World:

$$\mathrm{emis_l} = emis_{l,-1} \cdot (1 - g_l) \tag{A. 189}$$

$$\mathrm{emis} = \mathrm{emis}_{DK} + \mathrm{emis}_g + \mathrm{emis}_l \tag{A. 190}$$

$$\mathrm{co2}_{AT} = emis + \phi_{11} \cdot \mathrm{co2}_{AT,-1} + \phi_{21} \cdot \mathrm{co2}_{UP,-1} \tag{A. 191}$$

$$\mathrm{co2}_{UP} = \phi_{12} \cdot \mathrm{co2}_{AT,-1} + \phi_{22} \cdot \mathrm{co2}_{UP,-1} + \phi_{32} \cdot \mathrm{co2}_{LO,-1} \quad \text{(A. 192)}$$

$$\mathrm{co2}_{LO} = \phi_{23} \cdot \mathrm{co2}_{UP,-1} + \phi_{33} \cdot \mathrm{co2}_{LO,-1} \quad \text{(A. 193)}$$

$$F = F_2 \cdot \log_2 \left(\frac{CO2_{AT}}{\mathrm{co2}\ 2_{AT}^{PRE}} \right) + F_{EX} \quad \text{(A. 193)}$$

$$F_{EX} = F_{EX,-1} + fex \quad \text{(A. 194)}$$

$$T_{AT} = T_{AT,-1} + \tau_1 \cdot \left[F - \frac{F_2}{s} \cdot T_{AT,-1} - \tau_2 \cdot \left(T_{AT,-1} - T_{LO,-1} \right) \right] \quad \text{(A. 195)}$$

$$T_{LO} = T_{LO,-1} + \tau_3 \cdot \left(T_{AT,-1} - T_{LO,-1} \right) \quad \text{(A. 196)}$$

XII.) The ecosystem: ecological efficiency

ROW:

$$\mathrm{dep}_m^{ROW} = \frac{m_{at_G}^{ROW}}{k_{m,-1}^{G}} \quad \text{(A. 197)}$$

$$\mathrm{dep}_e^{ROW} = \frac{en_{ROW}}{k_{e,-1}^{ROW}} \quad \text{(A. 198)}$$

Newly added or changed equations (ROW) (A. 199)

$$\mu_{ROW} = \mu_{gr}^{ROW} * \frac{K_{gr}^{ROW}}{K_{ROW}} + \mu_{grim}^{ROW} * \frac{K_{grim}^{ROW}}{K_{ROW}} + \mu_{con}^{ROW} * \frac{K_{con}^{ROW}}{K_{ROW}} \quad \text{(A. 200)}$$

$$\beta_{ROW} = \beta_{AVGgr}^{ROW} * \frac{K_{gr}^{ROW}}{K_{ROW}} + \beta_{AVGgrim}^{ROW} * \frac{K_{grim}^{ROW}}{K_{ROW}} + \beta_{con}^{ROW} * \frac{K_{con}^{ROW}}{K_{ROW}} \quad \text{(A. 201)}$$

$$\epsilon_{ROW} = \epsilon_{gr}^{ROW} * \frac{K_{gr}^{ROW}}{K_{ROW}} + \epsilon_{grim}^{ROW} * \frac{K_{grim}^{ROW}}{K_{ROW}} + \epsilon\ {}_{con}^{ROW} * \frac{K_{con}^{ROW}}{K_{ROW}} \quad \text{(A. 202)}$$

$$\eta_{ROW} = \eta_{AVGgr}^{ROW} * \frac{K_{gr}^{ROW}}{K_{ROW}} + \eta_{AVGgrim}^{ROW} * \frac{K_{grim}^{ROW}}{K_{ROW}} + \eta_{con}^{ROW} * \frac{K_{con}^{ROW}}{K_{ROW}} \quad \text{(A. 203)}$$

$$\log\left(\eta_{impv}^{ROW}\right) = impv_0 + impv_1 * \log\left(GOV_{R\&D}^{ROW} + INV_{R\&D}^{ROW}\right) \quad \text{(A. 204)}$$

$$\eta_{gr}^{ROW} = \eta_{gr_{t-1}}^{ROW} + \eta_{impv}^{ROW}$$

$$\eta_{AVGgr}^{ROW} = \left(\frac{K_{GrNew}^{ROW}}{K_{gr}^{ROW}}\right) * \eta_{gr}^{ROW} + imp_{ROW} * \left(\frac{K_{gr}^{ROW} - K_{GrNew}^{ROW}}{K_{gr}^{ROW}} \right) * \eta_{AVGgr_{t-1}}^{ROW} + (1 - imp_{ROW}) * \left(\frac{K_{gr}^{ROW} - K_{GrNew}^{ROW}}{K_{gr}^{ROW}} \right) * \eta_{gr}^{ROW} \quad \text{(A. 205)}$$

$$K_{GrNew}^{ROW} = k_{gr}^{ROW} - k_{gr_{t-1}}^{ROW} \quad \text{(A. 206)}$$

$$\eta_{AVGgrim}^{ROW} = \left(\frac{K_{NEWgrim}^{ROW}}{K_{grim}^{ROW}} \right) * \eta_{gr}^{ROW} + \left(\frac{K_{grim}^{ROW} - K_{NEWgrim}^{ROW}}{K_{grim}^{ROW}} \right) * \eta_{AVGgrim}^{ROW} \quad \text{(A. 207)}$$

$$\beta_{gr}^{ROW} = \beta_{gr_{t-1}}^{ROW} * (1 - g_{\beta_{gr}}^{ROW}) \quad \text{(A. 208)}$$

$$\beta_{AVGgr}^{ROW} = (\frac{K_{NEWgr}^{ROW}}{K_{gr}^{ROW}}) * \beta_{gr}^{ROW} + imp_{ROW} * \left(\frac{K_{gr}^{ROW} - K_{NEWgr}^{ROW}}{K_{gr}^{DK}}\right) * \beta_{AVGgr_{t-1}}^{ROW} + (1 - imp_{ROW}) * \left(\frac{K_{gr}^{ROW} - K_{NEWgr}^{ROW}}{K_{gr}^{ROW}}\right) * \beta_{gr}^{ROW} \tag{A. 209}$$

$$\beta_{AVGgrim}^{ROW} = \left(\frac{K_{NEWgrim}^{ROW}}{K_{grim}^{ROW}}\right) * \beta_{gr}^{DK} + \left(\frac{K_{grim}^{ROW} - K_{NEWgrim}^{ROW}}{K_{grim}^{ROW}}\right) \beta_{AVGgrim}^{ROW} \tag{A. 210}$$

DK:

$$\mathrm{dep}_{m}^{ROW} = \frac{m_{t_{ROW}}}{k_{m,-1}^{ROW}} \tag{A. 211}$$

$$\mathrm{dep}_{e}^{ROW} = \frac{en_{ROW}}{k_{e,-1}^{ROW}} \tag{A. 212}$$

Newly added or changed equations (DK)

$$\mu_{DK} = \mu_{gr}^{DK} * \frac{K_{gr}^{DK}}{K_{DK}} + \mu_{grim}^{DK} * \frac{K_{grim}^{DK}}{K_{DK}} + \mu_{con}^{DK} * \frac{K_{con}^{DK}}{K_{DK}} \tag{A. 213}$$

$$\beta_{DK} = \beta_{AVGgr}^{DK} * \frac{K_{gr}^{DK}}{K_{DK}} + \beta_{AVGgrim}^{DK} * \frac{K_{grim}^{DK}}{K_{DK}} + \beta_{con}^{DK} * \frac{K_{con}^{DK}}{K_{DK}} \tag{A. 214}$$

$$\epsilon_{DK} = \epsilon_{gr}^{DK} * \frac{K_{gr}^{DK}}{K_{DK}} + \epsilon_{grim}^{DK} * \frac{K_{grim}^{DK}}{K_{DK}} + \epsilon_{con}^{DK} * \frac{K_{con}^{DK}}{K_{DK}} \tag{A. 215}$$

$$\eta_{DK} = \eta_{AVGgr}^{DK} * \frac{K_{gr}^{DK}}{K_{DK}} + \eta_{AVGgrim}^{DK} * \frac{K_{grim}^{DK}}{K_{DK}} + \eta_{con}^{DK} * \frac{K_{con}^{DK}}{K_{DK}} \tag{A. 216}$$

$$\log\left(\eta_{impv}^{DK}\right) = impv_0 + impv_1 * \log\left(GOV_{R\&D}^{DK} + INV_{R\&D}^{DK}\right) \tag{A. 217}$$

$$\eta_{gr}^{DK} = \eta_{gr_{t-1}}^{DK} + \eta_{impv}^{DK} \tag{A. 218}$$

$$\eta_{AVGgr}^{DK} = (\frac{K_{NEWgr}^{DK}}{K_{gr}^{DK}}) * \eta_{gr}^{DK} + imp_{DK} * \left(\frac{K_{gr}^{DK} - K_{NEWgr}^{DK}}{K_{gr}^{DK}}\right) * \eta_{AVGgr_{t-1}}^{DK} + (1 - imp_{DK}) * \left(\frac{K_{gr}^{DK} - K_{NEWgr}^{DK}}{K_{gr}^{DK}}\right) * \eta_{gr}^{DK} \tag{A. 219}$$

$$K_{NEWgr}^{DK} = k_{gr}^{DK} - k_{gr_{t-1}}^{DK} \tag{A. 220}$$

$$\eta_{AVGgrim}^{DK} = \left(\frac{K_{NEWgrim}^{DK}}{K_{grim}^{DK}}\right) * \eta_{gr}^{ROW} + \left(\frac{K_{grim}^{DK} - K_{NEWgrim}^{DK}}{K_{grim}^{DK}}\right) * \eta_{AVGgrim}^{DK} \tag{A. 221}$$

$$K_{NEWgrim}^{DK} = K_{grim}^{DK} - K_{grim_{t-1}}^{DK} \tag{A. 222}$$

$$\beta_{gr}^{DK} = \beta_{gr_{t-1}}^{DK} * (1 - g_{\beta_{gr}}^{DK}) \tag{A. 223}$$

$$\beta^{DK}_{AVGgr} = (\frac{K^{DK}_{GrNew}}{K^{DK}_{gr}}) * \beta^{DK}_{gr} + imp_{DK} * \left(\frac{K^{DK}_{gr} - K^{DK}_{GrNew}}{K^{DK}_{gr}}\right) * \beta^{DK}_{AVGgr_{t-1}} + (1 - imp_{DK}) * \left(\frac{K^{DK}_{gr} - K^{DK}_{GrNew}}{K^{DK}_{gr}}\right) * \beta^{DK}_{gr} \quad (A.\ 224)$$

$$\beta^{DK}_{AVGgrim} = \left(\frac{K^{DK}_{NEWgrim}}{K^{DK}_{grim}}\right) * \beta^{ROW}_{gr} + \left(\frac{K^{DK}_{grim} - K^{DK}_{NEWgrim}}{K^{DK}_{grim}}\right) \beta^{DK}_{AVGgrim} \quad (A.\ 225)$$

XIII.) The ecosystem: damages and feedbacks

ROW*:*

$$d^{ROW}_{T} = 1 - \left(1 + d^{ROW}_{1} \cdot T_{AT} + d^{ROW}_{2} \cdot T^{2}_{AT} + d^{ROW}_{3} \cdot T^{x_{ROW}}_{AT}\right)^{-1} \quad (A.\ 226)$$

$$\delta_{G} = \delta^{ROW}_{0} + \left(1 - \delta^{ROW}_{0}\right) \cdot \left(1 - ad^{ROW}_{K}\right) \cdot d^{ROW}_{T,-1} \quad (A.\ 227)$$

DK:

$$d^{DK}_{T} = 1 - \left(1 + d^{DK}_{1} \cdot T_{AT} + d^{DK}_{2} \cdot T^{2}_{AT} + d^{DK}_{3} \cdot T^{x_{DK}}_{AT}\right)^{-1} \quad (A.\ 228)$$

$$\delta_{DK} = \delta^{DK}_{0} + (1 - \delta^{DK}_{0}) \cdot (1 - ad^{DK}_{K}) \cdot d^{DK}_{T,-1} \quad (A.\ 229)$$

XIV.) Carbon tax

ROW:

$$Co2^{ROW}_{Tax} = (emis_{ROW} * Co2^{ROW}_{rate})/100 \quad (A.\ 230)$$

DK:

$$Co2^{DK}_{Tax} = (emis_{DK} * Co2^{DK}_{rate})/100 \quad (A.\ 231)$$

XV.) Redundant equations

$$H^{DK}_{S} = H^{DK}_{h} \quad (A.\ 232)$$

$$H^{ROW}_{S} = H^{ROW}_{h} \quad (A.\ 233)$$

Appendix -B Parameter Values:

Starting values of variables and Parameters	***notation***	***Baseline 1 value***	***Change in Baseline 2 values***	***Change in Baseline 3 values***	***Change in Baseline 4 values***
Danish capitalists' propensity to consume out of income*	α_{1r}^{DK}	0.49			
Danish workers' propensity to consume out of income*	α_{1w}^{DK}	0.89			
ROW capitalists' propensity to consume out of income*	α_{1r}^{ROW}	0.49			
ROW workers' propensity to consume out of income*	α_{1w}^{ROW}	0.79			
Danish capitalists' propensity to consume out of wealth*	α_{2r}^{DK}	0.02			
Danish workers' propensity to consume out of wealth*	α_{2w}^{DK}	0.03			
ROW capitalists' propensity to consume out of wealth*	α_{2r}^{ROW}	0.02			
ROW workers' propensity to consume out of wealth*	α_{2w}^{ROW}	0.02			
Parameter in Denmark export equation	ε_0	-6.1			-6
Parameter in Denmark export equation	ε_1	0.92			
Parameter in Denmark export equation	ε_2	0			0.05
Parameter in Denmark export equation	ε_3	0.5			
Parameter in Denmark green export equation	Ω_0^X	-3.75		-2.25	-2.25
Parameter in Denmark green export equation	Ω_1^X	1			
Parameter in Denmark green export equation	Ω_2^X	0		0.5	0.5
Portfolio parameter of demand for Danish bills by Danish capitalists	λ_{10}	0.2			
Portfolio parameter of demand for Danish bills by Danish capitalists	λ_{11}	1			
Portfolio parameter of demand for Danish bills by Danish capitalists	λ_{12}	1			
Portfolio parameter of demand for Danish bills by Danish capitalists	λ_{13}	0			
Portfolio parameter of demand for Danish bills by Danish capitalists	λ_{14}	0			

Portfolio parameter of demand for ROW bills by Danish capitalists	λ_{20}	0.3			
Portfolio parameter of demand for ROW bills by Danish capitalists	λ_{21}	1			
Portfolio parameter of demand for ROW bills by Danish capitalists	λ_{22}	1			
Portfolio parameter of demand for ROW bills by Danish capitalists	λ_{23}	0			
Portfolio parameter of demand for ROW bills by Danish capitalists	λ_{24}	0			
Portfolio parameter of demand for ROW bills by ROW capitalists	λ_{40}	0.4			
Portfolio parameter of demand for ROW bills by ROW capitalists	λ_{41}	1			
Portfolio parameter of demand for ROW bills by ROW capitalists	λ_{42}	1			
Portfolio parameter of demand for ROW bills by ROW capitalists	λ_{43}	0			
Portfolio parameter of demand for ROW bills by ROW capitalists	λ_{44}	0			
Portfolio parameter of demand for Danish bills by ROW capitalists	λ_{50}	0.0008			
Portfolio parameter of demand for Danish bills by ROW capitalists	λ_{51}	1			
Portfolio parameter of demand for Danish bills by ROW capitalists	λ_{52}	1			
Portfolio parameter of demand for Danish bills by ROW capitalists	λ_{53}	0			
Portfolio parameter of demand for Danish bills by ROW capitalists	λ_{54}	0			
Portfolio parameter of demand for ROW shares by Danish capitalists	λ_{70}	0.05			
Portfolio parameter of demand for ROW shares by Danish capitalists	λ_{71}	0			
Portfolio parameter of demand for ROW shares by Danish capitalists	λ_{72}	0			

Portfolio parameter of demand for ROW shares by Danish capitalists	λ_{73}	0.01			
Portfolio parameter of demand for ROW shares by Danish capitalists	λ_{74}	0.01			
Portfolio parameter of demand for ROW shares by Danish capitalists	λ_{75}	0.05			
Portfolio parameter of demand for Danish shares by ROW capitalists	λ_{80}	0.0001			
Portfolio parameter of demand for Danish shares by ROW capitalists	λ_{81}	0			
Portfolio parameter of demand for Danish shares by ROW capitalists	λ_{82}	0			
Portfolio parameter of demand for Danish shares by ROW capitalists	λ_{83}	0.01			
Portfolio parameter of demand for Danish shares by ROW capitalists	λ_{84}	0.01			
Portfolio parameter of demand for Danish shares by Danish capitalists	λ_{90}	0.05			
Portfolio parameter of demand for Danish shares by Danish capitalists	λ_{91}	0			
Portfolio parameter of demand for Danish shares by Danish capitalists	λ_{92}	0			
Portfolio parameter of demand for Danish shares by Danish capitalists	λ_{93}	0.01			
Portfolio parameter of demand for Danish shares by Danish capitalists	λ_{94}	0.01			
Portfolio parameter of demand for ROW shares by ROW capitalists	λ_{100}	0.1			
Portfolio parameter of demand for Danish shares by Danish capitalists	λ_{101}	0			
Portfolio parameter of demand for Danish shares by Danish capitalists	λ_{102}	0			
Portfolio parameter of demand for Danish shares by Danish capitalists	λ_{103}	0.01			
Portfolio parameter of demand for Danish shares by Danish capitalists	λ_{104}	0.01			

Shares issues to investment ratio in ROW	ξ_{ROW}	0.01			
Shares issues to investment ratio in Denmark	ξ_{DK}	0.01			
Real supply of shares in Denmark	e_S^{DK}	1			
Real supply of shares in ROW	e_S^{ROW}	1			
Unit price of shares in Denmark	p_e^{DK}	1			
Unit price of shares in ROW	p_e^{ROW}	1			
Parameter in Denmark import equation	μ_0	-0.45			-0.303
Parameter in Denmark import equation	μ_1	0.5			
Parameter in Denmark import equation	μ_2	0			0.05
Parameter in Denmark import equation	μ_3	1.45			
Parameter in Denmark green import equation	Ω_0^{IM}	-3.75			
Parameter in Denmark green import equation	Ω_1^{IM}	1			
Parameter in Denmark green import equation	Ω_2^{IM}	0			
Average tax rate on income in Denmark*	θ_{DK}	0.32			
Average tax rate on income in ROW*	θ_{ROW}	0.14			
Initial value of depreciation rate in Denmark*	δ_0^{DK}	0.08			
Initial value of depreciation rate in ROW*	δ_0^{ROW}	0.08			
Capital adaptation coefficient in Denmark*	ad_K^{DK}	0.75			
Capital adaptation coefficient in ROW*	ad_K^{ROW}	0.75			
Parameter of total investment function in ROW*	γ_0^{ROW}	0.09			
Parameter of total investment function in ROW*	γ_1^{ROW}	1.008			
Parameter of total investment function in ROW	γ_2^{ROW}	0.005			
Parameter of total investment function in Denmark*	γ_0^{DK}	0.0007			
Parameter of total investment function in Denmark*	γ_1^{DK}	1.008			
Parameter of total investment function in Denmark	γ_2^{DK}	0.005			
Parameter of Danish green investment function	χ_1^{DK}	0.2			
Parameter of Danish green investment function	χ_2^{DK}	0.02			

Parameter of Danish green investment function	χ_3^{DK}	0.09			
Parameter of ROW green investment function	χ_1^{ROW}	0.2			
Parameter of ROW green investment function	χ_2^{ROW}	0.02			
Parameter of ROW green investment function	χ_3^{ROW}	59.91			
Rate of increase for green investments in Denmark	g_{GrInv}^{DK}	0.015			
Rate of increase for green investments in ROW	g_{GrInv}^{ROW}	0.0075			
Parameter of Danish green R&D investment function	Γ_0^{DK}	-2.305	-1.42	-1.42	-1.42
Parameter of Danish green R&D investment function	Γ_1^{DK}	1			
Parameter of ROW green R&D investment function	Γ_2^{DK}	0	0.15	0.15	0.15
Parameter of ROW green R&D investment function	Γ_0^{ROW}	-2.66			
Parameter of ROW green R&D investment function	Γ_1^{ROW}	1			
Parameter of Danish green R&D investment function	Γ_2^{ROW}	0	0.15	0.15	0.15
Wage share to total income in Denmark	ω_{DK}	0.62			
Wage share to total income in ROW	ω_{ROW}	0.62			
Profit retention rate of Danish firms	ret_{DK}	0.02			
Profit retention rate of ROW firms	ret_{ROW}	0.02			
Percentage of money held in Denmark deposits	v_{DK}	0.7			
Percentage of money held in ROW deposits	v_{ROW}	0.7			
Parameter of dividend yield in ROW	π_{dy}^{ROW}	0.006			
Parameter of dividend yield in Denmark	π_{dy}^{DK}	0.006			
Share of exogenous green government spending going towards green MOIS in Denmark	S_{MOIS}^{DK}	0.95			
Share of exogenous green government spending going towards green R&D in Denmark	$S_{R\&D}^{DK}$	0.05			
Share of exogenous green government spending going towards green MOIS in ROW	S_{MOIS}^{ROW}	0.95			
Share of exogenous green government spending going towards green R&D in ROW	$S_{R\&D}^{ROW}$	0.05			

Starting values of variables and parameter values for the ecosystem					
Material intensity of green capital in Denmark (Kg/USD)	μ_{gr}^{DK}	0.71			
Material intensity of green capital in ROW (Kg/USD)	μ_{gr}^{ROW}	0.71			
Material intensity of conventional capital in Denmark (Kg/USD)	μ_{con}^{DK}	0.86			
Material intensity of conventional capital in ROW (Kg/USD)	μ_{con}^{ROW}	0.86			
Energy intensity of green capital in Denmark (Ej/USD)	ϵ_{gr}^{DK}	3.65			
Energy intensity of green capital in ROW (Ej/USD)	ϵ_{gr}^{ROW}	7.95			
Energy intensity of conventional capital in Denmark (Ej/USD)	$\epsilon_{\text{con}}^{DK}$	4.65			
Energy intensity of conventional capital in ROW (Ej/USD)	$\epsilon_{\text{con}}^{ROW}$	9.95			
CO2 intensity of green capital in Denmark (Gt/Ej)**	β_{gr}^{DK}	0.035			
CO2 intensity of green capital in ROW (Gt/Ej)**	β_{gr}^{ROW}	0.035			
CO2 intensity of conventional capital in Denmark (Gt/Ej)**	β_{con}^{DK}	0.055			
CO2 intensity of conventional capital in ROW (Gt/Ej)**	β_{con}^{ROW}	0.055			
Coefficient of CO2 annual emissions in Denmark (mean)**	β_0^{DK}	0.0098			
Coefficient of CO2 annual emissions in ROW**	β_0^{G}	4.4902			
Parameter of Danish improvements of the renewability share of green capital	$impv_0^{DK}$	-1.33			
Parameter of Danish improvements of the renewability share of green capital	$impv_1^{DK}$	0.5944			
Parameter of ROW improvements of the renewability share of green capital	$impv_0^{ROW}$	-4.242			
Parameter of ROW improvements of the renewability share of green capital	$impv_1^{ROW}$	0.5944			

The share of green capital stock not upgraded to new efficiency in ROW	imp_{ROW}	0.85			
The share of green capital stock not upgraded to new efficiency in ROW	imp_{DK}	0.85			
Degrowth rate of co2 intensity in ROW	$g_{\beta gr}^{ROW}$	0.015			
Degrowth rate of co2 intensity in Denmark	$g_{\beta gr}^{DK}$	0.03			
Carbon tax rate in Denmark ($ tax per ton co2)	$Co2_{rate}^{DK}$	0			
Carbon tax rate in ROW ($ tax per ton co2)	$Co2_{rate}^{ROW}$	0			
Temperature at the lower-ocean level	T_{LO}	0			
Speed of adjustment parameter in atmospheric temperature function	τ_1	0.027			
Heat loss from the atmosphere to the lower ocean in atmospheric temperature	τ_2	0.018			
Heat loss from the atmosphere to the lower ocean in lower ocean temperature	τ_3	0.005			
Equilibrium climate sensitivity	s	3			
Pre-industrial CO2 concentration in atmosphere	$co2_{AT}^{PRE}$	2156.2			
Pre-industrial CO2 concentration in upper ocean/biosphere	$\mathrm{co}2_{UP}^{PRE}$	4950.5			
Pre-industrial CO2 concentration in lower ocean	$\mathrm{co}2_{LO}^{PRE}$	36670			
CO2 transfer coefficient	ϕ_{11}	0.9817			
CO2 transfer coefficient	ϕ_{12}	0.0080			
CO2 transfer coefficient	ϕ_{21}	0.0183			
CO2 transfer coefficient	ϕ_{22}	0.9915			
CO2 transfer coefficient	ϕ_{23}	0.0005			
CO2 transfer coefficient	ϕ_{32}	0.0001			
CO2 transfer coefficient	ϕ_{33}	0.9999			
Land-use CO2 emissions	emis_l	4			
Rate of decline of land-use CO2 emissions (after 2020)	g_l	0.044			
Radiative forcing over pre-industrial levels (W/m^2)	F	2.3			
Increase in radiative forcing due to doubling of CO2 concentration	F_2	3.8			
Radiative forcing due to non-CO2 greenhouse gases	F_{EX}	0.28			

Annual increase in radiative forcing due to non-CO2 greenhouse gases	fex	0.005			
Waste generated by production activities in Denmark (Gt)	wa_{DK}	0.023			
Waste generated by production activities in ROW (Gt)	wa_{ROW}	10.98			
Recycling rate in Denmark	ρ_{DK}	0.2			
Recycling rate in ROW	ρ_{ROW}	0.2			
Conversion rate of material resources into reserves in Denmark	σ_m^{DK}	0.00034			
Conversion rate of material resources into reserves in ROW	σ_m^{ROW}	0.00034			
Conversion rate of non-ren. energy resources into reserves in Denmark	σ_e^{DK}	0.00177			
Conversion rate of non-ren. energy resources into reserves in ROW	σ_e^{ROW}	0.00177			
Initial value of matter resources of Danish (Gt)	res_m^{DK}	3031.426			
Initial value of matter resources of ROW (Gt)	res_m^{ROW}	395549.5			
Initial value of non-renewable energy resources in Denmark (Ej)	res_e^{DK}	4617.11			
Initial value of non-renewable energy resources in ROW (Ej)	res_e^{ROW}	602454.3			
Initial value of socio-economic stock of Danish (Gt)	k_{se}^{DK}	0			
Initial value of socio-economic stock of Danish (Gt)	k_{se}^{ROW}	0			
Coefficient converting Gt of carbon into Gt of CO2	car	3.67			
Parameter of damage function in Denmark	d_1^{DK}	0			
Parameter of damage function in Denmark	d_2^{DK}	0.00284			
Parameter of damage function in Denmark	d_3^{DK}	0.000005			
Parameter of damage function in Denmark	x^{DK}	6.6754			
Percentage of damages in Denmark	d_T^{DK}	0.0028			
Parameter of damage function in ROW	d_1^{ROW}	0			
Parameter of damage function in ROW	d_2^{G}	0.00284			

Parameter of damage function in ROW	d_3^G	0.000005			
Parameter of damage function in ROW	x^{ROW}	6.6754			
Percentage of damages in ROW	d_T^{ROW}	0.0028			
Proportion of durable discarded in Denmark every year	ζ_{DK}	0.015			
Proportion of durable discarded in ROW every year	ζ_{ROW}	0.015			
Share of renewable energy to total energy in Denmark, conventional capital	η_{con}^{DK}	0.05			
Share of renewable energy to total energy in ROW, conventional capital	η_{con}^{ROW}	0.05			
Share of renewable energy to total energy in Denmark, green capital	η_{gr}^{DK}	0.05			
Share of renewable energy to total energy in ROW, green capital	η_{gr}^{ROW}	0.05			
Starting values of exogenous variables for the two open economies					
Initial government green spending in Denmark after 1990	GOV_{gr}^{DK}	0.0098			
Initial government green spending in ROW after 1990	GOV_{gr}^{ROW}	1.5938			
Initial government conventional spending in Denmark*	GOV_{con}^{DK}	0.018			
Initial Government conventional spending in ROW*	GOV_{con}^{ROW}	2.380			
Coefficient of government conventional spending function in Denmark*	$\gamma_{GOV_0}^{DK}$	0.076			
Coefficient of government conventional spending in Denmark*	$\gamma_{GOV_1}^{DK}$	1.003			
Coefficient of government conventional spending function in ROW*	$\gamma_{GOV_0}^{ROW}$	0.076			
Coefficient of government conventional spending in ROW*	$\gamma_{GOV_1}^{ROW}$	1.003			
Return rate on government bonds in Denmark	r_b^{DK}	0.03			
Return rate on government bonds in ROW	r_b^{ROW}	0.03			
Interest rate on loans in Denmark	r_l^{DK}	0.035			

Interest rate on loans in ROW	r_l^{ROW}	0.035			
Exchange rate Denmark	xr_{DK}	1			
Exchange rate ROW	xr_{ROW}	1			
Starting values for endog. variables with lag for the two open economies					
Return rate on equity & shares in Denmark	r_e^{ROW}	0.03			
Return rate on equity & shares in ROW	r_e^{DK}	0.03			

Appendix -C Figures:

Section 4 figures:

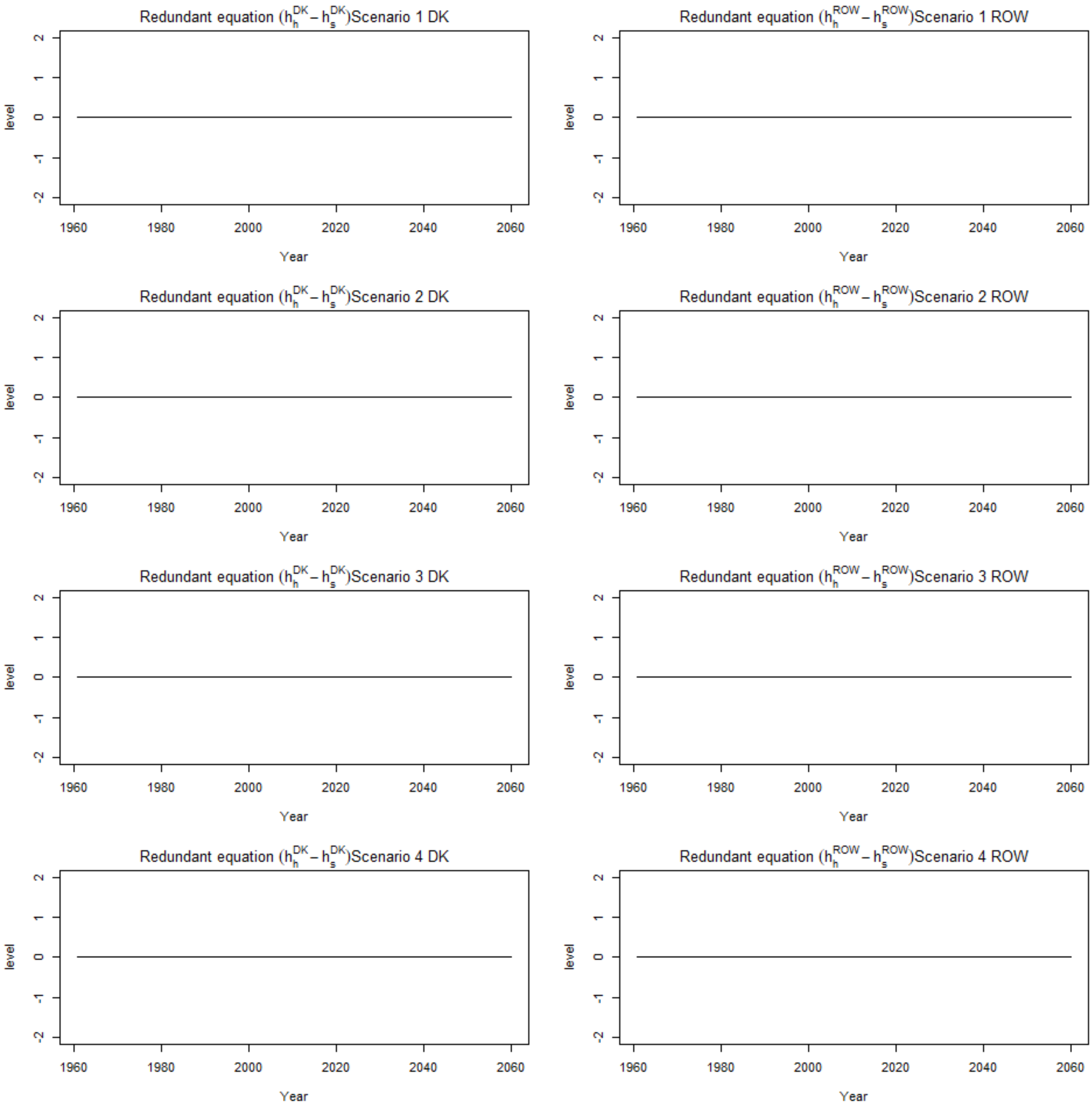


Figure 1 Appendix: Redundant equations scenario 1-4

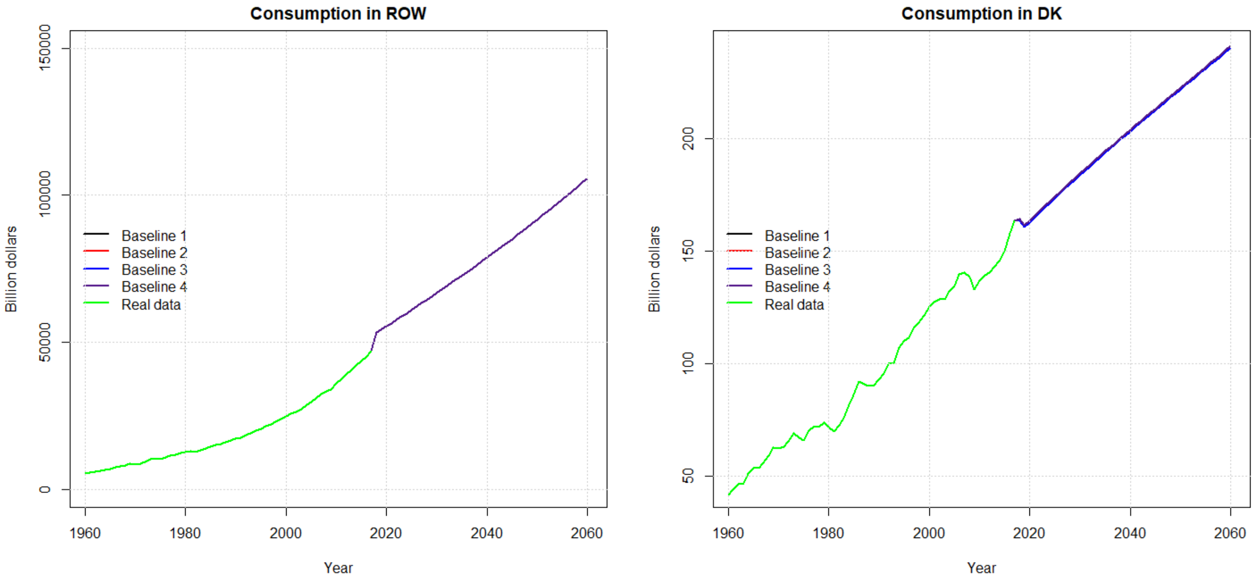


Figure 2 Appendix: Validation of baseline models: Consumption in Denmark and ROW

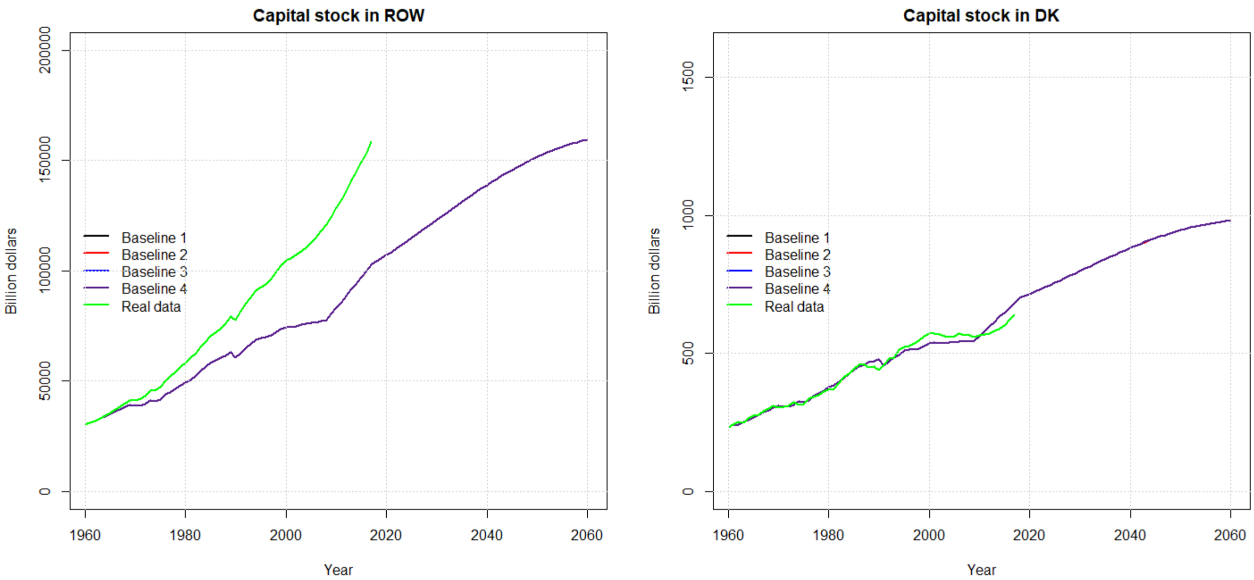


Figure 3 Appendix: Validation of baseline models: Capital in Denmark and ROW

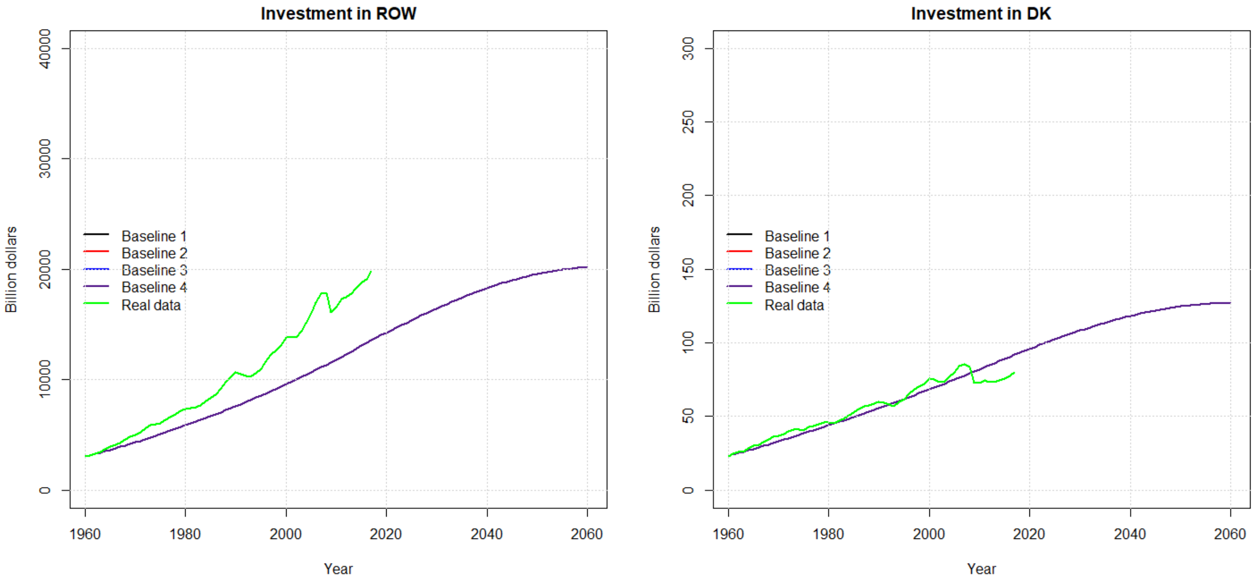


Figure 4 Appendix: Validation of baseline model: Investments in Denmark and ROW

Section 5 figures:

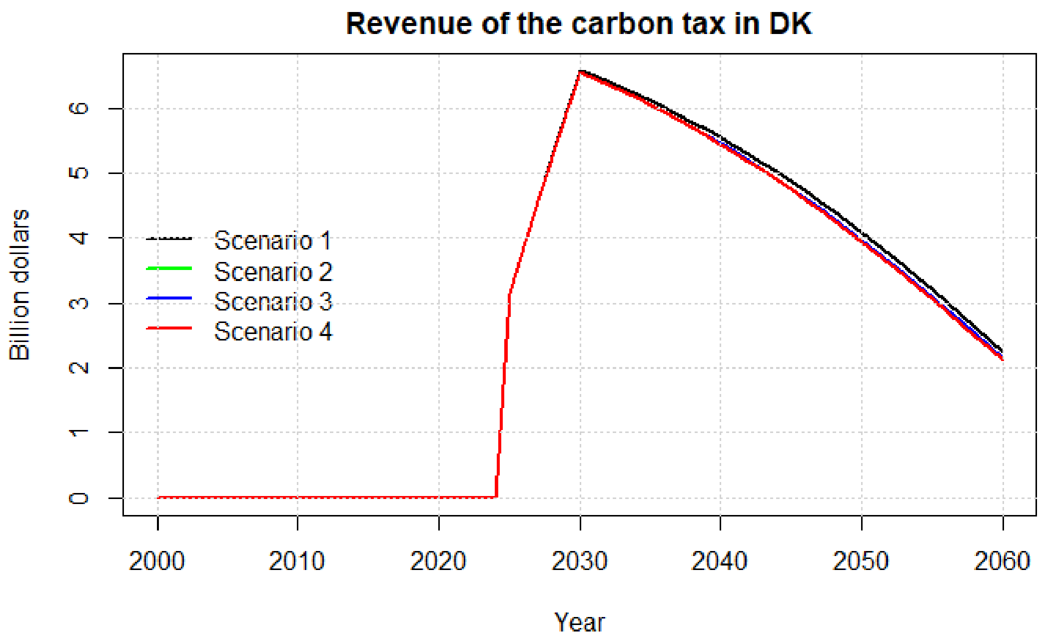


Figure 5 Appendix: Carbon Tax revenue in Denmark

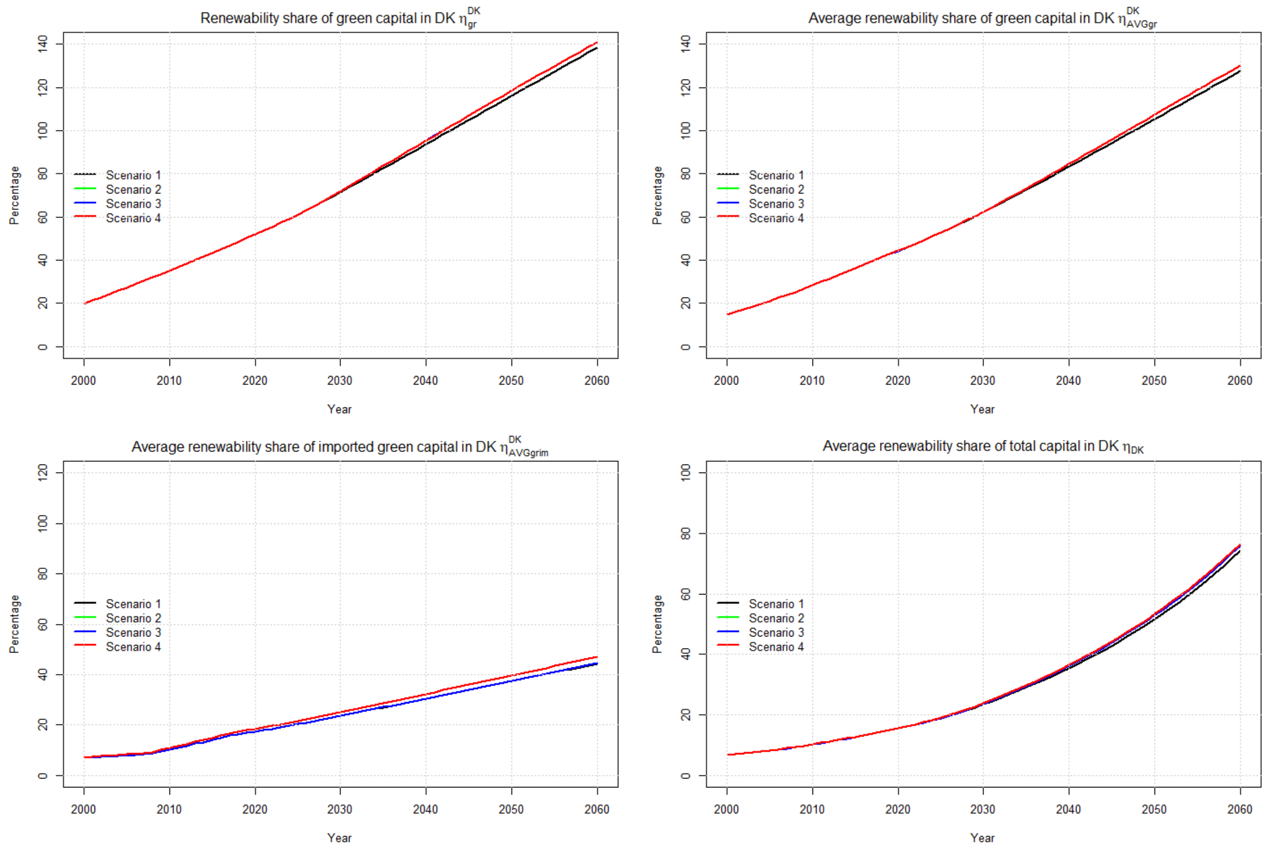


Figure 6 Appendix: Renewability shares in Denmark

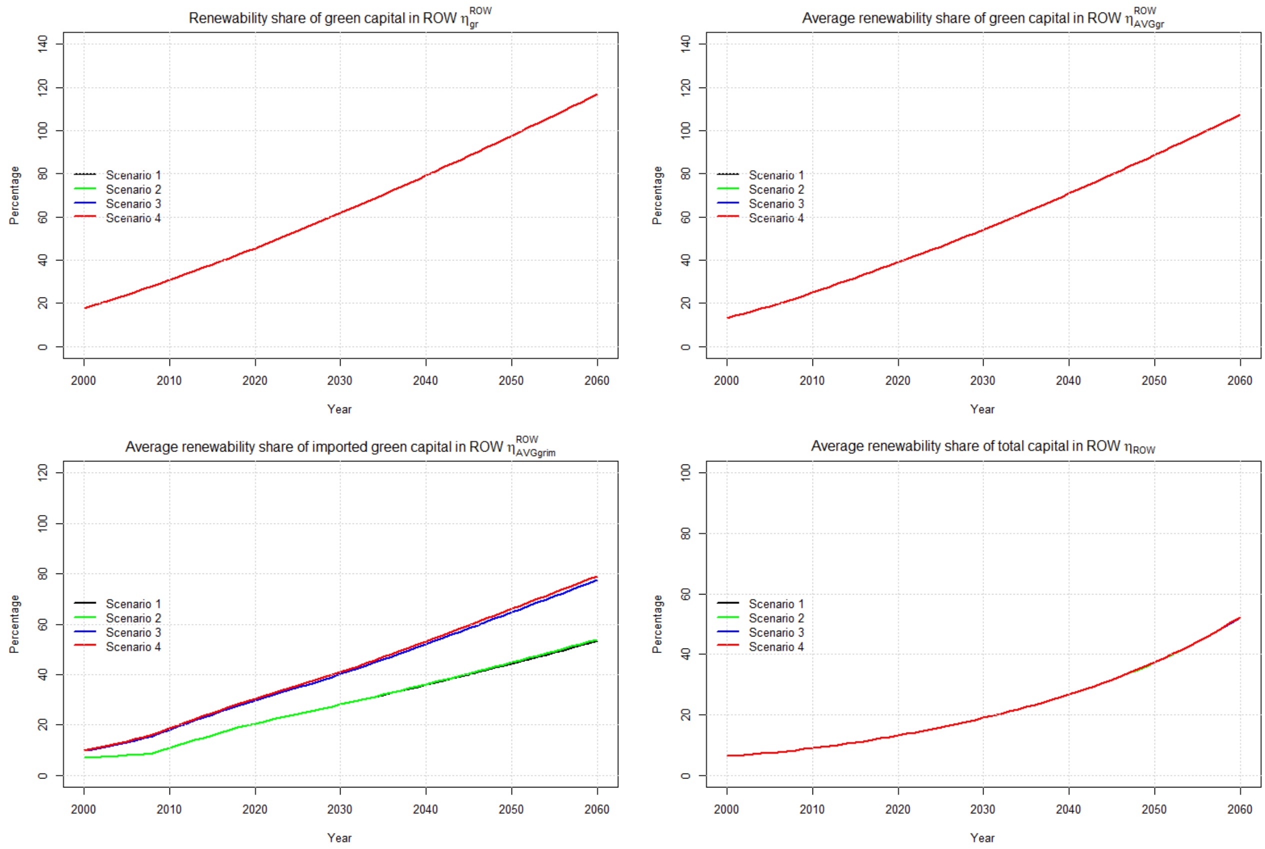


Figure 7 Appendix: Renewability shares in ROW

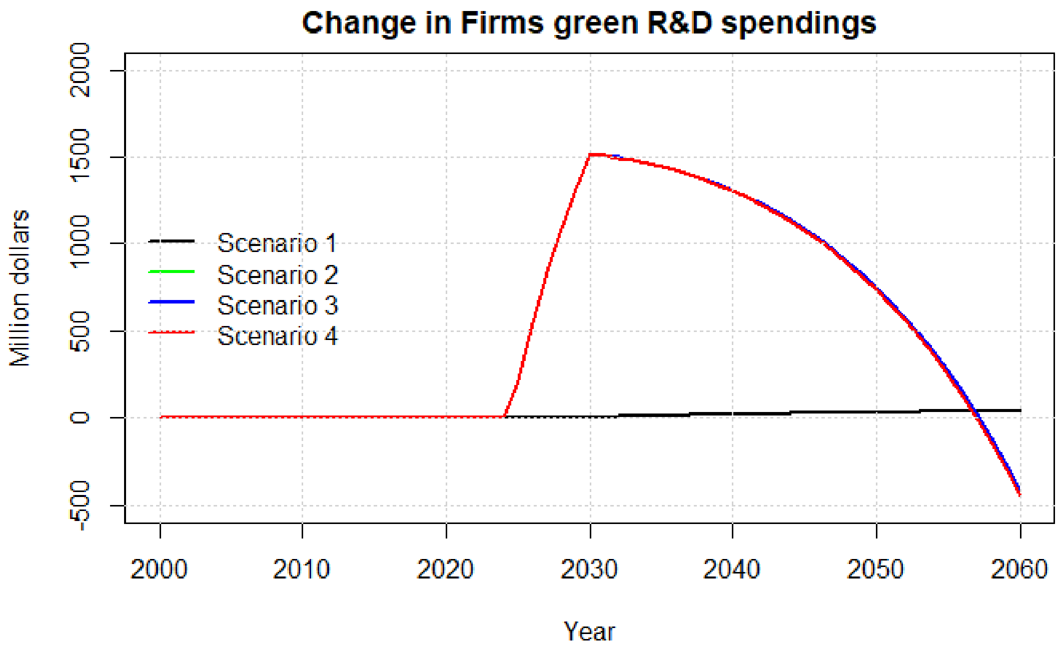


Figure 8 Appendix: Firms green R&D spending

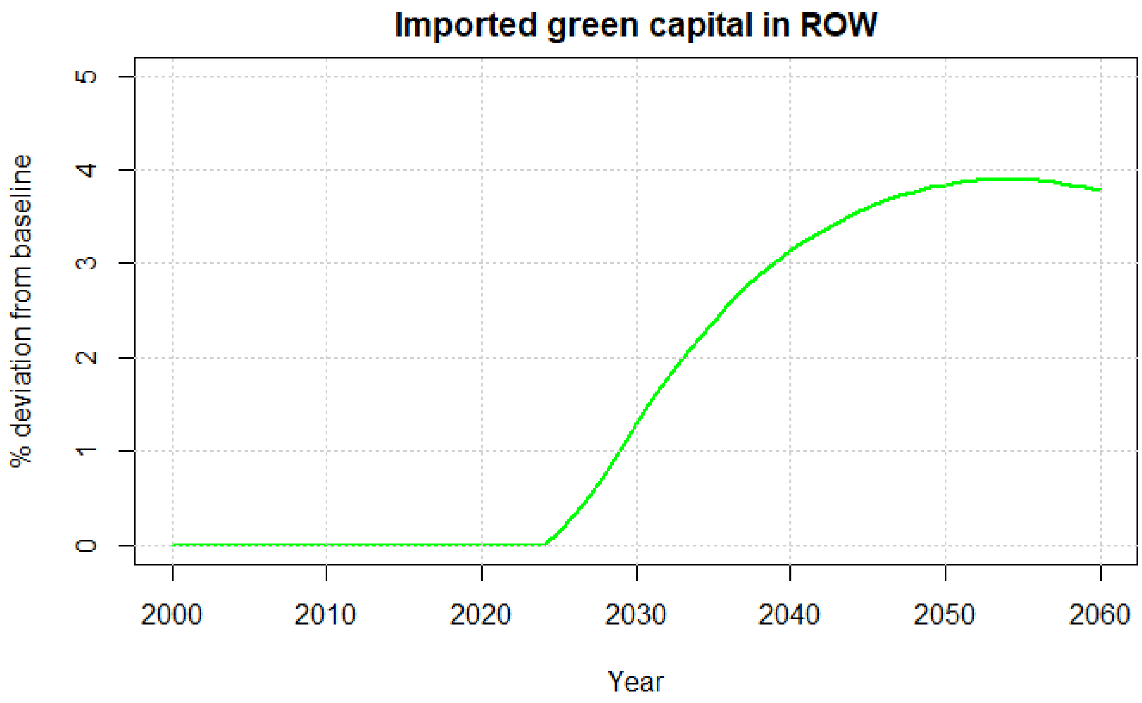


Figure 9 Appendix: Green imported capital by ROW

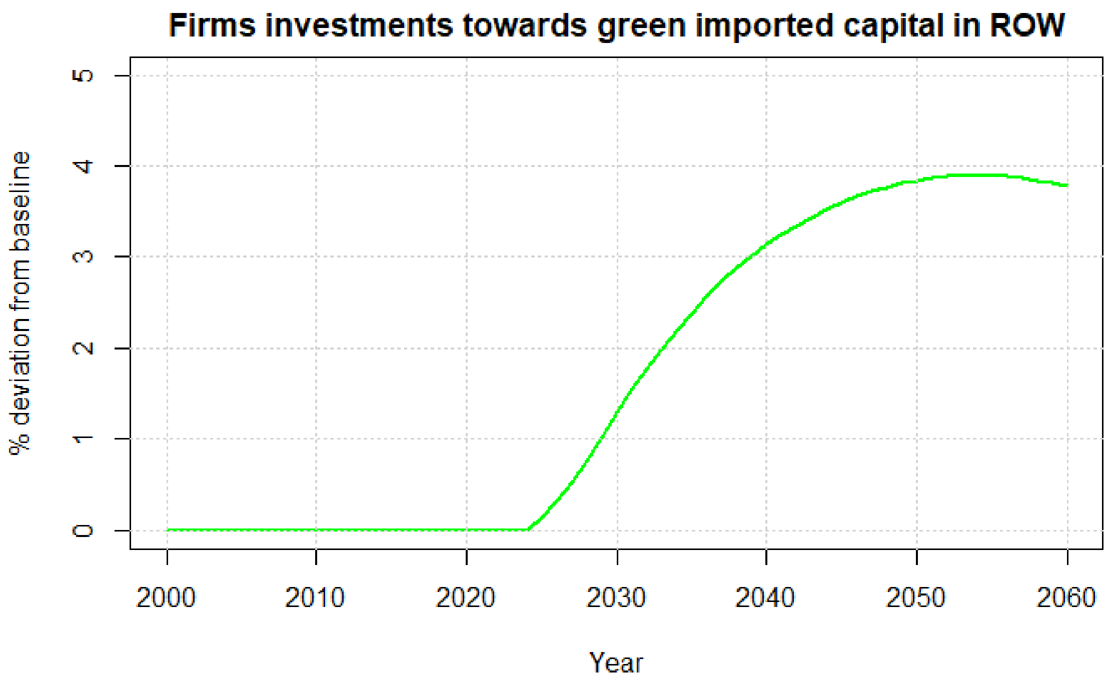


Figure 10 Appendix: Firms investments in green imports ROW

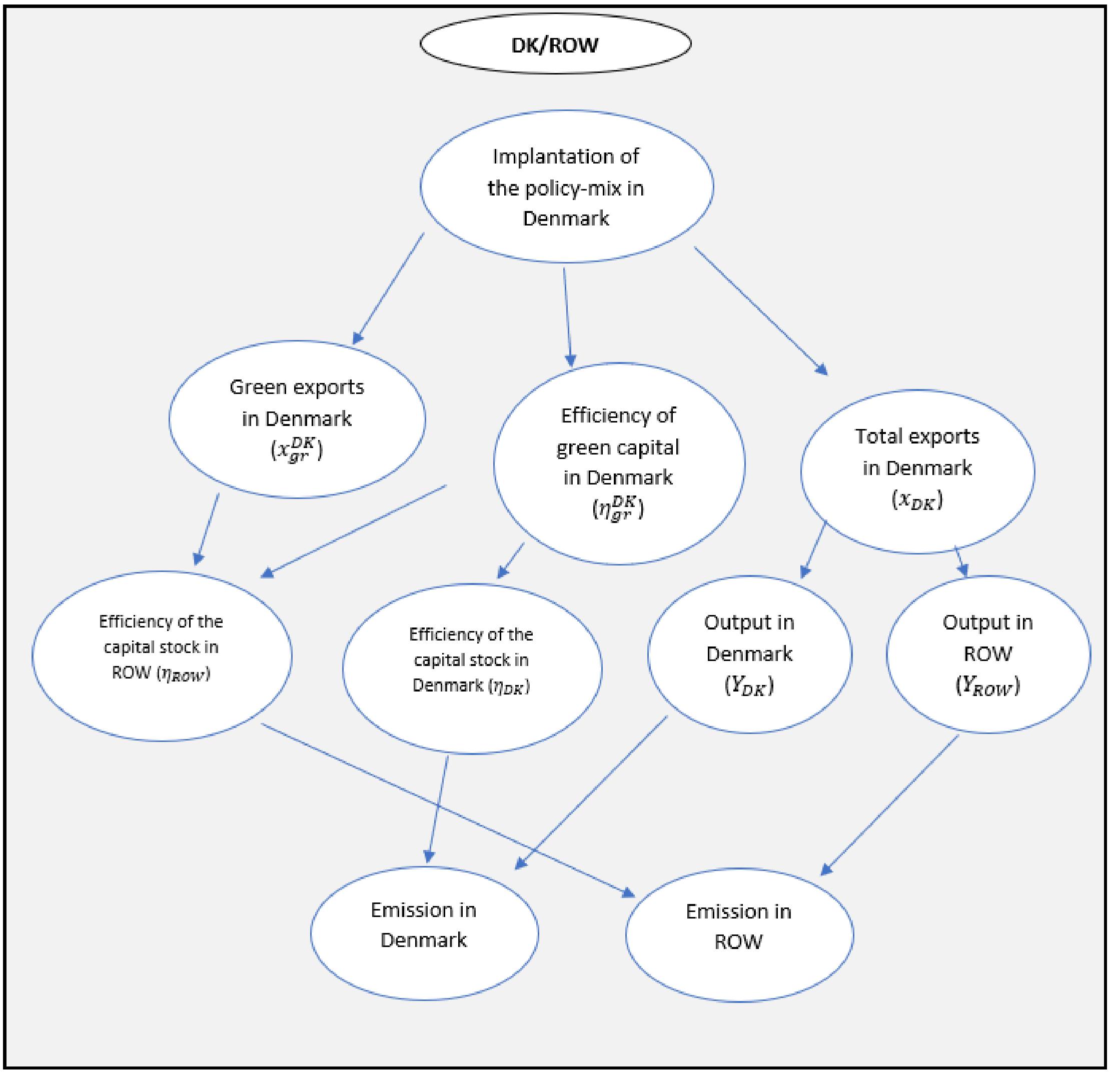


Figure 11 Appendix: DAG showing channels affecting emission

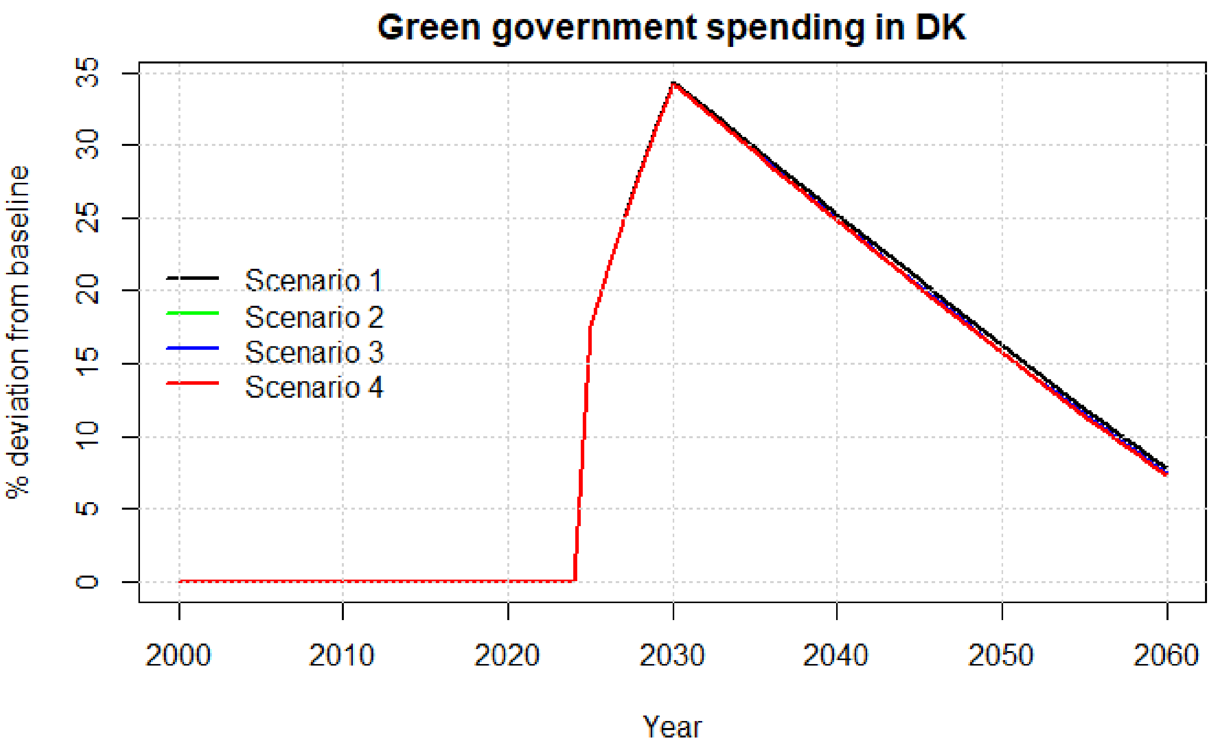


Figure 12 Appendix: Green Government spending in Denmark

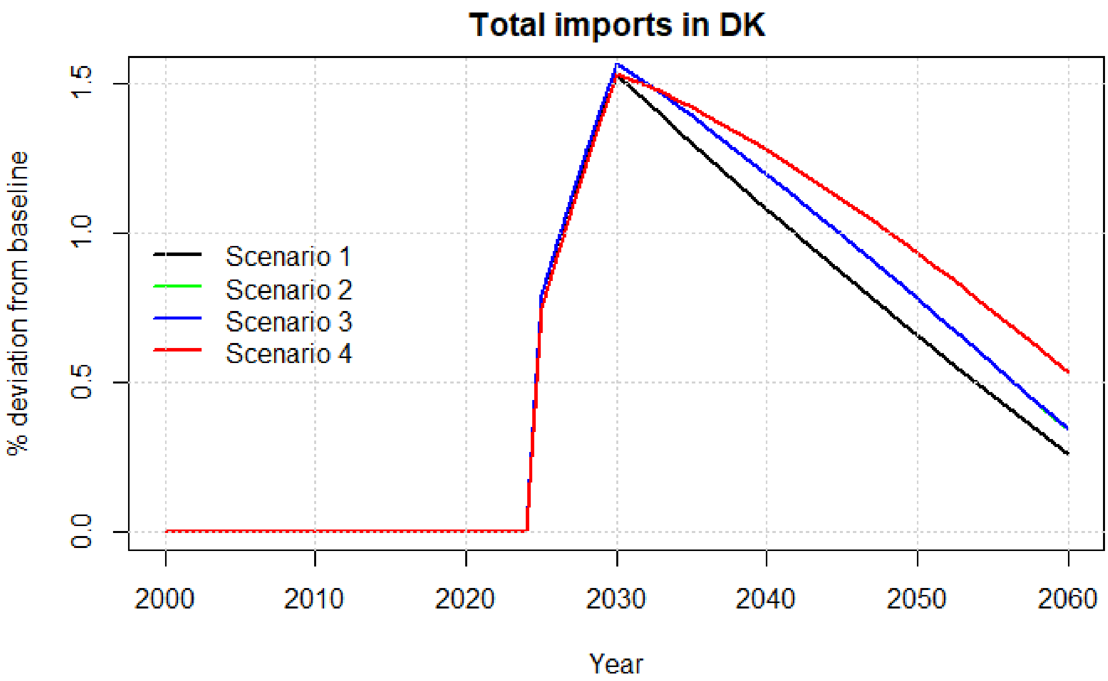


Figure 13 Appendix: Total imports in Denmark

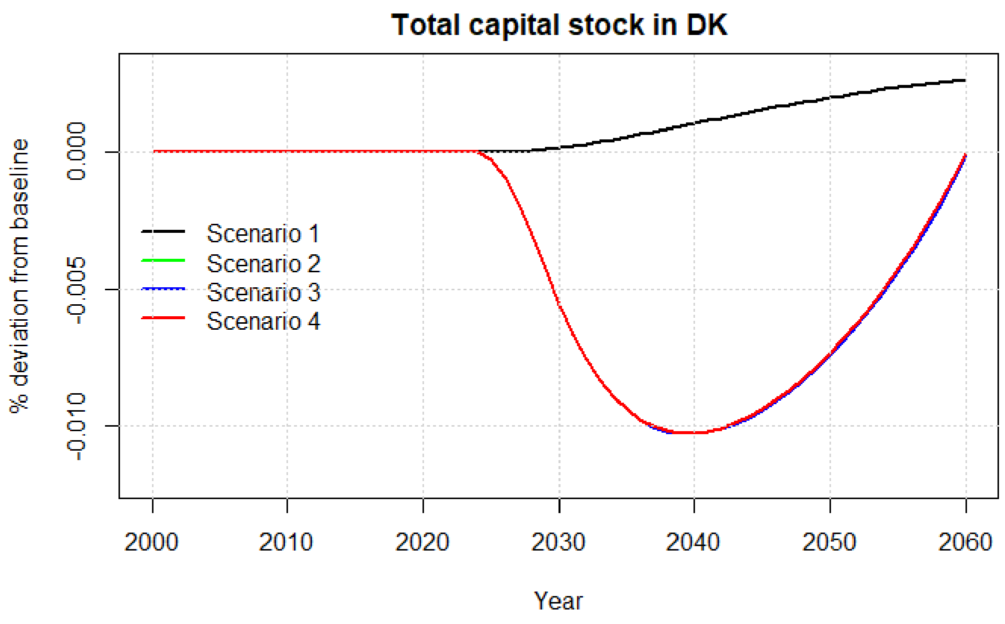


Figure 14 Appendix: Change in total capital Denmark

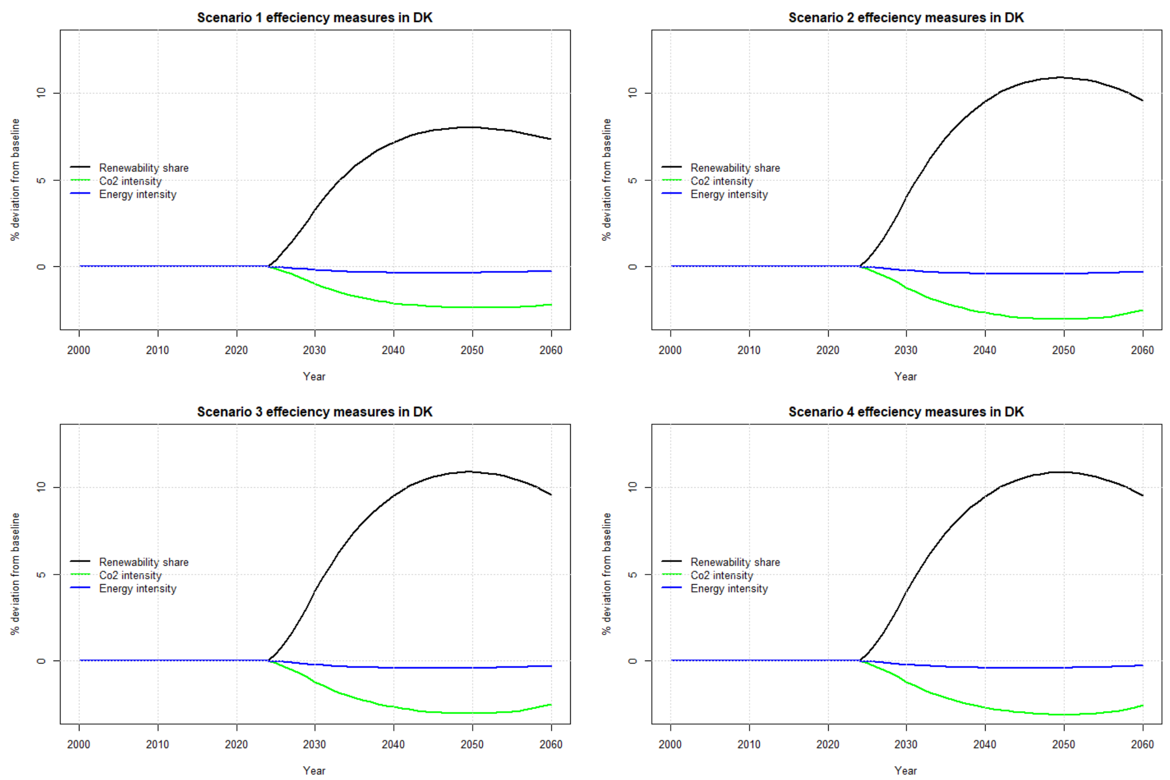


Figure 15 Appendix: Change in different efficiency measures Denmark

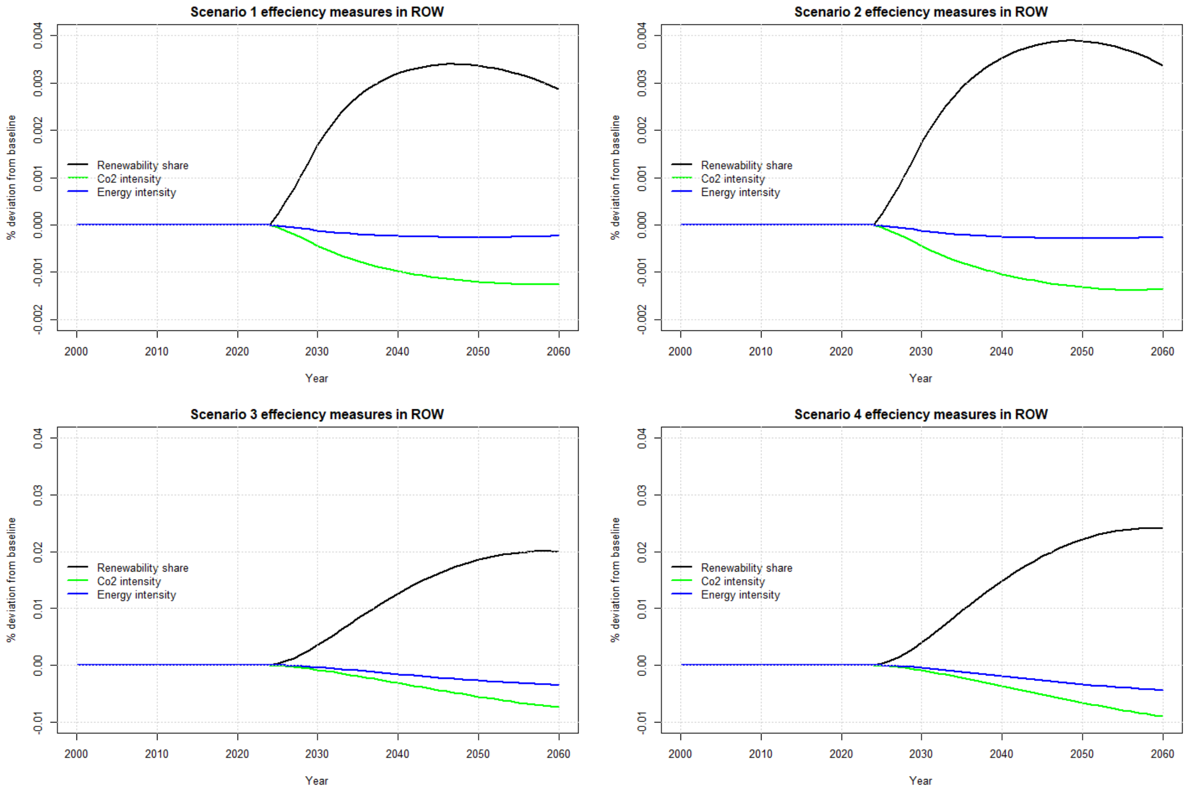


Figure 16 Appendix: Change in different efficiency measures ROW

Section 6 figures:

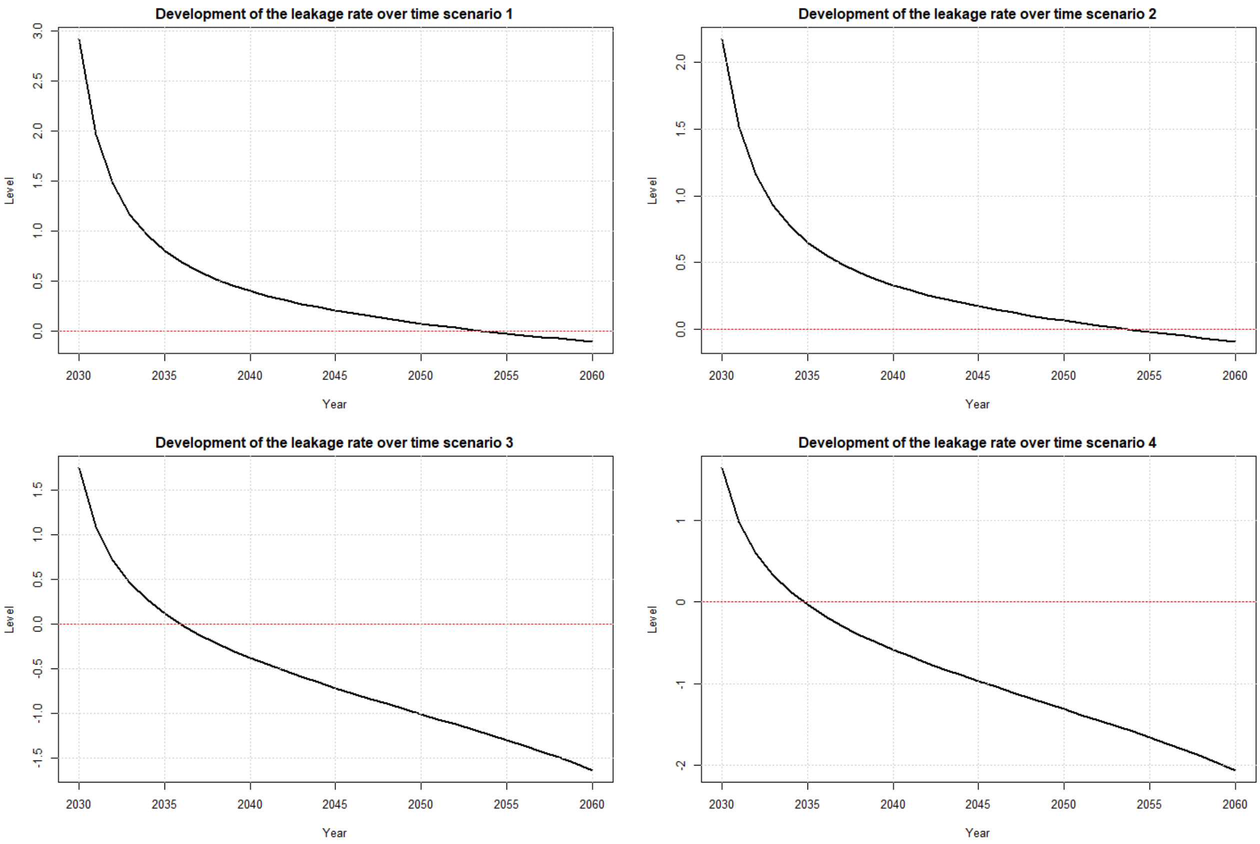


Figure 17 Appendix: Developments of leakage rates

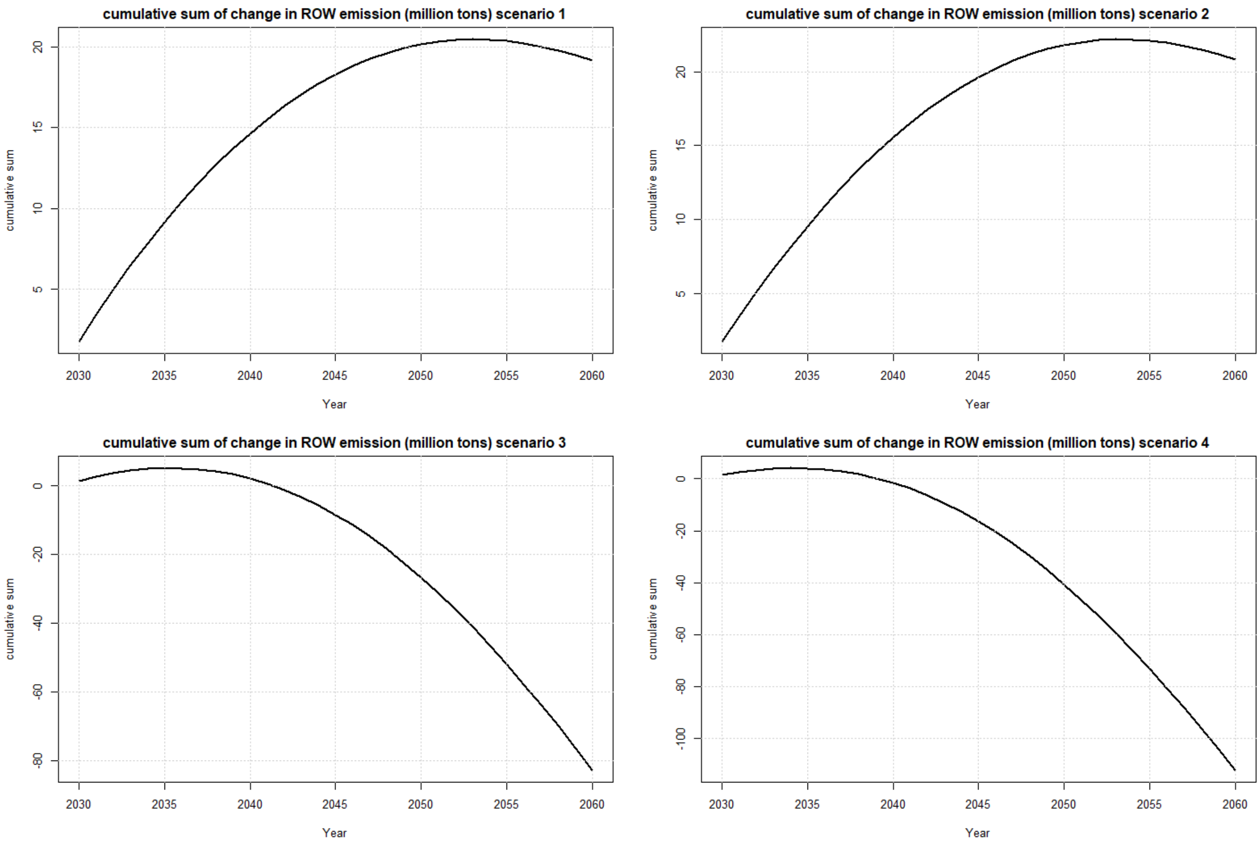


Figure 18 Appendix: Accumulative change in emission for ROW

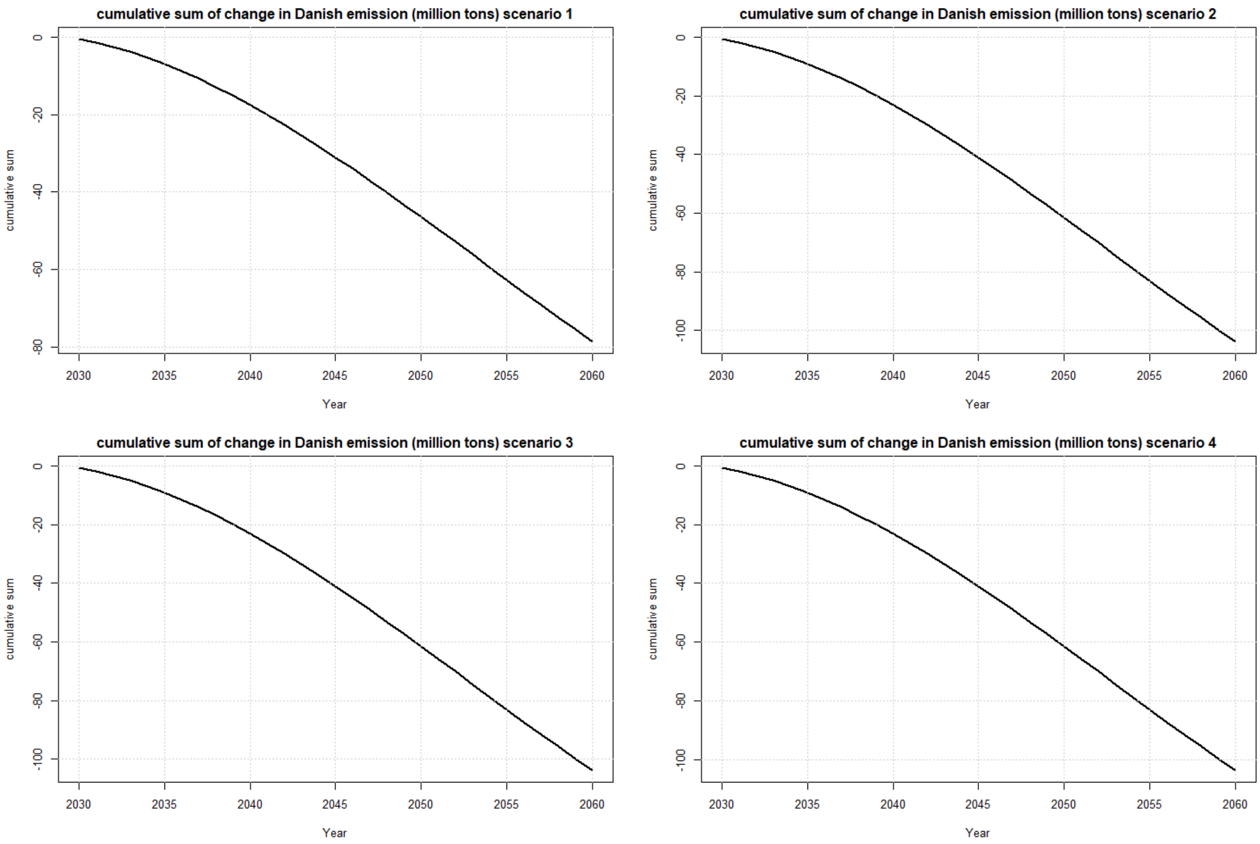


Figure 19 Appendix: Accumulative change in emission for Denmark

Appendix -D Sensitivity analysis:

Comparing the three versions in isolation: Effect on GDP, Efficiency, and emission.

In this sensitivity analysis, we compare the three versions of the PH framework in isolation, thereby looking at three scenario: First, only activating the Weak PH (same as scenario 2 in the main analysis). Second, only activating the Narrowly strong PH. Third, only activating the Strong PH. We look at the main results being changes in emission as well as the two underlaying channels affecting emission (Output, and the average renewability share of total capital).

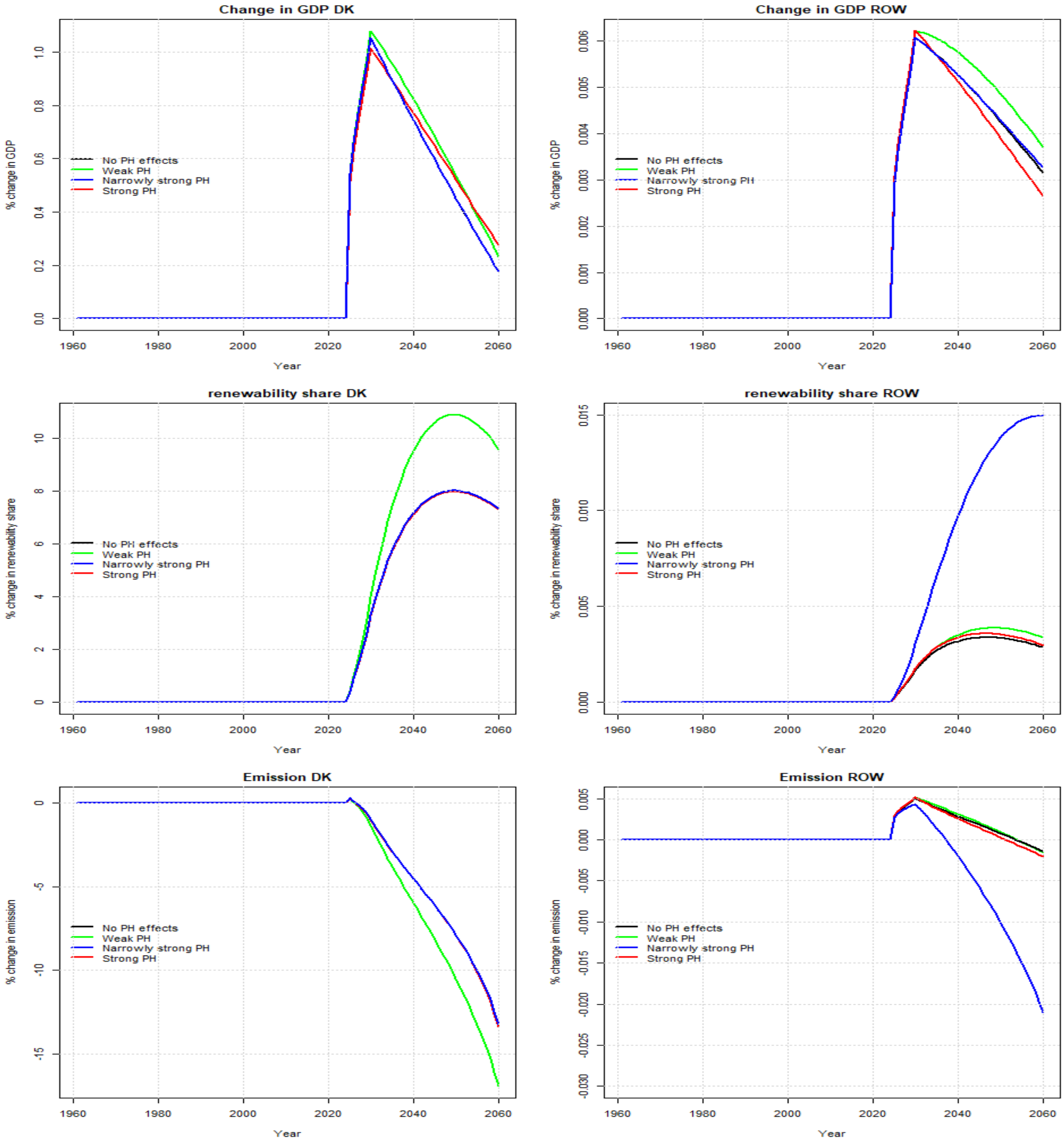


Figure 20 Appendix: Results of sensitivity analysis 1

Changing assumption of imported green capital improvements: (Sens 2)

In this sensitivity analysis, we change the assumption that already imported green capital cannot be updated to the new efficiency of green capital. We do so by allowing 15% of the already existing stock of imported green capital to be updated every period, thereby matching the effect on domestic produced green capital. We look at the main results being changes in emission as well as the two underlying channels affecting emission (output, and the average renewability share of total capital).

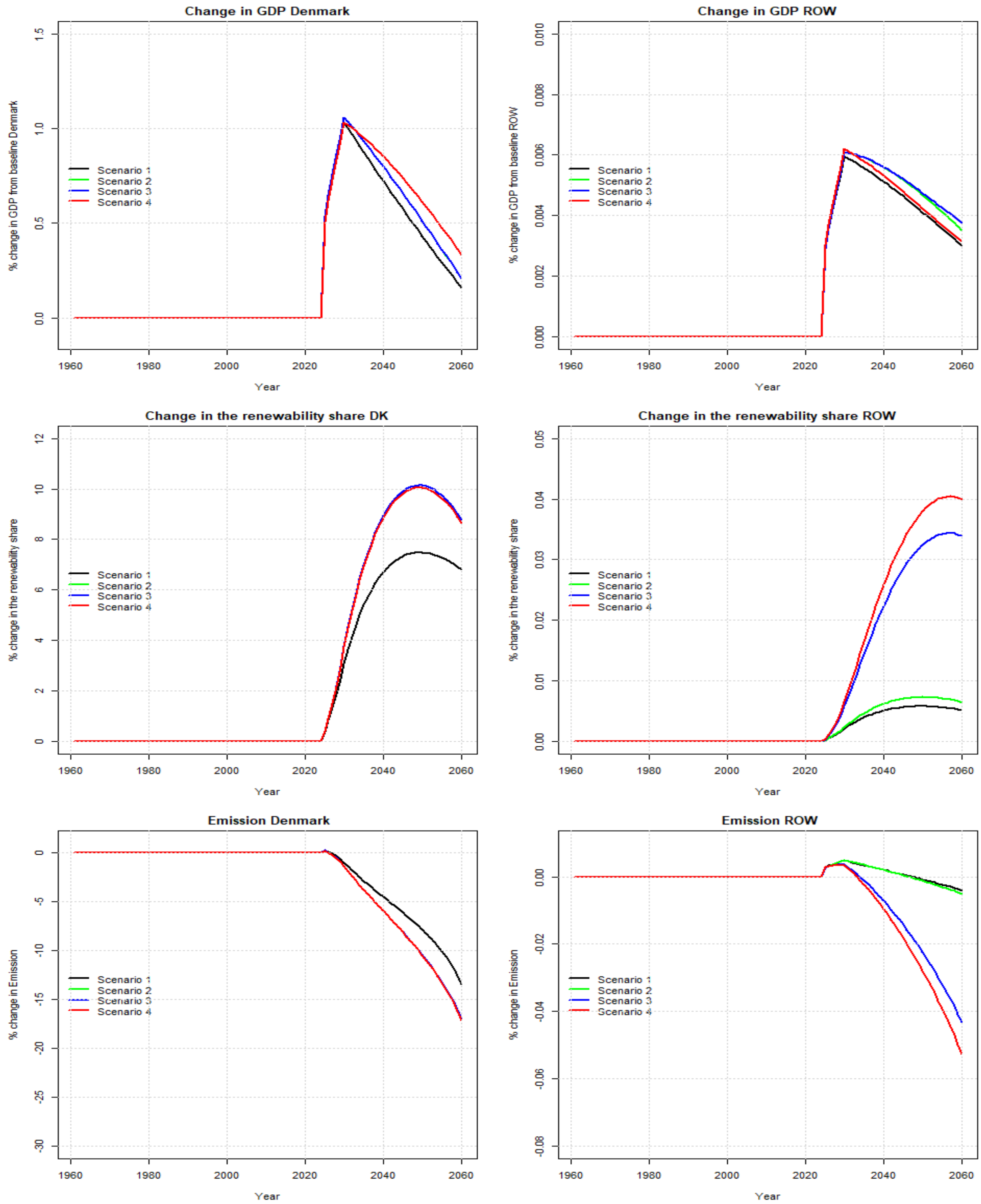


Figure 21 Appendix: Results of sensitivity analysis 2

Sensitivity analysis for coefficient used when activating the Narrowly strong PH: (Sens 3)

In this sensitivity analysis, we change the coefficient introduced when activating the Narrowly Strong PH, using evidence provided by Costantini & Mazzanti (2012) and Hwang & Kim (2017) setting the coefficient Ω_2^X to 0.22 instead of 0.5. We look at the main results being changes in emission as well as the two underlying channels affecting emission (output, and the average renewability share of total capital).

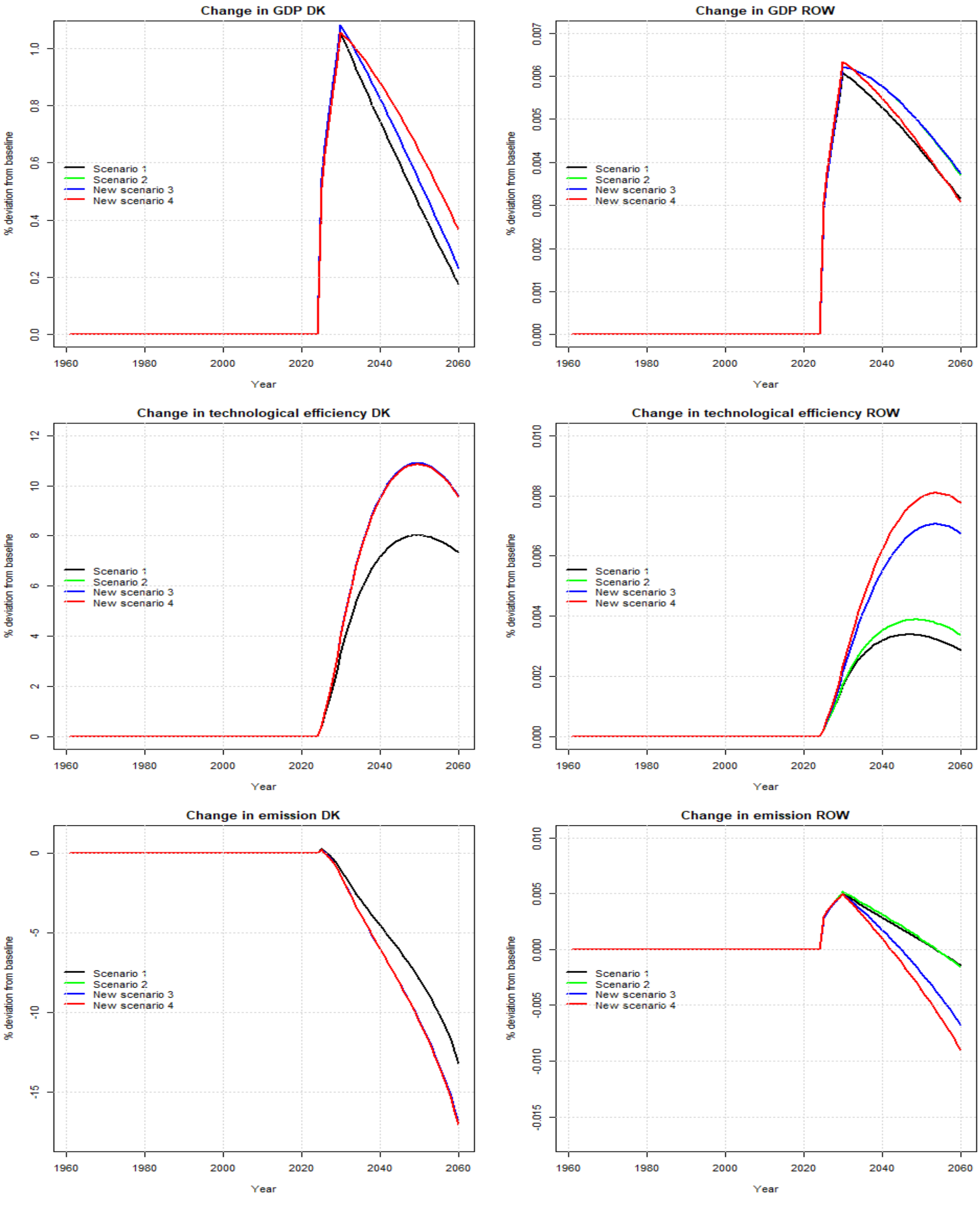


Figure 22 Appendix: Results of sensitivity analysis 3

Sensitivity analysis for coefficient used when activating the Strong PH: (Sens 4)

In this sensitivity analysis, we change the coefficient introduced when activating the Strong PH, using evidence provided by Costantini & Mazzanti (2012) setting the coefficient ε_2 & μ_2 to 0.1 instead of 0.05. We look at the main results being changes in emission as well as the two underlaying channels affecting emission (output, and the average renewability share of total capital).

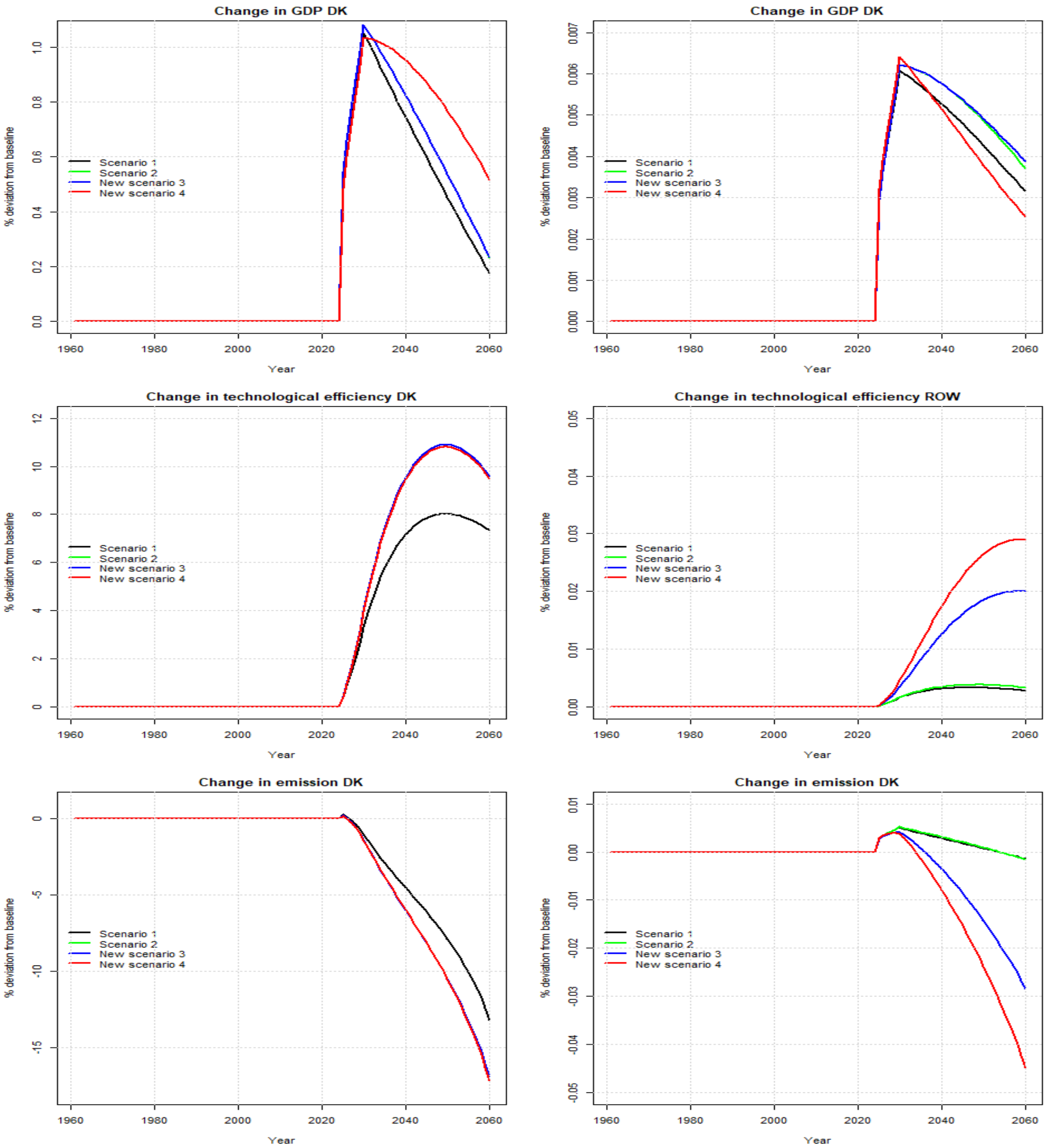


Figure 23 Appendix: Results of sensitivity analysis 4

Changing assumptions of Strong PH: (Sens 5)

In this sensitivity analysis, we relax the assumption that activating the Strong PH has an indirect effect on green exports through the increase in total exports. The main argument being that the Narrowly Strong PH should already account for this increase. Therefore, the total effect on export associated with the Strong PH will go towards conventional exports. We look at the main results being changes in emission as well as the two underlaying channels affecting emission (output, and the average renewability share of total capital).

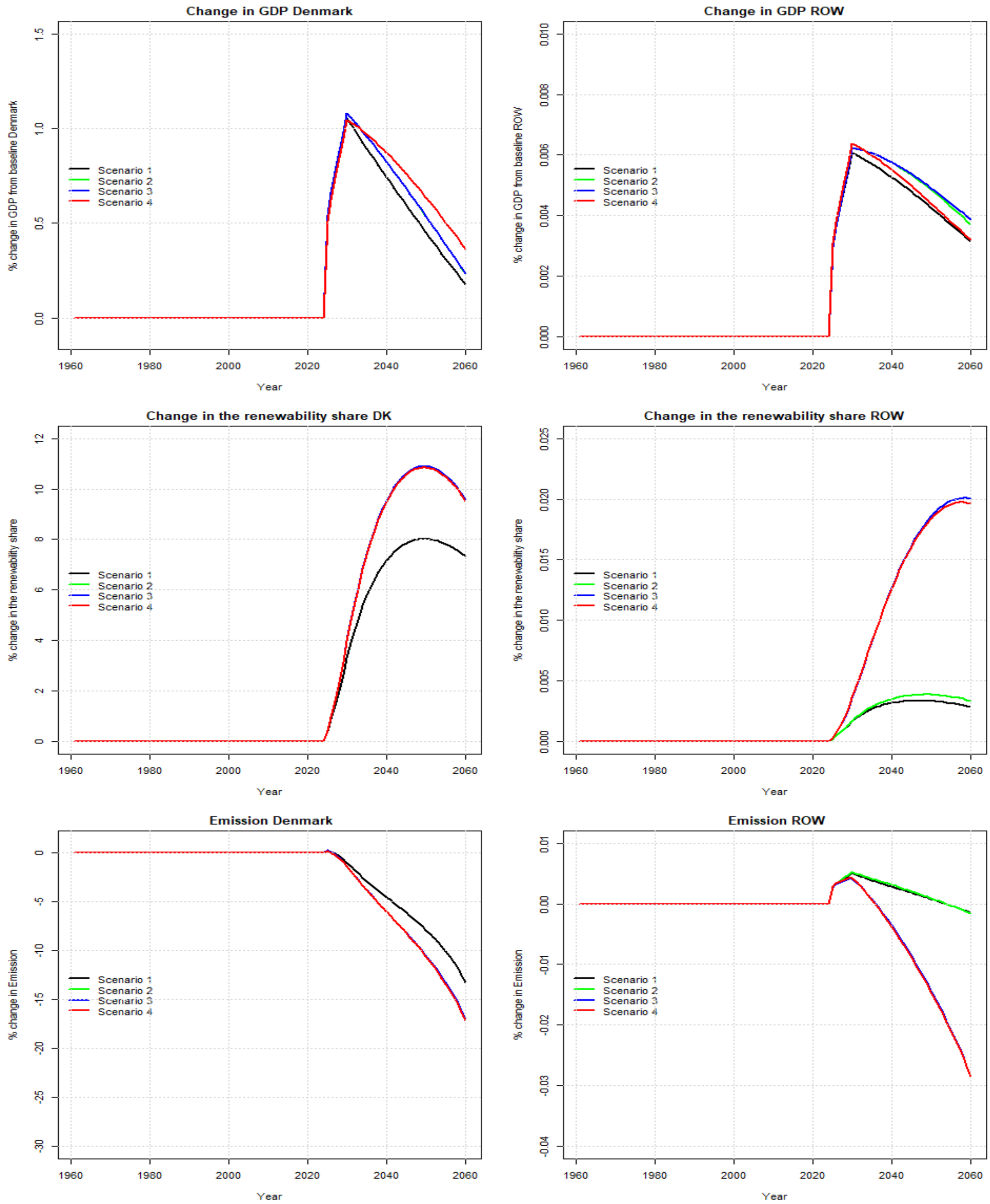


Figure 24 Appendix: Results of sensitivity analysis 5

Changing assumption of the Weak PH: (Sens 6)

In this sensitivity analysis, we change the assumption that introducing the carbon tax does not have a level effect on firms R&D spending when activating the weak PH. This assumption was mainly introduced for simplicity and could be seen as canceling out the opportunity costs argued to be a part of the weak PH. In this sensitivity analysis we allow firms R&D investments to increase from 10% of investments to 15% as the carbon tax is introduced.

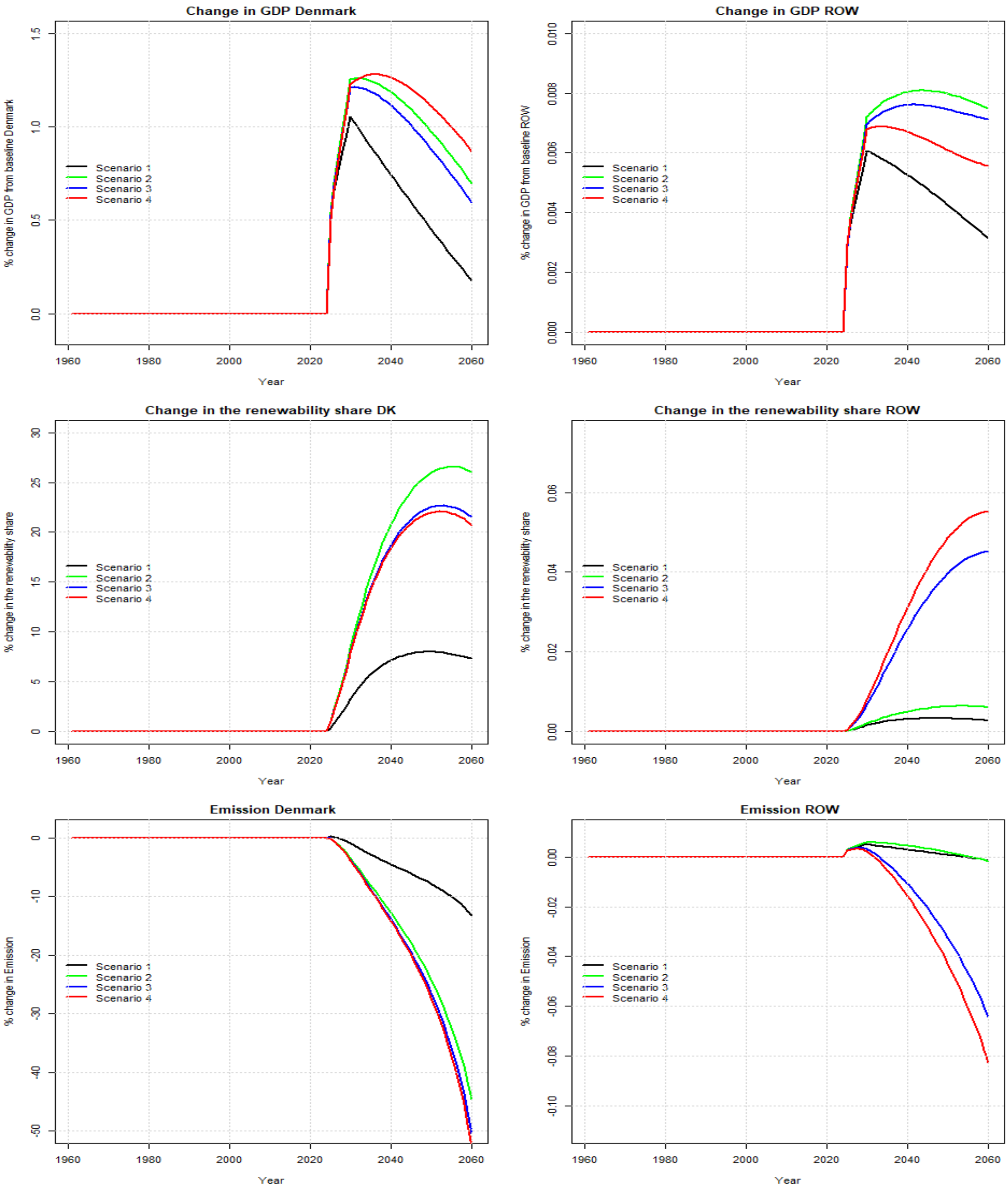


Figure 25 Appendix: Results of sensitivity analysis 6

Lowering green government spending: (Sens 7)

In this sensitivity analysis, we lower the share of government spending being green government spending. In the main analysis this share is set to 20% mainly to be able to match the observed data for the Danish renewability share of total production. Using data from Denmark's statistics indicate that this share instead should be close to 5% which is the share used in this sensitivity analysis. We look at the main results being changes in emission as well as the two underlying channels affecting emission (output, and the average renewability share of total capital).

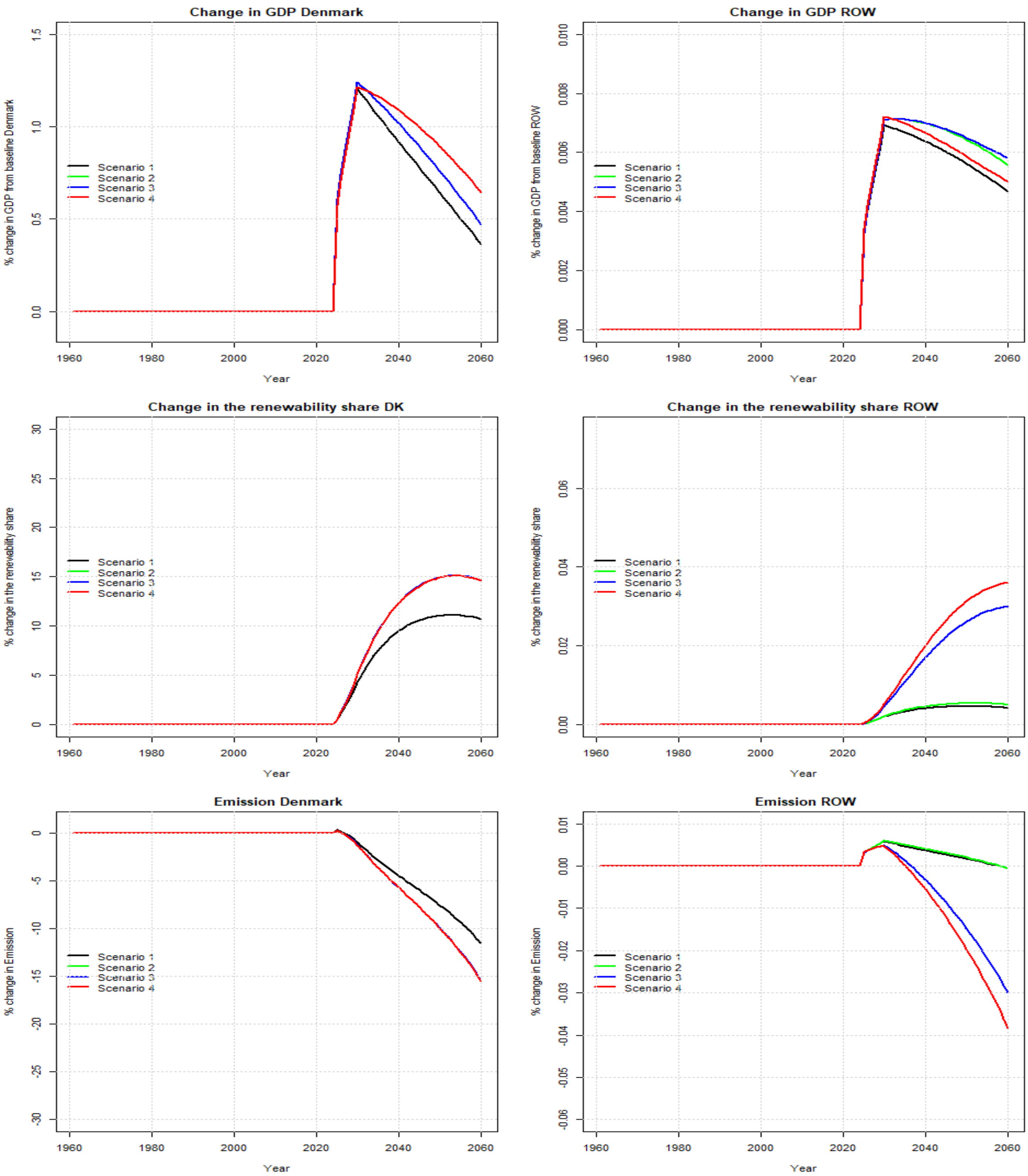


Figure 26 Appendix: Results of sensitivity analysis 7

Matching trade balance with 2017 data (Sens 8)

In this sensitivity analysis, we set exports and imports to match the percentage of GDP observed in real data in the year of 2017[112]. In the main analysis we calibrate import and export to match observed values in 1960 as this creates more realistic starting values for other variables like GDP, consumption, and investments. We look at the main results being changes in emission as well as the two underlying channels affecting emission (output, and the average renewability share of total capital).

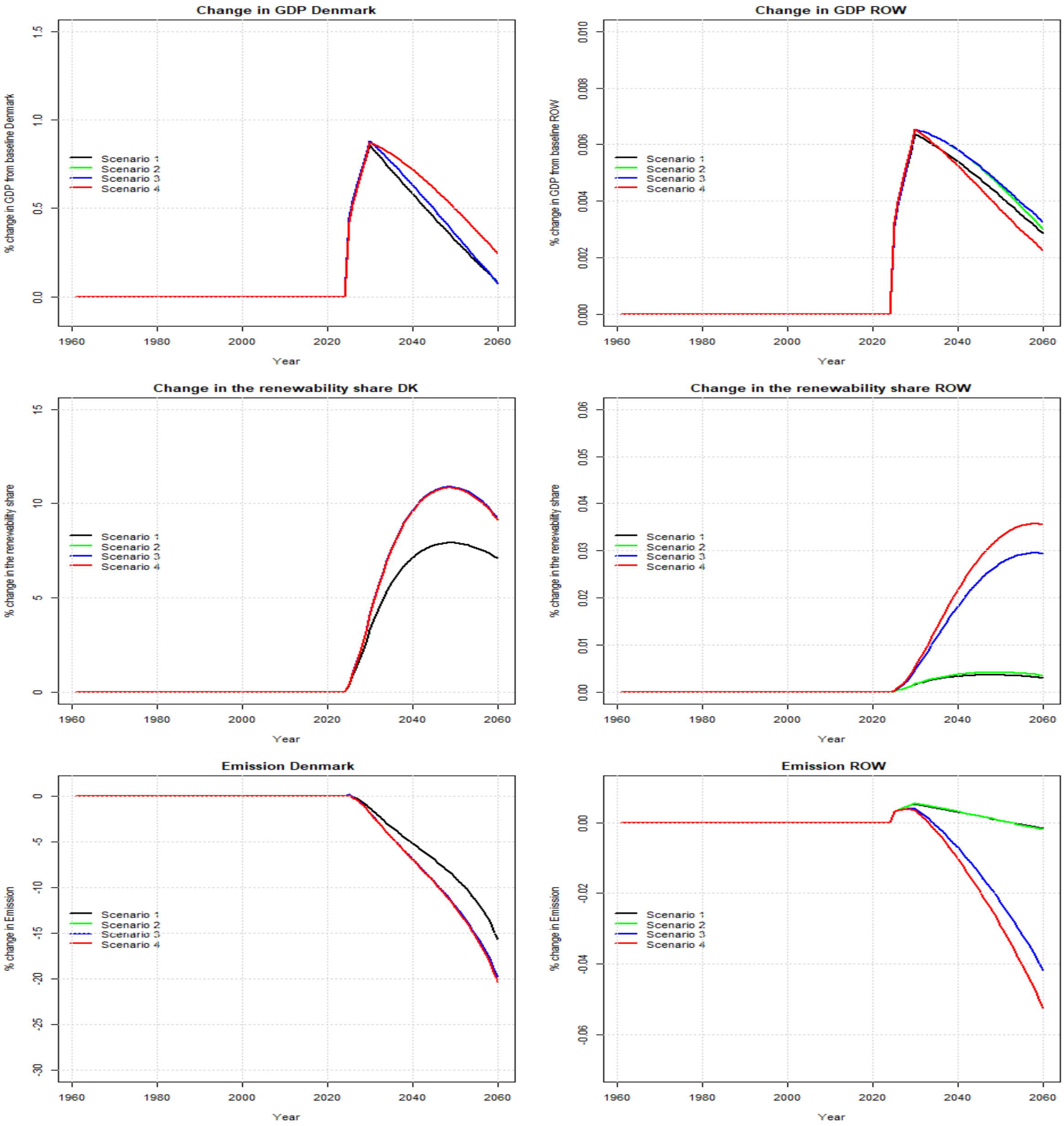


Figure 27 Appendix: Results of sensitivity analysis 8

[112] Data used for calibrating import and export to 2017 values is found following this link: https://www.macrotrends.net/countries/DNK/denmark/imports

Sensitivity analysis for coefficient used when activating the Weak PH: (Sens 9)

In this sensitivity analysis, we change the coefficient introduced when activating the Weak PH, setting the coefficient Γ_2^{DK} & Γ_2^{ROW} to 0.1 instead of 0.15. We look at the main results being changes in emission as well as the two underlying channels affecting emission (output, and the average renewability share of total capital).

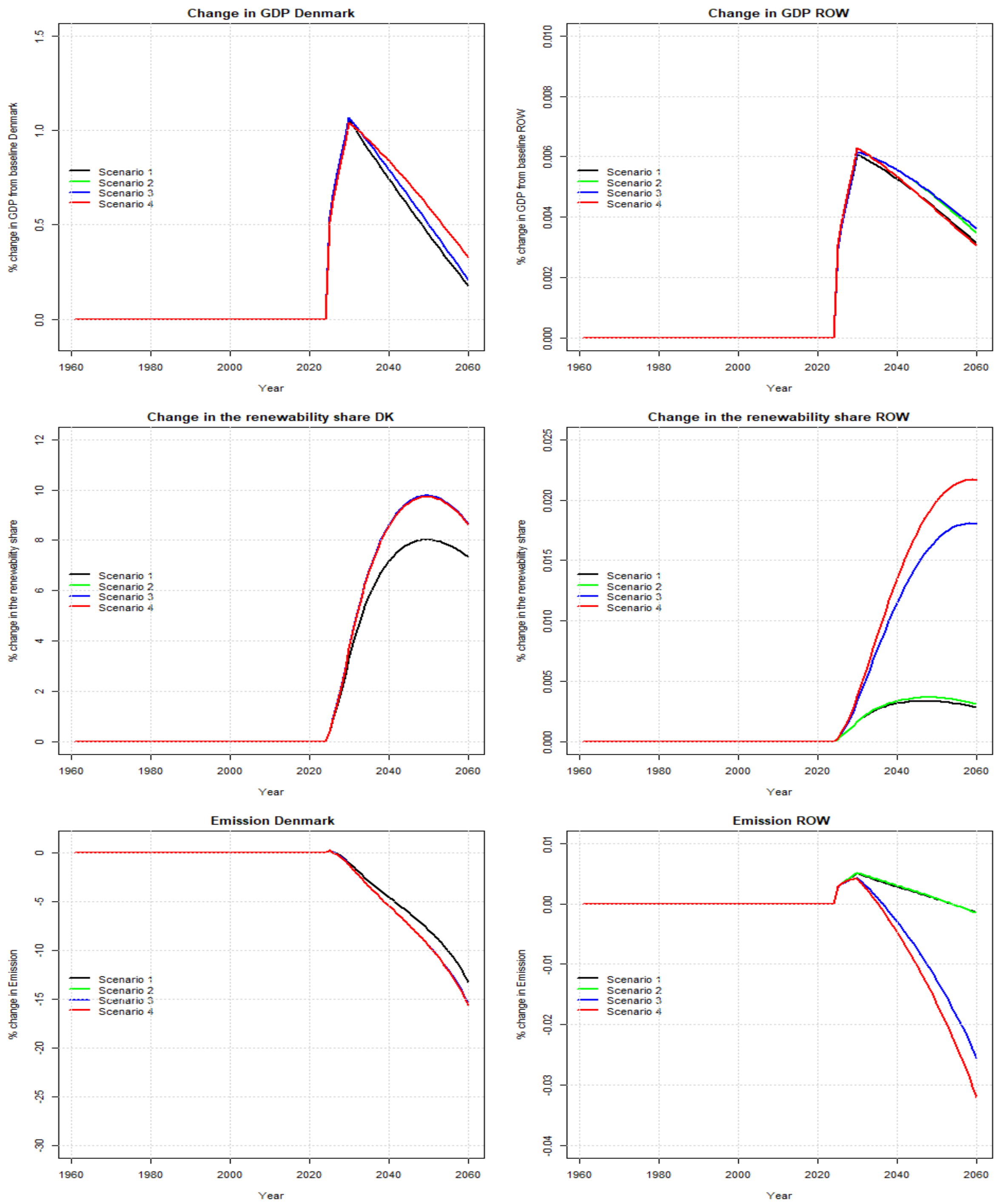


Figure 28 Appendix: Results sensitivity analysis 9

Leakage rates in the different sensitivity analysis

In this table, we show the calculated leakage rates for all sensitivity analyses (besides from sensitivity analysis 1) together with the results obtained in the main analysis. The darker market entries indicate changes from the results obtained in the main analysis.

Table 4 Appendix: Calculations of the leakage rate for sensitivity analysis 2-9

Scenario\ Measure	Main analysis L_R	Sens 2 L_R	Sens 3 L_R	Sens 4 L_R	Sens 5 L_R	Sens 6 L_R	Sens 7 L_R	Sens 8 L_R	Sens 9 L_R
Scenario 1 10 years	0.84	0.75	0.84	0.84	0.84	0.84	0.97	0.70	0.84
Scenario 1 20 years	0.43	0.32	0.43	0.43	0.43	0.43	0.52	0.37	0.43
Scenario 1 30 years	0.24	0.11	0.24	0.24	0.24	0.24	0.31	0.21	0.24
Scenario 2 10 years	0.67	0.58	0.67	0.67	0.67	0.40	0.8	0.55	0.73
Scenario 2 20 years	0.35	0.24	0.35	0.35	0.35	0.22	0.43	0.29	0.38
Scenario 2 30 years	0.20	0.06	0.20	0.20	0.20	0.12	0.25	0.16	0.21
Scenario 3 10 years	0.10	-0.23	0.55	0.10	0.10	-0.22	0.17	-0.15	0.16
Scenario 3 20 years	-0.43	-0.89	0.19	-0.43	-0.43	-0.61	-0.4	-0.71	-0.4
Scenario 3 30 years	-0.80	-1.41	0	-0.80	-0.80	-0.93	-0.77	-1.14	-0.76
Scenario 4 10 years	-0.08	-0.44	0.49	-0.27	0.08	-0.43	-0.01	-0.36	0
Scenario 4 20 years	-0.68	-1.19	0.11	-0.94	-0.45	-0.87	-0.64	-1.00	-0.62
Scenario 4 30 years	-1.11	-1.79	-0.1	-1.44	-0.81	-1.26	-1.06	-1.52	-1.05