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The Porter Hypothesis in a Two-Area Ecological Stock Flow Consistent Model – Should Political Decision Making Rely on Current Calculations of Leakage Rates?

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Abstract

In this paper, we investigate how the complex relationship between environmental regulations and competitiveness can be modeled through changes in technological developments. We do so by introducing the effects presented by the Porter Hypothesis in a two-area ecological Stock Flow Consistent model for Denmark and the rest of the world. Due to empirical evidence, we find it valid to model two underlying effects presented by the Porter Hypothesis. The first introduces a relationship between environmental regulations and innovation. The second introduces a relationship between technological development, as a result of innovation, and competitiveness of the green side of the economy.

We show how the introduction of the PH framework into a macroeconomic model, as expected, will lower carbon leakages through international trade. We argue that the PH framework should be given equal consideration alongside the Pollution Haven Hypothesis as suggested by empirical findings when making political decisions based on carbon leakage for a small open economy like Denmark.

Key words: Stock Flow consistent modelling, Carbon Leakage rates, Innovation & technological development.

JEL-codes: Q56, E12, E01, O33.

Section 1 Introduction

The Danish climate goals are by many considered to be highly ambitious, however, the use of territorial emission for the evaluation is a clear shortage of these goals as it neglects the effect of carbon leakages by keeping world emission fixed. The importance of analyzing how unilateral climate policies affect emission outside a regulated area seems especially important for a small open economy like Denmark, where carbon leakage through international trade can have a relatively large effect on world emission, due to the high degree of openness[1].
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 using 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.

In the case of Denmark, leakage through international trade is typically argued to be the most important channel of carbon leakage[2]. Within this channel the framework of the Pollution Haven Hypothesis is used, where the implementation of an environmental regulation will affect relative prices, by increasing production costs within the regulated country, thereby moving carbon-heavy production outside the borders (DØRS, 2019; Kjær Kruse-Andersen et al., 2022). Leakage through this channel therefore always affects emission outside the regulated area negatively (by increasing emission) whereas this relation is often used by politicians as the main argument for not implementing environmental regulations in a given industry.

In the discussion on how environmental regulations affect competitiveness, the Pollution Haven Hypothesis framework stood alone until the early 1990s when the popular framework was challenged by Porter & Van Der Linde (1995) presenting what today has come to be known as the Porter hypothesis (PH). Porter & Van Der Linde (1995) argue 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.
According to them, the debate has been framed incorrectly, coming from a static view of 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 benefit from properly crafted environmental regulations that are more stringent than competitors within other countries, the primary goal being to stimulate innovation.

If the Porter hypothesis holds, and environmental regulations enhance innovation leading to green technological development and thereby an increase in country-level competitiveness, we find it important that the Porter hypothesis is considered together with the framework of the Pollution Haven hypothesis when political decisions are being made. This seems especially important for small open economies like

[1] Compared to the small effect a reduction in territorial emission can have, due to a small open economy's (on a world scale) small size.
[2] DØRS (2019) argue that a larger degree of openness in the economy increases the effect of leakage through international trade, whereas this channel is argued to be the main channel of carbon leakage for a small open economy.

Denmark where international trade plays a large role, and the effect of green exports can be relatively large[3].

In this paper, we introduce three significant contributions to illustrate the importance of modeling the PH framework into a macroeconomic model, providing us with a set-up to analyze this framework's effect on carbon leakage rates: First, we develop an ecological two-area Stock Flow Consistent model representing Denmark and the rest of the world, even though the model is mainly theoretical, the model is capable of matching observed data of important variables in both Denmark and ROW. Second, we incorporate the Porter hypothesis into the model, creating three different models each including different degrees of the Porter hypothesis[4]. To the best of our knowledge, we are the first to incorporate the effects of the Porter hypothesis within a macroeconomic model and thereby analyze how this framework might affect the economy and environment. Third, we use the three models to analyze the effect on the leakage rate as a higher degree of the PH framework is introduced.

The remainder of this paper is organized as follows. Section 2 will present the empirical work for the underlying effects of the Porter hypothesis. Section 3 will present the two-area ecological SFC model used for the analysis of this paper. In section 4, we provide the calibration strategy and validate the model based on its ability to match real data. In Section 5, we analyze the effect of introducing a policy mix within the two-area ecological SFC model including different degrees of the Porter hypothesis. In Section 6, we use the results of Section 5 to calculate the leakage rate under different degrees of the PH framework. Lastly, we conclude the main results in Section 7.

[3] 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 green exports in 2021 alone is estimated to be 215 million tons of CO2 (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 suggest that utilizing the full potential of Danish green technology will result in a total reduction potential of 1.500 million tons of CO2 in 2030 within the EU borders alone. Through a larger focus from the government on improving green technology within Denmark, the goal is to double the Danish exports of green technology in the period from 2017 to 2030, thereby reaching 140 billion DKK of exported green technology (The Danish Parliament, 2020).

[4] Where a higher degree of the PH framework refers to including more effects of this framework, these effects will be introduced in Section 2.

Section 2 Literature review

In this section, we will focus specifically on the empirical evidence for the Porter hypothesis, to justify the implementation of this framework (or parts of this framework) within a macroeconomic model[5]. For the remainder of this paper, we will be splitting up the PH framework into three versions following the work of Jaffe & Palmer (1997). They split up the PH framework into the Weak PH, Narrowly Strong PH, and the Strong PH visualized in the figure below[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 first-mover advantages. The Narrowly Strong PH is a sub-version of the Strong PH (represented by the lower arrow) suggesting that an increase in green R&D spending can lead to greater competitiveness for the entire economy, as firms initially are not optimizing profits.

We will now provide the existing empirical evidence associated with each of the three versions. Thereby providing us with a validation for incorporating these hypotheses within a macroeconomic model.

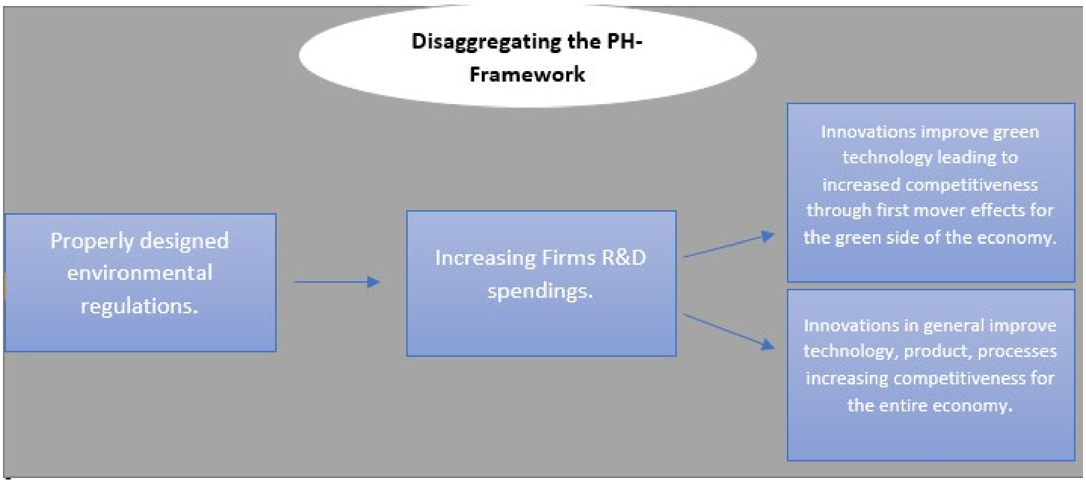

Figure 1: Disaggregating the Porter hypothesis into the Weak-, Narrowly Strong,- and Strong- Porter hypothesis.

Starting with 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. Looking at environmentally related patent applications, Lanjouw & Mody (1996), Brunnermeier & Cohen (2003), Popp (2003, 2006), Arimura et al. (2007), Lanoie et al. (2011), and J. Lee et al. (2011) all show a

[5] And thereby to some extent also the empirical evidence for the Pollution Haven hypothesis, as the two hypotheses contradict each other.

[6] Jaffe & Palmer (1997) 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, typically provided by flexible and market-based regulations (Jaffe & Palmer, 1997). Such policies were mainly introduced throughout the 1990s in the form of carbon taxes, thereby coinciding with the introduction of the PH framework. The higher degree of market-based regulations introduced since the early 1990s, as advocated by Porter, seems to explain a higher degree of empirical support for the PH framework since then. Moreover, if market-based instruments generate revenues (e.g., from taxes or permit auctioning), the efficient recycling of those revenues can improve competitiveness outcomes, thereby enhancing the effects of the PH framework (Ambec et al., 2013). We will use this later as we introduce an environmental regulation to the Danish economy in the form of a shock.

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 the current literature. A few newer studies further narrow it down by looking at the effect of environmental regulations on the 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 thereby minimizing costs through lower material waste and emission. Therefore, the Weak PH directly implies that environmental R&D spending will affect green technological development. One strand of literature investigates this relationship by looking at the effect of both public and private R&D spending on green patents finding the relationship to be positive and significant (Bäckström et al., 2014; Nicolli & Vona, 2016). Another strand of literature instead uses emission reduction measures like CO2 intensity of production to provide evidence that a higher level of green R&D spending improves technological development (K. H. Lee & Min, 2015; Többelmann & Wendler, 2019).

Meanwhile the literature seems very conclusive in finding empirical evidence for the Weak PH, the literature still seems relatively split when it comes to the Strong PH, having difficulties in determining a relationship between environmental regulations and the overall competitiveness of the economy. A meta-analysis by Cohen & Tubb (2017) uses 103 studies to investigate the empirical results of the Strong PH; their findings indicate that more than half the studies find 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. The first, using firm- or industry-level performance as a measure of competitiveness. The second, using country-level competitiveness measures such as exports.

Looking at firm-level competitiveness Cohen & Tubb (2017) find that most significant relationships between environmental regulations and competitiveness are negative. However, in the earliest of the two papers presented by Porter (1991), he examines competition among nations, investigating whether environmental regulations will positively affect country-level competitiveness. Contrary to the strand of literature focusing on the firm-level measures, Cohen & Tubb (2017) find that studies looking at country-level competitiveness are most likely to show positive significant relationships for the Strong PH (See also Grossman & Krueger (1995), Becker & Shadbegian (2008), Costantini & Mazzanti (2012)).

When looking at country-level competitiveness, most often the two opposing frameworks in the form of the Strong Porter hypothesis and the Pollution Haven hypothesis are analyzed. And even though the studies using country-level-measures seem to provide a higher degree of empirical evidence for the Strong PH compared to the Pollution Haven hypothesis (as most studies find environmental regulations to have a positive relationship with competitiveness), we will not include the effects of the Strong PH within our analysis based on the large number of insignificant results showed by Cohen & Tubb (2017)[7]. This is in contrast to the carbon leakage literature still including the effects of the Pollution Haven hypothesis in their calculations.

Instead, this paper will focus on the sub-version of the Strong PH, being the Narrowly Strong PH. At the moment, there is a limited amount of empirical work looking at the Narrowly Strong PH, still, the empirical work conducted seems conclusive in finding the effects of the Narrowly Strong PH to exist. One example is Costantini & Mazzanti (2012) finding that environmental regulations have a positive significant relationship with green exports for several European countries using different explanatory variables as a proxy for environmental regulations, thereby supporting the Narrowly Strong PH. Another example is Hwang & Kim (2017) who finds a negative relationship between environmentally friendly activities, measured by CO2

[7] In Appendix D, we show that including the effects of the Strong PH will only have small effects, further lowering the leakage rates in the main analysis.

intensity and trade performance, indicating that environmentally friendly activities encourage exports, therefore providing evidence that firms with higher environmental management can experience an increase in competitiveness as a result of environmental regulations supporting the Narrowly Strong PH.

Overall, the empirical results seem to support the existence of the Weak PH, as well as the Narrowly Strong PH (when using country-level competitiveness measures). Therefore, when we in the next section introduce the PH framework into a macroeconomic model, our main focus will be on including these two underlying versions of the PH framework.

Section 3 Incorporating the Porter hypothesis in a two-area ecological Stock-Flow-Consistent model

The model used in this paper 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 like the popular GTAP-E model[8]. The use of SFC models provides us with a simpler setup 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. Furthermore, the dynamic set-up of the SFC model allows us to look at the development of important variables like emission over time. The SFC model used in this paper is an extended version of the ecological two-area SFC model developed by Carnevali et al. (2021), modifying the model within a few areas. First, as the focus is towards a small open economy, we divide the world economy into a small open economy (represented by Denmark), and the rest of the world (ROW). Second, we implement a fixed exchange regime as Denmark in 1982 implemented a fixed exchange rate against the DEM and later the EUR[9]. As a result, one unit of output will always be worth the same in both economies. Third, we incorporate the effects presented by the PH framework whereas the focus of this section will be to introduce the equations used for incorporating this framework.

In Figure 2, we present a directed acyclic graph (DAG) to visualize how the implementation of the Weak- and Narrowly Strong- Porter hypothesis is carried out[10]. We have highlighted new variables added to the model of Carnevali et al. (2021) marked by the filled circles[11]. Three main effects should be considered when looking at the DAG represented by the red colored arrows:

I.) First, when a policy mix is introduced to the economy, the underlying carbon tax should affect firms spending towards green R&D through the effects of the Weak PH, additionally the revenue of the carbon tax should be used on government spending towards green MOIS (mission-oriented government spending) and green R&D subsidies, all three improving the greenness of green capital over time[12].

II.) As green capital becomes greener, the effects of the Narrowly Strong PH should be at play, increasing green exports and thereby also improving the country-level competitiveness of green firms.

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 greenness of the capital stock in ROW as they import a higher level of green capital from Denmark, as well as when green capital in Denmark becomes greener.

By including these effects within the model, we allow for the combination of two research areas, the first area being the literature performing empirical testing of the underlying versions of the PH framework. As we presented in Section 2, these relationships are shown to exist through empirical evidence, confirming the link between environmental regulations and innovation (Weak PH), and the link between

[8] For more information about the GTAP-E model see Truong et al. (2007).

[9] As Germany later changed its currency from the German D-mark (DEM) to the Euro (EUR).

[10] The DAG figure is built from the perspective of the Danish economy, an almost similar figure could be made from the perspective of the rest of the world.

[11] In the model, capital is divided into green and conventional capital, both green and conventional capital can be used for producing a specific good, but green capital will be associated with a lower energy intensity, CO2 intensity, material intensity as well as a higher share of renewable energy to total energy used for production.

[12] We will describe this policy mix and its underlying components in Section 4.1.

environmental regulations and competitiveness of green firms (Narrowly Strong PH). Still, no one seems to analyze the larger perspective of how the effects of the PH framework might provide channels of carbon leakage. This second area of research, concerned with carbon leakage rates, is still only relying on the Pollution Haven hypothesis framework when it comes to international trade, even though the empirical evidence looking at this hypothesis is still relatively split with a large share of insignificant results as shown by Cohen & Tubb (2017).

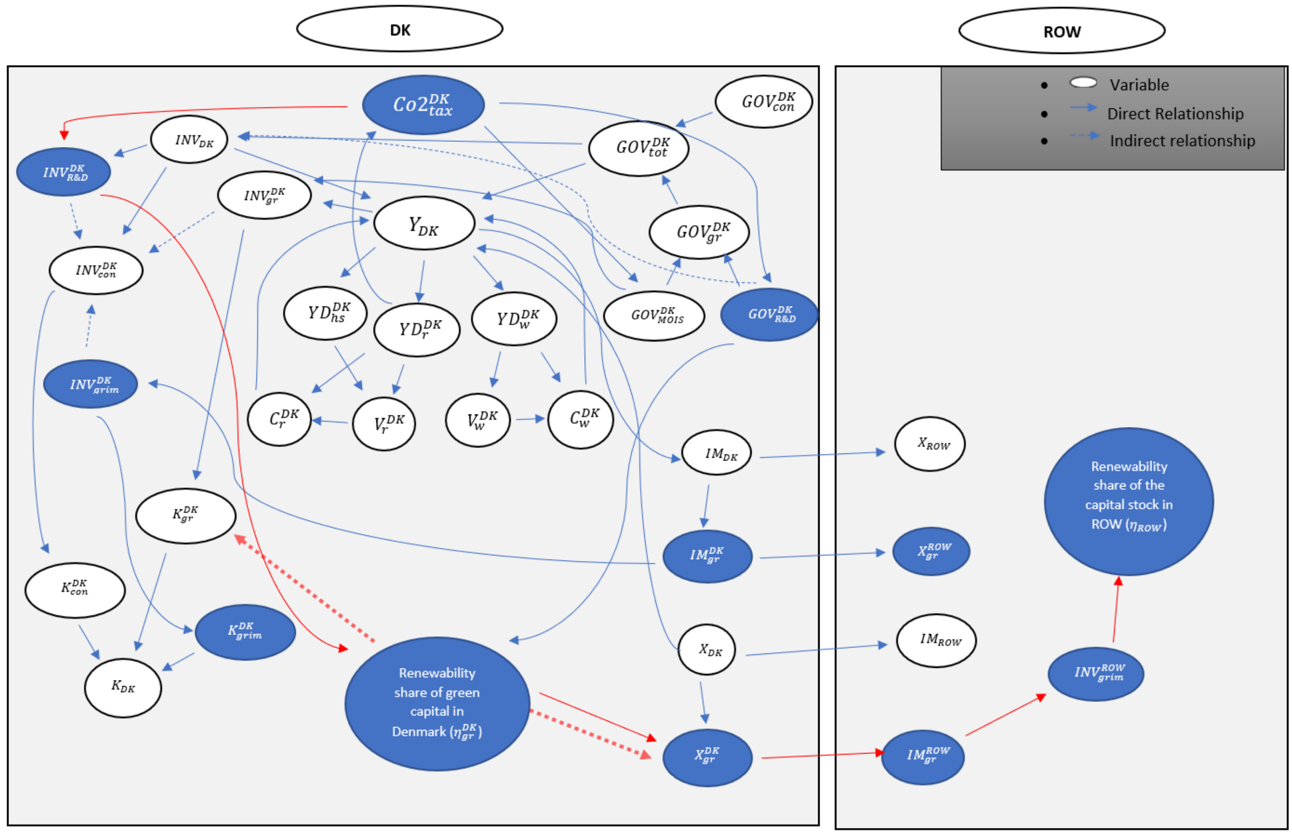

Figure 2: DAG-figure representing the newly added equations to the model of Carnevali et al. (2021), and the implementation of the Weak- and Narrowly Strong- Porter hypothesis.

3.1 Implementing the PH framework

Starting with the implementation of the Weak PH, we should start by looking at the equation for firms' green R&D investments. As we indicate by the red arrow going from $Co2^{DK}_{tax}$ to $INV^{DK}_{R\&D}$ a relationship between the total amount paid by firms in carbon taxes and firms' investments in green R&D is introduced, shown by the last term in the equation describing the dynamics of green R&D investments[13]:

$$INV^{DK}_{R\&D} = \exp\left(\Gamma_0^{DK} + \Gamma_1^{DK} * Log(INV_{DK}) + \Gamma_2^{DK} * Log(Co2^{DK}_{tax})\right) \qquad \text{Eq.1}$$

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

[13] For simplicity we set $\Gamma_1^{DK} = 1$ to keep firms green R&D investments as a fixed share of firms' total investments (INV_{DK}) when the Weak PH is not active in the model.

We should now focus on how green R&D spending improves the greenness of green capital within the model. As Denmark's largest source of green technology is within renewable energy (The Danish Energy Agency, 2022b) we endogenize the share of renewable energy to total energy used (in the rest of the paper referred to as the renewability share) when using green capital in the production (η_{gr}^{DK})[14]. We do so by modelling improvements in the renewability share of green capital (η_{impv}^{DK}) making it a function of the lagged total R&D expenditures in the economy ($GOV_{R\&D_{t-1}}^{DK} + INV_{R\&D_{t-1}}^{DK}$)[15].

$$\eta_{impv}^{DK} = \exp\big(impv_0^{DK} + impv_1^{DK} * log\big(GOV_{R\&D_{t-1}}^{DK} + INV_{R\&D_{t-1}}^{DK}\big)\big) \qquad \text{Eq.2}$$

This allows us to calculate the renewability share associated with using green capital for production:

$$\eta_{gr}^{DK} = \eta_{gr_{t-1}}^{DK} + \eta_{impv}^{DK} \qquad \text{Eq.3}$$

As a change in the renewability share of 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 in the current period (η_{gr}^{DK})[16]. In the second term, the share of already existing green capital that will not be updated will have the average renewability share of the previous period ($\eta_{AVGgr_{t-1}}^{DK}$). Lastly, the share of already existing capital, which we assume will be updated, has the renewability share of the current period (η_{gr}^{DK}). From this equation, we obtain a new average renewability share for the total stock of green capital (η_{AVGgr}^{DK}).

$$\eta_{AVGgr}^{DK} = (\frac{K_{NEWgr}^{DK}}{K_{gr}^{DK}}) * \eta_{gr}^{DK} + imp_{DK} * \left(\frac{K_{gr}^{DK} - K_{NEWgr}^{DK}}{K_{gr}^{DK}}\right) * \eta_{AVGgr_{t-1}}^{DK} + (1 - imp_{DK}) * \left(\frac{K_{gr}^{DK} - K_{NEWgr}^{DK}}{K_{gr}^{DK}}\right) * \eta_{gr}^{DK} \qquad \text{Eq.4}$$

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[17]. The equation for the renewability share of imported green capital ($\eta_{AVGgrim}^{DK}$) can be seen below, where we now use the renewability share of green capital in ROW (η_{gr}^{ROW}) in the moving average equation.

$$\eta_{AVGgrim}^{DK} = \left(\frac{K_{NEWgrim}^{DK}}{K_{grim}^{DK}}\right) * \eta_{gr}^{ROW} + \left(\frac{K_{grim}^{DK} - K_{NEWgrim}^{DK}}{K_{grim}^{DK}}\right) * \eta_{AVGgrim}^{DK} \qquad \text{Eq.5}$$

[14] We assume that the share of renewable energy to total energy for green capital can exceed 100%, whereas the additional energy produced will be used for conventional production. Still, the share of renewable energy to total energy associated with the total capital stock never exceeds 100%.

[15] We add together the government's and firms' R&D spending as we assume these to have similar effects on green technology.

[16] 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 introduced later ($K_{NEWgrim}^{DK}$) is calculated using the equation: $K_{NEWgrim}^{DK} = K_{grim}^{DK} - K_{grim_{t-1}}^{DK}$.

[17] This assumption implies that the renewability share of Danish exported green capital will not automatically be updated as Denmark improves its renewability share of newly produced green capital. We find this case to be the most realistic, but as presented in Appendix D relaxing this assumption does not change the conclusions of this paper.

As we have now introduced the average renewability share of domestic green capital (η_{AVGgr}^{DK}) and imported green capital ($\eta_{AVGgrim}^{DK}$), these measures are now used for calculating the average renewability share of the total capital stock (η_{DK}), multiplying the renewability shares on their associated weights:

$$\eta_{DK} = \eta_{AVGgr}^{DK} * \frac{K_{gr}^{DK}}{K_{DK}} + \eta_{AVGgrim}^{DK} * \frac{K_{grim}^{DK}}{K_{DK}} + \eta_{con}^{DK} * \frac{K_{con}^{DK}}{K_{DK}} \qquad \text{Eq.6}$$

Thereby, the implementation of the Weak PH is complete, showing how an increase in the carbon tax increases firms' investments in green R&D increasing the renewability share of newly produced green capital in Denmark which then has two indirect effects, first increasing the average renewability share of green capital in Denmark (indicated by the arrow going from η_{gr}^{DK} to K_{gr}^{DK}), and second, increasing the renewability share of the green capital exported by Denmark (indicated by the dashed red arrow going from η_{gr}^{DK} to X_{gr}^{DK})[18].

We will now start the implementation of the Narrowly Strong PH, allowing green technological development (measured by the renewability share) to improve the country-level competitiveness of Danish green firms (measured by green exports)[19]. We first introduce a link between green exports and the renewability share of newly produced green capital as shown below[20]:

$$X_{gr}^{DK} = \exp\left(\Omega_0^X + \Omega_1^X * log(X_{DK}) + \Omega_2^X * log\left(\eta_{gr}^{DK}\right)\right) \qquad \text{Eq.7}$$

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 exports[21].

With only the Weak PH active, the introduction of a carbon tax improves the renewability share of green imported capital by ROW. With the introduction of the Narrowly Strong PH, not only will the renewability share of green imported capital for ROW improve, but ROW will now also increase the level of imported green capital by ROW (indicated by the red arrow going from η_{gr}^{DK} to X_{gr}^{DK}).

Lastly, The equations allowing for the Weak- and Narrowly Strong- PH in Denmark to affect the renewability share of green capital in ROW will follow the red arrows shown in the DAG figure 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 renewability share of the total 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:

$$IM_{gr}^{ROW} = X_{gr}^{DK} \qquad \text{Eq.8}$$

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.

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[18] Which is the same as increasing the renewability share of green capital imported by ROW.

[19] In the literature review we found empirical evidence for the Narrowly Strong PH (e.g. Costantini & Mazzanti (2012) and Hwang & Kim (2017)), while the evidence for the Strong PH was not sufficient (see Cohen & Tubb (2017)). Therefore, the implementation of an environmental regulation should not increase the total exports. For this reason, we model the export of conventional firms to be the residual ($X_{con}^{DK} = X_{DK} - X_{gr}^{DK}$) whereas this variable in most cases will fall as the green exports increase. This implies that an increase in the competitiveness of green firms happens at the expense of the competitiveness of conventional firms.

[20] 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 advantages. Similar assumptions are used when estimating spillover effects when experiencing technological development (e.g. Bosetti et al. (2008)).

[21] As we set $\Omega_1^X = 1$ green exports will be a fixed share for total exports when the Narrowly Strong PH is not active, this is equivalent to the strategy applied for firms' green R&D investments as noted above.

$$INV_{grim}^{ROW} = IM_{gr}^{ROW} \quad \text{Eq.9}$$

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, and with Danish green capital having a higher renewability share than in ROW, this will improve the renewability share of the capital stock in ROW (η_{ROW})[22].

This concludes the equations needed for the implementation of the PH framework within the two-area ecological SFC, allowing the renewability share of the capital stock in ROW to be affected by environmental regulations in Denmark through international trade. In the next section, we discuss the calibration strategy and validate the model.

[22] One could argue that an increase in competitiveness for Danish firms, and thereby an increase in imports of green technology made by ROW would lower competitiveness of green firms in ROW which might lead them to reduce investments in green R&D. We do not include this effect in our analysis based on the lack of empirical evidence for this effect.

Section 4 Calibration and validation of the model

In this section, we both cover the calibration of new parameter values, associated with the implementation of the PH framework, as well as already existing parameter values used by Carnevali et al. (2021) as we calibrate key variables such as GDP, government spending, and consumption to match the observed data for Denmark and ROW[23]. As we create three different baseline models with different versions of the PH framework active, the three models will include slightly different parameter values[24].

4.1 The calibration strategy

To set existing parameter- and initial values used in the model of Carnevali et al. (2021) we use real data from both Denmark and ROW to make the adjustments, thereby creating realistic parameters in the sense that they replicate the observed trends of important variables for the two areas. Additionally, we include differences in parameters like the tax rate, rate of consumption, CO2 intensity, energy intensity, and others between the two areas, again, to make the model as realistic as possible. To create a realistic starting point for the model, we allow for a calibration period from 1960-2017 using a small databank consisting of the most central variables. After 2017 the model is made endogenous and does not require any data inputs.

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 should look at the relationship between the carbon tax (which we will introduce later) and firms' investments in green R&D (Γ_2^{DK})[25], to set this parameter, we use the empirical evidence presented by Jaffe & Palmer (1997) finding a coefficient of 0.15, implying that a 1% increase in the costs associated with the carbon tax increase green R&D spending by 0.15%[26].

For the relationship between green R&D spending and the improvements of the renewability share we set the parameter $impv_1^{DK}$ using the empirical evidence presented by Bäckström et al. (2014) and Nicolli & Vona (2016) who both find a significant estimate for the elasticity to be around 0.3[27]. Additionally, we set Important initial- and parameter values determining how R&D spending affects the renewability share of green capital in Denmark to match the growth rate of the renewability share observed in real data[28].

We will now turn towards the calibration of parameters for implementing the Narrowly Strong PH. Here, we set the parameter determining how the renewability share 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 increases green exports by 0.5%. This coefficient is set according to the empirical evidence found by Hwang & Kim (2017) who find

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

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

[25] 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.

[26] This estimate of 0.15 is also used by Bosetti et al. (2008) when analyzing international spillovers of technological development. We do 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.

[27] In Appendix D we perform a sensitivity analysis including a decreasing trend based on how close the average renewability share is to 100%. We do so as the development of renewable technologies are argued to slow down as the technologies mature (Beck & Kjær Kruse-Andersen (2020)). Overall, the more advanced relationship does not change the conclusions of this study whereas we go with the simpler setup presented in Equation 2.

[28] Using data on the renewability share for Denmark and the EU from Eurostat starting from 2004 up until 2021.

that reducing the CO2 intensity by 1% increases green exports by 0.46%[29]. Other important parameters affecting green exports are calibrated so that green exports are approximately 8% of total exports in 2021, matching the share presented by The Danish Energy Agency (2022b).

Besides 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), to reproduce the trends observed for the Danish economy as will be shown in the next section when performing the validation. Before presenting the validation, we will provide an overview of the three different baseline models used in this paper.

Baseline 1 does not include any of the effects presented by the PH framework and will be used as a basis for comparison as we start implementing this framework, still the effect of green technological development is included within this scenario, and the channel in which green technological development in Denmark affects emission in ROW will be active.
Baseline 2 introduces the coefficient of $\Gamma_2^{DK} = \Gamma_2^{ROW} = 0.15$ and thereby includes the Weak PH where environmental regulations affect firms spending towards green R&D.
Baseline 3 will like Baseline 2 include the effects of the Weak PH but also introduce the Narrowly Strong PH by setting the coefficient $\Omega_{\mathbf{2}}^{\boldsymbol{X}} = 0.5$ thereby creating a relationship between the renewability share of green capital and green exports within Denmark.

4.2 Validation of the three baseline models

We now turn to the validation of the three baseline 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. We observe that the simulated values of GDP overall fit the trend of the data both before and after 2017 for both Denmark and ROW. Looking at emission, the model matches 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[30]. After 2017, we see that the overall trend of emission starts falling in both areas mainly as a result of a higher green capital to total capital ratio as well as the greenness of the capital stock improving[31]. Overall, we can validate the three baseline models as we observe that they are capable of matching the trends observed in the data[32].

[29] Costantini & Mazzanti (2012) estimate a significant coefficient to lie within a range of 0.1-0.55 using different measures, while Hwang & Kim (2017) using two different explanatory variables find the coefficient to be between 0.46 and 0.22. As the estimate of 0.46 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 setting the parameter to 0.22 which also matches the range found by Costantini & Mazzanti (2012).

[30] Measures like energy intensity and matter intensity for both green and conventional capital are 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.

[31] The increasing share of green capital is a result of an exogenously set growth rate of firm's green investments ($INV_{gr}^{DK}, INV_{gr}^{ROW}$). Whereas the improved greenness of the capital stock 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 ($\beta_{gr}^{DK}, \beta_{gr}^{ROW}$).

[32] As there is almost no difference between the three baseline models, the lines representing each model lie on top of each other.

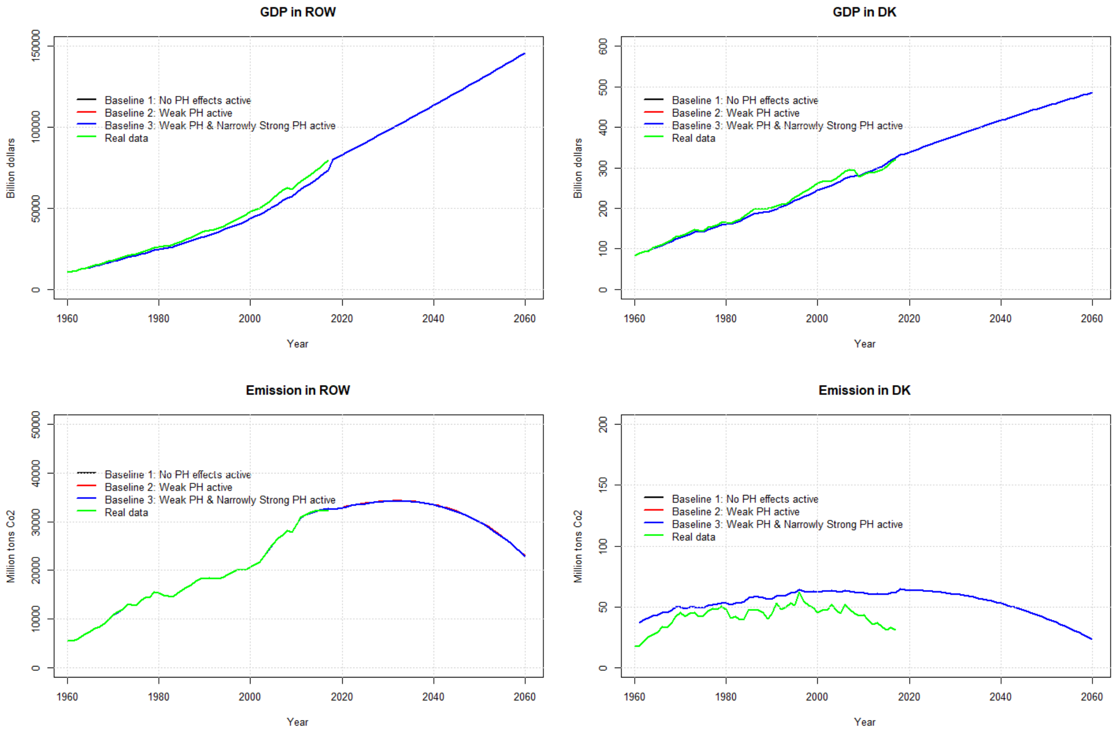

Figure 3 Validation of the three baselines using GDP and Emission for Denmark and the rest of the world.

We have now presented the calibration strategy and validation for the two-area ecological SFC model used in this paper. In the upcoming section, we will introduce a shock to all three baseline models, in the form of a policy mix, whereas differences across the three models should be attributed to what versions of the PH framework are active. The focus of the analysis will be on changes in emission both within Denmark and the rest of the world, which will allow us to calculate the carbon leakage rates for each of the three models in section 6.

Section 5 Introducing a policy-mix in the Danish Economy

We start this section by providing a description of the policy mix later introduced as a shock to the three baseline models presented in the previous section. Next, we analyze the effect on emission when introducing this shock, comparing the results of each scenario relative to each other, we will attribute differences to the inclusion of the Weak- or Narrowly Strong- PH.

5.1 The policy-mix

Most often the leakage rate literature bases their calculations on the implementation of a carbon tax, we take a similar approach as this type of flexible and market-based regulation is also preferred by the PH framework (Ambec et al., 2013). 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 (per ton CO2). Additionally, we allow the government to recycle the revenue of the carbon tax to spur innovation, further enhancing the effects of the PH framework (Ambec et al., 2013). Given this, the policy mix will have three important effects: I.) Increasing the firm's costs associated with emission through a carbon tax. II.) Increasing government spending towards green MOIS through recycling of the carbon tax revenue. III.) Increasing government spending towards green R&D also through the recycling of the carbon tax revenue. In the next section, we will see how these three effects play into the economy and the ecological sector, as the policy mix is introduced in Baseline 1 (Scenario 1), Baseline 2 (Scenario 2), and Baseline 3 (Scenario 3).

5.2 Analyzing the effect on emission within the three scenarios

For the comparison of Scenarios 1, 2, and 3, this analysis will focus on the effect on emission, as the change in emission is used in Section 6 to calculate the leakage rate for each scenario. As we are not using a fully empirical model the exact magnitude of a change in emission should be interpreted carefully, instead, the focus should be on the relative differences between Scenarios 1, 2, and 3. As Scenario 1 does not include any of the effects presented by the PH framework, we will mainly use this scenario as a basis for comparison. When looking at the change in emission associated with the implementation of the PH framework two overall channels are in play as the policy-mix is included. The channels will go through changes in output and changes in the renewability share of the capital stock[33].

[33] See Appendix C Figure 1 for a visualization of the two channels affecting emission.

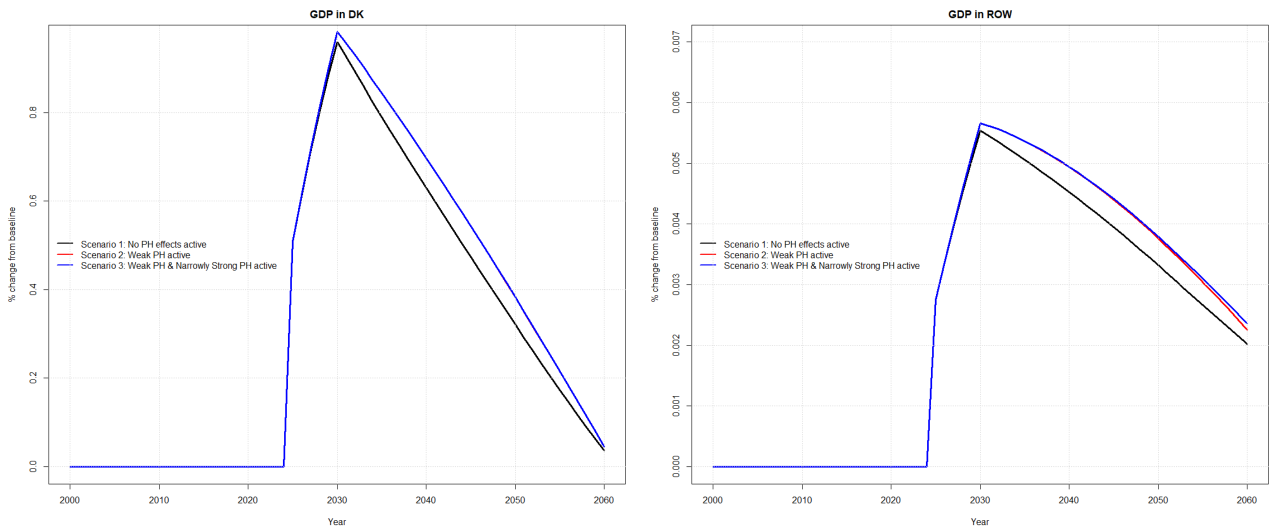

Figure 4 Changes in GDP when implementing the policy mix within each of the three baseline models.

Looking at the first channel, we observe that GDP increase in both Denmark and ROW for all three scenarios, the approximately 1% increase in Danish GDP is mainly associated with the increase in government spending, as the government recycles the carbon tax revenue, meanwhile, the approximately 0.006% increase in GDP for ROW is a result of Danish imports increasing (associated with the higher level of Danish GDP)[34].

Looking at the change in GDP in each scenario relative to each other, we find only small differences when including the effects of the PH framework in Scenarios 2 & 3, where the effects seem to increase output in both Denmark and ROW by a small amount[35]. The main reason for this minor relative difference should mainly be associated with the Weak PH increasing green R&D investments[36]. Besides the effect of the Weak PH, the minor differences between Scenarios 2 & 3 seen in GDP for the rest of the world should mainly be associated with the effect of climate damages due to different levels of emission.

[34] We see that the change in GDP relative to GDP in the baseline in both Denmark and ROW is following a downward-sloping trend after the carbon tax is held fixed in 2030. This is mainly because of the level of CO2 emission, where lower CO2 emission will reduce the tax income for the government thereby also reducing the green R&D spending by the government, reducing the positive effect on GDP through this channel over time. If emission at some point hits zero, or the carbon tax rate is set to zero, the downward trend observed for both Denmark and ROW will stop and will reach a value close to the level of GDP in the baseline model.

[35] In the plots showing the effect in Denmark, Scenario 2 including the Weak PH, and Scenario 3 including both the Weak- and Narrowly Strong- PH will lie on top of each other, whereas the green line showing the effect for Scenario 2 is not observed.

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

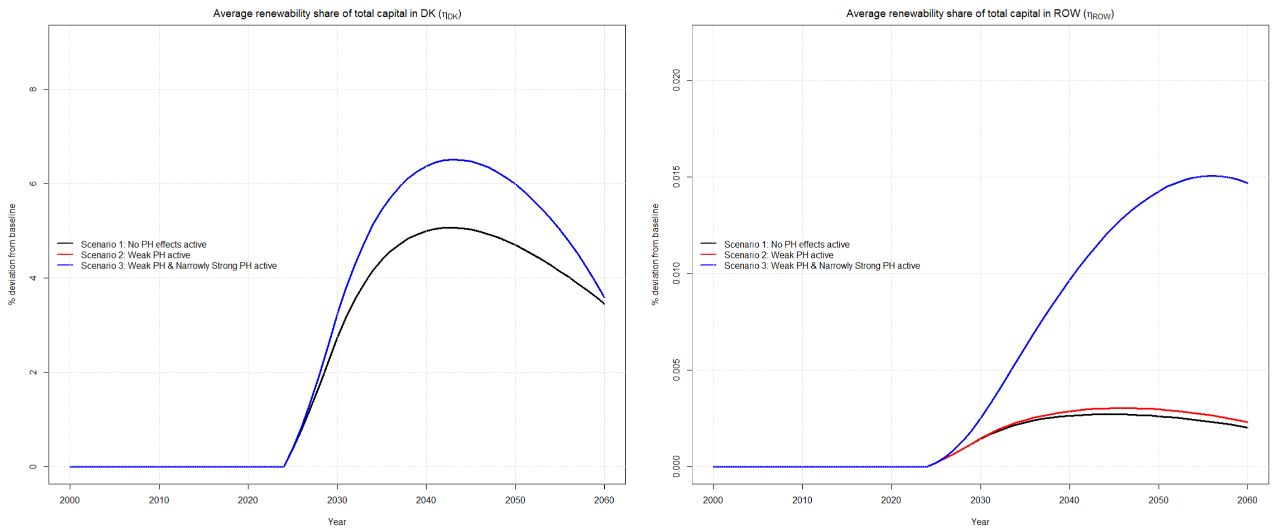

Figure 5: Changes in the renewability share of the capital stock when implementing the policy mix within the three baseline models.

We now turn to the second channel, associated with changes in the renewability share of the capital stock[37]. Starting with Denmark shown to the left in the plot above we see that the average renewability share of the total capital stock increase in all three scenarios. Looking at the effects relative to each other, the difference between Scenario 1 and the two other scenarios should be attributed to the inclusion of the Weak PH, where the higher level of R&D spending made by firms both increases the renewability share of Danish green capital and the share of green capital to total capital[38]. As one would expect, the effect of introducing the Narrowly Strong PH in Scenario 3 does not affect the average renewability share of the capital stock in Denmark, as it only increases the share of Danish green exports.
Looking at the rest of the world, the effect of implementing the policy mix in Denmark increases the average renewability share of the total capital stock in all three scenarios. We see that relative to the effect in Scenario 1, the inclusion of the Weak PH in Scenario 2 further increases the effect, as the Danish green exports become more efficient. Furthermore, as we look at the effect in Scenario 3, including both the Weak- and Narrowly Strong- PH, the effect is again further increased as the share of imported green capital to total capital increases in ROW.
After looking at the change in output and the average renewability share of the capital stocks for both Denmark and ROW, we can now turn towards the change in emission shown in the plot below:

[37] This second channel is affected by several underlying channels, to help the reader understand the underlying dynamics of this channel see Figure 2 in Appendix C.
[38] The share of green capital increases as the higher level of green R&D investments is a substitute for conventional investments thereby lowering the conventional investments and thereby the total capital stock while keeping the stock of green capital fixed.

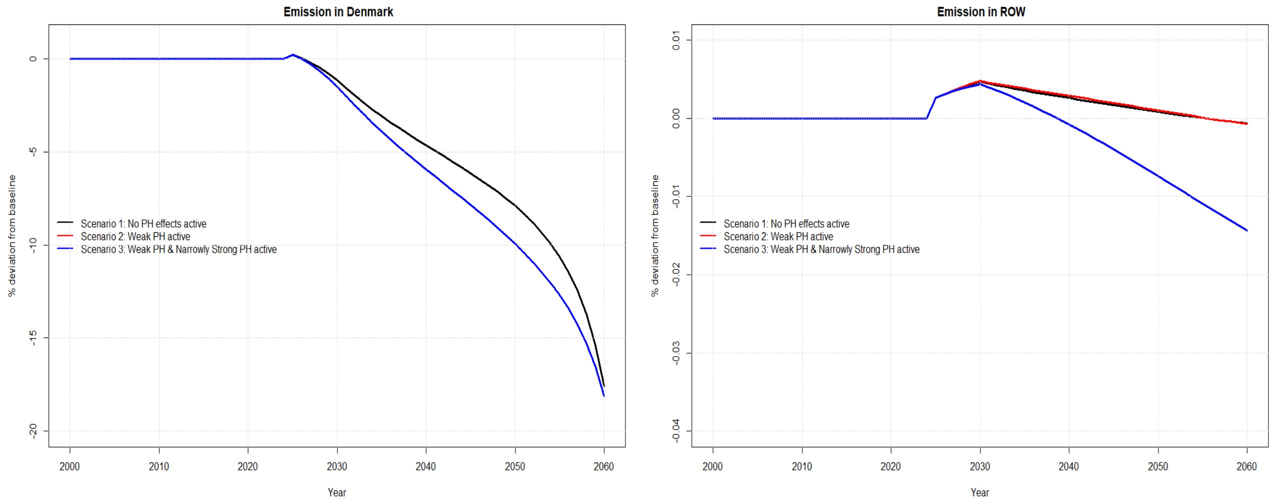

Figure 6 Changes in emission when implementing the policy mix within the three baseline models.

Starting with emission in Denmark (left side plot above), we again observe a difference between Scenario 1 and the two other scenarios, which is also consistent with our analysis of the two underlying channels. Again, the relative difference can be attributed to the higher level of R&D spending associated with the Weak PH, which results in a greater increase in the average renewability share of the total capital stock observed in the previous plot.

As we turn towards the change in emission outside Denmark, the effect on emission in the rest of the world seem to be almost similar for Scenarios 1 & 2. The main reason is that the two underlying channels have offsetting effects, as we in Scenario 2 see a higher level of GDP, reducing the magnitude of the fall in emission, but at the same time observe a larger increase in the average renewability share of the capital stock relative to what is observed in Scenario 1. For this reason, taking into account the Weak PH alone appears to have little or no effect when analyzing emission outside Denmark[39].
Looking at the introduction of the Narrowly Strong PH in Scenario 3, the relative difference compared to Scenario 1 is much larger, with the main reason being the increments in the average renewability share of the total capital stock, as a result of a higher level of Danish green exports and a higher renewability share associated with this green export.

The results provided in this section should be in accordance with expectations and thereby substantiate the inclusion of the PH framework in a macroeconomic model. Furthermore, the results also indicate the importance of including the Narrowly Strong PH together with the Weak PH when analyzing environmental regulations' effect on emission in macroeconomic models. In the next section, we will use the obtained results to calculate the leakage rate within each of the three models and discuss whether political measures to spur innovation could be capable of enhancing the green transition on a world basis.

[39] In the sensitivity analysis we isolate the effect of the Narrowly Strong PH, and see that the exclusion of the Weak PH lowers the effect on ROW emission, whereas the Weak PH in combination with the Narrowly Strong PH seems to have a larger effect on emission in ROW (see appendix D)

Section 6 Estimation of the leakage rates

DØRS (2019) presents five main channels of carbon leakage 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 spillovers, V.) Leakage through international trade[40].

As presented by DØRS (2019) carbon leakage through international trade is in the case of Denmark argued to be the main effect of carbon leakage, and seems to play a larger role the higher degree of openness in the economy. 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.

Throughout this paper, our main focus has been on the relationship between environmental regulations and country-level competitiveness, where the literature has mainly focused on the two opposing frameworks in the form of the Porter hypothesis and the Pollution Haven Hypothesis. Even though we find empirical evidence for the PH framework, the effects within this framework are negated when looking at the leakage rate literature[41], while on the other hand, the Pollution Haven hypothesis seems to be unquestioned. Thereby, carbon leakage through international trade can only lead to increases in emission outside Denmark[42].

In this paper, we show how the PH framework can be included within a macroeconomic model allowing us to analyze how the PH framework affects leakage rates.
We will now use the results presented in Section 5 to calculate the leakage rates associated with implementing the policy mix within the three models. When calculating the leakage rate, we use the equation presented 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.

$$L_R = -\frac{\Delta E_{ROW}}{\Delta E_{DK}} \quad \text{Eq.10}$$

It is important to highlight, that none of the above-mentioned channels of carbon leakage presented by DØRS (2019) are included in the results of this paper[43]. Whereas the leakage rate estimated in this section should only provide us with the effects associated with the implementation of the PH framework. This, and the fact that the model used in this paper is only partly empirical means that the magnitude of the leakage rates should not be interpreted as the total leakage rates for Denmark, instead, we should focus on the relative differences using Scenario 1 to compare with the results of Scenario 2 & 3.
As we use a dynamic model, some of the effects take time to play in, for this reason, we show how the leakage rates develop over time, again the focus should be on the relative difference between the three models. We also provide the reader with the cumulative change in emission for Denmark, ROW, and the

[40] See DØRS (2019) for a further explanation of these five channels of leakage.
[41] Often the argument is that these effects are difficult to model, but the flexible set-up of the model used in the paper allows us to include this effect.
[42] Following the Pollution Haven hypothesis even if a firm does not move its production elsewhere, a carbon tax in Denmark will force Danish firms to increase prices. As a result, customers might seek towards competitors operating outside the regulated area, thereby increasing production in the less environmentally regulated areas, and thereby still increasing emission outside Denmark.
[43] This also implies that this analysis only applies to industries not being part of the EU-ETS.

World (measured in million tons CO2) starting from 2030 whereafter the carbon tax stays fixed at 110 USD (per tons CO2).

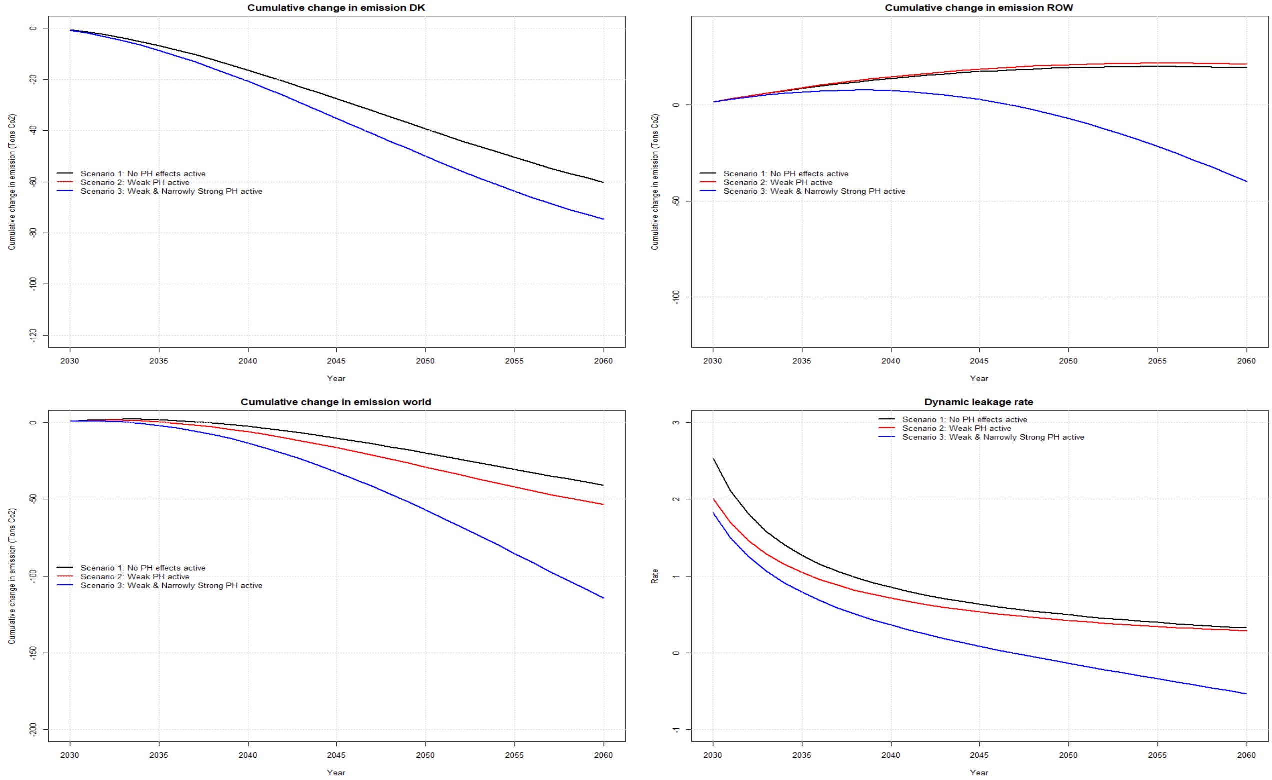

Figure 7: Accumulative change in emission for Denmark, ROW, and the World (million tons CO2), and the associated carbon leakage rates when implementing the policy mix within the three baseline models.

Looking at the upper left-, upper right-, and lower left- corner of the plot in Figure 7, we show the cumulative change in emission within Denmark (ΔE_{DK}), ROW (ΔE_{ROW}), and the World (ΔE_{World}) as a result of introducing the policy-mix in Denmark in all three models. Lastly in the bottom right plot, we calculate the leakage rate associated with the cumulative change in emission for Denmark and ROW[44].
We see that including the effects of the PH framework in Scenarios 2 & 3 reduces the leakage rate (relative to the results obtained in Scenario 1), especially when including the Weak- and Narrowly Strong- PH together in Scenario 3[45]. Thereby, taking into consideration the PH framework when calculating carbon leakage through the channel of international trade, will (as expected) lower the estimate of the leakage rate[46].

Politically this result is of great importance, as carbon leakages in the future should be playing a large role in designing political tools for reaching the Danish climate goals. If the idea is only to meet the Danish climate goals while not considering carbon leakage, the most cost-efficient policy is argued to be a uniform carbon tax across all industries[47] (DØRS, 2018; Kjær Kruse-Andersen & Birch Sørensen, 2021).
When introducing the effects of carbon leakages, several new political measures are taken into use mainly

[44] In Appendix D we show the estimations of the leakage rates associated with all sensitivity analyses performed. Looking at the estimates relative to each other they all provide us with a similar conclusion that the leakage rate drops as a higher degree of the PH framework is introduced.
[45] In the sensitivity analysis in Appendix D, we look at the effect of the Narrowly Strong PH in isolation, where we find that having the Weak PH active enhances the effect of the Narrowly Strong PH.
[46] Still the results do not indicate the magnitude in which the PH framework might lower the leakage rate, and whether including the effects of the PH framework might even lead to negative estimations of the leakage rate.
[47] Besides the industries included in the ETS.

to minimize the counter-effect on international competitiveness presented by the Pollution Haven hypothesis where firms relocate investments from one country to another to reduce costs associated with emission (Fischer & Fox, 2012; Kjær Kruse-Andersen & Birch Sørensen, 2021). For this 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 (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 for 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 environmental regulations. However, the results provided in this paper suggest that the PH framework might introduce new aspects to this discussion. Therefore, we will now present two focus areas for political initiatives to maximize the decrease in ROW emission through the effects of the PH framework.

The first political initiative is motivated by the discussion of the impact of technological development on carbon leakage in a small open economy, where DØRS (2019) argue that this effect should be minimal as the diffusion of new technologies is dependent on the innovator's world market share, which for companies in a small open economy is considered to be low. Still, we argue that 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 an industry's world market share, 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.

The second political initiative is based on the results of a questionnaire performed by several green Danish companies taking part in the climate partnership arranged by the Danish parliament. This questionnaire showed that Danish green technology has an estimated potential of reducing emission within Europe with up to 1500 million tons of CO2 (The Danish Parliament, 2020). One of the main obstacles being to create international relationships thereby creating opportunities for green firms to export their green technologies. Even when these relationships are established Munch & Schaur (2018) argue 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, like offering guidance and protection when engaging in exports (Jaffe et al., 2005). Therefore, a focus on governmental promotion and protection of Danish green exports could enhance the effects of the PH framework[48].

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.

[48] 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 (Munch & Schaur, 2018).

Section 7 Conclusion

In this paper, we investigate the importance of including the dynamic relationship between environmental regulations and competitiveness introduced by the PH framework, when analyzing carbon leakage rates. Based on our results, we conclude that introducing this relationship will lead to lower estimates of the leakage rate, thereby questioning the magnitude of this measure found in the literature today.
Including the PH framework in the leakage rate calculations seems especially important for understanding how a small open economy like Denmark might be able to affect emission through international trade, whereas the modeling of international trade in the literature today only allows for negative effect when introducing an environmental regulation, as the effects of innovation and technological development have shown to be difficult to model and are therefore excluded. Leaving out the effect of the PH framework might cause a bias in political decisions, where industries are excluded from environmental regulations using the argument that emission will just move elsewhere, inspired by the Pollution Haven hypothesis. Hopefully, the methods used, as well as the results presented in this paper will lead to an overall acceptance of the PH framework as a part of the leakage rate literature and will in the future provide a more adequate picture for future political decisions to be made.

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Appendix -A Model equations:

I.) Disposable income, wealth, and taxes

ROW:

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

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

$$YD_{hs,r}^{ROW} = YD_r^{ROW} + CG_b^{ROW} + CG_e^{ROW} \tag{A. 3}$$

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

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

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

$$V_w^{ROW} = V_{w,-1}^{ROW} + YD_w^{ROW} - C_w^{ROW} \tag{A. 7}$$

Newly added or changed equations (ROW)

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

DK:

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

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

$$YD_{hs,r}^{DK} = YD_r^{DK} + CG_b^{DK} + CG_e^{DK} \tag{A. 11}$$

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

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

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

$$V_w^{DK} = V_{w,-1}^{DK} + YD_w^{DK} - C_w^{DK} \tag{A. 15}$$

Newly added or changed equations (DK)

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

II.) Consumption and income shares

ROW:

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

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

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

$$Y_W^{ROW} = \omega_{ROW} \cdot Y_{ROW} \tag{A. 20}$$

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

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

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

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

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

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

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:

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

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

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

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

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

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

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

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

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

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

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:

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

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

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

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

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

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

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

Newly added or changed equations (ROW)

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

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

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

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

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

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

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

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

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

DK:

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

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

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

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

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

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

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

Newly added or changed equations (DK)

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

$$INV_{grim}^{DK} = IM_{gr}^{DK} \quad \text{(A. 63)}$$

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

$$INV_{con}^{DK} = INV_{DK} - INV_{gr}^{DK} - INV_{grim}^{DK} - INV_{R\&D}^{DK} \quad \text{(A. 64)}$$

$$INV_{gr}^{DK} \leq INV_{DK} - \ INV_{grim}^{DK} - INV_{R\&D}^{DK} \quad \text{(A. 65)}$$

$$K_{grim}^{DK} = K_{grim_{t-1}}^{DK} + INV_{grim}^{DK} - DA_{grim}^{DK} \quad \text{(A. 66)}$$

$$DA_{grim}^{DK} = \delta_{DK} \cdot K_{grim,-1}^{DK} \quad \text{(A. 67)}$$

$$K_{DK} = K_{gr}^{DK} + K_{con}^{DK} + K_{grim}^{DK} \quad \text{(A. 68)}$$

$$DA_{DK} = DA_{gr}^{DK} + DA_{\mathrm{con}}^{DK} + DA_{grim}^{DK} \quad \text{(A. 69)}$$

IV.) International trade

ROW:

$$X_{ROW} = IM_{DK} \quad \text{(A. 70)}$$

$$IM_{ROW} = X_{DK} \quad \text{(A. 71)}$$

Newly added or changed equations (ROW)

$$IM_{gr}^{ROW} = X_{gr}^{DK} \quad \text{(A. 72)}$$

$$X_{gr}^{ROW} = IM_{gr}^{DK} \quad \text{(A. 73)}$$

DK:

Newly added or changed equations (DK)

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

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

$$\log(X_{DK}) = \varepsilon_0 + \varepsilon_1 * \log(Y_{ROW}) + \varepsilon_3 * \log\left(xr_{DK_{t-1}}\right) \quad \text{(A. 76)}$$

$$\log(IM_{DK}) = \mu_0 + \mu_1 * \log(Y_{DK}) + \mathrm{\mu}_3 * \log\left(xr_{DK_{t-1}}\right) \quad \text{(A. 77)}$$

V.) Demand for financial assets

ROW:

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

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

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

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

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

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

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

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

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

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:

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

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

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

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

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

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

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

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

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

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)

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

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

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

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

$$\eta_{impv}^{DK} = \exp\left(impv_0^{DK} + impv_1^{DK} * log\left(GOV_{R\&D_{t-1}}^{DK} + INV_{R\&D_{t-1}}^{DK} \right) \right) \quad \text{(A. 204)}$$

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

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

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

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

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

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

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

DK:

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

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

Newly added or changed equations (DK)

$$\mu_{DK} = \mu_{gr}^{DK} * \frac{K_{gr}^{DK}}{K_{DK}} + \mu_{grim}^{DK} * \frac{K_{grim}^{DK}}{K_{DK}} + \mu_{con}^{DK} * \frac{K_{con}^{DK}}{K_{DK}} \quad \text{(A. 213)}$$

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

$$\epsilon_{DK} = \epsilon_{gr}^{DK} * \frac{K_{gr}^{DK}}{K_{DK}} + \epsilon_{grim}^{DK} * \frac{K_{grim}^{DK}}{K_{DK}} + \epsilon\,_{con}^{DK} * \frac{K_{con}^{DK}}{K_{DK}} \quad \text{(A. 215)}$$

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

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

$$\eta_{gr}^{DK} = \eta_{gr_{t-1}}^{DK} + \eta_{impv}^{DK} \quad \text{(A. 218)}$$

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

$$K_{NEWgr}^{DK} = k_{gr}^{DK} - k_{gr_{t-1}}^{DK} \quad \text{(A. 220)}$$

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

$$K_{NEWgrim}^{DK} = K_{grim}^{DK} - K_{grim_{t-1}}^{DK} \quad \text{(A. 222)}$$

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

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

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

XIII.) The ecosystem: damages and feedbacks

ROW*:*

$$d_T^{ROW} = 1 - \left(1 + d_1^{ROW} \cdot T_{AT} + d_2^{ROW} \cdot T_{AT}^2 + d_3^{ROW} \cdot T_{AT}^{x_{ROW}}\right)^{-1} \quad \text{(A. 226)}$$

$$\delta_G = \delta_0^{ROW} + \left(1 - \delta_0^{ROW}\right) \cdot \left(1 - ad_K^{ROW}\right) \cdot d_{T,-1}^{ROW} \quad \text{(A. 227)}$$

DK:

$$d_T^{DK} = 1 - \left(1 + d_1^{DK} \cdot T_{AT} + d_2^{DK} \cdot T_{AT}^2 + d_3^{DK} \cdot T_{AT}^{x_{DK}}\right)^{-1} \quad \text{(A. 228)}$$

$$\delta_{DK} = \delta_0^{DK} + (1 - \delta_0^{DK}) \cdot (1 - ad_K^{DK}) \cdot d_{T,-1}^{DK} \quad \text{(A. 229)}$$

XIV.) Carbon tax

ROW:

$$Co2_{Tax}^{ROW} = (emis_{ROW} * Co2_{rate}^{ROW})/100 \quad \text{(A. 230)}$$

DK:

$$Co2_{Tax}^{DK} = (emis_{DK} * Co2_{rate}^{DK})/100 \quad \text{(A. 231)}$$

XV.) Redundant equations

$$H_s^{DK} = H_h^{DK} \quad \text{(A. 232)}$$

$$H_s^{ROW} = H_h^{ROW} \quad \text{(A. 233)}$$

Appendix -B Parameter Values:

Starting values of variables and Parameters	***notation***	***Baseline 1 value***	***Change in Baseline 2 values***	***Change in Baseline 3 values***
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		
Parameter in Denmark export equation	ε_1	0.92		
Parameter in Denmark export equation	ε_2	0		
Parameter in Denmark export equation	ε_3	0.5		
Parameter in Denmark green export equation	Ω_0^X	-3.75		-2.25
Parameter in Denmark green export equation	Ω_1^X	1		
Parameter in Denmark green export equation	Ω_2^X	0		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		
Parameter in Denmark import equation	μ_1	0.5		
Parameter in Denmark import equation	μ_2	0		
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
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
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
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		
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)	$\epsilon_{\mathrm{con}}^{DK}$	4.65		
Energy intensity of conventional capital in ROW (Ej/USD)	$\epsilon_{\mathrm{con}}^{ROW}$	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)**	$\beta_{\mathrm{con}}^{DK}$	0.055		
CO2 intensity of conventional capital in ROW (Gt/Ej)**	$\beta_{\mathrm{con}}^{ROW}$	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	$impv_0^{DK}$	-2.282		
Parameter of Danish improvements of the renewability share of green capital	$impv_1^{DK}$	0.31		
Parameter of ROW improvements of the renewability share of green capital	$impv_0^{ROW}$	-4.383		
Parameter of ROW improvements of the renewability share of green capital	$impv_1^{ROW}$	0.31		
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	$\mathrm{co2}_{UP}^{PRE}$	4950.5		
Pre-industrial CO2 concentration in lower ocean	$\mathrm{co2}_{LO}^{PRE}$	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	$\eta_{\mathrm{con}}^{ROW}$	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		
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		
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:

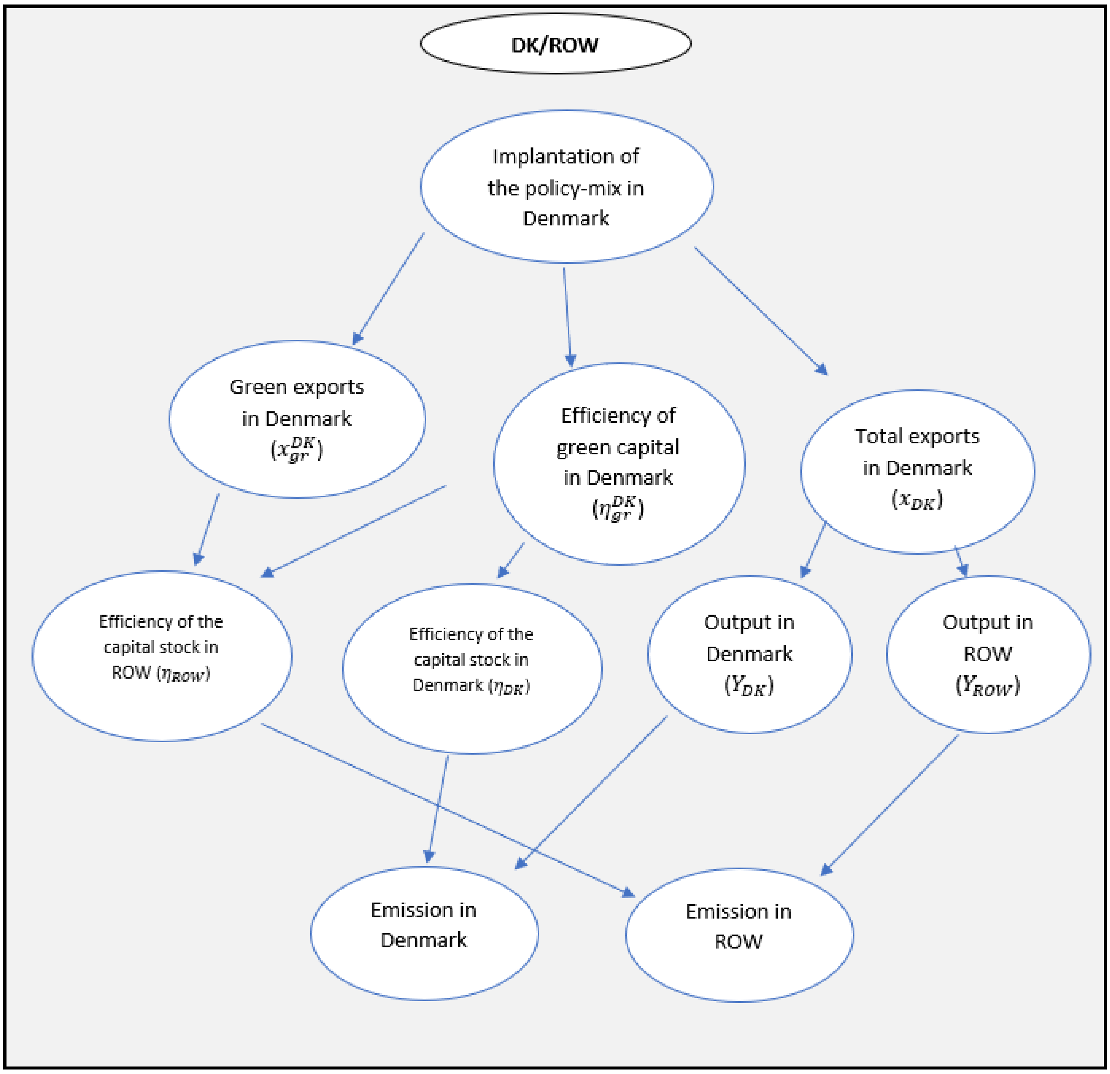

Figure 8 Appendix C: visualizing the simple relationships between the implementation of a policy-mix in Denmark and emission in Denmark and ROW.

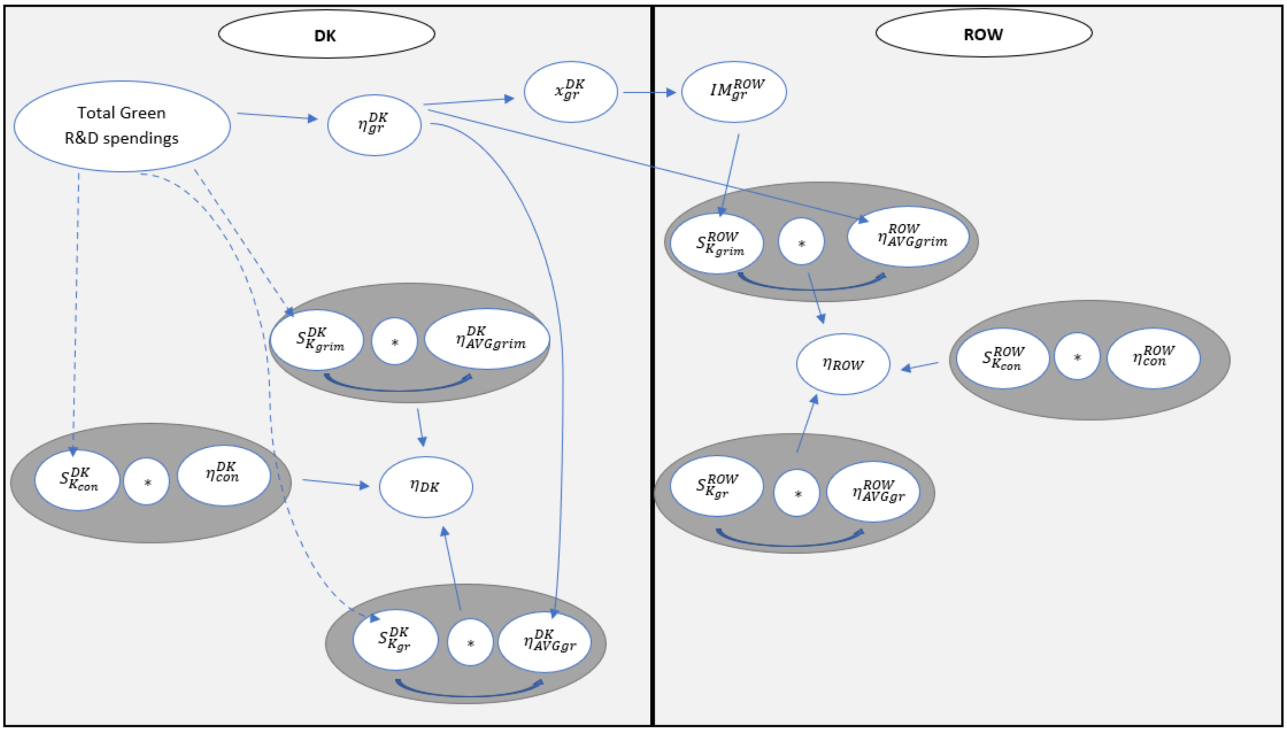

Figure 9 Appendix C: Visualizing the underlying effects going from the change in the renewability share in Denmark, to the average renewability share in Denmark and ROW.

Appendix -D Sensitivity analysis:

Including the effects of the Strong PH. (S1)

In the below, we introduce a new scenario also including the effects of the Strong PH to the analysis. When including the Strong PH, we allow for a relationship between technological efficiency in Denmark and the total Danish exports. We observe that the inclusion of the Strong PH mainly influences the emission in ROW, as the change in the technological efficiency is increased.

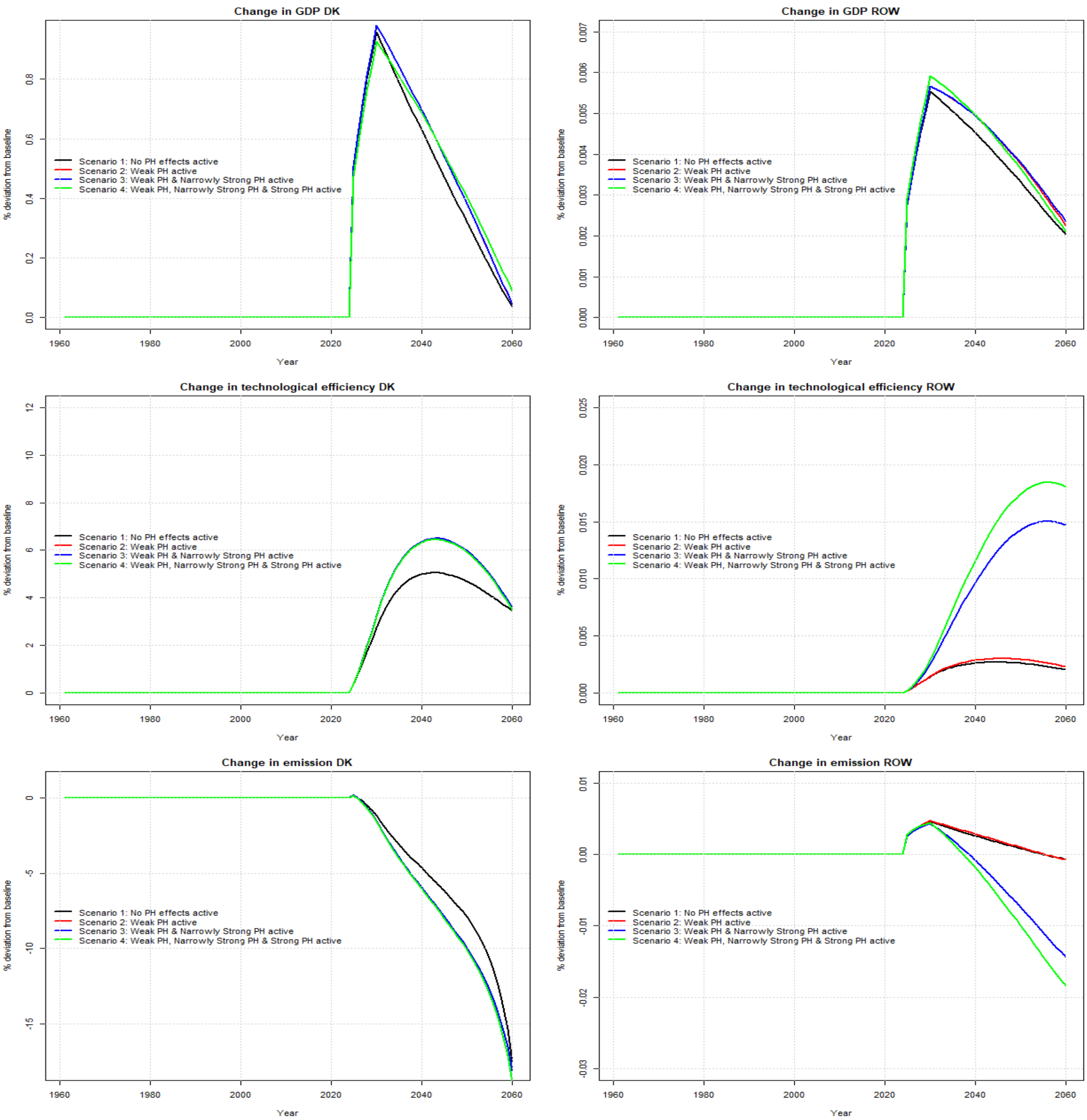

Figure 1 Appendix D: Introducing the effects of the Strong PH. (S1)

Comparing the three versions in isolation. (S2)

Below, we compare the three versions of the PH framework in isolation, thereby looking at three scenarios: 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).

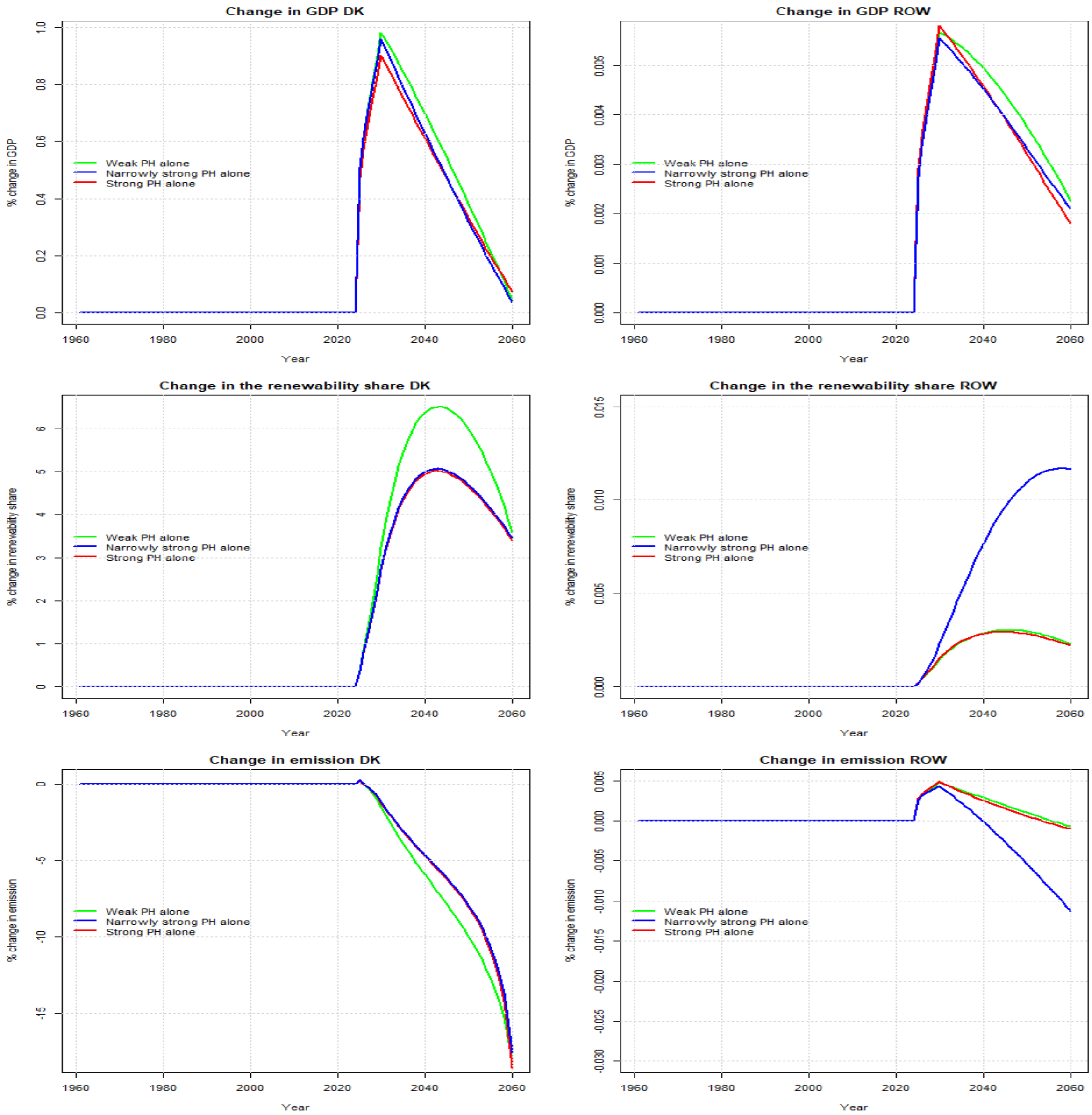

Figure 2 Appendix D: Comparing the three versions in isolation. (S2)

Changing assumption of imported green capital improvements. (S3)

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). No major changes seem to occur.

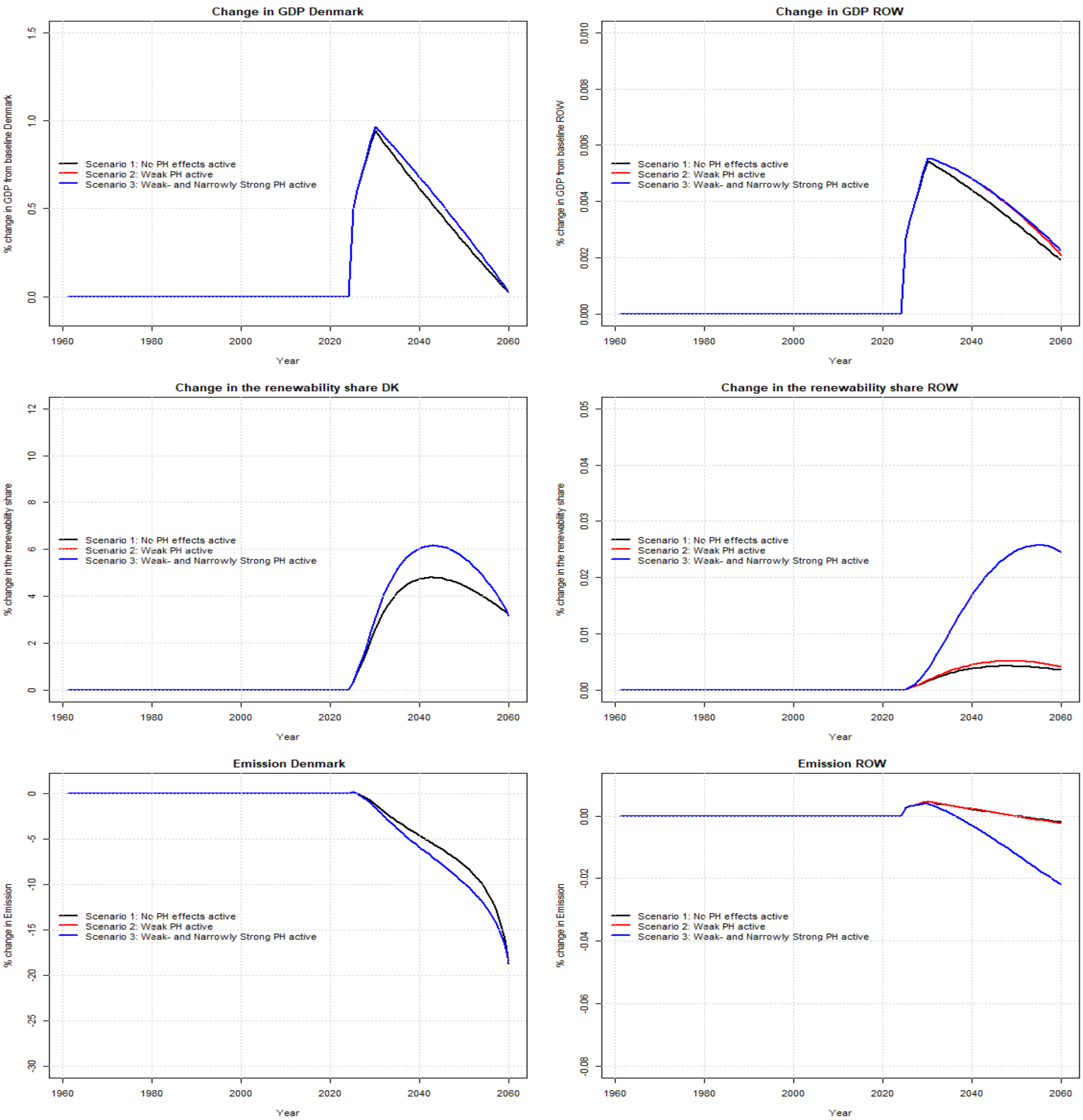

Figure 3 Appendix D: Changing assumption of imported green capital improvements. (S3)

Sensitivity analysis for coefficient used when activating the Narrowly strong PH. (S4)

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). The main difference found when lowering this estimate is seen on the change in technological efficiency for ROW, as the lower estimate will both affect the amount of green import by ROW, and the average efficiency of the capital imported.

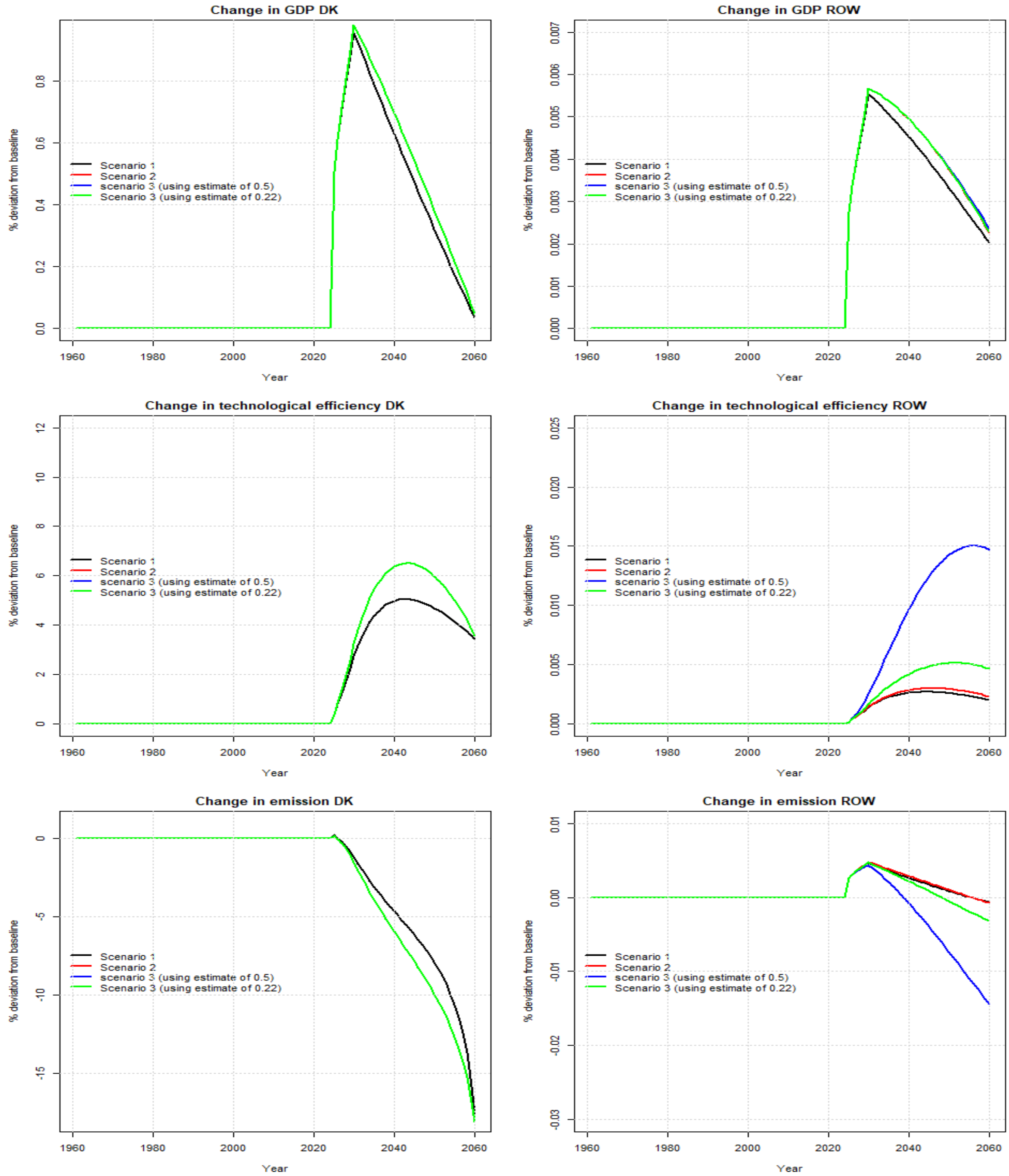

Figure 4 Appendix D: Sensitivity analysis for coefficient used when activating the Narrowly Strong PH. (S4)

Changing assumption of the Weak PH. (S5)

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. The main difference seems to be an increased effect on output as a result of implementing the Weak PH, as the higher level of firms R&D investments leads to a lower accumulation of capital and thereby lower depreciation.

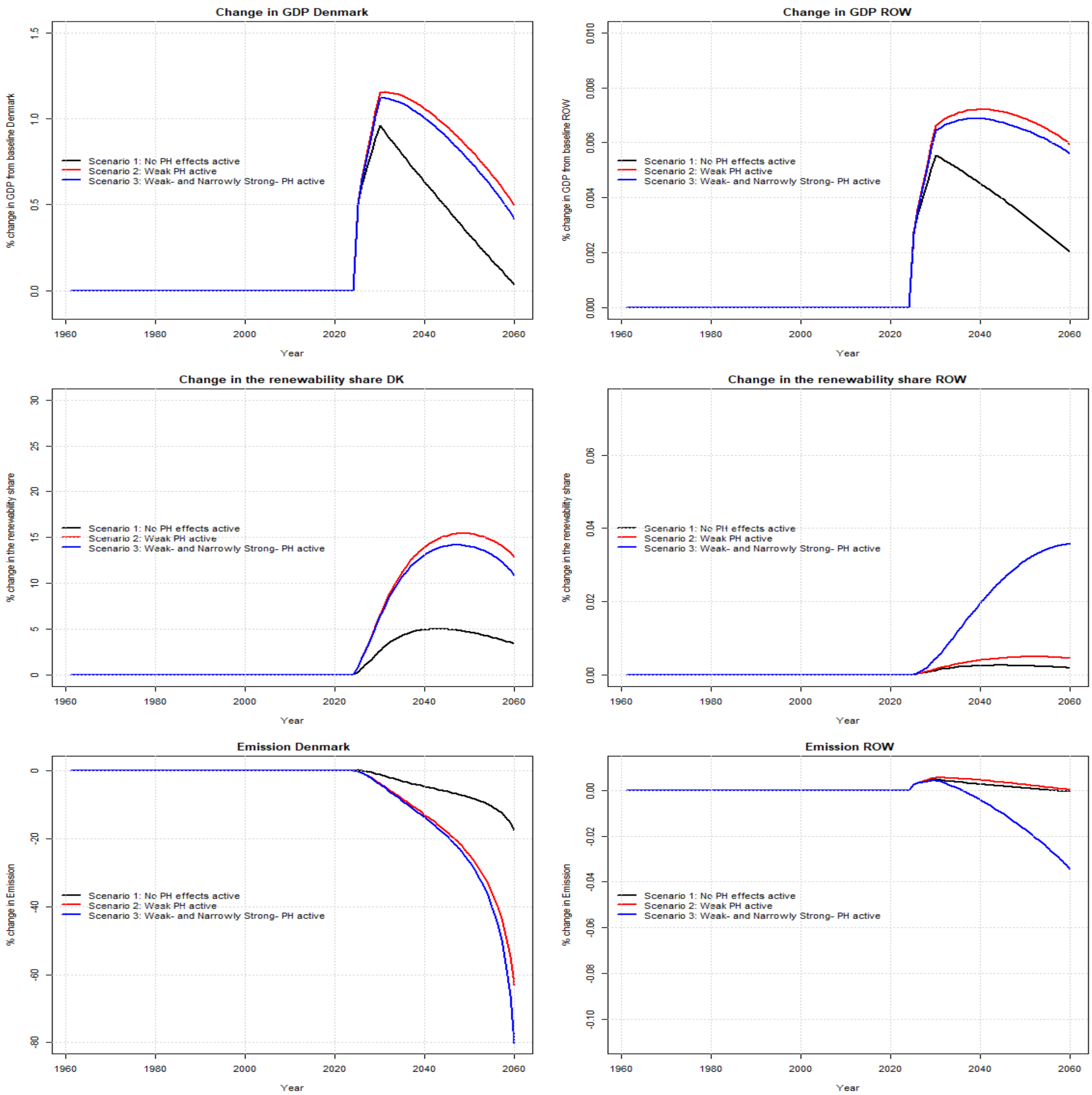

Figure 5 Appendix D: Changing assumptions in the Weak PH. (S5)

Lowering green government spending. (S6)

In this sensitivity analysis, we lower the share of 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). As a result, the relative differences seems to be the same, while the magnitudes are smaller.

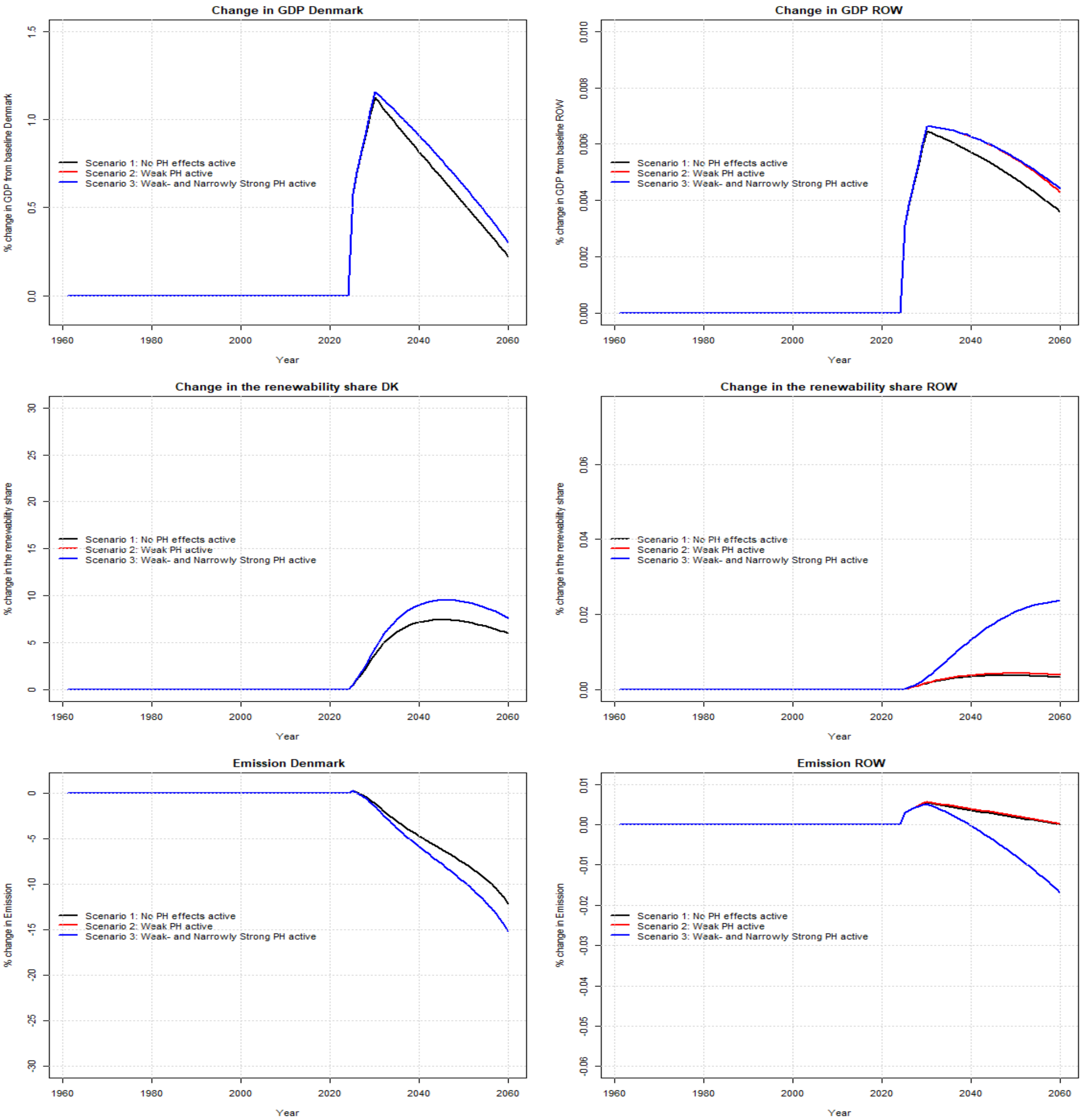

Figure 6 Appendix D: Lowering green government spending. (S6)

Matching trade balance with 2017 data. (S7)

In this sensitivity analysis, we set exports and imports to match the percentage of GDP observed in real data for the year 2017[49]. 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).

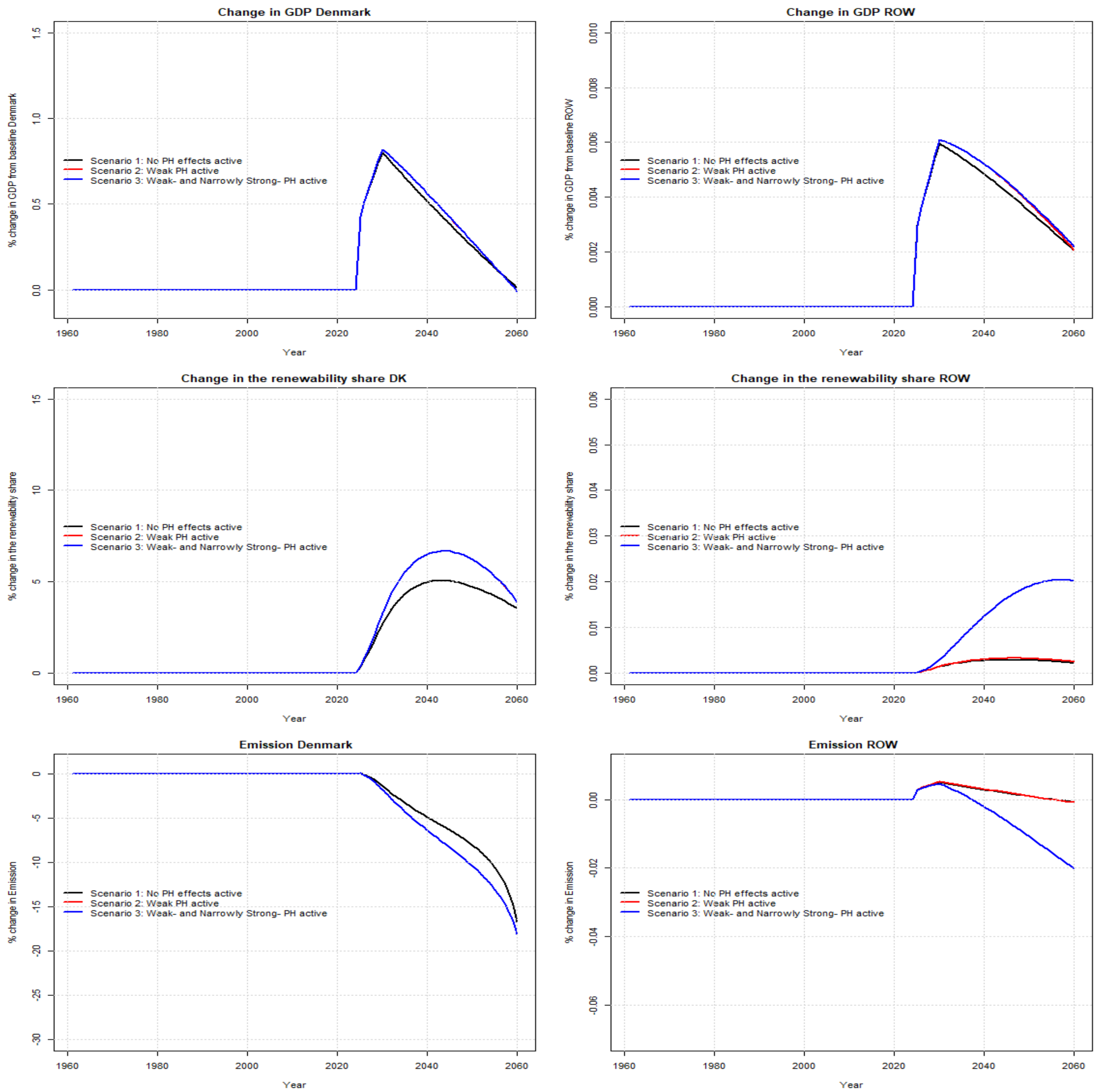

Figure 7 Appendix D: Matching trade balance with 2017 values. (S7)

[49] 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. (S8)

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).

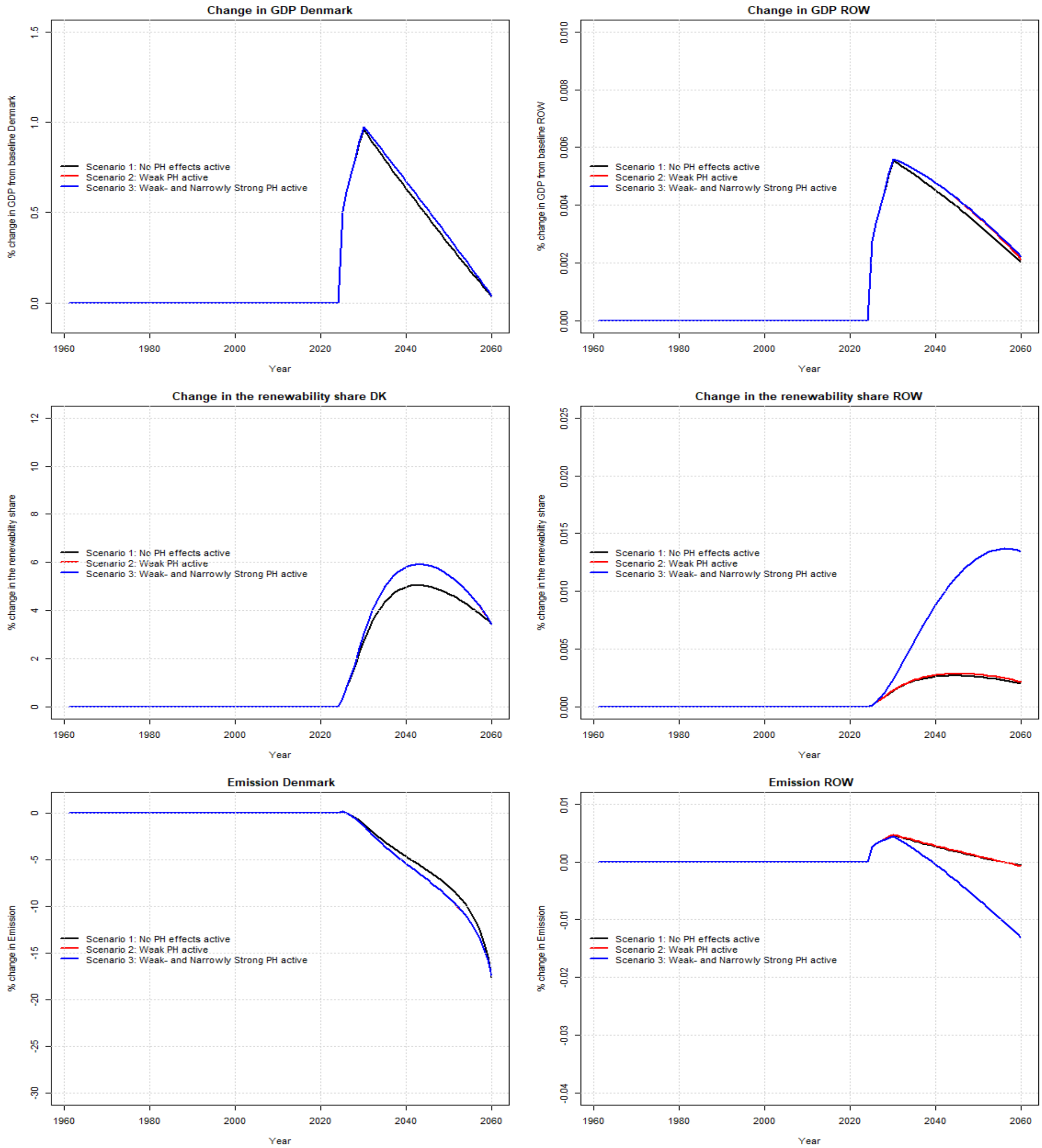

Figure 8 Appendix D: Sensitivity analysis for coefficient used when activating the Weak PH. (S8)

Sensitivity analysis for coefficient used when activating the Weak PH. (S9)

In this sensitivity analysis, we change the set-up of equation 2 showing the relationship between total R&D expenditures and the share of renewable energy used in production. We modify the equation in the following way:

$$\eta_{impv}^{DK} = \left(\exp\left(-3.56 + 0.31 * log\left(GOV_{R\&D_{t-1}}^{DK} + INV_{R\&D_{t-1}}^{DK}\right)\right)\right) * (1.02)^{(100-\eta_{DK}*100)}$$

Thereby the improvements of the renewability share drops as renewability technologies become more mature measured as how close we are to using 100% renewable energy in the production. Doing this, we see a further decline in the later years as the Danish renewability share is getting close to 100%. Following the above approach allows us to obtain a renewability share following the real data from 2004-2021 very close.

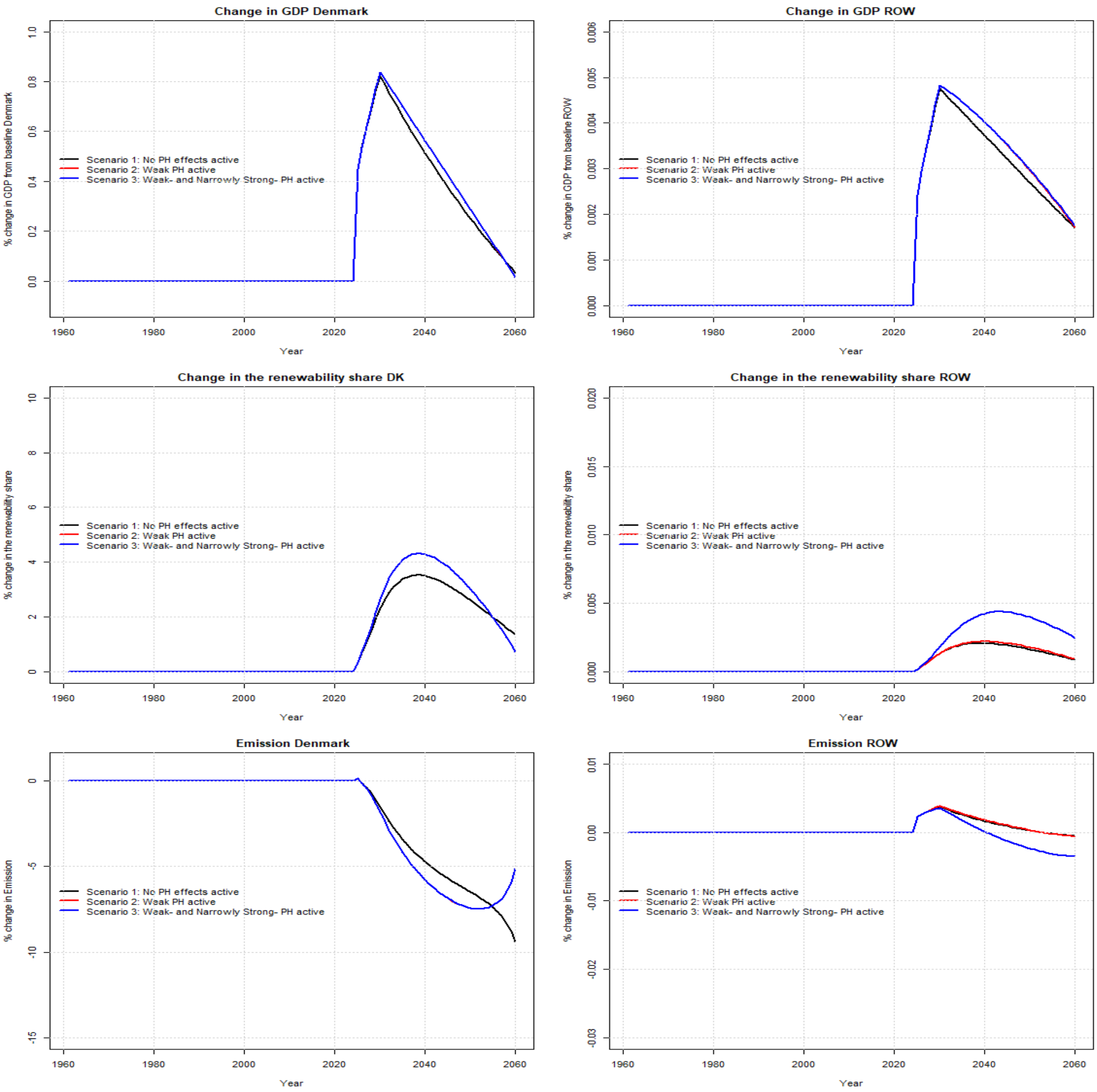

Figure 9 Appendix D: Sensitivity analysis for coefficient used when activating the Weak PH. (S8)

Leakage rates in the different sensitivity analysis

In this table, we show the calculated leakage rates for all sensitivity analyses (besides from sensitivity analysis 2) together with the results obtained in the main analysis.

Table 1 Appendix D: Calculations of the leakage rate for sensitivity analysis 2-8.

Scenario\ Measure	Main analysis L_R	S1 L_R	S3 L_R	S4 L_R	S5 L_R	S6 L_R	S7 L_R	S8 L_R	S9 L_R
Scenario 1 10 years	0.85	0.85	0.80	0.64	0.85	0.92	0.78	0.85	0.59
Scenario 1 20 years	0.49	0.49	0.42	0.31	0.49	0.54	0.46	0.49	0.35
Scenario 1 30 years	0.32	0.32	0.22	0.13	0.32	0.36	0.31	0.32	0.25
Scenario 2 10 years	0.71	0.71	0.65	0.61	0.43	0.80	0.63	0.76	0.50
Scenario 2 20 years	0.42	0.42	0.34	0.27	0.27	0.47	0.38	0.45	0.31
Scenario 2 30 years	0.28	0.28	0.18	0.06	0.19	0.32	0.26	0.30	0.23
Scenario 3 10 years	0.43	0.43	0.13	0.16	0.03	0.43	0.22	0.41	0.33
Scenario 3 20 years	-0.09	-0.09	-0.51	-0.49	-0.32	-0.08	-0.30	-0.10	0.06
Scenario 3 30 years	-0.53	-0.53	-1.08	-1.06	-0.65	-0.44	-0.75	-0.50	-0.10
Scenario 4 10 years	-	0.34	-	-	-	-	-	-	-
Scenario 4 20 years	-	-0.25	-	-	-	-	-	-	-
Scenario 4 30 years	-	-0.77	-	-	-	-	-	-	-