Thomsen, Simon Fløj

**Article**

# The impact of environmental regulations on competitiveness and carbon leakage: The pollution haven and Porter hypothesis in a two-area ecological stock-flow consistent model

European Journal of Economics and Economic Policies: Intervention (EJEEP)

**Provided in Cooperation with:**
Edward Elgar Publishing

*Suggested Citation:* Thomsen, Simon Fløj (2025) : The impact of environmental regulations on competitiveness and carbon leakage: The pollution haven and Porter hypothesis in a two-area ecological stock-flow consistent model, European Journal of Economics and Economic Policies: Intervention (EJEEP), ISSN 2052-7772, Edward Elgar Publishing, Cheltenham, Vol. 22, Iss. 3, pp. 454-479,
https://doi.org/10.4337/ejeep.2024.0140

European Journal of Economics and Economic Policies: Intervention, Vol. 22 No. 3, 2025, pp. 454–479
First published online: September 2024; doi: 10.4337/ejeep.2024.0140

# The impact of environmental regulations on competitiveness and carbon leakage

## The pollution haven and Porter hypothesis in a two-area ecological stock–flow consistent model

Simon Fløj Thomsen*
Aalborg University Business School, Aalborg University, Denmark

*A substantial amount of literature investigates environmental regulations and their effect on competitiveness. This often leads to a comparison of the two competing hypotheses: the pollution haven hypothesis and the Porter hypothesis. The later suggests that environmental regulations can positively affect country level competitiveness through green research and development, while the former proposes that environmental regulations negatively affect competitiveness through higher production costs. In this paper, we argue that the comparison between these two hypotheses should not only be limited to competitiveness alone but should also include a focus on carbon leakage. We use a two-area stock–flow consistent macroeconomic model calibrated to match key variables for the Danish economy. We incorporate the effects of both the pollution haven and Porter hypotheses within the model. As an environmental regulation is implemented in the Danish economy, we find an immediate negative effect on competitiveness, but as the innovational process is allowed time to play in, as suggested by the Porter hypothesis, the effect on competitiveness turns positive. Furthermore, we find negative carbon leakage rates when the effects of the Porter hypothesis are included together with the pollution haven hypothesis, contradicting the quite large positive estimates found for small open economies in the current literature. We find that the negative carbon leakage rates are a result of including the empirically validated effects of the Porter hypothesis, which are excluded in the current literature.*

**Keywords:** *stock–flow consistent modeling, carbon leakage rates, competitiveness*

**JEL codes:** *F18, Q56, E12, E01, O33*

## 1 INTRODUCTION

As a small open economy, Denmark—like many other countries—has been significantly impacted by increasing globalization, leading to greater integration of trade and capital flows. This, from an environmental perspective, means that a large share of Denmark's emissions is now embodied in international traded goods. The question of whether, and how, increasing globalization should influence the design and evaluation of environmental regulations is therefore highly relevant (Copeland 2021). With its ambitious climate goals of reducing carbon emissions by 70% by 2030 (relative to 1990 levels) and achieving climate neutrality by 2050, Denmark is often seen as a leader in the green transition. However, since these goals are evaluated based on territorial emissions, the effects of domestic regulations on emissions beyond national

* Email: sft@business.aau.dk.

Received 22 March 2024, accepted 31 May 2024

borders are often overlooked. This external impact is typically assessed using carbon leakage rates. For Denmark, estimates of the carbon leakage rate are often found to be within the range of 20–90 percent, depending on the industries in question as well as the channels of carbon leakage included (Copenhagen Economics 2011; DØRS 2019; Beck et al. 2023).[1] In the case of Denmark, one of the main channels of carbon leakage is argued to go through the channel of international trade, often associated with the pollution haven hypothesis (first postulated by Copeland/Taylor 1994), where the implementation of an environmental regulation will affect relative prices by increasing production costs within the regulated country. The overall effect of this regulation will be a reduction in the demand for produced goods in the regulated country, while the demand for similar goods produced in other 'non-regulated' countries will increase. Since lower production also affects the profit of firms in the regulated country, this might give the firms an incentive to move their production to less environmentally restricted areas (Copeland 2008).[2]

In the early 1990s, the Porter hypothesis, introduced by Porter/Van Der Linde (1995), offered a competing perspective. According to this hypothesis, environmental policies can have a net positive effect on the competitiveness of regulated firms by promoting cost-saving efficiency improvements, which can reduce or even fully offset regulatory costs. Furthermore, these policies can drive innovation in new technologies, potentially enabling firms to attain international technological leadership.

Even today, empirical evidence remains inconclusive regarding which of the two hypotheses is stronger, with many studies yielding a significant proportion of inconclusive or insignificant results (discussed in Section 2). Despite this, policymakers often rely on the pollution haven hypothesis to exempt industries from environmental regulations, citing concerns over competitiveness and high estimates of carbon leakage. However, these arguments are frequently based on calculations that excludes empirically validated effects presented by the Porter hypothesis. We seek to provide a more realistic picture of how environmental regulations affect competitiveness as well as carbon leakage, including both the effects of the pollution haven hypothesis and the Porter hypothesis.

The main contribution of this paper will be a comparison of the two competing hypotheses: the pollution haven hypothesis and the Porter hypothesis within the framework of a stock–flow consistent model. We use a modified version of the ecological two-area stock–flow consistent (SFC) model presented by Thomsen (2024), representing Denmark and the rest of the world (ROW). The model is partly empirical and is capable of reproducing the development of important variables in both Denmark and ROW. We compare the effects of the two hypotheses within two areas as an environmental regulation is implemented in the Danish economy. First, we investigate the effect on country-level competitiveness by looking at net exports. Second, we introduce a comparison of the two hypotheses in the context of carbon leakage rates.

To the best of our knowledge, we are the first to compare the effects of the pollution haven hypothesis and the Porter hypothesis in relation to their effect on carbon leakage; additionally, we add to the current literature investigating how environmental regulations affect country-level competitiveness.

1. Carbon leakage rates are often found to be larger for small open economies, like Denmark (DØRS 2019).
2. Copeland (2008) breaks the pollution haven hypothesis into two parts, one being the competitiveness hypothesis and the other being the pollution haven hypothesis. We do not make this division and will refer to both as the pollution haven hypothesis.

The remainder of this paper is organized as follows: Section 2 will present the empirical work for the underlying effects of the Porter, and pollution haven hypotheses. 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 three models used for our analysis. In Section 5, we analyze the effect of introducing a policy mix within the two-area ecological SFC model, focusing on the change in net exports and emission. In Section 6, we use the results of Section 5 to calculate the leakage rate within each of the three models. Lastly, we conclude the main results in Section 7.

## 2 LITERATURE REVIEW

In this section, we will review existing literature to investigate the empirical evidence of the pollution haven and Porter hypotheses. Although both of these hypotheses consist of multiple underlying effects, we will evaluate each of these underlying effects empirically. The literature review presented in Dechezleprêtre/Sato (2017) on both the pollution haven hypothesis and the Porter hypothesis will provide the point of departure for empirically validating the underlying effects of the two hypotheses.

### 2.1 Pollution haven hypothesis

The pollution haven hypothesis can be divided into two underlying effects: (i) the effect of environmental regulation on international trade as a result of relative price changes and (ii) the effect of environmental regulation on foreign direct investment (FDI).

#### *2.1.1 The price channel*

As concluded by Dechezleprêtre/Sato (2017), recent evidence supports that net imports increase as environmental regulations are tightened. However, this effect seems to be significant for energy-intensive goods only. Studies focusing on this effect use different identification strategies, some investigate the environmental stringency using the Pollution Abatement Cost and Expenditure (PACE) survey as a stringency measure. One example is Levinson/Taylor (2008), who find that a 1 percent increase in PACE in the US is associated with a 0.4 percent increase in net imports from Mexico and a 0.6 percent increase in net imports from Canada. Similar findings using the PACE survey include Ederington/Minier 2003; Ederington et al. 2005; Levinson 2010.

Using energy prices as a proxy for environmental stringency, Aldy/Pizer (2015) estimate the effect of energy prices on net imports using a panel data set covering 450 sectors. They find that, on average, across all sectors, the effect is not statistically different from zero. At the same time, they find that the effect is increasing (despite being small) with the energy intensity of the analyzed sector. Last, Sato/Dechezleprêtre (2015) use a data set of 42 countries and 62 manufacturing sectors from 1996 to 2011. Looking across all 62 sectors, they find that a 10 percent increase in the price gap between two trading partners increases bilateral imports by 0.2 percent.

While some previous literature seem to support the pollution haven hypothesis, a meta-analysis performed by Cohen/Tubb (2017) finds that 32 percent of studies show a significant positive relationship when looking at how environmental regulations affect competitiveness at the country or regional level, while only 14 percent find a significant negative relationship. The remaining 54 percent of the studies show insignificant results. Cohen/Tubb (2017) explain the large amount of insignificant results with the difficulties of isolating the negative effect on competitiveness through price increases from the positive effect of increased innovation as presented by the Porter hypothesis (for which relevant literature will be presented below).

### *2.1.2 Foreign direct investments*

In the pollution haven hypothesis, the relationship between environmental regulations and FDIs are often divided into push and pull factor explanations. The push factor argument is associated with more stringent regulations pushing investment decisions away from the regulating area, while the pull factor argument is used to explain how relatively more lax regulations attract more investments.[3]

For the push factor, empirical evidence looks relatively split, having only a few studies investigating the effect, most of these find little evidence (Eskeland/Harrison 2003; Manderson/Kneller 2012). Still Hanna (2010) finds that for 'nonattainment' counties in the US, their resident multinational firms increased foreign assets by 5.3 percent. The mixed evidence leads both Dechezleprêtre/Sato (2017) and an earlier literature review by Jeppesen et al. (2002) to conclude that the estimates found are highly sensitive to empirical specification.

For the pull factor, some literature looking at within-country differences in environmental stringency do find evidence for this effect, where more lax environmental regulations attract more investments (List et al. 2004; Dean et al. 2009; Keller/Levinson 2002; Fredriksson et al. 2003; Millimet/Roy 2016). For cross-country studies, the challenging part is determining relative stringency across countries. Xing/Kolstad (2002) use $SO_2$ emissions, finding a significant effect for two out of six industries (the two most energy intense industries) in 22 countries when looking at new investments from multinational companies in the US. Both Wagner and Timmins (2009) and Kellenberg (2009) utilize the World Economic Forum (WEF) index of environmental stringency. Wagner and Timmins (2009) find that environmental stringency affects incoming investments, though this effect is limited to the chemical industry. Similarly, Kellenberg (2009) concludes that more relaxed regulations tend to attract investments from multinational firms in the US. Still, some literature finds contradicting results, for example, Raspiller/Riedinger (2008) and Kheder/Zugravu (2012), who find no evidence of the pull factor when looking at French firms' FDI location.

Finally, the effects of FDI received by a hosting country have been the center of much empirical literature, arguing that FDI can either crowd-in (increase) or crowd-out (decrease) domestic investments. Al-Sadig (2013) use panel data for 91 developing countries over the period of 1970–2000, finding that FDI stimulates private domestic investments, but that it depends on the level of human capital in the receiving country. Wang (2010) splits up 50 countries into developed and less developed countries, only finding a positive relationship between FDI and domestic investments for the group of less developed countries. Lastly, Agosin/Machado (2005) find that FDI has no effect on domestic investments when using a theoretical model for investment, relying on estimations from a panel set in the period of 1971–2000. A small amount of literature also focusses on this relationship for developed countries, here Pilbeam/Oboleviciute (2012) find no significant impact of FDI on domestic investments for new EU member states, while finding

3. Many other aspects can affect both the pull and push factor such as market size and potential, human capital, infrastructure, and institutional quality. In this paper we solely focus on the effect through higher production costs as a result of implementing environmental regulations, for an overview of other aspects see Moran et al. (2005).

a significant crowding-out effect for the Older EU14 members (including Denmark). Mišun/Tomšík (2002) provide a similar analysis for Poland, the Czeck Republic, and Hungary; finding significant crowding-out effects for Poland, and significant crowding-in effects for Hungary and the Czeck Republic.

To summarize, empirical evidence seems to be supportive of the price channel when looking at the immediate effect of environmental regulations on competitiveness, still, the effects are mainly significant for energy-intensive industries. The empirical evidence of the pull factor seems to be empirically validated, while the push factor shows mixed results. The effect of FDI on domestic investments seems conclusive in finding a crowding-in effect for developing countries, while the relationship seems inconclusive for developed countries.

## 2.2 Porter hypothesis

We now turn towards the Porter hypothesis (PH), where we divide the PH framework into three versions following the work of Jaffe/Palmer (1997). They split up the PH framework into the weak PH, the narrowly strong PH, and the strong PH, as visualized in Figure 1. First, the weak PH implies that environmental regulations lead to an increase in firms' green R&D spending. Second, the narrowly strong PH states that green firms, through higher green R&D spending, improve competitiveness through first-mover advantages. Last, the strong PH suggests 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.

The empirical tests of the weak PH mainly use R&D expenses or patent data. Jaffe/Palmer (1997) 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 Lee et al. (2011) all show a positive relationship between environmental regulations and green patents. Thereby, we do find a large amount of evidence for the existence of the weak PH in the current literature. A few newer studies look at the effect of environmental regulations on the innovation of

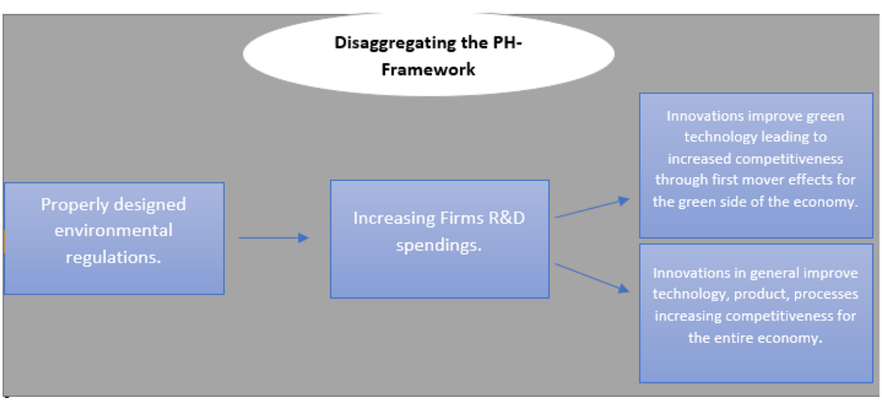


*Figure 1 Disaggregating the Porter hypothesis into the weak, narrowly strong, and strong Porter hypothesis.*

renewable energy technology (using patent and R&D expenditure data) also finding a positive relationship (Johnstone et al. 2010; Böhringer et al. 2017; Kim et al. 2017; Hille et al. 2020).

While the literature provides consistent empirical support for the weak PH, findings regarding the strong PH are more divided. As mentioned in the previous section, the literature has difficulties in determining a relationship between environmental regulations and competitiveness at a country level as presented in the meta-analysis by Cohen/Tubb (2017).

Still Cohen/Tubb (2017) conclude that when only focusing on flexible regulations (in contrast to command and control regulations), the results are much more likely to be positive and significant, which is also in line with the Porter hypothesis. Furthermore, both Cohen/Tubb (2017) and Ambec et al. (2013) find that dynamic estimations of the relationship between environmental regulations and country-level competitiveness are more likely to favor the strong Porter hypothesis. The dynamic set-up allows time for innovation to play, in the meantime, the immediate negative effect suggested by the pollution haven hypothesis is explained by the immediate cost faced by firms as a carbon tax is implemented.

In the previous section, empirical evidence suggested that the pollution haven hypothesis was mainly found in energy-intensive industries. A similar observation can be made for the Porter hypothesis, as we go from the strong to the underlying narrowly strong hypothesis, where the literature seems more conclusive in finding a positive relationship between environmental regulations and green exports. 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 find a negative relationship between environmentally friendly activities, measured by $CO_2$ intensity, and trade performance. This indicates 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.

To summarize the literature review, we find that both the pollution haven hypothesis and the Porter hypothesis consist of multiple underlying effects; some of these effects are highly empirically validated, while others are based on weak empirical results. In the next section, we will show how these underlying effects are introduced within a macroeconomic model. In this model, we will be able to close down these individual underlying channels, which is useful when comparing the two hypotheses' effects on competitiveness and carbon leakage.

## 3 INTERNATIONAL TRADE IN A TWO-AREA ECOLOGICAL STOCK–FLOW CONSISTENT MODEL

In this section, we introduce the macroeconomic model used for evaluating the pollution haven hypothesis and the Porter hypothesis. We use a type of model belonging to the class of SFC dynamic macroeconomic models (for example, Godley/Lavoie 2016; Nikiforos/Zezza 2017; Carnevali et al. 2019). The advantage of using a macroeconomic model compared to the empirical estimation approach is the opportunity to isolate underlying channels by closing certain channels down. We will utilize this advantage as we reach Section 4.

An alternative approach would be to utilize the GTAP-E macroeconomic model, which has become widely used in the literature on leakage rates and already incorporates the price channel proposed by the pollution haven hypothesis.[4] In this paper, we prefer the more dynamic set-up provided by SFC models, which allow us to compare the immediate effects of a carbon tax, where the pollution haven hypothesis seems to dominate, with the more long-term effects where innovation, as suggested by the Porter hypothesis, gets time to kick in. Lastly, the GTAP-E model does not include the financial side of the economy, whereas it does not allow for the analysis of the pull and push factors presented in the previous section, whereas the financial side of the economy is a crucial element in the SFC set-up.

The SFC model used in this paper is an extended version of the ecological two-area SFC model originally developed by Carnevali et al. (2021) and further designed to focus on a small open economy in the form of Denmark (DK) versus the ROW by Thomsen (2024). In this paper, we use a modified version of the model presented in Thomsen (2024) by introducing several new equations to allow for the effects presented by the pollution haven and Porter hypotheses. We do not comment on the parameter values until Section 4, where we validate the model.

### 3.1 Modeling the pollution haven hypothesis

As presented in the literature review, the pollution haven hypothesis consists of two underlying effects, one going through the price channel, and the second through the FDI channel. In this section, we present the equations introducing these two channels. In Appendix C (figure 8; available online at https://doi.org/10.4337/ejeep.2024.0140), a directed acyclic graph (DAG) is provided to give a better overview of how the implementation of a policy mix in Denmark (presented in Section 5) affects emission in the ROW.

We start by introducing the pricing dynamics in the model following the method used by Byrialsen/Raza (2018). In addition to their equations, we introduce the full amount of carbon taxes paid by firms when defining unit costs:[5]

$$UC_t^{DK} = \left(Y_{W,t}^{DK} + IM_t^{DK} + CO_{2Tax,t}^{DK}\right) / S_t^{DK} \tag{1}$$

where $UC_t^{DK}$ is the cost of producing one unit in Denmark, $Y_{W,t}^{DK}$ is the total sum of wages paid to workers in Denmark, $IM_t^{DK}$ is total imports made by Denmark, and $CO_{2Tax,t}^{DK}$ is the sum of carbon taxes paid by firms in Denmark. Finally, all production costs are then divided by the total sales ($S_t^{DK}$) defined as

$$S_t^{DK} = X_t^{DK} + C_t^{DK} + INV_t^{DK} + GOV_t^{DK} \tag{2}$$

We use the unit costs to define sales prices together with an exogenously set mark-up rate ($\phi_t^{DK}$):

$$P_{st}^{DK} = \left(1 + \phi_t^{DK}\right) * UC_t^{DK} \tag{3}$$

Therefore, an increase in the carbon tax will increase firms' unit costs and increase sales prices. Even though prices are included in the model, all variables are calculated in nominal values following the strategy of Carnevali et al. (2021). An implication of this decision

4. For more information about the GTAP-E model, see Truong et al. (2007).

5. We present the equations from the perspective of Denmark, still a similar equation is always introduced for the rest of the world unless mentioned otherwise.

is that we are unable to analyze the effect on variables expressed in real terms, leaving out a possible crowding-out effect due to price changes in the model. To address this problem, we catch some of this crowding-out effect by including the relative price level between Denmark and ROW in the export and import equations, following the set-up used by Byrialsen/Raza (2020):

$$\log(X_t^{DK}) = eps_0 + eps_1 \log\left(Y_t^{ROW}\right) + eps_2 * \log(\eta_{gr,t}^{DK}) + eps_3 * \log\left(\frac{P_{s,t-1}^{DK}}{P_{s,t-1}^{ROW}}\right) \tag{4}$$

$$\log(IM_t^{DK}) = mu_0 + mu_1 \log\left(Y_t^{DK}\right) + mu_2 * \log(\eta_{gr,t}^{ROW}) + mu_3 * \log\left(\frac{P_{s,t-1}^{DK}}{P_{s,t-1}^{ROW}}\right) \tag{5}$$

Besides the relative price level between Denmark and ROW, exports and imports are determined by GDP ($Y_t^{DK}$ and $Y_t^{ROW}$), and the share of renewable energy to total energy associated with green capital ($\eta_{gr,t}^{DK}$ and $\eta_{gr,t}^{ROW}$).[6]

To determine FDI, we use the equations originally presented by Carnevali et al. (2021) using two types of financial assets: bonds and equities.[7] Looking at bonds and equities these will be issued both by Denmark and ROW. We determine the demand for bonds and equities in both Denmark and ROW using the Tobin's portfolio allocation theory as also advocated by Godley/Lavoie (2016). Below, we show the Danish demand for bonds and equities:

$$B_t^{DK,DK} = W_{r,t}^{DK}\left(\lambda_{10} + \lambda_{11} r_{b,t}^{DK} - \lambda_{12} r_{b,t}^{ROW} - \lambda_{13} r_{e,t}^{DK} - \lambda_{14} r_{e,t}^{ROW}\right) \tag{6}$$

$$B_t^{DK,ROW} = W_{r,t}^{DK}\left(\lambda_{10} - \lambda_{11} r_{b,t}^{DK} + \lambda_{12} r_{b,t}^{ROW} - \lambda_{13} r_{e,t}^{DK} - \lambda_{14} r_{e,t}^{ROW}\right) \tag{7}$$

$$E_t^{DK,DK} = W_{r,t}^{DK}\left(\lambda_{10} - \lambda_{11} r_{b,t}^{DK} - \lambda_{12} r_{b,t}^{ROW} + \lambda_{13} r_{e,t}^{DK} - \lambda_{14} r_{e,t}^{ROW}\right) \tag{8}$$

$$E_t^{DK,ROW} = W_{r,t}^{DK}\left(\lambda_{10} - \lambda_{11} r_{b,t}^{DK} - \lambda_{12} r_{b,t}^{ROW} - \lambda_{13} r_{e,t}^{DK} + \lambda_{14} r_{e,t}^{ROW}\right) \tag{9}$$

where $r_{b,t}^{DK}$ and $r_{b,t}^{ROW}$ are the rates of return on bonds in Denmark and ROW, which is exogenously determined, while $r_{e,t}^{DK}$ and $r_{e,t}^{ROW}$ are the rates of return on equities calculated using the following equations:

$$r_{e,t}^{DK} = \left(1 - \pi_t^{DK}\right) * r_{b,t}^{DK} + \pi_t^{DK} * r_{e,t}^{DK^T} \tag{10}$$

6. The share of renewable energy to total energy associated with green capital will be further introduced in equations (19) and (20).

7. In this paper, we assume foreign direct investments (FDI) to consist of only financial assets, often referred to as foreign portfolio investments (FPI). We base this assumption on data presented by the Central Bank of Denmark, showing that the majority of inward and outward FDI in Denmark consists of financial assets.

The rate of return on equities in Denmark ($r_{e,t}^{DK}$) is determined by the rate of return on other financial assets, in our case bonds ($r_{b,t}^{DK}$), as well as the dollar earned per dollar share held $r_{e,t}^{DK^T}$, which is determined as follows[8]:

$$r_{e,t}^{DK^T} = \frac{F_{tot,t}^{DK}}{B_{S,t}^{DK} * p_{e,t}^{DK}} \tag{11}$$

$B_{S,t}^{DK}$ is the real value of equities issued by Danish firms, which is determined by last year's supply added by a fixed share ($\xi^{DK}$) of new real investments.

$$B_{S,t}^{DK} = B_{S,t-1}^{DK} + \xi^{DK} * \frac{INV_t^{DK}}{p_{e,t}^{DK}} \tag{12}$$

Finally, $p_e^{DK}$ is the price on equities issued by Danish firms, determined as follows:

$$p_{e,t}^{DK} = \frac{\left(E_t^{DK,DK} + E_t^{ROW,DK}\right)}{B_{S,t}^{DK}} \tag{13}$$

This introduces the channel through which a carbon tax affects FDI in Denmark and ROW. First, an increase in the carbon tax lowers the profits made by Danish firms decreasing the rate of return on equities in Denmark. The result is a decrease in demand for Danish equities while the demand for equities issued by ROW increases. We determine the flows of FDI from the perspective of Denmark, using inward FDI (FDI received by Denmark from ROW) and outward FDI (FDI received by ROW from Denmark).

$$FDI_{OUT,t}^{DK} = B_t^{DK,ROW} + E_t^{DK,ROW} \tag{14}$$

$$FDI_{IN,t}^{DK} = B_t^{ROW,DK} + E_t^{ROW,DK} \tag{15}$$

Lastly, some empirical evidence suggests that FDI, through the crowding-in or crowding-out effects, can affect domestic investments. We introduce a direct channel in which FDI can increase domestic investments depending on the ratio between FDI and GDP $\frac{FDI_{OUT,t}^{DK}}{Y_t^{ROW}}$. Furthermore, domestic investments are determined by domestic investments in the previous period and total government spending as in Carnevali et al. (2021) and Thomsen (2024).

$$INV_t^{DK} = \gamma_0^{DK} + \gamma_1^{DK} INV_{t-1}^{DK} + \gamma_2^{DK} GOV_t^{DK} + \gamma_3^{DK} \frac{FDI_{IN,t}^{DK}}{Y_t^{DK}} \tag{16}$$

$$INV_t^{ROW} = \gamma_0^{ROW} + \gamma_1^{ROW} INV_{t-1}^{DK} + \gamma_2^{ROW} GOV_t^{ROW} + \gamma_3^{ROW} \frac{FDI_{OUT,t}^{DK}}{Y_t^{ROW}} \tag{17}$$

This concludes the FDI channel as suggested by the pollution haven hypothesis, where the implementation of a carbon tax in Denmark will decrease the rate of return on Danish

8. We allow for different weights on these two components where $r_{b,t}^{DK}$ is weighted by $(1-\pi_t^{DK})$ and $r_{e,t}^{DK^T}$ by $\pi_t^{DK}$.

equities, increasing demand for equities issued by ROW and decreasing demand for equities issued by Denmark; this will, in the end, affect investments through inward FDI and outward FDI. In the next section, we turn to the equations implementing the Porter hypothesis.

## 3.2 Modeling the Porter hypothesis

In this section, we present the equations representing the weak, the narrowly strong, and the strong Porter hypothesis. As we did for the pollution haven hypothesis, we provide a DAG figure in Appendix C (figure 9) (available online at https://doi.org/10.4337/ejeep.2024.0140) for a better overview of the implementation of the Porter hypothesis and how the implementation of a policy mix affects emission in ROW.

Starting with the implementation of the weak PH, this will follow the implementation provided by Thomsen (2024). First, the equation for green R&D investments is a function of total investments as well as the carbon tax paid by firms:

$$INV_{R\&D,t}^{DK} = \exp\left(\Gamma_0^{DK} + \Gamma_1^{DK} * \log\left(INV_t^{DK}\right) + \Gamma_2^{DK} * \log\left(Co2_{tax,t}^{DK}\right)\right) \tag{18}$$

From this expression, we see that an increase in firms' costs as a result of a carbon tax will increase the incentive for firms to invest in green R&D, as suggested by the weak PH.

In Denmark, the largest source of green technology falls within renewable energy (The Danish Energy Agency 2022), whereas the share of renewable energy to total energy associated with green capital is endogenized in the model ($\eta_{gr,t}^{DK}$ – in the rest of the paper, this is referred to as the renewability share).[9] Improvements in the renewability share of green capital ($\eta_{impv,t}^{DK}$) is assumed to be a function of the lagged total R&D expenditures in the economy ($GOV_{R\&D_{t-1}}^{DK} + INV_{R\&D_{t-1}}^{DK}$).[10]

$$\eta_{impv,t}^{DK} = \exp\left(impv_0^{DK} + impv_1^{DK} * \log\left(GOV_{R\&D_{t-1}}^{DK} + INV_{R\&D_{t-1}}^{DK}\right)\right) \tag{19}$$

This allows us to calculate the renewability share of green capital as a function of last year's renewability share added by improvements:

$$\eta_{gr,t}^{DK} = \eta_{gr_{t-1}}^{DK} + \eta_{impv,t}^{DK} \tag{20}$$

A change in the renewability share of green capital does not mean that the existing green capital will be automatically updated since the new renewability share only affects the production of green capital from now on. To estimate the average renewability, share of green capital, we create a moving average, where we assume parts of the already existing green capital $(1 - imp_{DK})$ to be updated. Focusing on the first term in the equation below, we observe how new green capital ($K_{NEWgr,t}^{DK}$) is updated using the renewability share in the

9. We assume that the share of renewable energy to total energy for green capital can exceed 100 percent, 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 percent.
10. We add together the government's and firms' R&D spending as we assume these to have similar effects on green technology. We do admit that this assumption is a rather strong one, but since we are mainly focusing on the effect of R&D spending and not the effect from each sector, we use this assumption for simplicity.

current period ($\eta^{DK}_{gr,t}$).[11] In the second term, the share of the already existing green capital that will not be updated will have the average renewability share of the previous period ($\eta^{DK}_{AVGgr_{t-1}}$). Last, the share of the already existing green capital, which we assume will be updated, has the renewability share of the current period ($\eta^{DK}_{gr,t}$). From this equation, we obtain a new average renewability share for the total stock of green capital ($\eta^{DK}_{AVGgr,t}$).

$$\eta^{DK}_{AVGgr,t} = \left(\frac{K^{DK}_{NEWgr,t}}{K^{DK}_{gr,t}}\right) * \eta^{DK}_{gr,t} + imp_{DK} * \left(\frac{K^{DK}_{gr,t} - K^{DK}_{NEWgr,t}}{K^{DK}_{gr,t}}\right) * \eta^{DK}_{AVGgr_{t-1}} + \left(1 - imp_{DK}\right) * \left(\frac{K^{DK}_{gr,t} - K^{DK}_{NEWgr,t}}{K^{DK}_{gr,t}}\right) * \eta^{DK}_{gr,t} \tag{21}$$

A similar moving average equation is made for imported green capital in Denmark. However, we do not allow for the already existing imported green capital to be updated when the producing country improves the renewability share.[12] The equation for the renewability share of imported green capital ($\eta^{DK}_{AVGgrim,t}$) can be seen below, where we now use the renewability share of green capital in ROW ($\eta^{ROW}_{gr,t}$) in the moving average equation.

$$\eta^{DK}_{AVGgrim,t} = \left(\frac{K^{DK}_{NEWgrim,t}}{K^{DK}_{grim,t}}\right) * \eta^{ROW}_{gr,t} + \left(\frac{K^{DK}_{grim,t} - K^{DK}_{NEWgrim,t}}{K^{DK}_{grim,t}}\right) * \eta^{DK}_{AVGgrim,t} \tag{22}$$

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

$$\eta_{DK,t} = \eta^{DK}_{AVGgr,t} * \frac{K^{DK}_{gr,t}}{K^{DK}_{t}} + \eta^{DK}_{AVGgrim,t} * \frac{K^{DK}_{grim,t}}{K^{DK}_{t}} + \eta^{DK}_{con,t} * \frac{K^{DK}_{con,t}}{K^{DK}_{t}} \tag{23}$$

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, and second, increasing the renewability share of green capital exported by Denmark.[13]

We now start the implementation of the narrowly strong PH, mainly following the work of Thomsen (2024) but with a few additions. As we implement the narrowly strong PH, green technological development (measured by the renewability share) should improve the country-level competitiveness of Danish green firms (measured by green exports). To start

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

12. 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 (available online at https://doi.org/10.4337/ejeep.2024.0140), relaxing this assumption does not change the conclusions of this paper.

13. Which is the same as increasing the renewability share of green capital imported by ROW.

off, we introduce a link between green exports and the renewability share of newly produced green capital, as shown below[14]:

$$\log(X_{gr,t}^{DK}) = \Omega_0^X + \Omega_1^X * \log\left(Y_t^{DK}\right) + \Omega_2^X * \log\left(\eta_{gr,t}^{DK}\right) + \Omega_3^X * \log\left(\frac{P_{s,t-1}^{DK}}{P_{s,t-1}^{ROW}}\right) \tag{24}$$

Compared to the equation used in Thomsen (2024), GDP and the relative price level now also affect green exports. Thereby, the equation for green exports uses the same determinants as the equation for the total exports function but uses different parameter values (presented in Section 4).

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 from Denmark. Last, the equations representing the strong Porter hypothesis have already been introduced in the form of the export and import equations (equations (4) and (5)), where $eps_2$ and $mu_2$ indicate a relationship between green technological development in the form of the renewability share of green capital ($\eta_{gr}^{DK}$ and $\eta_{gr}^{ROW}$), and total exports and imports of Denmark.

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

## 4 CALIBRATION AND VALIDATION OF THE MODEL

In this section, we cover the calibration of parameter values with the aims of (i) matching the empirical evidence presented in Section 2 for the pollution haven and Porter hypothesis; and (ii) matching key variables for the two areas (Denmark and ROW) such as GDP, consumption, and government spending with real data.[15] We create three different baseline models, each including different effects in line with the pollution haven and Porter hypotheses. As a result, the three baseline models will include slightly different parameter values.

### 4.1 The calibration strategy

We use real data for both Denmark and ROW to create realistic parameters and starting values in the sense that they replicate the observed trends of relevant variables for the two areas. Additionally, we include differences in parameters like the tax rate, rate of consumption, $CO_2$ intensity, and energy intensity between the two areas to make the model as realistic as possible. To create a starting point for the three models, we calibrate each model

14. 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 (for example, Bosetti et al. (2008).

15. All parameter values will be presented in Appendix B (available online at https://doi.org/10.4337/ejeep.2024.0140).

in the period 1960–2017 using a small databank consisting of central macroeconomic and environmental variables. After 2017, the model is simulated and does not require any data.

The parameters used for the underlying channels of the pollution haven and Porter hypotheses are based on the empirical findings presented in Section 2. Furthermore, we also calibrate parameters to match real data for important variables like the FDI to GDP ratio, the green exports to total exports ratio, and the share of renewable energy to total energy ratio.

#### *4.1.1 Weak Porter hypothesis*

Starting with the parameters for the weak PH, we look at the relationship between the carbon tax (which we will introduce later) and firms' investments in green R&D ($\Gamma_2^{DK}$)[16]; to set this parameter, we use the empirical evidence presented by Jaffe/Palmer (1997), finding a coefficient of 0.15. This implies that a 1% increase in the costs associated with the carbon tax would increase green R&D spending by 0.15%.[17]

For the relationship between green R&D spending and the improvements in 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. Additionally, we set important initial and parameter values determining how R&D spending affects the renewability share of green capital in Denmark so that the growth rate of the renewability share matches the observed data.[18]

#### *4.1.2 Narrowly strong Porter hypothesis*

Here, we set the parameter determining how the renewability share of green capital affects green exports ($\Omega_2^X$) 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 that reducing $CO_2$ intensity by 1% increases green exports by 0.46%.[19] Other important parameters affecting green exports are calibrated so that green exports are approximately 8% of the total exports in 2021, matching the share presented by The Danish Energy Agency (2022).

#### *4.1.3 Strong Porter hypothesis*

When introducing the strong Porter hypothesis, we create a link between the renewability share and total exports. We use the empirical evidence presented by Costantini/Mazzanti

16. The weak PH is also active in the rest of the world through the parameter $\Gamma_2^{ROW}$, but this parameter will play no role, as ROW does not implement a carbon tax.
17. 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 (available online at https://doi.org/10.4337/ejeep.2024.0140).
18. Using data on the renewability share for Denmark and the EU from Eurostat starting from 2004 up until 2021.
19. 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 (available online at https://doi.org/10.4337/ejeep.2024.0140), setting the parameter to 0.22, which also matches the range found by Costantini/Mazzanti (2012).

(2012) who find a significant positive relationship between environmental regulations (using different proxy variables) and total exports. The estimates found using technological development, as utilized in this paper, lies around 0.05–0.27 for different degrees of technological advancement for the firms analyzed. Most estimates lie around 0.1, whereas we will use this estimate in the export and import function ($eps_2$ and $mu_2$).

### *4.1.4 The price channel*

The most central parameters for the price channel are the ones relating price changes in Denmark and ROW to changes in Danish exports and imports. We use the coefficients estimated by Byrialsen/Raza (2020) relating the relative price level between Denmark and ROW to Danish exports and imports in an empirical stock–flow consistent macroeconomic model. Using their estimations, we set $eps_3 = -0.47$ and $mu_3 = 0.09$. Using these coefficients for the analysis in Section 5, we find that a 4% increase in the relative price ratio ($P_{s,t}^{DK}/P_{s,t}^{ROW}$) decreases net exports by 2.5% (elasticity of 0.625), close to the elasticity of 0.6 presented by Levinson/Taylor (2008) using the PACE index in Section 2.

### *4.1.5 The FDI channel*

For the FDI channel, we calibrate the Tobin's portfolio allocation theory parameters presented in equations (6)–(9), so that inward FDI and outward FDI for Denmark as a percentage of GDP matches the observed data presented by the central bank of Denmark. Lastly, we use the empirical findings presented in Section 2, showing that the effect of FDI on investments is mainly found in developing countries, whereas we only introduce a relationship between outward FDI in Denmark and investments in ROW (setting $\gamma_3^{DK} = 0$). As we only have two areas in the model, outward FDI for Denmark is equal to inward FDI for ROW. This also means that using the elasticities found for specific countries in the empirical literature does not make sense, as the percentage change in inward FDI received by ROW will appear large because Denmark is its only counterpart. Instead, we assume that a 1 unit increase in inward FDI toward ROW as a ratio of GDP in ROW increases domestic investments in ROW by 1 dollar, thereby setting $\gamma_3^{ROW} = 1$. [20]

Besides the parameter values presented above, the remaining parameter values are set to reproduce the trends observed for Denmark and ROW, as shown in the next section when performing the validation.

## 4.2 Validation of the three baseline models

Before presenting the validation, we will provide an overview of the three different baseline models used in this paper.

*Baseline 1* represents the Porter hypothesis case, in which only the channels of the weak, the narrowly strong, and the strong Porter hypotheses will be active.

*Baseline 2* represents the pollution haven hypothesis case, in which only the price channel and the FDI channel are activated.

*Baseline 3* will include all channels, which we argue to be a more realistic case, where both the Porter and pollution haven hypotheses are active.

20. As the analysis is performed in Section 5, we find the effects of the FDI channel to be minimal with investments in ROW increasing by US$ 42,028,467 more at the end of the simulation (year 2060) when this channel is activated and the shock is introduced, compared to not including this channel when introducing the shock.

 

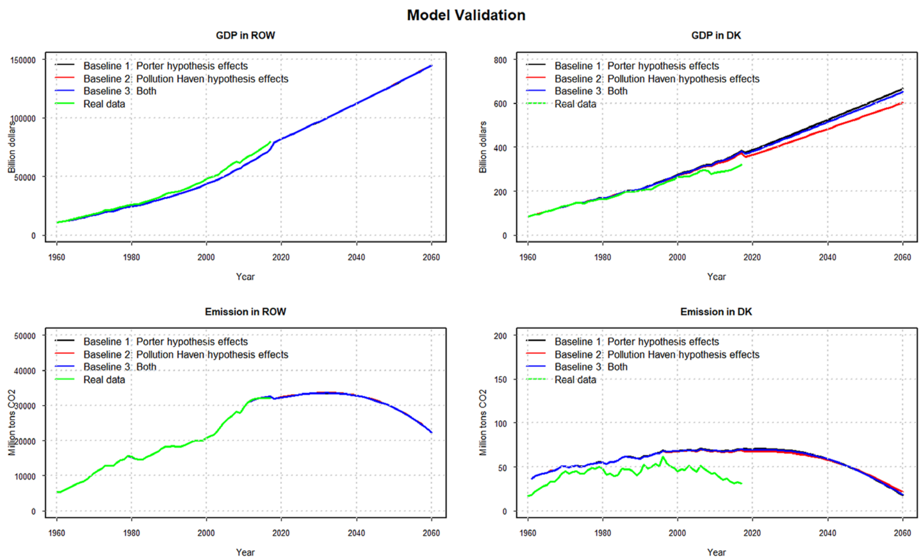


*Figure 2 Validation of the three baselines using GDP and emission for Denmark and the rest of the world*

We now turn to the validation of these 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, with a slightly undershooting of GDP in ROW and a slightly overshooting of GDP in Denmark. Also, we observe different trends in the three baseline models for Danish GDP after 2017, this is mainly a result of the Price channel as well as the strong PH channel affecting net exports. Looking at emission, the model matches data up until 2017 for the ROW, while we observe an overshoot in the Danish emission, especially from 2000 to 2017, with the main reason being that all other measures than the renewability share and $CO_2$ intensity are held fixed over time.[21] 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.[22] Overall, we can validate the three baseline models as they seem to be capable of matching the trends observed in the data (Figure 2).[23]

21. 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.
22. The increasing share of green capital is a result of an exogenously set growth rate of firms' green investments ($INV_{gr}^{DK}, INV_{gr}^{ROW}$). However, 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 $CO_2$ intensity of green capital ($\beta_{gr}^{DK}, \beta_{gr}^{ROW}$).
23. In cases where there is little to no difference between the three baseline models, the lines representing each model lie on top of each other.

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 channels are activated in the model. The focus of the analysis will be on international trade and changes in emission both within Denmark and the rest of the world; the latter will allow us to calculate the carbon leakage rates for each of the three models in Section 6.

## 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 net exports (as a measure of competitiveness) and emission, as we introduce the policy mix in the Danish economy.

### 5.1 The policy mix

As in Thomsen (2024), we use the political agreement recently presented by the Danish Parliament (2022) setting the carbon tax to US$ 50 in 2025, with increments of US$ 12 each year until 2030; after which the tax rate is held fixed at US$ 110 (per ton $CO_2$). Additionally, we allow the government to recycle the revenue from the carbon tax to spur innovation, as suggested by the Porter hypothesis (Ambec et al., 2013). The policy mix will have three important effects: (i) increase firms' costs associated with emission through a carbon tax; (ii) increase mission-oriented government spending (MOIS) through recycling of the carbon tax revenue; and (iii) increase government spending toward 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 the three different baseline models. We will refer to the implementation of the policy mix in Baseline model 1 as Scenario 1, Baseline model 2 as Scenario 2, and Baseline model 3 as Scenario 3.

### 5.2 The effect on international trade

To analyze the effect of implementing the policy mix on competitiveness, we plot the percentage change in Danish exports, imports, net exports, and GDP from the baseline model (Figure 3).

Starting with Scenario 1 (the Porter hypothesis model), we observe an increase in exports, associated with the inclusion of the strong PH channel, while imports also increase as a result of an increase in Danish GDP.[24] The immediate effect on the net export is negative, with a drop of approximately 1% as the shock is introduced. Still, as the innovational process gets time to kick in, the effect turns positive in 2040, which is also in line with the PH framework.

24. The increase in Danish GDP is a result of recycling the carbon tax in the form of government spending. The downward trend observed in the change of GDP is because of the downward trend in government spending, as emission is lowered over time, the recycling of the carbon tax also lowers, thereby lowering government spending.

 

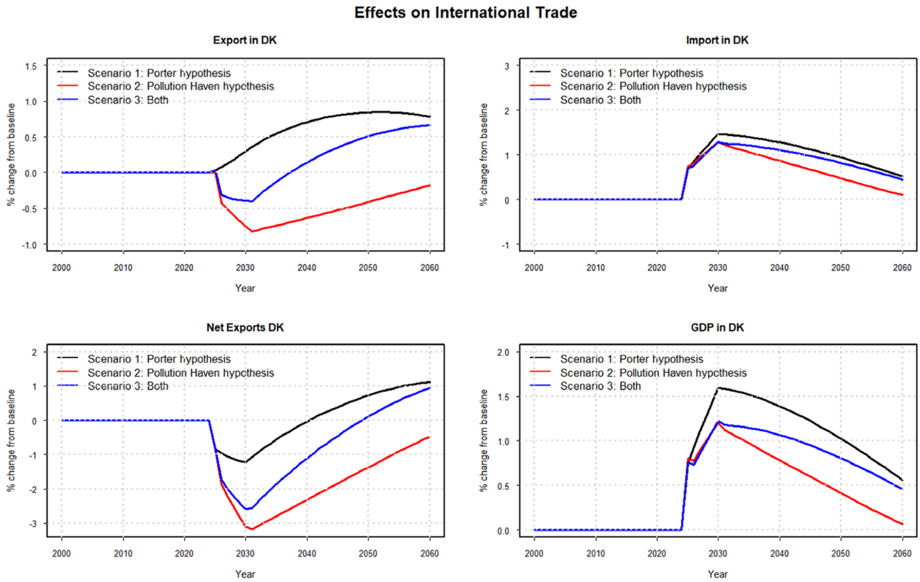


*Figure 3 Effect on measures of international trade: exports, imports, net exports, and GDP*

In Scenario 2 (the pollution haven hypothesis model), exports decrease as a result of the price channel while imports increase not only as a result of the price channel but also mainly as a result of the Danish GDP increasing. The effect on net exports is negative through all of the simulation period, still the drop is diminishing over time. The immediate negative effect on net exports is in line with the pollution haven hypothesis, while the diminishing negative effect should be attributed to the lowering of government spending over time, which then reduces the magnitude of the increase in Danish GDP. The lowering of government spending over time is a result of emission falling, which then lowers the revenue from the carbon tax.[25] Furthermore, the lower emission also reduces unit costs for firms as the carbon tax is reduced, thereby lowering exports and imports over time through the mechanics of the price channel.

Finally, in Scenario 3 (including both the Porter hypothesis and the pollution haven hypothesis), we see an immediate drop in exports related to the price channel, followed by an increase associated with the strong PH channel. As a result, the effect on exports turns positive in 2037, as the effects of the strong PH outweigh the effects of the price channel. The magnitude of the increase is accelerated by the effect explained above, where the lower emission reduces firms' costs, lowering prices toward the initial level. The immediate effect on imports is the same as in Scenario 2, while the effect over time seems to be higher relative to Scenario 2. Danish imports mainly follow the development of Danish GDP, whereas the difference between Scenarios 2 and 3 over time can be attributed to the strong PH increasing Danish exports and thereby GDP.[26] The final result observed on the net

25. This effect is also active in the two other scenarios.
26. The effect of the price channel on imports is in all three models outweighed by the increase in Danish GDP; this is expected as the parameters used in this paper and estimated by Byrialsen/Raza

exports is an immediate drop (as exports fall and imports increase), whereafter the effect turns positive around the year 2050, mainly because the change in exports turns positive over time.

To summarize the effect of implementing the policy mix in Denmark on competitiveness, we obtain results in line with both the Porter and pollution haven hypotheses in Scenarios 1 and 2. Scenario 3 confirms the empirical findings presented in Section 2, where a majority of studies looking at the immediate effects find the pollution haven hypothesis to be the strongest, while the strong Porter hypothesis seems to be favored in a dynamic set-up where innovations are allowed time to kick in. The implementation of a policy mix like the one adopted in this paper seems to increase competitiveness in the long run due to the effects of the Porter hypothesis outweighing the pollution haven hypothesis. Despite this result, some politicians still argue against environmental regulations based on research only accounting for the effects of the pollution haven hypothesis, arguing that it carries a loss in competitiveness. Furthermore, the loss of competitiveness is often associated with carbon leakage and is supported by the literature finding high leakage rates for a small open economy like Denmark in the range of 20–90% (Copenhagen Economics 2011; DØRS 2019; Beck et al. 2023). In the next section, we shift the focus away from competitiveness alone, to also consider the environmental aspects by looking at the change in emission in Denmark and ROW.

## 5.3 The effect on emissions

In this model, emission is affected in two ways: (i) through changes in output and (ii) through changes in the renewability share of the capital stock. First, we show the change in GDP for Denmark and ROW in Figure 4.

In Scenario 1, we observe an increase in GDP for both Denmark and ROW. The increase in Danish GDP is first of all a result of not only recycling the carbon tax through government spending but also the introduction of the strong PH increasing net exports due to the higher technological progression in Denmark (which we will show later). In ROW, the immediate increase in GDP is a result of the initial increase in Danish GDP crowded out by increased Danish imports. However, the change in GDP turns negative, because of the strong PH increasing Danish exports over time, which by accounting results in a similar increase in imports by ROW. In Scenarios 2 and 3, the immediate increase in Danish GDP is lower compared to Scenario 1 as the price channel is introduced lowering Danish exports and increasing Danish imports as prices increase due to higher unit costs in Denmark. However, the effect on GDP for ROW is higher for Scenarios 2 and 3 relative to Scenario 1 as a result of not only the price channel just described but also the FDI channel, in which investments increase in ROW as outward FDI in Denmark increases.[27] The main difference between scenarios 2 and 3 lies in the inclusion of the strong PH (included in Scenario 3) increasing Danish net exports, thereby increasing Danish GDP while decreasing GDP in ROW over time relative to Scenario 2 (Figure 5).

In the renewability share of the capital stock, the effect is close to identical for Scenarios 1 and 3 for both Denmark and ROW. Still, it might come as a surprise that the average renewability share in ROW increases by a larger magnitude in Scenario 3 compared to

(2020) find the effect of relative price changes between Denmark and ROW to have a much lower effect on imports compared to exports.

27. Outward FDI in Denmark increase as the level of return on equities in Denmark is lowered by the carbon tax.

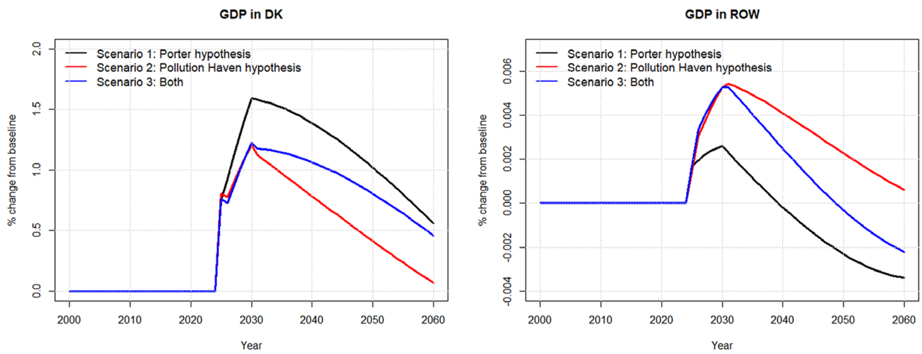


*Figure 4 Changes in GDP when implementing the policy mix within each of the three baseline models.*

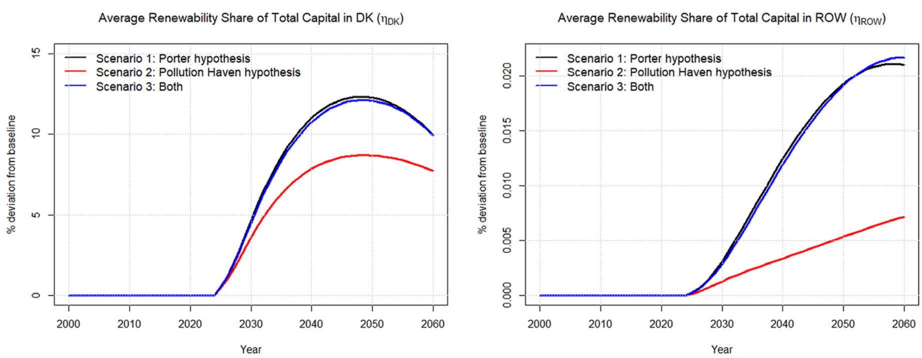


*Figure 5 Changes in the renewability share of the capital stock when implementing the policy mix within the three baseline models*

Scenario 1. The explanation goes through the inclusion of the price channel in Scenario 3, which first lowers the amount of green exports going from Denmark to ROW. But as emission starts falling, so do the carbon taxes paid by firms, which lead firms to reduce prices. This decrease in prices will again increase exports 'faster' than in Scenario 1 (but from a lower level) as shown in Figure 5, where export starts increasing 'later' and more rapidly in Scenario 3. As a result, the renewability share of Danish green capital will reach a higher renewability share before exports (and also green exports) start to increase, enhancing the effect on the average renewability share in ROW through green imports, as shown at the end of the simulation period above.

Finally, in Scenario 2, none of the effects suggested by the Porter hypothesis are active, still the Danish Government uses some of the tax revenue to invest in public green R&D. This increases the renewability share of the green capital stock in Denmark, thus affecting the renewability share in ROW through Danish green exports.

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 toward the change in emission shown in the plot (Figure 6).

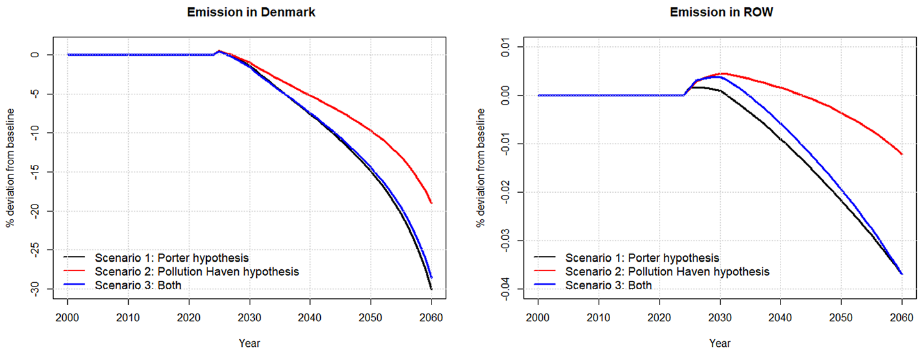


*Figure 6 Changes in emission when implementing the policy mix within the three baseline models*

The differences between the three scenarios are solely due to differences in the output and renewability share of the capital stock. For emission in Denmark, we see a small increase in all scenarios immediately after the implementation of the policy mix due to the increase in output (known as the rebound effect). Still, as we allow time for the innovational process, the renewability share improves and lowers emission in all three scenarios. The largest effect is found for scenario 1 in which Danish emission drops by 30% in 2060.

For emission in ROW, the immediate increase in output has a larger relative effect on emission compared to that in Denmark. [28] As the output increases by different magnitudes for the three scenarios so does the immediate increase in emission. Over time the effect of the renewability share lowers emission in Scenarios 1 and 3 substantially (as a result of the Porter hypothesis) leaving emission to drop by 0.038% in 2060 for ROW in both scenarios. In Scenario 2, the fall in emission is 0.011% in the year 2060 and thereby much lower relative to Scenarios 1 and 3.

Furthermore, we can utilize the SFC framework to see who is financing the drop in emission within the three scenarios. From figure 10 in Appendix C (available online at https://doi.org/10.4337/ejeep.2024.0140), we plot the development of financial variables for Denmark in the form of bonds supplied by the government, the stock of wealth for wage receivers, loans made by firms, and the stock of wealth for capital owners. The main pattern in all three scenarios is that the stock of wealth for wage receivers increases while the stock of wealth for capital owners decreases. This is mainly a result of re-using the carbon taxes (reducing firms' profits and thereby also the profits received by capital owners) stimulating the economy through higher government spending. As firms not only experience lower profits but also increase investments, especially in Scenarios 1 and 3, in which the Porter hypothesis is active, the loans made by firms increase.

In the next section, we will use the change in emission to calculate the leakage rate associated with each of the three scenarios and discuss the importance of not only comparing the Porter hypotheses and the pollution haven hypothesis with a focus on competitiveness alone but also within the area of carbon leakage rates.

28. The larger relative effect of the change in output on emission in ROW is a result of the rather small increase in the renewability share in ROW relative to Denmark, as only the imported capital is associated with the improved renewability share which is a very small part of the total capital stock in ROW.

## 6 CALCULATION OF CARBON LEAKAGE

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, and (v) leakage through international trade.[29]

According to DØRS (2019), the importance of carbon leakage through the international trade channel rises with the degree of economic openness. Therefore this channel is especially important for a small open economy like Denmark. 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.

In this paper, we also only include the channel of international trade, but include both the effects associated with the pollution haven and Porter hypothesis. When calculating the leakage rate, we use the equation presented below with $L_R$ being the leakage rate, $\Delta E_{ROW}$ being the change in emission for ROW, and $\Delta E_{DK}$ being the change in emission for Denmark, all as a result of implementing the policy mix within Denmark.

$$L_R = -\frac{\Delta E_{ROW}}{\Delta E_{DK}} \tag{25}$$

Utilizing the dynamic set-up of SFC models, we show how the leakage rates develop over time presented in Figure 7. Additionally, we present the cumulative change in emission for Denmark, ROW, and the World (measured in million tons $CO_2$), the first two are used as inputs in the leakage rate equation. We start the plot in 2030, where the carbon tax is fully phased in and fixed at US\$ 110 (per ton $CO_2$).

The dynamic leakage rate for each scenario is shown in the bottom-right plot; in Scenario 2, where only the pollution haven hypothesis is active, the leakage rate is mainly positive. It is falling over time as a part of the carbon tax in Denmark is recycled into public R&D spending, increasing the renewability share of green capital in Denmark, which is then exported to ROW.[30] As no surprise, the leakage rate in Scenario 1 is much lower compared to Scenario 2. This is a result of including the Porter hypothesis, which not only improves the magnitude but also the 'greenness' of Danish international trade (as a result of the weak and the narrowly strong PH). When including both the Porter and pollution haven hypotheses in Scenario 3, we obtain a leakage rate in between the two previous scenarios. Here, we obtain a leakage rate of around 1 in 2030, but over time it drops below 0 and reaches –0.8 in the last period of simulation.[31]

29. See DØRS (2019) for a further explanation of these five channels of leakage.

30. In most analyses of the leakage rate, parts of the carbon tax revenue are not used for public R&D spending like in this paper, whereas this might put a downward bias on the leakage rate if such a policy mix is not introduced. As a result, the leakage rate turns negative even though none of the effects presented by the pollution haven hypothesis should leave one to expect a negative leakage rate.

31. Negative leakage rates are also found by Gerlagh/Kuik (2014), who allow for a channel of technological spillovers in a two-area CGE analysis.

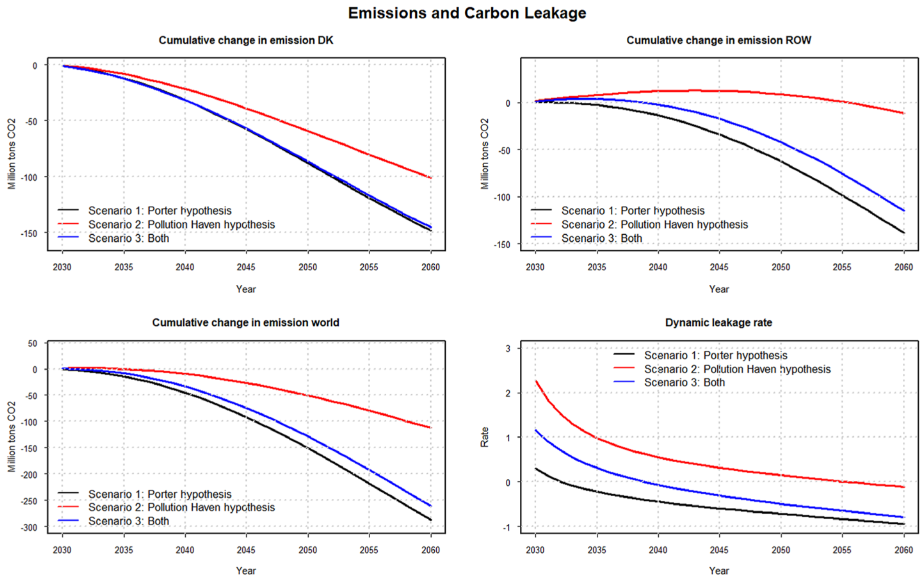


*Figure 7 Accumulative change in emission for Denmark, ROW, and the World (million tons $CO_2$), and the associated carbon leakage rates when implementing the policy mix within the three baseline models*

From a policy perspective, this result is of great importance as the fear of negative effects on competitiveness as well as high carbon leakage rates has been used as an argument against climate regulations. This paper suggests that this fear might be based on deficient calculations, where empirically validated effects of the Porter hypothesis are excluded, leading to an upward bias in the carbon leakage. Even though the results of this paper should be interpreted with uncertainty, it contributes to the inclusion of technological development in the carbon leakage literature where these aspects have often been left out (Beck et al. 2023).

## 7 CONCLUSION

The pollution haven hypothesis and the Porter hypothesis have been empirically tested several times when evaluating environmental regulations and their effect on competitiveness. Still, the empirical evidence for which of these two opposing hypotheses we should believe in seems inconclusive. In this paper, we utilize a two-area stock-flow consistent model to compare the two competing hypotheses and their underlying effects. In contrast to previous literature, we focus on both competitiveness and carbon leakage. Our results back up the empirical findings that the immediate effect of environmental regulations might worsen competitiveness, but as the innovational process is allowed time to kick in, competitiveness is improved by these regulations. More importantly, our results indicate that current calculations of carbon leakage rates are upward biased when only the pollution haven hypothesis is accounted for. We find that including the effects of the pollution haven hypothesis together with the Porter hypothesis result in negative leakage rates over time. These findings suggest that small open economies can introduce more strict environmental regulations, in the form of flexible and market-based regulations supported by the Porter hypothesis, without losing competitiveness. We find such a regulation to not only reduce national emission but also emission internationally through the channels of green exports, leaving an overall reduction in world emission, which should be the ultimate goal when implementing environmental regulations.

## REFERENCES

Agosin, M.R., Machado, R. (2005): Foreign investment in developing countries: does it crowd in domestic investment?, in: *Oxford Development Studies*, 33(2), 149–162.

Aldy, J.E., Pizer, W.A. (2015): The competitiveness impacts of climate change mitigation policies, in: *Journal of the Association of Environmental and Resource Economists*, 2(4), 565–595.

Al-Sadig, A. (2013): The effects of foreign direct investment on private domestic investment: evidence from developing countries, in: *Empirical Economics*, 44(3), 1267–1275.

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

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

Bäckström, K., Lundmark, R., Söderholm, P. (2014): Public policies and solar PV innovation: an empirical study based on patent data, 37th IAEE International Conference.

Beck, U.R., Kruse-Andersen, P.K., Stewart, L.B. (2023): Carbon leakage in a small open economy: the importance of international climate policies, in: *Energy Economics*, 117, 106447.

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

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

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

Byrialsen, M., Raza, H. (2020): An empirical stock-flow consistent macroeconomic model for Denmark, Levy Economics Institute, Working Papers Series.

Carnevali, E., Deleidi, M., Pariboni, R. (2019): Stock–flow consistent dynamic models: features, limitations and developments, in: Arestis, P., Sawyer, M. (eds) *Frontiers of Heterodox Macroeconomics*, London: Palgrave Macmillan, doi: https://doi.org/10.1007/978-3-030-23929-9

Carnevali, E., Deleidi, M., Pariboni, R., Veronese Passarella, M. (2021): Cross-border financial flows and global warming in a two-area ecological SFC model, in: *Socio-Economic Planning Sciences*, 75, 100819, doi: https://doi.org/10.1016/j.seps.2020.100819.

Cohen, M.A., Tubb, A. (2017): The impact of environmental regulation on firm and country competitiveness: a meta-analysis of the Porter hypothesis, Paper Knowledge. Toward a Media History of Documents, 12–26.

Copeland, B.R. (2008): The pollution haven hypothesis, in: Gallagher, K.P. (ed), *Handbook on Trade and the Environment*, Cheltenham, UK and Northampton, MA: Edward Elgar Publishing.

Copeland, B.R., Shapiro, J.S., Taylor, M.S. (2021): Globalization and the Environment, NBER Working Papers 28797, National Bureau of Economic Research, Inc.

Copeland, B.R., Taylor, M.S. (1994): North–south trade and the environment, in: *The Quarterly Journal of Economics*, 109(3), 755–787, doi: https://doi.org/10.2307/2118421.

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

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

Danish Parliament. Government of Denmark, Venstre, Socialistisk Folkeparti, Radikale Venstre, & Det Konservative Folkeparti. (2022): Aftale om grøn skattereform for industri mv. [Agreement on green tax reform for industry, etc.]. URL: https://ens.dk/en/our-responsibilities/ccs-carbon-capture-and-storage/political-agreements-and-applicable-legislation (accessed 9 September 2024).

Dean, J.M., Lovely, M.E., Wang, H. (2009): Are foreign investors attracted to weak environmental regulations? Evaluating the evidence from China, in: *Journal of Development Economics*, 90(1), 1–13.

Dechezleprêtre, A., Sato, M. (2017): The impacts of environmental regulations on competitiveness, in: *Review of Environmental Economics and Policy*, 11(2), 183–206.

DØRS. (2019): Økonomi og miljø 2019. URL: https://dors.dk/vismandsrapporter/oekonomi-miljoe-2019 (accessed 20 April 2023).

Ederington, J., Minier, J. (2003): Is environmental policy a secondary trade barrier? An empirical analysis, in: *Canadian Journal of Economics/Revue canadienne d'économique*, 36(1), 137–154.

Ederington, J., Levinson, A., Minier, J. (2005): Footloose and pollution-free, in: *Review of Economics and Statistics*, 87(1), 92–99.

Eskeland, G.S., Harrison, A.E. (2003): Moving to greener pastures? Multinationals and the pollution haven hypothesis, in: *Journal of Development Economics*, 70(1), 1–23.

Fredriksson, P.G., List, J.A., Millimet, D.L. (2003): Bureaucratic corruption, environmental policy and inbound US FDI: theory and evidence. in: *Journal of Public Economics*, 87(7–8), 1407–1430.

Gerlagh, R., Kuik, O. (2014): Spill or leak? Carbon leakage with international technology spillovers: a CGE analysis, in: *Energy Economics*, 45, 381–388.

Godley, W., Lavoie, M. (2016): *Monetary Economics: An Integrated Approach to Credit, Money, Income, Production and Wealth*, London: Palgrave Macmillan.

Hanna, R. (2010): US environmental regulation and FDI: evidence from a panel of US-based multinational firms, in: *American Economic Journal: Applied Economics*, 2(3), 158–189.

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

Hwang, J.A., Kim, Y. (2017): Effects of environmental regulations on trade flow in manufacturing sectors: comparison of static and dynamic effects of environmental regulations, in: *Business Strategy and the Environment*, 26(5), 688–706, doi: https://doi.org/10.1002/bse.1965.

Jaffe, A.B., Palmer, K. (1997): Environmental regulation and innovation: a panel data study, in: *The MIT Press*, 79(4), 610–619, doi: https://www.jstor.org/stable/2951413.

Jeppesen, T., List, J.A., Folmer, H. (2002): Environmental regulations and new plant location decisions: evidence from a meta-analysis, in: *Journal of Regional Science*, 42(1), 19–49.

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

Kellenberg, D.K. (2009): An empirical investigation of the pollution haven effect with strategic environment and trade policy, in: *Journal of International Economics*, 78(2), 242–255.

Keller, W., Levinson, A. (2002): Pollution abatement costs and foreign direct investment inflows to US states, in: *Review of Economics and Statistics*, 84(4), 691–703.

Kheder, S.B., Zugravu, N. (2012): Environmental regulation and French firms location abroad: an economic geography model in an international comparative study, in: *Ecological Economics*, 77, 48–61.

Kim, K., Heo, E., Kim, Y. (2017): Dynamic policy impacts on a technological-change system of renewable energy: an empirical analysis, in: *Environmental and Resource Economics*, 66(2), 205–236, doi: https://doi.org/10.1007/s10640-015-9946-5.

Lanjouw, J.O., Mody, A. (1996): Innovation and the international diffusion of environmentally responsive technology, in: *Research Policy*, 25(4), 549–571, doi: https://doi.org/10.1016/0048-7333(95)00853-5.

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

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

Levinson, A. (2010): Offshoring pollution: is the US increasingly importing pollution intensive production?, in: *Review of Environmental Economics and Policy*, 4(1), 63–83.

Levinson, A., Taylor, M.S. (2008): Unmasking the pollution haven effect, in: *International Economic Review*, 49(1), 223–254.

List, J.A., Millimet, D.L., Fredriksson, P.G., McHone, W.W. (2003): Effects of environmental regulations on manufacturing plant births: evidence from a propensity score matching estimator, in: *Review of Economics and Statistics*, 85(4), 944–952.

List, J.A., McHone, W.W., Millimet, D.L. (2004): Effects of environmental regulation on foreign and domestic plant births: is there a home field advantage?, in: *Journal of Urban Economics*, 56(2), 303–326.

Manderson, E., Kneller, R. (2012): Environmental regulations, outward FDI and heterogeneous firms: are countries used as pollution havens?, in: *Environmental and Resource Economics*, 51(3), 317–352.

Millimet, D.L., Roy, J. (2016): Empirical tests of the pollution haven hypothesis when environmental regulation is endogenous, in: *Journal of Applied Econometrics*, 31(4), 652–677.

Mišun, J., Tomšík, V. (2002): Foreign direct investment in central Europe – does it crowd in domestic investment?, in: *Prague Economic Papers*, 11(1), 57–66.

Moran, T.H., Graham, E.M., Blomström, M. (2005): Conclusions and implications for FDI policy in developing countries, new methods of research, and a future research agenda, in: Moran, T.H., Graham, E.M., and Blomstrom, M. (eds), *Does Foreign Direct Investment Promote Development*, Washington, DC: PIIE, 375–395.

Nicolli, F., Vona, F. (2016): Heterogeneous policies, heterogeneous technologies: the case of renewable energy, in: *Energy Economics*, 56, 190–204, doi: https://doi.org/10.1016/j.eneco.2016.03.007.

Nikiforos, M., Zezza, G. (2017): Stock–flow consistent macroeconomic models: a survey, in: *Journal of Economic Surveys*, 31(5), 1204–1239, doi: https://doi.org/10.1111/joes.12221.

Pilbeam, K., Oboleviciute, N. (2012): Does foreign direct investment crowd in or crowd out domestic investment? Evidence from the European Union, in: *The Journal of Economic Asymmetries*, 9(1), 89–104.

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

Popp, D. (2006): International innovation and diffusion of air pollution control technologies: The effects of $NO_X$ and $SO_2$ regulation in the US, Japan, and Germany, in: *Journal of Environmental Economics and Management*, 51(1), 46–71, doi: https://doi.org/10.1016/j.jeem.2005.04.006.

Porter, M.E., Van Der Linde, C. (1995): Toward a new conception of the environment-competitiveness relationship, in: *Journal of Economic Perspectives*, 9(4), 97–118, doi: https://doi.org/10.1257/jep.9.4.97.

Raspiller, S., Riedinger, N. (2008): Do environmental regulations influence the location behavior of French firms?, in: *Land Economics*, 84(3), 382–395.

Sato, M., Dechezleprêtre, A. (2015): Asymmetric industrial energy prices and international trade, in: *Energy Economics*, 52, S130–S141.

The Danish Energy Agency. (2022): Global Afrapportering 2022. 13–13, URL: http://www.ens.dk (accessed 16 June 2023).

Thomsen, S.F. (2024): The porter hypothesis in a two-area ecological stock flow consistent model – should political decision making rely on current calculations of leakage rates?, Macroeconomic Methodology, Theory and Economic Policy (MaMTEP) Working Paper Series.

Truong, T.P., Kemfert, C., Burniaux, J.-M. (2007): GTAP-E: an energy-environmental version of the GTAP Model with emission trading, in: *Lancet Neurology*, 6(5), 394, doi: https://doi.org/10.1016/S1474-4422(07)70100-X.

Wagner, U.J., Timmins, C.D. (2009): Agglomeration effects in foreign direct investment and the pollution haven hypothesis, in: *Environmental and Resource Economics*, 43(2), 231–256.
Wang, M. (2010): Foreign direct investment and domestic investment in the host country: evidence from panel study, in: *Applied Economics*, 42(29), 3711–3721.
Xing, Y., Kolstad, C.D. (2002): Do lax environmental regulations attract foreign investment?, in: *Environmental and Resource Economics*, 21(1), 1–22.