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Trade-off or tension: Can carbon be priced without risking economic competitiveness?

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Abstract: While reducing industrial greenhouse gas (GHG) emissions is undoubtedly necessary to avoid an ecological disaster, political support for environmental regulation depends largely on its effectiveness and expected side-effects. A potential fallout often associated with environmental policies is a decline in economic competitiveness. Therefore, it is vital to understand whether there is a trade-off, implying that climate mitigation policies necessarily lead to competitiveness losses, or if a suitable policy design can achieve climate change mitigation without risking significant losses in competitiveness.

This paper provides a systematic overview of the existing literature – including modelling studies and econometric analyses – regarding the association between GHG emissions reductions and competitiveness risks. To structure the literature, we develop a framework that allows us to cluster the reviewed papers by their theoretical and their empirical approach, rendering possible the analysis of differences between the resulting clusters. Scrutinising the findings of 80 papers, we determine that declines in competitiveness and industrial relocation to unregulated countries (carbon leakage) have so far not been relevant outcomes of existing environmental policies, neither on the firm nor on the country level. Nevertheless, they should not be neglected in the assessment of future policies, as modelling studies foresee small but significant levels of comparative disadvantages and carbon leakage. We discuss potential reasons for this discrepancy between study approaches. Overall, the empirical evidence suggests that carbon pricing regulation and economic competitiveness can be reconciled under specific circumstances, which must be provided by a coherent policy mix that takes climate change mitigation seriously while addressing possible negative side-effects.

Keywords: Carbon Pricing; Comparative Advantage; Competitiveness; International Trade; Technological Innovation

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ZOE Diskussionspapiere präsentieren wirtschafts- und sozialwissenschaftliche Analysen von Potentialen und Hemmnissen für eine zukunftsfähige Wirtschaftsordnung. ZOE Discussion Papers present economic and socio-scientific analyses of potentials and barriers for a future-fit economic system.

1 Introduction

Recent estimations reveal that in 2020 global warming reached 1.2°C above pre-industrial levels, leaving a limited leeway to stay within the 1.5°C Paris Agreement goal (Climate Action Tracker, 2021b). In August 2021, the Intergovernmental Panel on Climate Change (IPCC) published the first part of its Sixth Assessment Report, reaffirming that we will exceed global warming of 1.5°C, and even 2°C, within this century if we do not immediately take measures to drastically reduce greenhouse gas (GHG) and especially carbon dioxide (CO_2) emissions (IPCC, 2021). The pressing necessity of subsequent GHG reductions is scientifically proven. Moreover, because – economically speaking – climate change and environmental degradation are negative externalities that are not considered in price mechanisms (Centemeri, 2009), political regulations[1] are indispensable to correct these market failures (Benjamin, 2007). The most discussed method to address such market failures is ensuring that market prices account not only for direct production costs, but also the costs of those negative externalities. This method is typically supported by the argument that internalising negative effects into market mechanisms is the most effective and cost-efficient regulation (Hamid et al., 2007). The following analysis will focus on the two most implemented climate regulations to date, benefitting from nearly unanimous support from economists (Parry et al., 2015, p. xxv): These two market-based options to internalise negative effects are carbon taxes (Pigou, 1920) and cap-and-trade programmes (Peace and Stavins, 2010).

Despite the urgency, the political introduction of appropriate measures is delayed. Policies currently in place – excluding not acted upon targets and pledges – will cause global warming of between 2.0°C–3.6°C before 2100 (Climate Action Tracker, 2021a). The political inertia can in part be explained by two commonplace assumptions. First, scholars and policymakers contend that unilaterally introduced environmental policies increase production prices. This worsens firms' competitive position in international markets and impairs a country's industrial production, thereby diminishing its citizens' prosperity (Aldy, 2017). Second, it is often assumed that a phenomenon known as carbon leakage will take place: Polluting industrial processes will not be cut back but instead relocated to countries where they are less regulated and therefore less expensive. This concern questions the effectiveness of such policies, since they would not result in a net change in global emissions, and furthermore adds on the competitiveness risks, because the regulated country's industry would become weaker (ibid.). Conversely, other scientists and politicians argue that in the long run, the early introduction of strict environmental regulations improves a country's competitive position because it pushes industrial sectors into future-oriented markets, e.g., by incentivising innovations in climate-neutral technologies and high-quality sustainable products (Porter and van der Linde, 1995). While the former, more pessimist, perspective is adopted by the pollution haven hypothesis (PHH), the latter optimist perspective is expressed by proponents of the Porter hypothesis (PH).

As political support for such regulations largely depends on their effectiveness and potential adverse side-effects, the key question to move forward in policymaking is: Will firms and, by extension, countries inevitably face competitiveness risks when implementing climate change mitigation policies? It is unquestionable that some regulations, e.g., a high carbon tax, can have an impact on economic competitiveness. However, it is less clear if appropriately designed policy mixes can effectively circumvent those negative impacts. To answer this key question, it is helpful to distinguish between trade-offs and tensions (Hafele et al., 2021). If competitiveness and climate change mitigation policies are in *tension*, progress along both dimensions is not mutually exclusive and can, under specific circumstances, be achieved by the right policy mix (see ibid. for how to accomplish policy coherence and consistency). A *trade-off*, however, implies that the attainment of one policy goal will necessarily lead to the deterioration of the other, in which case policymakers would need to prioritise either environmental regulation or competitiveness. Therefore, it is paramount to investigate whether the two objectives are merely in tension or in complete trade-off.

Economists have explored the relationship between emissions reductions, competitiveness, and carbon leakage from a variety of angles, which results in a large body of literature on this topic. In this paper, we aim to summarise and systematise the literature to ultimately assess whether the two policy goals are in trade-off or tension. The sample for this study was constructed by means of purposive sampling, beginning with strategic keyword searches in two databases and then applying the snowballing method. In total, we examined 80 papers published between 1995–2021 which concern the compatibility of carbon pricing policies and economic competitiveness. Based on theoretical considerations and methodical approaches, we developed a framework to structure the existing findings to both discern the controversies in the literature and recognise uncontested results within and between clusters. To address the ambiguous use of the concept of competitiveness in the literature and to lay a theoretical foundation for the following analysis, section 2 provides an overview of the notion of competitiveness. Section 3 outlines the procedure for the literature review and section 4 details the clustering approach. Section 5 describes the main findings resulting from our analysis. Section 6 contains the discussion of the paper's key question, and section 7 concludes.

[1] We focus explicitly on economic regulations, leaving aside interventions such as information campaigns and other incentives. Although the latter are politically less contended, these measures will not sufficiently reduce emissions by themselves.

2 The concept of competitiveness

An essential prerequisite before analysing the competitiveness risks associated with environmental regulation is to employ a precise definition of economic competitiveness. The literature we surveyed however tends to use the concept in an elusive way. One reason for this is that competition plays a role in various areas of modern life, and hence the concept is used across academic communities. This makes an interdisciplinary definition of the concept necessary (Altreiter et al., 2020). But even within economics, competition is conceptualised and theorised in widely different ways, each definition implying specific characteristics (static or dynamic), analytical methods, and normative connotations (positive or negative; ibid., p. 1). Based on this observation, Pühringer et al. (2020) developed a framework to systematise different approaches to the study of competition, taking into account the scope (universal or particular) and the normative implications of the concepts. Within this framework, the approach to competition and competitiveness implicitly employed in the surveyed literature can be classified as a particular conceptualisation, since it is restricted to a singular societal field, i.e., the economic realm of trading commodified goods (ibid., pp. 4f.). We will assess the normative connotation after a brief synopsis of a selection of contributions to this field.

International trade theory relies heavily on the concept of comparative advantage when discussing competitiveness. This concept was first introduced by Ricardo (1817) to explain the occurrence of economic exchange. Its basic premise is that under conditions of free trade, countries will specialise in goods that they can produce relatively more efficiently than other countries. In turn, they will import goods that other countries produce with greater efficiency. Thus, this model uses productivity differences between countries to explain inter-industry specialisation. Since productivity is assumed to be fixed at a certain level, the Ricardian model is static.

Until today, the basic Ricardian model has been further developed by numerous economists. One seminal variation is that of Heckscher (1919) and Ohlin (1933) who established the idea of different factor endowments: The resulting model equilibrium consists of each country exporting the good or service which uses the abundant factor of production and importing the one which uses the scarce factor of production. This rationale is central to the discussion on carbon pricing policies because a higher energy price modifies the factor endowment by making this input scarcer. As a result, regulated countries supposedly lose their comparative advantage in carbon-intensive production. By assuming that factor inputs are determined externally, this variation of the model remains static.

However, the Heckscher-Ohlin model's predictive power and empirical accuracy have been questioned from the very beginning (e.g., Leontief, 1953). This resulted in further revisions, most notably by new trade theorists in the 1970s and 1980s. Following the empirical observation that, to a large extent, international trade takes place between countries with similar characteristics (productivity, factor endowment), they introduced increasing returns of scale and network effects as explanatory factors for intra-industry specialisation (Krugman, 1979). In this line of argument, one country's industry concentrates in producing a niche product, which results in economies of scale for the firms involved in its production. Trading these specialised niche products with each other, countries can take advantage of large economies of scale and end up with greater product diversity (Neary, 2009). While this development marks a departure from the theory of comparative advantage, Krugman (1981) also successfully integrated his new trade theoretic reflections with old trade theory, namely the Heckscher-Ohlin competitive trade model.

Notable contributions to the study of economic competition in international trade have recently been put forward. For instance, scholars revived old trade theoretic responses to the core question of why nations engage in the trade of goods by further theorising as well as empirically investigating comparative advantage (Costinot, 2009a,b; Costinot and Donaldson, 2012). In this, Costinot re-centred the constitutional elements technology and factor endowment, but also used new explanatory variables such as workers' education and the quality of institutions to explain comparative advantage and thus international specialisation (Costinot, 2009b). Beyond that, the model's applicability has been broadened by generalising it to an arbitrarily large number of countries, goods, and factors (Costinot, 2009a). Another significant contribution to this strand of literature is Melitz' 'new' new trade theory, which shifts the focus to firm level exports (Melitz, 2003). The development of this model was prompted by the empirical observation that only a small share of high-productivity firms within one country engage in export activities (Tanaka, 2010). While old and new trade theories assume that firms (at least within one industry) are qualitatively the same and are thus not able to explain this pattern, Melitz' theory is based on the premise that firms operate at varying productivity levels. The corresponding model accounts for heterogeneous productivity across firms and for the fact that only highly productive firms engage in export. It is argued that only firms with above-average productivity levels are able to pay the fixed costs necessary for export operations because their profits are large enough (ibid.).

Understood as a positive science, international trade theory offers descriptive tools to explain trade patterns and identify the determinants of international specialisation. Despite this descriptive nature, however, it also carries normative implications (Pühringer et al., 2020, pp. 9ff.). Particularly the notion of comparative advantage is frequently used as a political argument in favour of trade liberalisation, because it suggests that free trade is advantageous for all participating nations (Schumacher, 2013, p. 87). Therefore, it is a key discursive tool in the current policy debate on international trade. Moreover, new trade theory suggests that gains from trade – greater diversity of commodities and lower prices resulting from specialisation and large-scale production – may even arise between very similar countries (Krugman, 1979). In a similar vein, 'new' new trade theory points out that lowering trade barriers will stimulate global competition and thus crowd out low-productivity firms, thus making countries on the whole more productive and increasing real incomes and prosperity (Melitz, 2003).

In consideration of the definitions stated above, as well as an intuitive understanding of the notion of competitiveness, it is essential to bear in mind that the importance of competitiveness in international trade and climate politics is contingent on the extent to which it is acknowledged as a *relative* concept: One country's competitiveness is defined in relation to other countries' competitiveness. The transformation towards a climate-neutral, equitable economy, however, must necessarily be an *absolute*, global, and multilateral effort, which requires all countries to increase their levels of regulation. As such, the basis for country comparisons would stay constant and individual countries' levels of competitiveness would not be altered by universally adopted climate change policies.

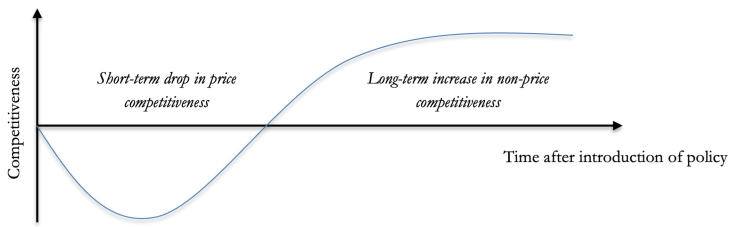
The relational component of competitiveness is for instance reflected in the formula for revealed comparative advantage (RCA), a common empirical measure of the degree of specialisation within a country. The RCA of country A for good i compares this country's trade profile with the world average (UNCTADStats, 2021). It is classically defined as country A's ratio of exports of product i to the total exports of all products j relative to the ratio of the whole world's exports of good i to the world's total exports of all products j; or, mathematically,

$$RCA_{Ai} = \frac{X_{Ai}/\sum_{j\in P} X_{Aj}}{X_{wi}/\sum_{j\in P} X_{wj}} \qquad (1)$$

where P is the set of all products ($i \in P$), X_{Ai} is country A's exports of product i, X_{wi} is the world's exports of product i, $\sum_{j\in P} X_{Aj}$ is country A's total exports (of all products $j \in P$), and $\sum_{j\in P} X_{wj}$ is the world's total exports (of all products $j \in P$). Country A then has revealed comparative advantage in product i if the ratio is larger than 1.

To further systematise the literature, it is essential to recognise two interrelated aspects of competitiveness: its temporal dimension and the existence of different types of comparative advantage. We will illustrate both characteristics in the context of environmental regulations and international trade. The first elementary distinction is between short-term and long-term competitiveness. In the short term, one can assume that when unilateral environmental policies increase energy prices or other compliance costs, firms' overall production costs rise as well – since price competitiveness is determined "by a country's industrial costs relative to other exporters" (European Commission, 2017, p. 37), it is affected negatively. Hence, supposing that the cost increase is reflected in the end products' prices and that consumers prefer to buy cheaper products, regulated companies will be less price competitive. However, in the mid or long term, non-price competitiveness gains in importance; "a broad concept which encompasses many different determinants of export performance [...]: export quality, tastes, integration in global value chains and institutional factors" (ibid., p. 43). It is reasonable to expect that in the future, the demand for environmentally friendly products will continue to rise (Kerle et al., 2021; Kronthal-Sacco and Whelan, 2019). This means that firms that are the first to innovate accordingly, invest in green technologies, and construct their corporate image around sustainability will end up having a comparative advantage and higher non-price competitiveness, because they will be better prepared to meet consumers' preferences and offer high-quality products (Xifré, 2021, p. 3). Thus, while climate change policies may harm a country's price competitiveness upon their introduction, they will contribute to the ecological transformation of the economy by incentivising firms to realign with values that will be demanded on future markets, hence making the economy more competitive in the long run (Figure 1).

Figure 1: Stylised development of economic competitiveness after the introduction of an environmental policy



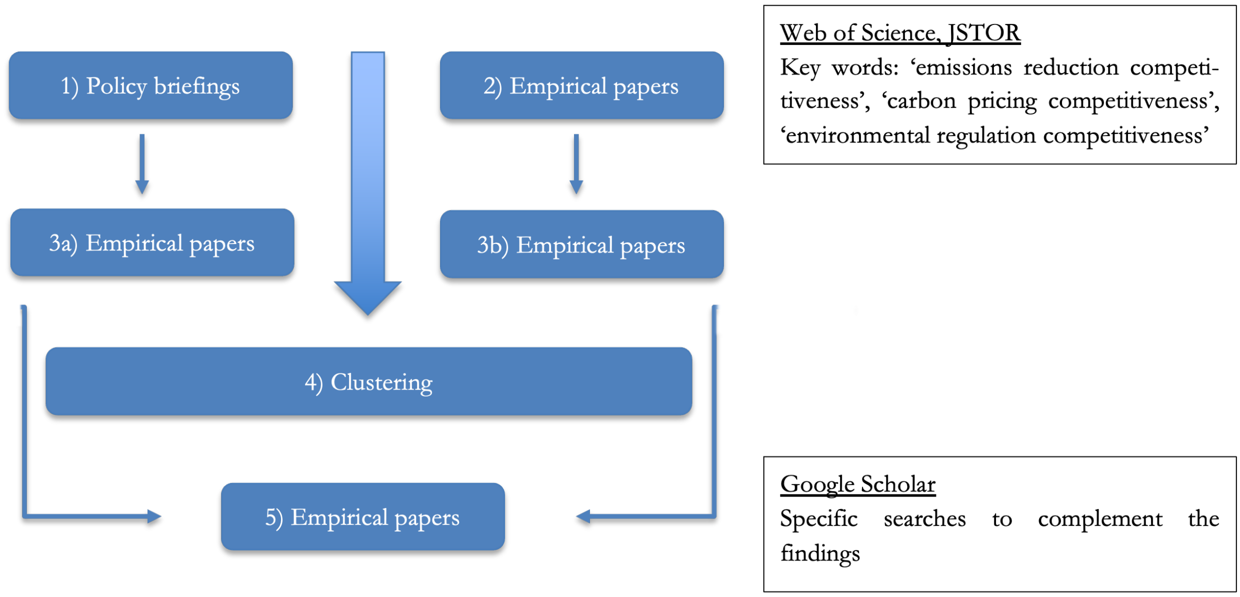
Source: Own illustration.

To conclude, the core challenge when discerning the concept of competitiveness in the literature is that most papers only implicitly use different definitions. Due to the lack of conceptional sharpness and the overall heterogeneity of empirical measures used, the definitions remain somewhat vague. The above section thus described the scope of the notion of competitiveness relevant for the present literature review and narrowed it down as far as possible. To further deal with the diversity of understandings, we used the broadest definition possible for the literature review. In addition, we explicitly state the measure and analytical unit to which each study relates whenever possible and useful. The conclusion encompasses final thoughts on different notions of competitiveness.

3 Research procedure

The literature research for this analysis relied on methods of purposive sampling. In particular, it was conducted combining database searching and the snowballing approach – both characterised by Pawson (2006, p. 85) to be essen-

Figure 2: Research procedure



Source: Own illustration.

tial ingredients for a realist synthesis of literature that can inform evidence-based policymaking. These methods aim to reach theoretical saturation, a concept first developed in the context of grounded theory (Glaser and Strauss, 1967). Applied to systematic literature reviews, theoretical saturation describes a point where the evidence gathered suffices to answer the research question, or meets the theoretical need whereby an addition to the sample would not add new knowledge (Pawson, 2006, p. 86).

Figure 2 illustrates how we proceeded to constitute our sample. The initial search for literature was conducted by database searching in two standard search engines, focusing on published journal articles in the Web of Science and on grey literature, such as research reports and working papers, in JSTOR. The search was completed in May–June 2021 and replicated in January 2022. In both databases, we used the keywords 'emissions reduction competitiveness', 'carbon pricing competitiveness', and 'environmental regulation competitiveness'. For these keywords, the search resulted in lists of 997, 437, and 1.314 articles, respectively, in the Web of Science, and 1.314, 785, and 1.156 pieces of grey literature in JSTOR. First, we started by scanning policy briefings to identify key thematic threads, seminal works, and relevant authors, to serve as starting points for the snowballing.

Second, we turned to the first wave of empirical papers[2] resulting from the initial search. Third, we applied the snowballing approach and added empirical papers which were either mentioned by the policy briefings or referenced by the studies from the initial search. Fourth, we clustered the main findings of each relevant paper according to both its methodical approach and the author's theoretical point of departure (cf. section 4). Fifth, we included further empirical literature that was connected to those papers by consulting their literature reviews and citations. This step was accompanied by further searches in another database, Google Scholar, looking especially for complementary and contrary results by means of targeted keywords. All in all, this research procedure demonstrates how "purposive samples have a progressive focus as understanding unfolds" (Pawson, 2006, p. 85), as for each step, we utilised the understanding of the research field that we had acquired in the previous steps.

This procedure resulted in our sample, made up of 80 papers dating from 1995–2021. Most papers (55) are published in academic journals, while some (25) are classified as grey literature. The majority (45) use econometric tools, while another part (14) relies on modelling techniques. Moreover, we included 21 literature reviews of existing empirical findings to cover a more diverse body of work.

4 Clustering framework

In the following, we survey the literature on economic competitiveness and carbon pricing policies in the aim to qualify their relationship as either a trade-off or a tension. Our inductive approach revealed two fundamental distinctions within this research field which are used to classify the empirical literature. The first one is the studies' theoretical background, indicating the authors' positioning on the field of tension between competitiveness and environmental protection. Since the two most common hypotheses regarding the theoretical

[2] For the purpose of this literature review, we understand empirical research to be all research that is data-driven, "originating in or based on observation or experience" (Merriam-Webster, 2021). Therefore, we subsume under this term econometric studies as well as modelling studies which exploit empirical data to calibrate their models and make predictions, acknowledging that the latter category is more reliant on theoretical assumptions than the former (cf. section 4.2).

background imply differing analytical starting points, we moreover detail their respective empirical strategies in this section. The second central distinction made in the literature is between two different methodical approaches.

4.1 Theoretical background

The first distinction refers to the studies' theoretical background (Table 1). Using an inductive approach, one can discern two opposing hypotheses in the literature: the pollution haven hypothesis (PHH) and the Porter hypothesis (PH). The former postulates a trade-off between environmental regulation and economic competitiveness, while the latter assumes a positive association.[3] Even though some papers mention both lines of argumentation, their operationalisation and research objective allow for an evaluation of the author's position in the discourse between these two hypotheses.

Based on international trade theory, the PHH emphasises the effect of increased energy and thus production costs, which will be an inevitable consequence of more stringent unilaterally imposed environmental regulation. Within the Heckscher-Ohlin theoretical framework (cf. section 2), environmental policy can be regarded as a constraint to factor endowment (Costantini and Mazzanti, 2012, p. 133; Koźluk and Timiliotis, 2016, p. 7). The country with stricter regulations will consequentially have a comparative advantage and specialise in 'clean' low-carbon industries, while countries with laxer regulations have a comparative advantage in 'dirty', emission-intensive industries. The result of this regulatory differential is twofold: It causes operational as well as investment leakage, meaning that industrial plants and capital connected to dirty industries will relocate to countries or regions with less stringent environmental policies, so-called pollution havens – this phenomenon is known as carbon leakage (Fahl et al., 2021, pp. 8–9). Furthermore, emissions are simply moved to another country, producing no net change in environmental harm on the global level – some scholars even expect an increase in emissions as a result of rising transport costs or lower emission intensity in unregulated countries (ibid., p. 6). Postulated economic results of unilateral climate change policies are therefore an overall decline of international competitiveness and domestic job loss due to higher factor prices as well as a reduction in tax revenues.

Even though carbon leakage and competitiveness are fundamentally different concepts, the corresponding literature is closely related. On the one hand, competitiveness and carbon leakage are discursively intertwined since they both are considered side-effects of unilateral carbon pricing and are employed as arguments against it. On the other hand, they are related to each other via two theoretical channels. A quote from a seminal literature review illustrates the first theoretical connection, which argues that a comparative disadvantage gives rise to carbon leakage: "This loss of competitiveness is believed to be reflected in declining exports, increasing imports, and a *long-term movement of manufacturing capacity* from the United States to other countries, particularly in 'pollution-intensive' industries" (Jaffe et al., 1995, p. 133, emphasis added). In other words, the "short-term competitiveness channel" (Reinaud, 2008, p. 3) is considered to be one of the main drivers of carbon leakage. The second connection takes carbon leakage as its starting point and contends that if the movement of manufacturing capacities or business operations has a systemic character, carbon leakage constitutes declining competitiveness on the industry or even country level. Within this static model, competitiveness is understood as being reflected in indicators such as employment or output. In sum, firm level carbon leakage not only results from comparative disadvantage, but also in turn gives rise to declining competitiveness on the macro level. It is not our aim to separate the two concepts analytically, but rather to reproduce how they are used in the literature. Our research design thus accounts for the intricate relationship between the two concepts by including studies of traditional measures of competitiveness as well as carbon leakage.

Conversely, the PH postulates a positive association between the stringency of environmental regulation and economic competitiveness (Porter, 1991; Porter and van der Linde, 1995). Adopting a dynamic perspective on business decisions, this hypothesis posits that pollution is a result of wasting resources and not employing the most efficient technologies. Thus, environmental regulation can incentivise firms to invest in R&D, thereby enhancing (energy and overall material) efficiency and productivity through technological progress. In other words, given that public policies are well-designed and suited to encourage innovative activity, combining environmental policies with private and public innovation programmes has the potential to positively impact targeted firms' competitiveness.

Moreover, some scholars distinguish between three variations of the PH. The weak version solely proposes that environmental regulation induces innovation, with no assumption concerning the scope of the innovation. In contrast, the strong version claims that well-designed regulation leads to innovation that improves business performance to an extent that fully compensates for the compliance costs, thus generating profit. Further, the narrow version of the PH concerns the type of regulations and argues that flexible, e.g., market-based, environmental policy instruments are more effective in incentivising firms to innovate than prescriptive regulations (Ambec, 2017, p. 12; Bianco and Salies, 2016, p. 1). This line of argumentation is well-known from the policy discourse: Advocates of green growth propose that innovation will eventually offset compliance costs and at the same time stimulate a non-price competitive advantage in future markets.

When comparing the PHH and the PH, the importance of distinguishing short-term from long-term effects as well

[3] Although the PHH and the PH are not mutually exclusive and collectively exhaustive categories, we will rely on this classification because it best reflects the surveyed studies' approaches.

Table 1: Summary of hypotheses

Pollution haven hypothesis (PHH)	**Porter hypothesis (PH)**
Trade-off between environmental regulation and economic competitiveness	Positive association between environmental regulation and economic competitiveness
International trade theory	Business/management literature
Comparative advantage and specialisation in clean industries	Investments in R&D, innovations
Operational and investment leakage to 'pollution havens'	Increases in efficiency and productivity through technological progress
Alleged loss of competitiveness, job loss, reduction in tax revenues	Higher competitiveness through first-mover advantage
No net change in environmental harm (or even increase in emissions)	Reduction of environmental harm by efficiency improvements
Short-term; price competitiveness	Long-term; non-price competitiveness

as price-competitiveness from non-price competitiveness becomes apparent (cf. section 2). While this connection is seldomly mentioned in the literature we surveyed, the PHH is in line with the short-term, static perspective that predicts a drop in price competitiveness resulting from environmental regulation, as this increases firms' compliance and thus production costs. According to Rentschler and Kornejew (2016), this is one of four distinct ways in which companies can adapt to new market conditions with higher energy prices. First, they can pass through the higher cost of production to consumers by increasing the goods' end prices, lowering their price competitiveness. The second adaption mechanism consists of inter-energy substitution, switching to less costly energy sources. Third, firms can increase their energy efficiency or overall productivity, thereby offsetting the cost increase and increasing their price competitiveness. Lastly, they might react by decreasing their profit margins whenever cost pass-through is not feasible, holding their price competitiveness constant while reducing profits. To add to this, the PH illustrates that when considering a long-term perspective and dynamic business decisions, another logical adjustment path in response to the price disadvantage is improving the non-price competitiveness, e.g., by offering innovative, climate-friendly products. Therefore, we argue that a firm's strategic decision to invest in the green economy early on offers a long-run comparative advantage stemming from a non-price competitiveness increase.

To conclude, the concept of non-price competitiveness is only vaguely defined in the literature on effects of emission reductions, and the function of non-price competitiveness is seldomly discussed explicitly (Xifré, 2021, p. 2). We contend that the 'first-mover advantage', which constitutes a comparative advantage that can be utilised by companies that move into new markets first, represents a non-price competitiveness factor (Lieberman and Montgomery, 1988; Sofka and Schmidt, 2004). The argument that companies which detect changes in consumer demand and international trends in climate regulations early and restructure their production accordingly have a so-called 'early-mover advantage' has already been recognised by Porter and van der Linde (1995, pp. 104–105). Thus, companies moving into low-carbon markets first can gain a non-price competitiveness advantage. By extension, suitable policy instruments that systematically encourage this firm behaviour can enhance a whole sector's or even country's competitive position on international markets (Porter, 1990).

4.2 Methodical approach

The second distinction according to which we will classify the research contrasts the studies' methodical approaches and is summarised in Table 2 (Zachmann and McWilliams, 2020; Zenghelis and Bassi, 2014). On the one hand, ex-ante studies model the impact of hypothetical environmental regulations, usually in the form of a future carbon price. Most of these modelling studies employ historical data to calibrate computable general equilibrium (CGE) models, and some work with sectoral or multi-sectoral partial equilibrium models. According to Carbone and Rivers (2017, p. 25), these models' strength is to enable researchers to quantitatively analyse counterfactual experiments, complementing standard empirical and theoretical analyses. In contrast to common statistical approaches, CGE models rely on microeconomic theoretical assumptions, e.g., regarding the demand and production functions. On the other hand, ex-post approaches use econometric methods to evaluate existing environmental policies that regulate energy prices, such as the EU ETS or carbon tax schemes, with regards to their effect on various measures of competitiveness.

Apart from their theoretical classification and methodical approaches, the studies we discuss also differ in terms of how they define two relevant concepts. The first one

Table 2: Summary of methods

Ex-ante studies	Ex-post studies
Impact of hypothetical environmental regulations (e.g., future carbon price)	Impact of existing environmental policies that regulate energy prices (e.g., EU ETS)
Modelling techniques using historical data for calibration	Econometric methods
Based on theoretical assumptions	No explicit theoretical assumptions

is the unit of analysis, as some studies evaluate emission reduction policies on a national level, some on a sectoral level, and others on a firm level. We will specify the papers' ontological levels where necessary to achieve analytical clarity. The second one is the concept of competitiveness, which is not well defined in the literature nor in the policy debate (cf. section 2; Algieri, 2015, p. 158; Carbone and Rivers, 2017, p. 25). Since competitiveness mostly stays an elusive construct, empirical studies often use 'outcome indicators' to measure the 'symptoms' of competitiveness, namely revenues, profits, market share, employment, investments, exports, patents, and productivity growth (Rentschler and Kornejew, 2017, p. 5). Relatedly, these outcomes also refer to different units of analysis. The complexity stemming from the diverse competitiveness indicators can be partially reduced by (heuristically rather than definitely) assigning them to the two hypotheses. As to the PHH, carbon leakage is often employed as one proxy for a decline in competitiveness. Moreover, this perspective on comparative advantage implies that trade flows (e.g., export volume, net imports), production/output, and employment levels can measure competitiveness. All these indicators can either refer to the whole economy, to the sectoral or to the firm level. Meanwhile, business performance, profitability, market share, revenues, and innovative activity (e.g., patenting) are indicators that correspond to the PH's perception of competitiveness.

5 Findings

In this section, we discuss the conclusions drawn from our systematic literature review. For clarity, the key messages resulting from the clustering strategy have been simplified in the diagram shown in Figure 3.[4] A large part of this section is dedicated to examining the evidence from the four main clusters highlighted above. In this, we emphasise potential reasons for differing conclusions, the most striking one being that most modelling studies detect declines in competitiveness while econometric evaluations of current carbon pricing schemes do not. Beyond that, we highlight an additional strand of literature that revealed complementary findings to paint a more holistic picture of the association under investigation.

[4] Please note that several uncertainties and controversies in the literature are not portrayed in this simplified coordinate system.

5.1 Ex-ante analyses of the PHH

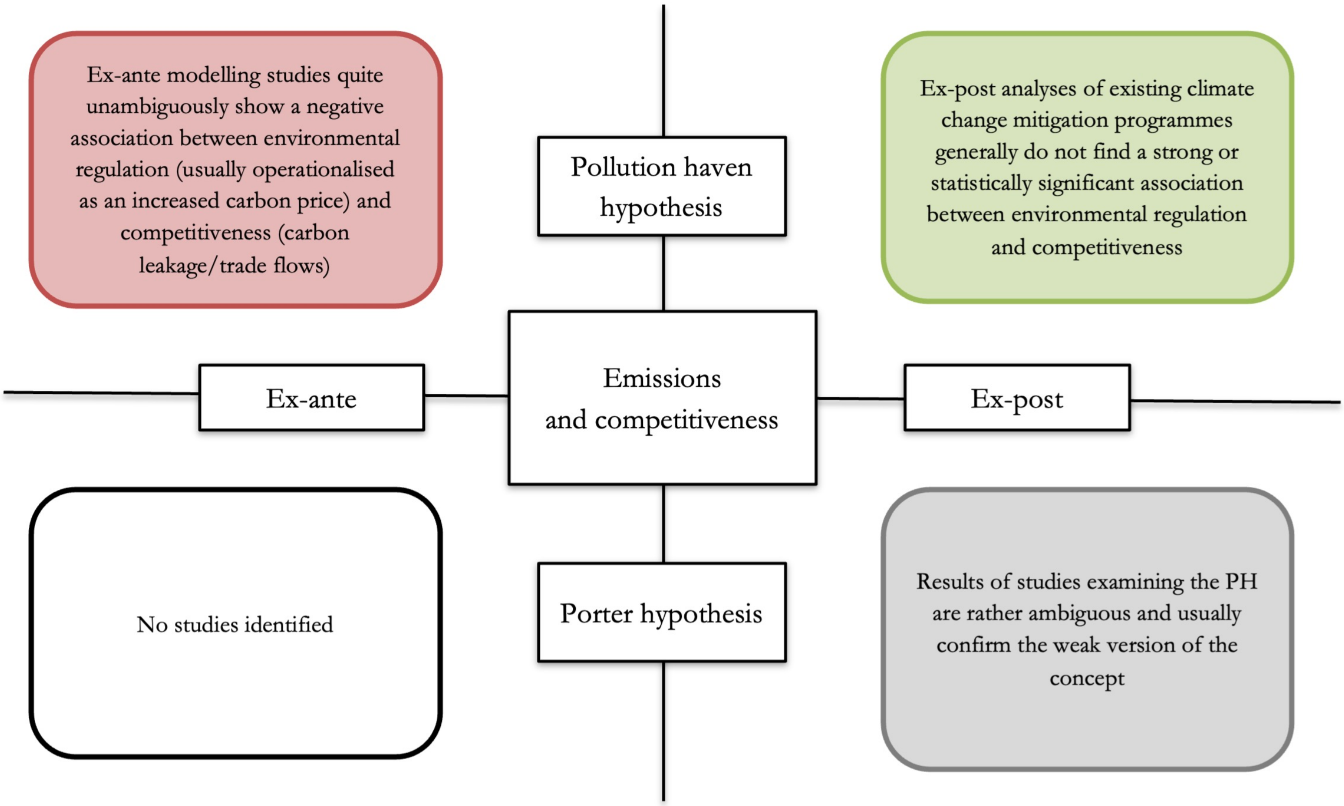
First, the main conclusion to be drawn from the ex-ante analyses of the PHH is: Modelling studies, based on their assumptions, find a negative association between increasing carbon prices and competitiveness as well as carbon leakage, even though it differs in size between sectors.

With regards to carbon leakage as a proxy for comparative disadvantage, the empirical papers, meta-analyses and literature reviews we surveyed found carbon leakage rates in the range between 5 to 30 percent (Aldy, 2017; Böhringer et al., 2012; Branger and Quirion, 2014; Carbone and Rivers, 2017; Condon and Ignaciuk, 2013; Demailly and Quirion, 2005; Interagency Competitiveness Analysis Team, 2009; Zachmann and McWilliams, 2020; Zenghelis and Bassi, 2014). This means that regardless of the specific study setup (country specificities, dataset and CGE model used for estimation and simulation, level of carbon pricing), a significant proportion of the domestic emissions reductions achieved through carbon pricing mechanisms would be offset by increasing emissions in non-regulated countries.

Some scholars and policymakers call for measures that reduce carbon leakage and combat competitiveness risks to make carbon pricing schemes more environmentally effective and economically feasible. Envisioned mechanisms would supplement the domestic regulations with regulations for imports from other countries, thereby aligning international production costs. Such a disincentive to relocate production or investments abroad could be introduced via a carbon border adjustment mechanism (CBAM). The modelling studies that account for a CBAM found that this measure, implemented in parallel to a hypothetical carbon price, is able to significantly reduce leakage rates and counteract declines in domestic production and in market shares (Böhringer et al., 2012; Demailly and Quirion, 2005; Dissou and Eyland, 2011; Löschel et al., 2008).

Even though the association in question is negative across all studies, when inspecting the economic impacts of simulated carbon prices, studies found that competitiveness risks are usually small in size and concentrated in a few vulnerable sectors. These are especially emission-intensive and trade-exposed (EITE), such as iron and steel, aluminium, chemicals, and agricultural products (Aldy, 2017; Aldy and Pizer, 2014, 2015; Demailly and Quirion, 2005; Rivers, 2010; Zenghelis and Bassi, 2014). Competitiveness measures used in these studies include production, employment,

Figure 3: Simplified clustering results



Source: Own illustration.

market share, value of shipments, and net imports. The production drop is estimated to be between 1 and 7.5 percent, varying with the type of industry and the level of carbon prices imposed (e.g., Grover et al., 2016). The employment effect is estimated to be quite small, e.g., 1/3 of 1 percent in the analysis conducted by Aldy (2017). This heterogeneity of effects is consistent with the PHH and the notion of comparative advantage, as these predict a specialisation in green industries and disadvantages in emission-intensive sectors.

Casey et al. (2020) demonstrated that competitiveness risks also arise when carbon pricing is introduced regionally – i.e., in some selected US states. The authors found that with a \$10/t CO_2 allowance price, production and employment mainly relocate to other US states rather than to foreign countries, with larger effects for more energy-intensive industries. Overall, the regulated region would lose 2.7 percent of manufacturing employment. In contrast, a two-region dynamic CGE modelling study of the Chinese economy found heterogeneous competitiveness effects of a carbon tax that is higher in the Chongqing region than in the rest of the country (Xie et al., 2018). On the one hand, the carbon tax led to an overall GDP decrease of 1.54–2.5 percent in the regulated region, and the paper, chemicals, and nonmetal production sectors suffered output losses. On the other hand, industrial competitiveness of some sectors was enhanced: For instance, the agriculture, textile, electronics, and machinery sectors increased their output activity.

We identified one study with contrasting findings: McKibbin et al. (2018) conclude that in the US, the introduction of a hypothetical carbon tax of \$27/t CO_2 and including annual increases would not result in carbon leakage – on the contrary, such a tax might even lead to negative leakage (a reduction of emissions produced abroad). The authors suggest the following mechanism to explain this surprising result: The input price of energy increases because of the carbon tax, reducing US exports and slowing down the US economy. In consequence, the demand for imports drops, diminishing the amount of CO_2 set free abroad for domestic consumption. Simulating a CBAM, the authors determined that imports would become more expensive, further decreasing the demand for imports. Moreover, consistent with the studies mentioned before, they only found small effects on GDP, wages, employment, and consumption.

5.2 Ex-post analyses of the PHH

Second, the literature providing ex-post examinations of the PHH evidences the opposite conclusion: On average, existing environmental regulations do not negatively impact competitiveness and do not lead to significant carbon leakage at the aggregate level. The first notable literature review on this topic was published by Jaffe et al. (1995). The scholars analysed the effects of environmental regulations in the US on competitiveness and found that “there is relatively little evidence to support the hypothesis that environmental regulations have had a large adverse effect on competitiveness" and that "studies attempting to measure the effect of environmental regulation on net exports, overall trade flows, and plant location decisions have produced estimates that are either small, statistically insignificant, or not robust to model specification" (pp. 157f.). More recent empirical studies, while employing newer econometric techniques, using larger datasets, and examining different kinds of regulations in more countries, usually come to the same conclusion.

Most contributions in this cluster either analyse the impacts of the world's largest carbon market, the EU ETS, or various kinds of carbon taxes. On the firm level, the findings are mostly generated using statistical methods such as propensity score matching and difference-in-difference approaches to compare regulated to non-regulated firms. On the country or sectoral level, bilateral trade flows are the most common dependent variable. For a comprehensive meta-analysis of ex-post assessments of different types of carbon pricing see esp. the tabular overview in Arlinghaus (2015, pp. 24–28). Starting with carbon taxes, one can conclude that empirical studies and literature reviews do not find (statistically or economically) significant adverse effects of existing carbon or energy taxing systems (Arlinghaus, 2015; Dechezleprêtre and Sato, 2017; Flues and Lutz, 2015; Martin et al., 2014; Rentschler and Kornejew, 2017; Zhang and Baranzini, 2004). Firms that are subject to carbon taxes do not, or only marginally and in the short-term, perform worse than firms that are exempt from them but have otherwise similar characteristics.

Coming to the effects of the EU ETS, the above conclusion also holds true: There seems to be no significant trade-off between firms' emissions reduction, achieved by participation in the trading system, and their competitiveness, indicated by turnover, exports, value added, profits, employment, productivity, and investment decisions (Abrell et al., 2011; Anger and Oberndorfer, 2008; Arlinghaus, 2015; Bassi et al., 2013; Chan et al., 2013; Joltreau and Sommerfeld, 2018; Petrick and Wagner, 2014; Verde, 2020; Zenghelis and Bassi, 2014). Solely one study by Wagner et al. (2014) indicates a 7 percent decrease in French manufacturing firms' employment in the second phase of the EU ETS. Conversely, three papers discovered that during the first compliance period, the system even increased the productivity and value added of regulated firms (Klemetsen et al., 2020; Löschel et al., 2016; Lutz, 2016). In their analysis of China's pilot ETSs, Zhang and Duan (2020), however, detected significant negative effects of this policy instrument on gross industrial output value and employment in regulated sub-sectors.

The picture on carbon leakage appears to be mixed. Neither Dechezleprêtre et al. (2019) nor Naegele and Zaklan (2019) found evidence that the EU ETS led to operational carbon leakage. Investment leakage, indicated by firms' holdings of fixed assets and by foreign direct investments, seem to not be a relevant result of participation in the EU ETS (aus dem Moore et al., 2019; Koch and Basse Mama, 2019). While Koch and Basse Mama (2019) determined that regulated firms have increased their number of affiliates outside the EU, which implies that these companies are preparing for future relocations, this increase of foreign affiliates was not observed in a study of Italian firms by Borghesi et al. (2020). However, on the intensive margin, the shift of production to existing foreign subsidiaries has increased.

While the performance of the manufacturing sector seems to be affected only to a negligible extent, a certain heterogeneity of sectors becomes evident. This finding constitutes an important exception to the overall conclusion, namely that certain vulnerable EITE sectors are disproportionately affected and carbon leakage may occur (Abrell et al., 2011; Chan et al., 2013). With regards to competitiveness, we identified several studies whose results correspond quite strongly: The adverse effect is more prevalent in dirty, pollution-intensive industries, while the regulation evokes a comparative advantage in clean industries (Cheng et al., 2015; Koźluk and Timiliotis, 2016; Martínez-Zarzoso et al., 2016; Thivierge, 2020). This outcome is in line with the PHH and the original definition of comparative advantage, as they predict a specialisation in clean and a weakening of dirty industries. The authors of the studies conclude that overall, there is no significant negative relationship between environmental policy stringency and national competitiveness and trade patterns. This could be because they use bilateral trade flow data in which the positive influence on clean industries and the negative one on dirty industries balance each other out statistically – in other words, the comparative advantages in different types of industries might change the composition of exports via specialisation but have no effect on their overall volume.

Furthermore, several papers evaluated the effects of either general indicators of environmental regulation or policies not mentioned so far. Overall, they identified stronger competitiveness risks than the studies above. For example, the ratification of the Kyoto Protocol was associated with carbon leakage (Aichele and Felbermayr, 2015) and Japanese firms with stronger self-reported environmental protection efforts are more likely to outsource parts of their production overseas (Cole et al., 2014). In a gravity setting, the GDP p.c. differential between two countries – used as a proxy of environmental regulation – is related to bilateral trade in such a way that environmental stringency harms a country's competitiveness (de Santis, 2012). However, the author also found that membership in major multilateral environmental agreements positively influenced the EU-15's bilateral export flows. Moreover, within a new trade theoretic framework, Cole and Elliott (2003) ascertained that environmental regulation differentials influence the composition of trade (whether countries trade within the same or different industries), which is consistent with the predictions of the PHH. However, they found no evidence for the PHH within the traditional comparative advantage framework. Lastly, examining the EEG levy exemptions in Germany, Gerster (2017) concluded that they had no effect on manufacturing firms' competitiveness, providing evidence against the PHH.

5.3 Discussion of the evidence on the PHH

Finally, the literature provides several explanations for the stark difference of results achieved by ex-ante and ex-post approaches: Why do modelling studies usually detect some kind of competitiveness risks while they are either economically or statistically insignificant in econometric evaluations of environmental regulations that are currently in place (Rivers, 2010, p. 1093; Zachmann and McWilliams, 2020, pp. 4–6)? To answer this question, we took a cursory look at studies from different institutional contexts to consider as many explanations as possible. On the downside, this approach implies that the incorporated works consider the issue at hand from differing angles and are thus not always directly comparable.

The first and most apparent reason is that the data available mostly covers carbon prices that are low enough to induce no significant competitiveness risks for firms (Dechezleprêtre and Sato, 2017; Fahl et al., 2021; Zachmann and McWilliams, 2020; Zenghelis and Bassi, 2014; Zhang and Baranzini, 2004). In this context, Arlinghaus (2015, p. 23) stresses that ex-post empirical studies only assess the impact of carbon pricing schemes at their current design, which does not rule out that higher carbon pricing differentials, e.g., in later phases of the EU ETS, might have significant adverse effects on competitiveness (Fahl et al., 2021, p. 2).

Apart from the low price, one relevant feature of carbon pricing schemes is that they usually entail exemptions and rebates or compensation schemes for vulnerable EITE sectors to not threaten their competitiveness in the first place. Therefore, one could assume that without this pre-emptive relaxation of environmental measures for especially harmful industries, the adverse effects might be stronger (Zachmann and McWilliams, 2020; Zenghelis and Bassi, 2014). In this context, Ederington and Minier (2003) argue that the reason for insignificant or small statistical effects of environmental regulation on competitiveness is that countries utilise environmental regulations to protect their domestic industries. To stay internationally competitive, they might introduce climate policies while adapting the level of policy stringency to the vulnerability of specific sectors: This might account for marginal competitiveness risks, but also questions the overall effectiveness of these policies, since many trade-exposed sectors are also very polluting. The authors suggest that if this form of constructing a secondary trade barrier is overlooked, the comparative disadvantage of stringent environmental policies might be underestimated, because trade flows might falsely appear to be only weakly correlated with the level of environmental regulation across industries. Aiming to verify these considerations, they demand that the level of environmental regulation be incorporated into models as an endogenous variable. In their study, they simultaneously estimated a second equation which represents an industry's level of environmental protection as a function of tariffs, trade flows, and several political-economy variables, to test whether countries distort levels of environmental regulation by endogenously relaxing policies for very trade exposed sectors. This method further allowed the authors to highlight which effects environmental regulation would have if it prioritised emission reduction in all sectors of the economy over the stability of competitiveness in exposed sectors. In line with their demand, the authors found that when they account for the proposed endogeneity of environmental regulation, the correlation between carbon pricing policies and trade flows is stronger than previous estimates suggested. However, this contrasts the findings by Anger and Oberndorfer (2008) who compared German firms that are practically exempt from payments under the EU ETS to those that are not and noticed no difference in their revenue and employment. This result supports the conclusion that the nonexistence of competitiveness effects is not caused by the regulations' exemptions and rebates (Arlinghaus, 2015, p. 17). Beyond that, Cole and Elliott (2003) did include the possible endogeneity of climate policies into their analysis, which did not change their conclusion that the policies neither affected trade patterns nor led to dirty net exports.

The two aforementioned reasons for the absence of economic effects – low prices and generous exemptions – raise the question of whether these policies have an environmental effect at all. Do the incentives suffice to reduce GHG emissions? First, several studies detected statistically significant emission reductions amongst EU ETS regulated firms of up to 20 percent (Abrell et al., 2011; Klemetsen et al., 2020; Petrick and Wagner, 2014; Wagner et al., 2014). Inspecting the EU as a whole, the ETS reduced CO_2 emissions by over 1 billion tons in the years 2008–2016, which corresponds to 3.8 percent of total EU-wide emissions (Bayer and Aklin, 2020). In addition, most of these studies refer to Phase II of the EU ETS, when the emissions cap and thus the prices were much lower. This delay in empirical analyses is mostly due to logistical reasons (Verde, 2020, p. 335), and it can be expected that the steep carbon price increase of the past two years has provoked further GHG emission reductions – and perhaps also affected the EU's economic performance. The current price of carbon permits within the EU ETS (87.45€/t CO_2, 25.01.2022) is close to the level that is needed to achieve net-zero emissions until 2050 (88€/t CO_2), according to a recent survey of climate economists (Bhat, 2021).

With regards to the envisioned ecological transformation of the EU economy, it is noteworthy that Zenghelis and Bassi (2014) assert that one reason for small or no competitiveness effects of the EU ETS is that complex technologies are usually not very emission-intensive and thus don't suffer strong competitiveness effects from increasing carbon prices. Referencing a study by the European Commission (2013), they argue that the EU should administer a knowledge-driven reindustrialisation process, because the European comparative advantage increasingly relies on its manufacturing of high-value-added goods. Thus, instead of hanging onto its dependence of mature products, the EU economy should further incentivise the shift to sophisticated, complex products. These knowledge-intensive goods are characterised by high quality competitiveness, while price competitiveness is less important for firms' success. In turn, this implies that energy costs are less likely to influence their overall competitiveness, which is determined mostly by labour and capital costs as well as demand. Therefore, according to the authors, the restructuring of the EU economy towards high-technology sectors will not only result in climate neutrality, but will also make the economy less susceptible to price competitiveness risks from environmental regulations.

Moreover, modelling studies predict production declines and leakage to particularly affect EITE sectors, because these firms cannot pass on the additional cost to consumers due to strong international competition. While ex-post analyses find some of these sectors to be strongly affected by carbon pricing schemes, it also becomes clear that a relocation of energy-intensive production is not a necessary consequence of differences in energy prices (Zachmann and McWilliams, 2020, p. 1). One reason for negligible competitiveness risks might be that carbon-intensive sectors generate fewer jobs and less value added than other sectors, which limits the competitiveness effects, as these are often measured in terms of employment and value added (ibid.). In addition, rather than energy prices, other factors might be more important in determining (re)location decisions, firms' performance and the structure of international trade – namely market structure, quality of the local workforce, infrastructure, finance, and political regulation (Dechezleprêtre and Sato, 2017; Rentschler and Kornejew, 2017; Zachmann and McWilliams, 2020; Zenghelis and Bassi, 2014). These factors can be subsumed under the label 'footlooseness' of industries, which is said to moderate the relationship between environmental policies and competitiveness effects by determining the acceptability of relocation (Aldy, 2017; Ederington et al., 2005). As energy and pollution abatement costs are only a small component of firms' total costs (Joltreau and Sommerfeld, 2018), their footlooseness is the more important factor – for instance, high transportation costs might prevent production from locating farther away from consumers (Demailly and Quirion, 2005). As most energy-intensive sectors are not very footloose, they do not tend to relocate in response to environmental regulation (Aldy, 2017).

Additionally, the empirical evidence suggests that many firms are able to pass through the compliance costs to consumers by increasing the goods' end prices, such that relocation is not required (Arlinghaus, 2015, pp. 18ff.). In some cases, the combination of this cost pass-through, leading to rising consumer prices, and the energy price drop resulting from the over-allocation of free allowances even enables firms to reap windfall profits (Joltreau and Sommerfeld, 2018, pp. 459f.). In this case, empirical studies cannot detect competitiveness risks if they are proxied by declining profits or production.

5.4 Ex-post analyses of the PH

Coming to a final explanation for the abovementioned discrepancy between the clusters, Joltreau and Sommerfeld (2018) affirm that a small amount of innovation has taken place which countered the negative competitiveness impacts. This leads us to scrutinise the third cluster, namely the ex-post analyses of the PH. Overall, the findings from these studies are less conclusive than in the other clusters. One unambiguous result is that environmental regulations do indeed spur green, low-carbon innovation and improve resource and energy efficiency (Calel, 2013; Calel and Dechezleprêtre, 2016; Dechezleprêtre et al., 2016; Dechezleprêtre and Sato, 2017; Ellis et al., 2019; Rexhäuser and Rammer, 2014).

Interestingly, the knowledge spillovers from green technologies appear to be significantly larger than from grey technologies. This supports the notion that the costs of environmental regulations could be compensated by directed technological change (Dechezleprêtre and Sato, 2017, p. 18). The authors of the study name two main reasons for the existence of larger spillovers: Some clean innovations have a very general and original nature and can thus be used in more varied technology fields; and since they often entail radically new inventions, green technologies have early returns to scale and steep learning curves. Furthermore, knowledge spillovers from green technologies often have a local component and thus strengthen domestic markets. More than half (52 percent) of knowledge spillovers take place in the same country as the original low-carbon innovation, which implies that in the long run, unilateral climate change policies might increase the respective country's competitiveness. When looking at the EU as a whole, 61 percent of the spillovers generated by a green innovation in one member state take place in one of the other member states instead of in non-EU countries (Dechezleprêtre et al., 2014, cited from Dechezleprêtre et al., 2016, p. 15). In addition, the authors determined that spillovers from low-carbon technologies are more economically valuable than spillovers from high-carbon technologies. This result is in line with a more recent global study which empirically supports the idea that firms researching, developing, and patenting clean innovations on average possess higher stock market value (Dechezleprêtre et al., 2021).

Nonetheless, it is unclear whether these economic gains can fully offset the additional costs incurred by the regulations: What are the consequences of these innovations for overall business performance, productivity, profitability, and international competitiveness? Here, the evidence is conflicting. On the one hand, Costantini and Mazzanti (2012) found empirical evidence for the strong version of the PH, concluding that innovation efforts made EU exports more competitive. As their analysis is based on a gravity model of export flows, it is not possible to assess whether this increase is based on stronger price or non-price competitiveness, because both might increase a country's exports. Cohen and Tubb (2018) reached the same conclusion that flexible environmental regulations raise a country's competitiveness by means of stimulating innovation. On the other hand, based on their comprehensive literature review, Dechezleprêtre and Sato (2017) contend that the increase in efficiency achieved via green innovations does not raise firms' profits to a level that suffices to offset their compliance costs. Therefore, one cannot expect an overall improvement in international competitiveness. Brännlund and Lundgren (2009) reviewed the PH on a theoretical and empirical basis and inferred that most likely, 'extra profits' from innovative activity are not large enough to neutralise or even exceed the regulation's original costs. One seminal study that also reached this conclusion by finding no evidence for the strong version of the PH is that of Lanoie et al. (2011). They found out that while climate policy does provoke investment in environmental R&D, which enhances business performance, this does not outweigh the negative effect of environmental regulations. This study measured firm competitiveness in terms of profits and in turn, one cannot distinguish between price and non-price competitiveness as drivers for competitive advantage, because profits might rise as a result of both.

Moreover, analyses of the PH revealed that the impact of environmental regulation on competitiveness differs strongly between sectors, countries, and policies (Ambec et al., 2013; Costantini and Mazzanti, 2012; Liu and Xie, 2020). The PH also postulates a dynamic process where the firms' adjustment requires some time. Thus, Lanoie et al. (2008) took on a long-term perspective on the PH and their empirical analysis confirmed that productivity might be reduced during the first years of stricter regulations and that the economic benefits of innovations will only set in after some years have passed – an idea also mirrored in the meta-analysis of Cohen and Tubb (2018).

Another striking observation made by van Leeuwen and Mohnen (2016) is that green innovations that result from political regulations do not improve labour productivity. Thus, in this study, a crucial interpretation of the link between environmental policies and increased competitiveness suggested by the PH was not evident. This is specifically interesting with regards to the expectation that there is a trade-off between emissions reduction and competitiveness, because one might assume that only such industries are competitive which are also productive in terms of emissions per labour unit. Therefore, the ecological transformation would require less productive industries that create a larger number of jobs with lower emission intensity. This study could be a hint to that direction: Green innovation might trigger resource efficiency while at the same time not increasing resource use per labour unit.

To conclude this cluster, it is necessary to differentiate between the effect that increased innovative activity has on individual firms and on sectors or the whole economy. On the one hand, companies are generally not able to make additional profits that fully compensate them for the regulatory costs. On the other hand, environmental policies may nevertheless be beneficial for the economy as a result of intensified innovation spillovers and path dependencies supporting economic restructuring (Cohen and Tubb, 2018, p. 397; Dechezleprêtre et al., 2016, p. 14).

5.5 Ex-ante analyses of the PH

Regarding the fourth and final cluster, we did not encounter any ex-ante analyses of the PH in our general searches in steps 1–5. When conducting a more specific search using combinations of 'Porter hypothesis', 'emissions reductions innovation', 'ex-ante', and 'modelling', we obtained only two studies that are loosely connected to the issue at hand. First, van Leeuwen and Mohnen (2016) came up with a 'Green innovation' structural model to test the weak and strong versions of the PH using firm level panel data – thus, this is rather an ex-post assessment. Second, Kriechel and Ziesemer (2009) theoretically modelled the PH by constructing a game of timing of technology adoption. However, this paper is purely theoretical and lacks empirical evidence.

5.6 The effect of non-policy-induced energy price variations

In the following, we present selected research analysing the effect of variations in energy prices not induced by environmental regulations, but rather by different factors. Strikingly, the unambiguous conclusion from these ex-post studies is that there is a negative association between higher energy prices and competitiveness indicators, even though it is quite small.

Using panel data covering the years 1996–2011, 42 countries, and 62 sectors, Sato and Dechezleprêtre (2015) estimated the short-run effects of sector level energy price asymmetries on bilateral trade flows and found that imports are statistically significantly impacted by changes in relative energy prices, albeit only to an economically very small extent, this impact being larger for energy-intensive sectors. However, the authors also note that in no sector, the changes in industrial energy price differences account for more than 0.01 percent of the variation in trade flows.

Employing a different approach, Rentschler and Kornejew (2017) analysed the effects of geographic energy price variations in Indonesia which is due to the country's insular geography. They also conclude that competitiveness is adversely affected by increasing energy prices since higher energy prices are associated with smaller profit margins for almost all sectors and energy types, though this long-run effect is small in size. Furthermore, they ascertain that firms use all four response mechanisms detailed above (absorption, energy efficiency, pass-on, inter-energy substitution), which is why they conclude that concern over severe long-term competitiveness losses is unfounded.

The third paper examining energy price variations in a different setting is that of Aldy and Pizer (2015). They performed a statistical analysis of historic energy prices in the US in the 1974–2009 period and their relation to production and net imports of 450 US manufacturing industries. While higher industry-specific energy prices are indeed associated with a decline in domestic production, especially for energy-intensive industries, there is no statistically significant link to an increase in net imports. Therefore, the authors contend that the production decline is a result of decreasing domestic consumption. As industry-specific energy prices can serve as a proxy for market-based carbon pricing regulation, the results indicate that these measures could potentially also lead to a production decline.

Finally, Kumar and Prabhakar (2020) investigated the export performance of 11 energy-intensive sectors of the Indian economy in response to sectoral energy price asymmetries. While a negative relationship between energy prices and sectoral exports became apparent, the impact on competitiveness is marginal: An 11 percent energy price increase is, on average, associated with a 1 percent decline of sectoral exports, where energy-intensive sectors are the most strongly affected. The authors conclude that their findings do not substantiate grave concerns about carbon leakage.

6 Discussion: trade-off or tension?

Following the presentation of the findings regarding the PHH and the PH, one is inclined to wonder which hypothesis is more in line with the evidence and thus represents reality more accurately. Indeed, it is a common scholastic undertaking to empirically compare the validity of the two hypotheses (e.g., Cheng et al., 2015; Dechezleprêtre and Sato, 2017; Joltreau and Sommerfeld, 2018; Martínez-Zarzoso et al., 2016).[5]

When taking all clusters into consideration, the empirical evidence on the relationship between trade competitiveness and environmental policies appears inconclusive, which can be traced back to several factors. First, studies differ in the indicators they employ to measure policy stringency. Second, the temporal dimension differs strongly between studies. Third, the idea of competitiveness is often vague and indicators are diverse, targeting firm level to country level competitiveness. Lastly, there is no consistency in empirical methods used. Nonetheless, specific tendencies can be ascribed to the clusters, as has been illustrated above. In particular, most literature reviews make a strong differentiation between ex-ante and ex-post studies, arguing that the former usually do detect competitiveness risks and carbon leakage, while the latter do not. However, the present literature review evidences that this division is over-simplified and disregards several ambiguities in the literature. First, while ex-ante assessments do expect carbon leakage to take place, environmental protection has only small effects on economic competitiveness that are mostly concentrated in vulnerable sectors. Second, while the relationship between the EU ETS and most carbon taxing systems and different measures of competitiveness and carbon leakage is statistically non-significant, other regulations and general energy price variations do have small effects in ex-post assessments. Third, while policies to reduce emissions do incentivise firms to innovate and improve their efficiency, the empirical evidence does not suffice to conclude that the overall outcome for firms is positive.

Due to the fundamental limitation underpinning a comparison of studies of the PH and the PHH – the fact that their guiding questions, methods, and perspectives are incongruent to a degree where they are incomparable – and, in addition, as a result of the ambiguities even within the clusters, it is not feasible to make a sound assessment of which one is more likely to be *correct*. Despite this constraint, the present analysis suggests important inferences regarding the key question: Are carbon pricing policies and economic competitiveness characterised by a tension or a trade-off?

This framework invites us to take a step back and reconsider our research interest. It goes beyond a dualistic view about which perspective is the *right* one and allows for the recognition of interlinkages and synergies between policy objectives, acknowledging that the relationship between carbon pricing policies and economic competitiveness depends on a variety of factors. To achieve public approval and efficiency of political measures at the same time, policy coherence and consistency in policy instruments are paramount (Hafele et al., 2021). This, in turn, requires a nuanced understanding of the association between the policy objectives in question.

To answer the key question, Table 3 visualises the translation of study findings reported in section 5 into the framework that differentiates between synergies, trade-offs, and tensions. First, can we rule out that carbon pricing and economic competitiveness are characterised by synergetic effects – i.e., that the attainment of one policy goal promotes the attainment of the other? Considering the concerns that dominate the public discourse around these political instruments, one would presume that the answer is yes. Speaking in terms of the reviewed hypotheses, a synergetic relationship would correspond with the literature finding evidence for the PH and not for the PHH. In that case, carbon pricing policies would spur innovation to a degree where the net impact on economic prosperity is positive. This is not supported by the findings reported above: While there is evidence for the weak version of the PH, the strong version does not seem to be in line with the findings. Moreover, one can generally not conclude that there is no empirical evidence for the PHH, since e.g. ex-ante analyses quite clearly show competitiveness risks resulting from carbon pricing.

The case for the relationship being a trade-off, implying that the realisation of one policy objective leads to the deterioration of another, is equally strong. A trade-off is in line with the assumptions of the PHH, contending that car-

[5] We recognise the impossibility of empirically verifying a theoretical hypothesis, and emphasise that the aim of this paper is neither to falsify nor to verify one or the other, but rather to investigate the roots and justification of their discursive power (Popper, 1959).

Table 3: Conversion between the two frameworks

	PHH	PH
Synergy	✗	✓
Tension	✓	✓
Trade-off	✓	✗

bon pricing regulations unavoidably cause carbon leakage and a decline in competitiveness. However, the findings regarding the PHH are rather ambiguous and only ex-ante analyses have consistently found negative competitiveness effects of carbon pricing schemes. Similarly, it is noteworthy that research on the PH demonstrates that a somewhat positive relationship between the two policy goals is observable, because the policies have caused innovation which partly countered the negative competitiveness impacts. Moreover, the empirical evidence suggests that significant knowledge spillovers have taken place in low-carbon sectors.

A tension between two policy objectives implies that although they do not necessarily reinforce each other, it is possible to design a policy mix that ensures "that the improvement of one objective does not come at the detriment of another" (Hafele et al., 2021, p. 3). This definition finds support in the empirical research on the PHH and the PH. On the one hand, the findings regarding the PHH demonstrate that the trade-off between the two policy goals neither has general validity, since ex-post analyses generally show no significant negative relationship, nor that significant trade-offs are unrealistic and impropable, because ex-ante analyses unambiguously foresee competitiveness risks. On the other hand, several studies found evidence for the weak version of the PH, implying that it is equally possible for such regulations to have positive effects. Designing a suitable policy mix can therefore turn the trade-off predicted by the PHH into a tension by harnessing the regulations' potential for transforming industries in a future-oriented manner, as suggested by the PH.

The quality of the tension becomes clearer when we reconsider our ambitions about economic competitiveness. While the previous discussion targets the economy as a whole, the literature review demonstrated the need to acknowledge persistent sectoral heterogeneity in the results and to distinguish between the firm and sectoral level. The concept of comparative advantage and its application to the PHH forecast a specialisation in clean, less emission-intensive industrial sectors. Both streams analysing this hypothesis are in accordance with that prediction, as ex-post studies do detect some carbon leakage and competitiveness risks in EITE sectors and ex-ante modelling approaches further underline differing effects between sectors. In addition, investigations of the PH confirm that while individual firms' economic performance will most likely not be impacted positively, overarching benefits for environmentally friendly sectors are a plausible product of innovative activities and subsequent spillover effects. Taken together, these considerations imply that policymakers should shift their focus from the concern over whole-economy competitiveness losses to the opportunities for the ecological transformation of the economy by strengthening future-oriented high-technology sectors. This emphasis on less emission-intensive production can attract price-competitive businesses manufacturing complex and knowledge-intensive goods, compensating the initial loss in price competitiveness incurred in EITE sectors. Meanwhile, international diplomacy and suitable measures must make sure to avoid carbon leakage to unregulated countries, as this would undermine the impact of climate mitigation measures.

To summarise, even though the stand-alone research results are ambiguous and difficult to compare, putting the puzzle pieces together in a different framework results in a clearer picture. It is neither true that the policy aims of competitiveness and climate change mitigation automatically positively reinforce each other nor that they are mutually exclusive. Instead, the empirical evidence suggests that carbon pricing regulation and economic competitiveness can be reconciled under specific circumstances, which must be provided by a coherent policy mix that takes climate change mitigation seriously while addressing possible negative side-effects.

7 Conclusion

Oftentimes, the discourse around GHG reductions constructs a dichotomy between climate change policies and competitiveness, asserting that countries with more stringent environmental regulations suffer from comparative disadvantages and carbon leakage. However, the present literature review finds no conclusive evidence for a negative effect of carbon pricing policies on international competitiveness.

Empirically, this is supported by the fact that the ex-post literature on the consequences of existing regulations shows no significant adverse effects on competitiveness measures and carbon leakage on the country level. Nevertheless, the non-existence of competitiveness risks can in some cases be traced back to the design of the regulations currently in place; specifically, available data only captured the effects of relatively low allowance prices and taxes as well as mechanisms containing significant exemptions and rebates. While firm level emission reductions of regulated entities are nevertheless apparent, the scope of economy-wide reductions is relatively modest. Consequently, it is unclear whether more ambitious regulations will involve higher competitiveness risks. Ex-ante simulations unambiguously predict negative effects on competitiveness to occur, such that that these concerns should be taken seriously when considering future policies. However, there is also empirical evidence suggesting that climate policies induce low-carbon innovation, which has the potential to increase competitiveness.

Thus, whether stricter environmental regulation will lead to competitiveness losses in the future largely depends on the specific circumstances and implemented policy mixes. The present analysis suggests that with the right policy design, market-based climate change mitigation policies can be implemented without competitiveness losses. In other words, while there is clearly a tension between carbon pricing and competitiveness, the present analysis revealed no definitive evidence for a strict trade-off between the two objectives.

Against the theoretical backdrop of this study, the literature review confirmed that there is no common understanding of competitiveness. Many papers solely inspect outcomes such as exports or profits, thereby neglecting the fact that these figures are determined by two different features: price and non-price competitiveness. While carbon leakage and comparative disadvantage are relevant mostly with regards to short-term price competition, strict environmental policies may generate a long-term non-price advantage in future technologies and products. This is fundamentally important for political decision making as non-price competitiveness advantages such as early-mover advantages (Porter, 1990) have the potential to mitigate negative price competitiveness impacts of strong environmental regulation: If well-designed environmental policies incentivise regulated firms to innovate and increase their energy efficiency, the targeted industry's or country's overall competitiveness will rise as well. Despite its relevance for the interrelation in question, the link between non-price competitiveness and environmental regulation remains underinvestigated in the literature.

Furthermore, we want to stress another limitation of the literature we surveyed. Even when employing very broad terms for the keyword search, we predominantly found studies addressing emission reductions through one channel, namely price-based market mechanisms as explained in section 1. This focus on market-based interventions is problematic because it excludes policies that could be similarly effective, such as phasing out subsidies to environmentally harmful industries or imposing prescriptive regulations on the supply side by specifying quality standards for end products (Taylor, 2021). Both types of regulations might prove to be valuable additions to the policy strategy addressing the climate crisis and underline our central conclusion that the right policy mix can mitigate climate change without necessarily risking competitiveness losses. Thus, these policies should be integrated into economics research on their effectiveness and possible competitiveness effects.

It is essential to bear in mind that becoming carbon neutral is an uncontested economic necessity and that it will either happen by political strategising or by disaster. This study suggests that there is a way to design environmental policies in a way that mitigates the risk of comparative disadvantages. Moreover, we conclude that the aims of competitiveness and climate change mitigation are compatible: In the future, only climate neutral industries can be competitive industries, and the EU's aspiration to be a technology leader is aligned with the need to politically guide the green industrial transformation. Hence, the political and academic debate should move beyond the question whether climate policies are associated with competitiveness risks and instead focus on how environmental policies can be implemented with the speed and scale needed to avoid climate breakdown.

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