The impacts of environmental regulations on competitiveness

Forthcoming, *Review of Environmental Economics and Policy*

Antoine Dechezleprêtre and Misato Sato

Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science

Abstract

This article reviews the empirical literature on the impacts of environmental regulations on firms' competitiveness, as measured by trade, industry location, employment, productivity and innovation. The evidence shows that environmental regulations can lead to statistically significant adverse effects on trade, employment, plant location and productivity in the short run, in particular in pollution- and energy-intensive sectors, but that these impacts are small in comparison to general trends in production, and transitory. However, the small average impacts across the economy might hide large effects on small subsets of companies. At the same time, there is ample evidence that environmental regulations induce innovation activity in cleaner technologies, but the benefits brought forward by these innovations do not seem to be high enough to outweigh the costs of regulations for the regulated entities. More research is needed to precisely identify which sectors or groups of companies are particularly exposed to competitiveness effects, and for these activities where pollution leakage and competitiveness issues represent a genuine risk, to determine the best policy options available to prevent adverse impacts on trade and investment whilst avoiding the creation of new distortions and maintaining the incentives to develop new abatement technologies.

Acknowledgements

We would like to thank Milan Brahmbhatt, Raphael Calel, Baran Doda, Damien Dussaux, Carolyn Fischer, Matthieu Glachant, Colin McCormick and Dimitri Zenghelis for helpful comments on an earlier version of the paper. We are grateful to three anonymous referees for very constructive comments and suggestions. Financial support has come from the Global Green Growth Institute, the Grantham Foundation for the Protection of the Environment, the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 308481 (ENTRACTE) as well as the UK Economic and Social Research Council through the Centre for Climate Change Economics and Policy.

1. Introduction

Ever since the first major environmental regulations were enacted in the 1970s, there have been concerns about their potential impacts on the competitiveness of polluters. In a world characterised by increased integration in trade and capital flows, there is concern that large differences in the stringency of environmental policies between countries and regions could induce pollution intensive activities to gravitate towards regions with lax regulation, thus altering the spatial distribution of industrial production and the subsequent trade flows internationally. Countries leading the action against environmental degradation worry that their lead might come at the cost of disadvantaging their own producers in the face of global competition. The ongoing dilemma of managing the balance between protecting the environment and minimising the economic impacts of environmental regulation has in recent years become more acute with the Great Recession combined with rising competition from emerging economies.

The economics literature offers two differing views on the effects of asymmetric environmental policies on the performance of companies competing for the same market. First, the pollution haven effect based on trade theory predicts that more stringent environmental policies increase compliance costs and shift pollution-intensive production to low-abatement cost regions, such that regulated firms will lose out in competition as a result. This could happen, for example, if those firms reduce profit margins to absorb the regulation-induced increase in marginal costs, or if regulatory costs are passed onto product prices and export competitiveness suffers as a consequence. If businesses expect differences in regulation to persist, polluting activities may agglomerate in lax-regulation countries and create pollution havens, thus causing policy-induced pollution leakage. This problem is particularly troubling for global pollutants such as carbon dioxide because it means that on top of economic impacts on domestic firms, the effort of abatement is to some extent offset by increasing emissions in another region.

In sharp contrast, the Porter hypothesis postulates that more stringent policies can actually deliver a net positive effect on the competitiveness of companies. The argument here is that policies promote cost-cutting efficiency improvements which in turn reduces or completely offsets regulatory costs, and foster innovation in new technologies that may help firms achieve international technological leadership and expand market share.

Competitiveness issues are particularly relevant in the area of climate and energy, where ambitious regulations will be necessary over the next decades to deliver the deep emission reductions needed to meet policy goals, but different regions are expected to take action at different speeds and industrial emissions are heavily concentrated in a few energy intensive sectors. First-mover countries face pressure from domestic industry lobby groups and the public to minimise the adverse effects on competitiveness in a globalising world where there is fierce competition to gain export share, attract new investments and retain jobs. Reflecting these political pressures, compensation measures intended to alleviate potential competitiveness effects are entrenched in the design of many policies, for example energy tax reliefs and exemptions, levy reductions, reduction in other payments (for example, employers' pension contributions) or free allocations of permits in emissions trading schemes.

The potential distributional consequences of environmental regulations, and the questionable impact of compensation measures on the effectiveness of these policies, have led to a vast and growing body of research attempting to objectively quantify the effects of uneven environmental policies on many aspects of competitiveness, including trade, industry location, employment, productivity and innovation. Isolating these effects has proved a challenging task, given the multitude of factors that influence firms' operational and investment decisions such as availability and costs of raw materials, transport costs, market structure and fixed plant costs. This paper reviews the recent empirical literature, updating the first major review on the topic by Jaffe et al. (1995), which concluded that there is relatively little evidence to support the idea that environmental policies lead to large losses of competitiveness. Over the last two decades, empirical research in this area has benefited from a growth in the number of environmental policies worldwide, and from the availability of high quality data, especially at the firm and facility level, that allows assessing the economic effects of asymmetric environmental policies. Our aim is to critically assess the vast evidence to ascertain where, if any, the conclusions have changed. By consolidating the evidence, we hope to elevate the surrounding political debate.

In the context of environmental policies, competitiveness[1] effects occur as a result of differences in regulatory stringency[2] applied across entities (e.g. firm or sector) that are competing for the same market. For example, some firms might be regulated while others are exempt, some sectors might face stricter pollution standards than others, or environmental stringency may vary across jurisdictions. Environmental regulations generally incite polluting facilities to undertake abatement activities, which can trigger changes to the firm's output, pricing and productive investments and affect their economic performance. These general effects of regulation are necessary but not sufficient conditions for competitiveness effects, which arise due to asymmetries in policies across competing entities. There are no concerns of competitiveness effects if two firms are exposed to identical regulation, or if two firms face different regulations but do not compete with each other.[3] Hence, the “competitiveness effects from environmental policies” that we discuss in this paper can be clearly distinguished from more general impacts of environmental policies on businesses.

Since competitiveness concerns stem largely from differences in environmental regulation across countries, we primarily review studies that empirically exploit cross-country differences in environmental stringency. Studies exploiting differences between smaller-scale jurisdictions (typically cross-county differences in the US) are also included where informative. Importantly, the scope of this review covers *ex post* evaluation studies only and excludes *ex ante* modelling studies, which have been recently reviewed by Carbone and Rivers (2014). We also focus on environmental regulations that affect the manufacturing sector and target industrial emissions, which are at the centre of most competitiveness debates.[4]

The paper is organised as follows. We start by explaining how competitiveness effects occur in the context of environmental regulation, and how they are measured. We then turn

[1] ‘Competitiveness’ is a term that is often used but ill-defined. In general, it refers to the ability of a firm or sector to survive competition in the market place, grow and be profitable (Bristow 2005). Some concepts discussed in the literature include the ‘ability to sell’ (which reflects the capacity to increase market share), ‘ability to earn’ (the capacity to increase profit), ability to adjust and ability to attract (see e.g. Berger 2008 for an overview).

[2] Here we use the term “policy stringency” to describe a general level of policy ambition. In practice, measuring relative policy stringency across different forms of regulation and enforcement regimes is far from straightforward as is discussed below.

[3] Note, moreover, that if there are no regulatory differences across companies, it is not possible to establish a counterfactual scenario (what would have happened had the policy not been implemented) against which to evaluate the impact of a given regulation.

[4] Regulations on fishing, agriculture, forestry, mining, waste, sometimes explicitly directed at protecting environment and human health, are not covered.

to a review of the existing evidence. We first discuss the impact of relative environmental stringency on trade, industry location and employment, then move onto the effects on productivity and innovation which could also impact firms' competitiveness. We conclude by summarizing what advances have been made to the evidence base on competitiveness and identifying priorities for future research.

2. Understanding the regulation-competitiveness relationship

How do competitiveness effects occur?

Environmental regulations tend to impose costs on businesses. For example, the European Union Emissions Trading System (EU ETS), which regulates carbon emissions of around 14,000 installations across Europe, is estimated to have increased average material costs (including fuel) for regulated firms in the power, cement and iron & steel sectors by 5% to 8% (Chan et al. 2013).[5] Regulatory differences across jurisdictions can thus induce changes to relative costs. This could arise from straightforward differences in *direct* costs. Firms may, for example, be required to pay a higher NOx emissions tax or they may be subject to a stricter standard that requires expensive NOx control equipment and hence face higher abatement costs. Relative costs rises could also result from higher *indirect* costs, due to policy induced changes to input costs, for example, higher electricity costs due to a carbon tax.

Pasurka (2008) finds evidence that differences in environmental stringency across countries induce important differences in pollution abatement costs. Comparing across nine countries in Europe, North America and Asia, the share of manufacturing capital expenditure assigned to pollution abatement ranged between 1 percent (Taiwan) and 5 percent (Canada) in 2000. In terms of sectoral variation, abatement costs are typically higher for pollution intensive industries such as pulp and paper, steel, and oil refining. In the US, each of these sectors spent approximately 1% of their shipments to comply with

[5] In addition to affecting marginal and average costs of production, environmental regulations can also affect entry and investment costs for companies. Ryan (2012) estimates the impact of the 1990 US Clean Air Act Amendments (CAAA) on the cost structure of the cement industry and finds the marginal (variable) costs remained unchanged but the average sunk costs of entry increased, with the costs of building a greenfield facility increasing by $5 million to $10 million due to the rigorous environmental certification and testing required by the Amendments.

environmental regulations in 2005 while the average for all manufacturing plants was 0.4% (Ferris et al, 2014). Importantly, differences in relative costs may also arise from the nature and design of regulation and not only the stringency (Irlado et al., 2011), in particular because of the degree of uncertainty associated with different instruments (Goulder and Parry, 2008).

Table1. Competitiveness effects from environmental stringency differences

1st order effect	2nd order effect	3rd order effects			
Cost impacts	Firm responses	Economic outcomes	Technology outcomes	International outcomes	Environ-mental outcomes
Changes to relative costs (direct and indirect costs)	- Production volume - Product prices - Productive investments	- Profitability - Employment - Market share	- Product innovation - Process innovation - Input saving technologies - Total factor productivity (TFP)	- Trade flows - Investment location - Foreign direct invest-ment (FDI)	- Pollution leakage

Firms can respond in a number of ways to changes in costs, through decisions on output, pricing and productive investment (see Table 1). A firm may for example absorb the cost increase by reducing output, employment or productive investments, or may choose to pass on the marginal cost increase to product prices to maintain profitability, as has been observed in the case of electricity prices in response to the EU ETS carbon prices. Reflecting pollution abatement costs in product prices is desirable and necessary to drive demand-side switch away towards cleaner products. However, not all firms have pricing power if they operate in globally competitive markets, for example in commodities like gasoline or aluminium.

Different policies will trigger different responses by firms, giving rise to different competitiveness outcomes. According to the pollution haven view, if competing companies differ only in terms of the environmental policy stringency they face, then those facing relatively stricter regulation will lose out. Higher regulatory costs could, for example, crowd out productive investment in innovation or efficiency improvements and slow down productivity growth. If increased regulatory costs are passed through to product prices, in fiercely competitive product markets, distortions in trade could occur, as product prices of countries with relatively strict regulation will rise more and lose market share to those producing pollution intensive exports more cheaply. If environmental regulatory differences are expected to last, companies' decisions on new production facilities location or foreign direct investment may also be influenced, so that pollution intensive sectors may gravitate towards countries with relatively lax policies, creating pollution havens.

From a more dynamic perspective, however, more stringent policies could trigger greater investment in developing new pollution-saving technologies. If these technologies induce input (e.g. energy) savings which would not have happened in the absence of policy, they can offset part of the compliance costs. Porter and van der Linde (1995) go further in arguing that environmental regulation can even lower overall production costs and enhance the competitiveness of firms, a proposition that has become known as the “Porter hypothesis”. This can occur if cleaner technologies lead to higher productivity, input savings and innovations, which over time offset regulatory costs, improve export performance and market share. For example, in Mohr (2002), the existence of learning externalities prevents the replacement of an old polluting technology by a new, cleaner and more productive technology, as firms have a second-mover advantage if they wait for someone else to adopt. The introduction of an environmental regulation induces firms to switch to the new, cleaner technology. This simultaneously improves environmental quality and eventually increases productivity. A related argument postulates that countries can generate a first-mover advantage to domestic companies by regulating pollution sooner than others and lead domestic firms towards international leadership in clean technologies that are increasingly in demand globally. Ambec et al. (2013) gives a complete overview of the theoretical justifications for the Porter hypothesis that have been proposed in the literature.

Assessing competitiveness effects empirically

Since Jaffe et al. (1995), empirical analysis on the competitiveness effects of environmental regulation has benefited from the general trend in greater data availability. Issues around unobserved heterogeneity between firms (whereby firms unobserved characteristics might be correlated with both regulatory stringency and the outcome measure, e.g. productivity) and aggregation bias stemming from the use of sector-level data (Levinson and Taylor 2008) have been largely overcome with better estimation methods enabled by increasingly disaggregated panel data sets over longer time horizons.

There are a number of outstanding challenges facing credible empirical analysis on the competitiveness impacts of environmental regulations. First, an accurate measure of environmental stringency is necessary to construct a control group, capturing what happens in the absence of a policy or in the event of a weaker policy, against which to evaluate the impact of a given regulation. However, the complex and multidimensional nature of environmental regulation is likely to make the measurement of relative stringency fraught with measurement error. A popular choice has been to proxy stringency by environmental outcome (pollution level) or measures of compliance costs as a share of value added, typically using data on pollution abatement and control expenditures (PACE) which has been collected since the 1970s for the US and since the 1990s in Europe and Asia Pacific countries. Yet PACE is far from an ideal measure. Because the production level is used as a denominator, it is unlikely to be exogenous. Being based on survey data, PACE is not readily comparable across countries. PACE data do not account for how compliance costs may impact market competition (Ryan, 2012; Sweeney, 2015). The data also exist only for surviving firms, hence any impacts on firms that exit due to the environmental regulation would not be captured when using PACE as a proxy for stringency.

There are many alternative measures used in the literature - including environmental or energy tax revenue, renewable energy capacity, recycling rates, legislation counts and composite indicators - but all have shortcomings as discussed in Brunel and Levinson (2013) and Sato et al. (2015). Price-based policies such as emissions trading with observable price levels are seemingly easy to compare, yet this is complicated by differences in the system set-ups including sector coverage and exemption rules, such as differences in free allowance allocation provisions. Such provisions not only affect the level of policy stringency but also alter incentives and influence the behaviour of firms[6], yet few measures of stringency take account of such compensation provisions.

A second challenge to empirical analysis on competitiveness impacts of environmental regulation is that policies could be endogenous for a number of reasons (Levinson and Taylor 2008). For example, it may be correlated with the unobserved determinants of trade (e.g. supply chain linkages or other firm specific factors, political institutions, the stringency of other regulations like labour standards). Governments could also strategically set

[6] See Branger et al., (2015) for an analysis of the influence of free allocation rules under the EU ETS on operational, investment and trade decisions as an example.

stringency levels for example by exempting key export sectors from environmental regulations suggesting the possibility of reverse causality when using sectorally aggregated data. Insights from the new economic geography literature also suggest that bias in inference could result from the lack of proper treatment of agglomeration effects or geographical spillovers, if the location of polluting firms is influenced by other firms in that location.[7]

Lastly, due to the complex economic adjustment to regulation (see Table 1) and the lack of clarity on the underlying theory, there is no one established test or measure of competitiveness effects of environmental regulation. As a result, the literature uses a vast variety of outcome measures that might be linked to competitiveness including effects on trade[8], FDI, output, employment, pricing (cost pass through), productivity and innovation activity. Estimates of the effect of policies on these different aspects are usually derived using reduced form rather than structural equations.

3. Environmental regulation, outsourcing and offshoring

The potential impact of environmental policies on international trade and investment location and the employment consequences of these effects has been a central focus of the competitiveness debate. Analogous to this are political economy concerns around the abuse of environmental policy by governments as an implicit trade barrier to circumvent international free-trade agreements. We start by consolidating the evidence on these.

3.1 Trade impacts

[7] A particularly appealing source of exogenous variation in environmental regulatory stringency across US counties is the federal designation of counties into "attainment" or "non-attainment" status depending on local air quality for various pollutants. Counties in nonattainment face much stricter environmental regulation. Being federally mandated, this status is unlikely to be related to differences in tastes, geographic attributes, or underlying economic conditions across counties. Moreover, local pollution levels depend heavily on weather patterns (in particular wind and precipitation) which are unlikely to be systematically related to local manufacturing sector activity (Greenstone et al., 2012).

[8] Jaffe et al. (1995) argued that the ideal measure to study competitiveness would be the effect of relative policies on net exports. With aggregated sector level data, this is a theoretical measure because it is impossible to measure the reduction in net exports 'before' adjustments in the exchange rates holding real wages and exchange rates constant. Only the change after the adjustment is observed in practice. However, it is less of a problem when using data at a disaggregated level, because changes to trade are unlikely to affect exchange rates.

Many of the earlier studies tested the Pollution Haven Hypothesis (PHH) and Effects (PHE)[9] by looking at the overall effect of international trade on the quality of the environment. Grossman and Krueger (1995) for example, asks how openness to trade affects the environment through its effects on the scale of economic activity, sector composition and technology adoption and found limited empirical evidence that trade made developing countries dirtier.[10] Antweiler et al. (2001) finds that across 43 countries studied, international trade is in fact beneficial to the environment (as measured by sulphur dioxide concentration) because the increase in economic activity (scale effect) is offset by changes in technology as well as in the composition of output in the economy. One explanation is that higher price of capital in low-income countries offsets their 'advantage' of having lax environmental policies, because pollution intensive industries are also capital intensive. Levinson (2010) instead asks if the composition of US imports has shifted towards more polluting goods whilst taking account of intermediate inputs. He uses a descriptive statistics approach to examine the composition of US imports and exports between 1972 and 2001, and finds that the US imports has increasingly shifted away from pollution intensive goods. He argues this does not contradict the PHE (as the green shifts in imports may have been smaller without environmental regulations) but suggests that if there has been a pollution haven effect, it is likely to have been overwhelmed by other forces. Subsequent analyses find that international trade has a modest impact on pollution (e.g. McAusland and Millimet 2013).

A number of studies have assessed more directly whether environmental regulation causes changes to trade flows, using a variety of relative environmental stringency measures, PACE being a popular choice. Ederington and Minier (2003) for example uses a panel of US manufacturing industries at 4 digit SIC level from 1978-1992 and finds net imports rise with higher PACE which is treated as an endogenous variable (using an instrumental variables approach) suggesting that policy stringency is indeed determined strategically by governments. Ederington et al. (2005) use the same data but takes account of key factors that limit the geographical mobility of economic activity such as transportation costs, fixed plant costs and agglomeration economies of an industry and find that the pollution haven effect is difficult to detect in capital intensive industry. They

[9] The Pollution Haven Hypothesis is that trade liberalisation will lead to a shifting of pollution intensive industries from stringent regulation countries to lax regulation countries. The Pollution Haven Effect instead occurs if relative environmental policies, at the margin, influence trade and investment location decisions. See Copeland and Taylor (2004) for a detailed presentation of the pollution haven arguments.

[10] For a review of earlier studies see Jaffe et al (1995) and Taylor and Copeland (2004).

point out that quantifying average effects on competitiveness across all sectors understates the effects of regulatory differences on 'footloose' sectors. Levinson and Taylor (2008) instead uses a panel for 1977-86 and a fixed effects model and find that a 1% increase in PACE in the US is associated with a 0.4% increase in net imports from Mexico and a 0.6% increase from Canada. The model accounts for unobserved sector characteristics that are correlated with regulation and trade[11], unobserved foreign pollution regulation levels, and aggregation bias in sectoral data (due to changes to industry composition). Levinson (2010), however, points out that Levinson and Taylor (2008)'s result does not in fact show that higher PACE causes higher imports. Rather, it shows that imports are rising in sectors where the stringency relative to the rest of the world is increasing more over time.

Identifying the effect of the EU ETS – to date the largest carbon market in the world – on trade is difficult with sectoral data because it is not possible to separate the installations that are covered or exempt from the carbon prices within a given sector.[12] Branger et al (2016) uses time-series analysis to tests the hypothesis that high EU ETS carbon price during 2004-2012 increased net EU imports of cement and steel, but finds limited evidence. Two papers use an alternative approach, by exploiting the historic variation in energy prices to estimate the effect of carbon price differences on trade, taking advantage of the fact that carbon prices essentially work by increasing energy prices. Aldy and Pizer (2015) use state-level variation in industrial energy prices and fuel composition to estimate how production and net imports change in response to energy prices, with a detailed panel of US state level manufacturing production covering 450 sectors between 1974 and 2005. They find that the effect of energy price on net imports is statistically indistinguishable from zero when averaging across all sectors, but find evidence that both net imports and production are more sensitive to energy prices in sectors with higher energy intensity, including iron and steel, chemicals, paper, aluminium, cement and bulk glass. The

[11] When using data from only one country, the effects of environmental regulation on trade can only be estimated by comparing sector level net imports as a function of industry characteristics, however, the variation in pollution abatement expenditures across sectors may reflect unobserved heterogeneity rather than relative stringency.

[12] A substantive body of literature on carbon leakage explores the potential environmental consequences of the effects of regulatory differences on trade. This literature mostly uses ex-ante modelling approaches and is hence excluded from this review (See Branger and Quirion (2014) for a review). The carbon leakage literature can be distinguished from the literature on trade embodied carbon (e.g. Peters et al 2011), which quantifies all embodied emissions in trade regardless of whether they are induced by asymmetric policies or other underlying economic factors that influence trade patterns.

magnitude of the effect is small, however, at 0.1-0.8% increase in net imports for these energy-intensive industries, from a hypothetical \$15 per ton CO_2 price imposed unilaterally in the US. Sato and Dechezleprêtre (2015) instead specifies an energy price gap between two trading partners and examines its influence on bilateral trade flows using a panel dataset with 42 countries and 62 manufacturing sectors over 1996-2011 and a gravity model framework. They find on average that a 10% increase in the energy price gap increases bilateral imports by 0.2%, and that overall, energy price differences explain 0.01% of the variation in trade flows.[13]

In sum, the recent evidence seems to broadly support the existence of a Pollution Haven effect, as imports of pollution- or energy- intensive goods increase in response to tighter regulation, but these effects tend to be small and concentrated in few sectors. In general, the effect of relative stringency on trade flows is overwhelmed by other determinants of trade such as skilled labour availability, access to raw materials and transport costs.

3.2 Location of production and foreign investment

Exploring the effects on new plant location as evidence on pollution havens has been an active area of empirical investigation in parallel to trade, in part motivated by the environmental concerns around 'race to the bottom' if governments competing for FDI strategically undercut each other's environmental standards.

Earlier studies exploiting within-country variation in environmental standards across US states in the 1970s and 1980s found little systematic effect on the location of new firms. Using the 1982 establishment-level Census of Manufacturers data, Levinson (1996) examines the effect of six different measures of environmental stringency and finds that interstate differences in environmental regulations do not systematically influence the location choice of new manufacturing plants. Henderson and Millimet (2005) examines the impact on state-level aggregate output between 1977 and 1986 using the Levinson index[14] and finds no effect. In sharp contrast, three studies using more disaggregated data for New York State between 1980 and 1990 find that county-level differences in the 1997

[13] The more recent time-frame of these studies enables the results to be interpreted in the post 2000 context which saw rapid growth in global trade particularly between industrialised countries and emerging economies such as China when competitiveness concerns have become more acute.

[14] This is a state-year level industry adjusted index of environmental stringency based on pollution abatement costs.

CAAA regulatory status have very large statistically significant effects. Being a strictly regulated "nonattainment" county relative to an “attainment” one decreases the flow of relocating plants by nearly 63% (List et al. 2003) and decreases the expected flow of new dirty plants by 44-61% or 150-600% depending on the estimator used (List et al. 2004). Comparing the results from these inter and intra-state studies from the US suggests that studies with smaller geographical scope tends to find stronger effects, possibly because smaller areas tend to have less variation in other determinates of production location. Indeed Millimet (2004) finds with the New York State dataset that the effect of stricter regulation is spatially heterogeneous and varies systematically on location specific attributes such as unemployment levels.

Examining the relationship between environmental policy and international FDI flows has also been an active area of research, but the evidence is highly mixed. List et al. (2004), finds very high effects of environmental stringency on new plant births for domestic companies' plants, but no effect on locational choice in the case of foreign owned pollution intensive plants. Eskeland and Harrison (2003) find little evidence that stringent regulation in the US (using energy intensity as a proxy) gives a push for outbound investment to Mexico, Cote d’Ivoire, Morocco and Venezuela. Dean et al. (2009) examine inward FDI in China between 1993 and 1996 and finds that equity joint ventures in polluting industries are generally not attracted by weak environmental standards. In contrast, Keller and Levinson (2002) find using US state level data that during 1977-1994 a 10% increase in relative manufacturing pollution abatement cost is associated with a 0.79% fall in manufacturing FDI, and a 1.98% fall in the chemical industry FDI more specifically. Work by Fredrikson et al. (2003) and Millimet and Roy (2015) also find that environmental regulation plays a role in the locational outcome of US inbound FDI and both highlight the importance of treating environmental regulation as endogenous in this type of estimation, as influx of FDI can lead to a change in environmental regulation.

Hanna (2010) instead uses a panel of firm level data to test if the exogenous changes in regulatory status under the CAAA caused US multinational firms to increase their foreign assets and foreign output in the 1980s to 1990s. In addition to avoiding reverse causality issue, using disaggregated data allows controlling for unobserved heterogeneity at the firm level as well as industry trends, thus goes a long way to tackle omitted variable bias. She finds that counties falling under nonattainment caused their resident multinational firms to increase foreign assets by 5.3% and foreign output by 9%.

When it comes to establishing whether countries use environmental regulation strategically to attract FDI, a major difficulty is measurement error arising from the lack of measures that accurately capture international variability in environmental stringency. Xing and Kolstad (2002) uses SO_2 emissions, but this is likely to capture only one component of environmental stringency and bias estimates towards affecting energy intensive industries. Indeed they report that across the 22 countries studied between 1985 -1990 and in just two of the six sectors studied (chemicals and primary metals), a decrease in SO_2 emissions by 1% is associated respectively with a 0.27 and 0.20 million dollar increase in new investments from US multinational companies in these sectors, which is small compared to the total outflow of US FDI ($4 billion in 1991 in the chemicals sector). Wagner and Timmins (2009) use an index of environmental stringency and enforcement published by the World Economic Forum (WEF), based on interviews with business executives, to study the effect on German FDI across 163 countries and 23 industrial sectors. They find that in the chemicals sector, a country reducing environmental stringency by one standard deviation (for example, moving from Austria's stringency to Slovakia's) would increase German FDI by 122,000 euros per year, which corresponds to almost two thirds of the standard deviation of annual investment flows in the chemical industry. However, no effects are found in the other sectors studied. Kellenberg (2009) also using the WEF index and accounting for endogeneity using spatially lagged covariates, finds strong evidence that countries with lax environmental policy enforcement (more than stringency) attracted more US multinational firms' production. Specifically, they find that for the top 20th percentile countries in terms of US multinational affiliate value added from 1999 to 2003, 8.6% of the value added growth was attributed to falling environmental policy stringency. In contrast, Raspiller and Riedinger (2008) and Ben-Kheder and Zugravu (2012) experiment with a number of different measures of stringency but do not find systematic evidence for French firms' FDI activity.

Overall, the empirical validity of the PHE as far as foreign investment is concerned remains a contentious one. A meta-analysis of eleven studies in this literature by Jeppsen et al. (2002) reported that estimates are highly sensitive to the empirical specification, data, the definition of the regulatory variable, included control variables and geographical coverage. This appears still to be the case.

3.3 Consequences on employment

Given that the offshoring of pollution-intensive production is the corollary of the offshoring of pollution-intensive jobs, discussions about the impacts of environmental regulations on competitiveness are often framed as 'jobs versus the environment' (Morgenstern et al., 2002), particularly in regions where falling employment in manufacturing has been an important political issue.[15] At the macroeconomic level, in the long run, environmental regulations might simply induce a *substitution* between polluting and non-polluting activities, so that the impact of this substitution on net employment is a priori undetermined and likely small because of general equilibrium effects (Hafstead and Williams, 2016). However, at the micro level, the evidence, although mixed, points to small effects on employment in energy- and pollution-intensive sectors.

The evidence to date, unfortunately, is exclusively based on within-country differences in environmental stringency across subnational jurisdictions. Therefore, if one assumes that relocation barriers are higher across than within countries, then the results presented below can reasonably be thought of as an upper bound of the effect of a hypothetical equivalent cross-border difference in stringency.

Morgenstern et al. (2002) use PACE as a proxy for environmental stringency and find that higher environmental regulation generally does not cause a statistically significant change in employment. There are even statistically significant and positive effects in two industries (plastics and petroleum), but the total number of affected jobs remains quite small. They find that at most, environmental regulation accounted for 2 percent of the observed decline in employment from 1984 to 1994, by applying the most adverse estimate in their 95% confidence interval for the overall effect. In one of the very few non-US studies, Cole and Elliott (2007) similarly find no evidence that environmental regulations reduce employment based on data on 27 industries in the UK.

Studies using sector-level data are unable to capture job reallocation within firms, industries or regions, but a few studies use plant or firm-level data. Berman and Bui (2001b) compare petroleum refineries in the Los Angeles area, subject to some of the strictest air pollution regulations in the United States, to all other refineries in the country.

15 This is true for example in the US where between 1998 and 2009, aggregate manufacturing jobs declined by 35 percent while the total production of this industry grew by 21 percent (Kahn and Mansur 2013).

They find no evidence that environmental regulation decreased labour demand, even when allowing for induced plant exit and dissuaded plant entry. They actually find weak evidence that regulations may have resulted in a small net increase in employment, possibly because more labour is required for pollution control activities, a finding similar to that of Morgenstern et al. (2002). The lower bound of their estimates implies fewer than 3,500 jobs lost due to regulation over 12 years.

Kahn (1997) and Greenstone (2002) combine large micro datasets with long panels, thus providing the most compelling evidence to date on the impact of the US CAAAs on employment. Kahn (1997) finds 9% lower growth rates in manufacturing employment in nonattainment counties with more stringent air pollution regulations relative to attainment counties. However, the magnitude of the effect differs across sectors. The impact of the stringency gap ranges from not statistically significant (but negative) in half of the sectors covered, to over 10% slower growth rate in the chemicals, primary metals, industrial machinery and instruments sectors. Using a longer panel of plant level data (1972-1987), Greenstone (2002) estimates that the CAAAs of the 1970s led to a loss of around 590,000 jobs in nonattainment counties. This represents 3.4 percent of manufacturing employment in the United States and less than 0.5 percent of total employment. Greenstone (2002) explicitly tests the hypothesis that the pollutant regulation effects are equal across industries, which he cannot reject even at the 10% level. Obviously, part of this lost activity may have moved to attainment counties, so that the net national effect on employment is likely to be smaller but would have represented job exports in an international context. Ferris et al. (2014) examine employment effects of Phase I of the Title IV cap-and-trade program for SO_2 emissions implemented under the 1990 CAAAs and provide evidence suggesting that the impact of environmental regulations on employment may be transitory. Using a small panel data set that includes 61 regulated and 109 unregulated plants, they find that employment is significantly lower in Phase I plants relative to non–regulated plants, but only in the first year of compliance and not in subsequent years.

Walker (2013) finds that the labour transition costs associated with reallocating workers to other sectors because of environmental policy are large. He estimates these transitional costs associated with the CAAAs and finds that the average worker in a regulated sector experienced a total earnings loss equivalent to 20 percent of their pre-regulatory earnings. Workers in newly regulated plants experienced, in aggregate, more than $5.4 billion in forgone earnings for the years after the change in policy. Almost all of the estimated earnings losses are driven by unemployment.[16]

A few recent studies have examined how differences in energy price levels impact employment, giving insights into the effect of carbon tax differentials on jobs. Deschênes (2010) relies on within-state variation in electricity prices in the US and finds that employment rates are weakly related to electricity prices: a 1 percent increase in electricity prices leads to a change in full-time equivalent employment ranging from -0.16 percent to -0.10 percent. Kahn and Mansur (2013) exploit variation in energy prices and in environmental regulation among adjacent counties and use a relatively long panel (1998-2009). They find evidence that energy intensive sectors tend to locate in low electricity-price areas and that polluting sectors seek out low regulation areas, reducing employment in high regulation areas. The effects are modest for the typical manufacturing industry, but the most electricity-intensive industry, primary metals, has an implied price elasticity of employment of −1.65. The predicted effect of a $15 per ton carbon tax varies considerably across states according to the carbon intensity of electricity production and to the energy intensity of the industry, ranging from a 3.8 percent fall in employment in Ohio to a mere 0.3 percent in California.

Importantly, the effects of relative environmental policy on employment levels and distribution depend on the design of the policy. In one of the first econometric analyses of the impact of British Columbia's unilateral revenue-neutral carbon tax, Yamazaki (2015) finds that the carbon tax generated a small but statistically significant 2 percent increase in employment over the 2007-2013 period in British Columbia relative to other (free of carbon taxes) provinces, but that the magnitude of the effect depends on carbon intensity and trade exposure. For example, at CAD10/tonne of CO_2 equivalent, the basic chemical manufacturing sector, one of the most emission-intensive and trade-exposed industries, experiences the largest decline in employment at 30 percent,[17] while the health care industry experiences an increase in employment by 16% which the author attributes to the positive demand shock induced by the redistribution of tax revenues to residents of British Columbia. Hence, this paper finds that there are winners and losers but that a revenue-neutral carbon tax may not adversely affect aggregate employment.

[16] However, earnings losses depend on the strength of the local labour market, suggesting that policy-induced labour market reallocation may be more costly in periods of high unemployment.
[17] Note that the 95% confidence interval ranges from -15% to -48%.

Hence, the most rigorous studies that use installation or county level data from the United States and long panels provide evidence of a pollution haven effect within the US, by finding negative effects on employment in pollution intensive sectors from environmental regulations, as measured by CAAA nonattainment status or by the level of energy prices. This suggests that – in the United States at least – differences in environmental regulations between states or counties have led to small negative effects on employment in polluting sectors. However, it is important to keep in mind that employment effects might be larger within national boundaries (where relocation barriers are lower) than across countries.

4. Productivity, innovation and competitiveness

Environmental regulation may also alter firms' decisions on the volume, type or timing of productive investments, and affect firms' competitiveness through their effect on productivity and innovation.

4.1 Productivity

Productivity growth can enhance competitiveness of firms operating in internationally-traded markets, by lowering firms' marginal production costs and hence prices, which can boost exports and market share.[18] However, because pollution control diverts resources away from production towards non-productive activities, theory predicts that environmental regulation hampers productivity growth. Indeed, early studies found evidence to support this effect, at least for some sectors of the economy. For example, Gollop and Roberts (1983) estimate that SO_2 regulations in the US reduced productivity growth by 44% during the 1973–1979 period in the fossil fueled electricity utilities. More recently, Gray and Shadbegian (2002) linked higher pollution-abatement operating costs with lower productivity in pulp and paper mills. Most of these early studies, however, use small samples (56 utilities in Gollop and Roberts, 1983; 116 plants in Gray and Shadbegian, 2002). Greenstone et al. (2012) have conducted the largest plant-level study so far with

[18] See the seminal paper by Melitz (2003), in which only firms that are sufficiently productive can become exporters (as being more productive allows firms to secure a market share that is large enough to cover the fixed cost of exporting) and trade raises average productivity by forcing the least productive firms to exit. For the consequences of using the Melitz model for competitiveness in a CGE setting, see Balistreri and Rutherford (2012).

1.2 million plant observations from the 1972-1993 Annual Survey of Manufactures, which allows controlling for many confounding factors that may affect both productivity and regulation. They investigate the economic costs of the 1970 CAAA using nonattainment designation as a measure of regulation and find that total factor productivity declines by 4.8 percent for polluting plants in strictly regulated counties compared to weakly or unregulated counties. Almost all of the effect occurs in the first year of nonattainment status, suggesting that abatement capital investments impose only a short-term hit to productivity.

The evidence base suggests the impacts of relative environmental regulation on productivity varies across pollutants and industries. For example, Greenstone et al. (2012) find that while nonattainment of 0_3 concentrations negatively affects productivity, CO nonattainment leads to statistically significant increases in productivity. The paper does not provide reasons for these differences in outcomes across pollutants. Alpay et al. (2002) find that the productivity of the Mexican food-processing industry increased with the pressure of local environmental regulation, while pollution regulations in the United States have had no impact on the profitability or productivity of its food manufacturing industry. This leads them to conclude that, contrary to what was expected, stricter environmental law in the United States did not provide Mexican companies with a cost advantage. Berman and Bui (2001a) report that refineries located in the Los Angeles (South Coast) Air Basin area experience a short-run fall in productivity, but it appears that this effect is transitory, and after a few years they enjoy significantly higher productivity than other refineries in the United States despite the more stringent air pollution regulation. Similarly, Lanoie et al. (2008) find that the negative short-run effects of regulation are outweighed by subsequent positive effects on multifactor productivity growth. In one of the few European studies to date, Rubashkina et al. (2015) find that environmental regulation (as proxied by PACE) negatively affects TFP but the effects dissipates within two years. Albrizio et al. (2014) conduct a multi-level analysis based on a dataset covering 60,000 companies across 23 OECD countries, 22 manufacturing sectors and 21 years. They find no evidence of permanent effects of environmental policy tightening on multifactor productivity (MFP) growth either at the country or industry level. In fact, a tightening in environmental stringency is associated with a short-run increase in productivity growth, which translates into permanently higher MFP levels. All effects tend to fade away within less than five years. Albrizio et al. (2014) also find that the most productive industries and firms experience highest gains in productivity levels, while less productive firms see negative effects, possibly because highly productive firms are better suited to profit from changes stemming from environmental regulations.

In sum, the evidence supports the existence of both negative, short-term impacts of environmental regulation on productivity in some sectors and for some pollutants and positive productivity impacts in others (see Kozluk and Zipperer, 2013, for a review specifically focused on productivity). However, more work is needed to investigate the productivity impacts of environmental regulations in the longer run.

4.2 Environmental regulations and innovation activity

From an economic perspective, it is crucial that environmental regulations provide incentives for technological change, since new technologies may substantially reduce the long-run cost of abatement (Jaffe et al., 2003). From a political perspective, induced innovation may also improve the acceptability of these policies. Indeed, in today's knowledge-based economy, firms' competitiveness is largely reliant on innovation, which is considered a key component of productivity growth (Aghion and Howitt, 1992). As a result, there is a growing body of research seeking to quantify the link between environmental regulations and technological change (see Carraro et al., 2010; Popp et al., 2010; and Ambec et al., 2013, for recent surveys). The 'induced innovation' hypothesis, dating back to Hicks (1932), suggests that when regulated firms face a higher price on polluting emissions relative to other costs of production, this gives an incentive to develop new emissions-reducing technologies. Many studies have shown unambiguously that environmental regulation affects the development of pollution saving technologies. For example, it has been shown that stricter regulation, as proxied by higher pollution control expenditures, lead to higher research and development expenditures (Jaffe and Palmer, 1997) and to more environment-related patents (Brunnermeier and Cohen, 2003). Similarly, higher energy prices induce the development of energy efficient technologies (Newell et al., 1999; Popp, 2002). Recent studies use firm-level data, allowing to control for macroeconomic factors that might affect both environmental regulation and innovation at the sector level, and confirm these earlier results. For example, Aghion et al. (2016) use data on around 3,000 firms in the car industry and show that firms tend to innovate more in clean technologies (electric, hybrid and hydrogen cars) in response to higher road fuel prices. Calel and Dechezleprêtre (2016) show that the EU ETS has increased innovation activity in low-carbon technologies among regulated companies by 30 percent compared to a carefully constructed control group.

An important question from a policy perspective is, which regulatory instruments provide the strongest incentives for innovation. The theoretical literature on this topic suggests that market-based instruments provide stronger incentives for innovation than technology mandates and performance standards, and that within market-based instruments, emissions taxes and auctioned emission permits encourage more innovation than freely allocated emission permits (Milliman and Prince 1989; Fischer et al. 2003; Parry et al. 2003). However, the handful of empirical studies on this issue seem to partly contradict the premise that market-based policies encourage more innovation than command-and-control regulations. Popp (2003) shows that after the passage of the 1990 CAAAs which instituted permit trading, innovation activity *decreased* in intensity. Taylor (2012) shows that for both Title IV (the US cap-and-trade programme for SO_2 emissions introduced by the 1990 Clean Air Act Amendments) and the Ozone Transport Commission NOx Budget Program, patenting activity collapsed when traditional regulation was replaced by a cap-and-trade programme. Therefore, this question constitutes a fruitful avenue for future research. A related question which may require more attention is, what combinations of R&D and environmental policies best encourage innovation in green technologies (Burke et al., 2016).

4.3 Induced innovation and firms' competitiveness

The Porter hypothesis (Porter and van der Linde, 1995) asserts that environmental regulations can "trigger innovation that may partially *or more than fully* offset the costs of complying with them". While there is evidence that the actual cost of reaching some environmental objective is usually smaller than anticipated as a consequence of induced innovation (see e.g. Harrington et al., 2000 and 2010; Simpson, 2014), the literature to date does not provide much empirical support for the Porter hypothesis in its so-called "strong" version.

Environmental regulation can in theory increase productivity growth if it leads to a permanent increase in the *rate* of innovation. There is some emerging evidence, however, that regulation-induced environmental innovations tend to replace other innovations such that the overall level of innovation is unaffected. Gray and Shadbegian (1998) find that more stringent air and water regulations improved environmental innovation in paper mills in the United States, but that the increased investment in emissions and water abatement technologies came at the cost of other types of productivity-improving innovation. Popp and Newell (2012) find that alternative energy patenting crowds out other types of patenting at the firm level. This crowding out effect seems larger for small firms that are credit constrained (Hottenrott and Rexhaüser, 2013). Aghion et al. (2016) show that innovations in clean cars (electric, hybrid and hydrogen) almost completely come at the expense of innovation in dirty vehicles (combustion engines). In contrast, Noailly and Smeet (2015) and Calel and Dechezleprêtre (2016) find no evidence of such substitution effect at the firm level, suggesting that environmental regulations can raise the overall rate of innovation of regulated firms rather than redirect innovation.[19]

A number of studies look at the causality chain implied by the Porter hypothesis, from regulation to innovation through to profitability, and find that the positive effect of innovation on business performance does not outweigh the negative effect of the regulation itself (Lanoie et al., 2011). Thus, environmental regulation is costly, but less so than if one was to consider only the direct costs of the regulation itself without the ability of innovation to mitigate those costs, because over time, regulation-induced innovations which improve a firm's resource efficiency in terms of material or energy consumption have a positive impact on profitability (Rexhauser and Rammer, 2014).

Another argument put forward by Porter and van der Linde (1995) is that countries that take early action in environmental protection will induce higher costs in the short-run for domestic firms, but the induced innovation will generate economic benefits in the long run by giving a competitive advantage over foreign firms that will be constrained by the same regulation later on. However, to our knowledge, no study has empirically analysed whether this first-mover advantage leads to competitiveness improvements in the long-run.

While it is uncertain that firms' competitiveness benefits from the policy-induced environmental innovation activities, the global benefits may be more likely. Popp and Newell (2012) find that the social value of renewable energy patents, as measured by patent citations, seems to be higher than that of the patents in conventional fossil fuel technologies that are crowded out. This is confirmed by a comparison of knowledge

[19] Crowding out between firms, which could happen as a result of the number of inventors available in the economy in the short run being somewhat fixed, has not been analysed to our knowledge.

spillovers from clean and dirty technologies in the transportation and energy production sectors by Dechezleprêtre et al. (2014). Therefore, regulation-induced innovation in clean technologies might increase innovation activity (and possibly competitiveness) of some unregulated companies through knowledge spillovers. This would improve the net social benefit or cost of the regulation but does not cancel competitiveness effects on regulated companies.

5. Conclusion: advancing the debate on competitiveness effects

Some 20 years ago, in their influential review of the literature on the competitiveness impacts of environmental regulation in the United States, Jaffe, Peterson, Portney and Stavins (1995) concluded that “there is relatively little evidence to support the hypothesis that environmental regulations have had a large adverse effect on competitiveness”. Since then, there have been hundreds of studies, using ever larger datasets at increasingly finer levels of disaggregation, employing up-to-date econometric techniques and covering a wider set of countries and this conclusion has only become more robust.

Still today, the cost burden of environmental policies are often found to be very small. The recent evidence shows that taking the lead in implementing ambitious environmental policies can lead to small, statistically significant adverse effects on trade, employment, plant location and productivity in the short run, in particular in pollution- and energy-intensive sectors; yet the scale of these impacts are small compared to other determinants of trade and investment location choices such as transport costs, proximity to demand, quality of local workers, availability of raw materials, sunk capital costs and agglomeration. At the same time, there is now ample evidence that environmental regulations induce innovation activity in cleaner technologies, but so far, the benefits brought forward by these innovations do not seem to be high enough to outweigh the costs of regulations for the regulated entities. This, of course, does not preclude the ability of environmental regulations to spark the creation of domestic technological leaders in new, more expensive technologies, but suggests that the evidence for the most controversial interpretation of the Porter hypothesis is lacking.

An obvious question arising from this synthesis is: why are the effects of environmental regulations on international industry relocation found to be so small and narrow when competitiveness concerns are so high and abound in public policy circles? This is perhaps not surprising considering that this debate is usually far from being grounded in evidence. This is reinforced by the fact that regulated companies have an incentive to overstate potential competitiveness impacts of regulations, attributing unpopular offshoring decisions to these rather than to the shifting locus of supply and demand in global manufacturing or falling transport costs. Some papers attribute the lack of empirical support for large pollution haven effects to endogenous environmental policy i.e. the fact that stringency levels are set strategically by governments, suggesting that competitiveness concerns could trigger a 'race to the bottom' in global environmental protection efforts. Continuing research efforts to measure competitiveness impacts accurately can help providing the environment and climate policy debates with evidence-based analyses that are much welcome in this highly politically sensitive area, especially as there are apparent stark divergences in the political will to tackle climate change among developed countries' governments, as exemplified by Australia's decision to abolish carbon taxes in 2014 and Germany's ambitious energy transition programme (Energiewende) which aims to reduce greenhouse gas emissions by 80-95 percent by 2050.

However, it is important to recognise that the small average impacts across the economy typically uncovered by existing studies sometimes hide large effects on small subsets of companies, who legitimately voice their concerns. Key vulnerable sub-sectors for whom environmental and energy regulatory costs are significant have been identified in the literature (Sato et al 2014). These are a small group of basic industrial sectors, characterised by: very energy intensive production processes; limited ability to fully pass through pollution abatement costs to consumers (whether due to regulation or international competition); and the lack of innovation capacity to advance new production processes privately (often due to high capital intensity of production, relatively homogeneous nature of products, substantial existing surplus production capacity and limited re-investment opportunities in new production capacity). For such economic activities where pollution leakage and competitiveness issues represent a genuine risk, assessing the various policy options available to prevent adverse impacts on trade and investment whilst avoiding the creation of new distortions is a critical input into the policy process. In fear of potential adverse effects on competitiveness and leakage, almost all recent climate policies shield industrial sectors from the full regulatory costs through exemptions of free emission permits, whether it's the EU ETS, the Californian-Quebec cap-and-trade, Chinese ETS pilot schemes or Germany’s Energiewende. However, these measures to mitigate competitiveness and leakage effects might have severely dampened the incentives to improve energy efficiency and develop low-carbon processes and products, and have had adverse consequences on output, investment and trade (Pahle et al., 2011, Martin et al., 2014; Branger et al., 2015) and may run counter to international trade law on subsidies (Rubini and Jegou, 2012).[20] Thus, in addition to refining the evidence about where competitiveness and leakage effects are real to determine whether such interventions are justified, a key question for advancing the competitiveness debate is to rethink the current solution to competitiveness concerns which might prevent firms from unlocking available abatement opportunities.

[20] A number of alternative anti-leakage solutions have been discussed in the literature including the use of Output Based Allocation (Branger et al. 2015), Border Carbon Adjustments (Ismer and Neuhoff 2007) and the inclusion of consumption into emissions trading (Pauliuk et al. 2016).

References

Aghion, P. and Howitt, P. (1992). A model of growth through creative destruction. Econometrica, 60 (2):323–351.

Aghion, P., Dechezleprêtre, A., Hemous, D., Martin, R. and Van Reenen, J., 2016. “Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry”. *Journal of Political Economy* 124(1), 1-51.

Albrizio, S., T. Kozluk, and V. Zipperer. 2014. Empirical evidence on the effects of environmental policy stringency on productivity growth. OECD Economics Department Working Papers, (1179).

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

Alpay, E., J. Kerkvliet, and S. Buccola, 2002. Productivity growth and environmental regulation in Mexican and US food manufacturing. *American Journal of Agricultural Economics*, 84(4): 887-901.

Ambec, S., Cohen, M., S. Elgie, and P. Lanoie. 2013. The Porter hypothesis at 20: Can environmental regulation enhance innovation and competitiveness? *Review of Environmental Economics and Policy*, 7(1): 2-22.

Antweiler, W., B. R. Copeland, and M. S. Taylor. 2001. Is free trade good for the environment? *American Economic Review*, 91(4): 877-908.

Balistreri and Rutherford, 2012. Subglobal carbon policy and the competitive selection of heterogeneous firms. *Energy Economics*, 34(S2) : S190–S197

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

Berger, T. 2008. Concepts on National Competitiveness. *Journal of International Business and Economy*, 9(1): 3–17.

Berman, E. and L. Bui. 2001a. Environmental Regulation and Productivity: Evidence from Oil Refineries. *Review of Economics and Statistics*, 83(3): 498-510.

Berman, E. and L. Bui. 2001b. Environmental regulation and labor demand: Evidence from the south coast air basin. *Journal of Public Economics*, 79(2): 265-295.

Branger, F., Ponssard, J., Sartor, O. and M. Sato. 2015. EU ETS, free allocations and activity level thresholds: The devil lies in the details. *Journal of the Association of Environment and Resource Economists,* 2(3):401-437.

Branger, F. & Quirion, P. 2014. Climate policy and the ‘carbon haven’ effect. *Wiley Interdisciplinary Reviews: Climate Change*, 5(1): 53–71.

Branger, F., Quirion, P., and Chevallier, J. 2016. Carbon leakage and competitiveness of cement and steel industries under the EU ETS: much ado about nothing. *The Energy Journal*, 38(3).

Bristow, G. 2005. Everyone's a 'winner': problematising the discourse of regional competitiveness. *Journal of Economic Geography*, 5(3): 285–304.

Brunel, C. and A. Levinson. 2013. *Measuring Environmental Regulatory Stringency*. Trade and environment working papers, OECD.

Brunnermeier, S. B. and M. A. Cohen. 2003. Determinants of environmental innovation in US manufacturing industries. *Journal of Environmental Economics and Management*, 45(2): 278-293.

Burke, M., Craxton, M., Kolstad, C. D., Onda, C., Allcott, H., Baker, E., Tol, R. S. J. (2016). Opportunities for advances in climate change economics. *Science*, *352*(6283), 292–293.

Calel, R. and Dechezleprêtre, A., 2016. Environmental Policy and Directed Technological Change: Evidence from the European carbon market. *Review of Economics and Statistics,* 98(1), 173–191.

Carbone, J. C. and Rivers, N. 2014. Climate policy and competitiveness: Policy guidance and quantitative evidence. Working Paper 2014-05, Colorado School of Mines, Division of Economics and Business.

Carraro, C., De Cian, E., Nicita, L., Massetti, E., and Verdolini, E. 2010, Environmental Policy and Technical Change: A Survey, *International Review of Environmental and Resource Economics*: 4(2): 163-219.

Chan, H., S. R. Li, S. and F. Zhang. 2013. Firm competitiveness and the European Union Emissions Trading Scheme. *Energy Policy*, 63: 1056-1064.

Cole, M. and R. J. R. Elliott. 2007. Do Environmental Regulations Cost Jobs? An Industry-Level Analysis of the UK. *The B.E. Journal of Economic Analysis & Policy*, 7(1): 1-27.

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

Dechezleprêtre, A., R. Martin, and M. Mohnen. 2014. Knowledge spillovers from clean technologies: A patent citation analysis. Working Paper 135, Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy.

Deschenes, O. 2010. Climate policy and labor markets. Working Paper 16111, Technical report, National Bureau of Economic Research.

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

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

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

Ferris, A., E. and A. McGartland.2014. A Research Agenda for Improving the Treatment of Employment Impacts in Regulatory Impact Analysis. *In Does Regulation Kill Jobs?* (pp. 170).

Fischer, C., I.W.H. Parry and W.A. Pizer. 2003. Instrument Choice for Environmental Protection when Technological Innovation is Endogenous, Journal of Environmental Economics and Management 45(3): 523–545.

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

Gollop, F., M. and M. J. Roberts.1983. Environmental regulations and productivity growth: the case of fossil-fuelled electric power generation. *Journal of Political Economy*, 9: 654-674.

Goulder, L., H.and I. W. H. Parry.2008. Instrument Choice in Environmental Policy. Review of Environmental Economics and Policy, 2(2): 152–174.

Gray, W. and R. Shadbegian. 1998. Environmental regulation, investment timing, and technology choice. *The Journal of Industrial Economics*, 46: 235-256.

Gray, W. and R. Shadbegian. 2003. Plant vintage, technology, and environmental regulations. *Journal of Environmental Economics and Management* 46: 384-402.

Greenstone, M. 2002. The impacts of environmental regulations on industrial activity: Evidence from the 1970 and 1977 clean air act amendments and the census of manufactures. *Journal of Political Economy*, 110(6): 1175-1219.

Greenstone, M., J. List, and C. Syverson. 2012. The Effects of Environmental Regulation on the Competitiveness of U.S. Manufacturing. Working Paper 2012-013, MIT Centre for Energy and Environmental Policy Research.

Grossman, G., M. and A. B. Krueger. 1995. Economic growth and the environment. *The Quarterly Journal of Economics*, 110(2): 353-377.

Hafstead, M. A. C., & Williams, R. C. I. (2016). Unemployment and Environmental Regulation in General Equilibrium. NBER Working Paper No. 22269

Hall, B., Mairesse, J. and Mohnen, P. (2010) “Measuring the returns to R&D.” Handbook of the Economics of Innovation. Vol. 2, Ch. 24 1033-1082. Elsevier.

Hanna, R. 2010. Us environmental regulation and fdi: Evidence from a panel of us-based multinational firms. *American Economic Journal: Applied Economics*, 2:158–189.

Harrington, W., Morgenstern, R., & Nelson, P. (2010). How Accurate Are Regulatory Cost Estimates? Policy Brief, Resources for the Future.

Harrington, Winston, Richard D. Morgenstern, and Peter Nelson. 2000. On the accuracy of regulatory cost estimates. Journal of Policy Analysis and Management 19(2): 297–322.

Henderson, D. J. & Millimet, D. L. 2005. Environmental regulation and US state-level production. *Economics Letters*, 87(1): 47–53.

Hicks, J., R. 1932. *The Theory of Wages*. Basingstoke: Palgrave MacMillan.

Hottenrott, H., and S. Rexhäuser. 2013. Policy-Induced Environmental Technology and Inventive Efforts: Is There a Crowding Out*?* ZEW Discussion Paper No. 13-115, Mannheim: ZEW.

Iraldo, F., Testa, F., Melis, M. and Frey, M., 2011. A literature review on the links between environmental regulation and competitiveness. *Environmental Policy and Governance*, 21(3), pp.210-222.

Ismer, R. and Neuhoff, K. 2007. Border tax adjustment: A feasible way to support stringent emission trading. *European Journal of Law and Economics*, 24(2): 137–164.

Jaffe, A. B., R. G. Newell, and R. N. Stavins, "Technological Change and the Environment" (pp. 461–516), in Karl-Göran Mäler and Jeffrey R. Vincent, eds., Handbook of Environmental Economics (New York: Elsevier, 2003).

Jaffe, A. B., Peterson, S. R., P. R. Portney, and R. N. Stavins. 1995. Environmental regulation and the competitiveness of US manufacturing: What does the evidence tell us? *Journal of Economic Literature*, 33(1): 132-163.

Jaffe, A.,B., and K. Palmer. 1997. Environmental Regulation and Innovation: A Panel Data Study. *The Review of Economics and Statistics*, 79(4): 610-619.

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

Kahn, M., E. 1997. Particulate pollution trends in the United States. *Regional Science and Urban Economics*, 27(1): 87-107.

Kahn, M., E., and E. T. Mansur. 2013. Do local energy prices and regulation affect the geographic concentration of employment? *Journal of Public Economics*, 101: 105-114.

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

Kozluk, T., and V. Zipperer. 2013. Environmental policies and productivity growth – a critical review of empirical findings. Working Paper No.1096, OECD Economic Department.

Lanoie, P., M. Patry and R. Lajeunesse, 2008. Environmental Regulation and Productivity: New Findings on the Porter Hypothesis, Journal of Productivity Analysis (2008) 30, 121-128.

Lanoie, P., Laurent-Luccheti, J., N. Johnstone, N. and S. Ambec. 2011. Environmental policy, innovation and performance: New insights on the Porter hypothesis. *Journal of Economics and Management Strategy*, 20(3): 803-842.

Levinson, A. 1996. Environmental regulations and manufacturers' location choices: Evidence from the census of manufactures. *Journal of Public Economics*, 62(1): 5–29.

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

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

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? *Journal of Urban Economics*, 56(2): 303–326.

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

McAusland, C. & Millimet, D. L. 2013. Do national borders matter? intranational trade, international trade, and the environment. *Journal of Environmental Economics and Management,* 65(3): 411–437.

Martin, R., Muûls, M., L. De Preux, and U. Wagner. 2014. Industry compensation under the risk of relocation: A firm-level analysis of the EU emissions trading scheme. *American Economic Review*, 104: 2482-2508.

Melitz, M. J. (2003). The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity. *Econometrica*, *71*(6), 1695–1725.

Milliman, S. R., and R. Prince. 1989. Firm Incentives to Promote Technological Change in Pollution Control. Journal of Environmental Economics and Management 17: 247-265.

Millimet, D. L. & List, J. A. 2004. The case of the missing pollution haven hypothesis. *Journal of Regulatory Economics*, 26(3): 239–262.

Millimet, D. L. & Roy, J. 2015. Empirical Tests of the Pollution Haven Hypothesis When Environmental Regulation is Endogenous. *Journal of Applied Econometrics.*

Mohr, R. D. (2002). Technical change, external economies, and the porter hypothesis. Journal of Environmental economics and management, 43(1):158–168.

Morgenstern, R., D., W.A. Pizer, and J.S. Shih. 2002. Jobs versus the environment: An industry-level perspective. *Journal of Environmental Economics and Management*, 43(3): 412-436.

Newell, Richard G., Adam B. Ja§e, and Robert N. Stavins. 1999. "The Induced Innovation Hypothesis and Energy-Saving Technological Change." The Quarterly Journal of Economics 114 (3):941—975.

Noailly, J., & Smeets, R. (2015). Directing technical change from fossil-fuel to renewable energy innovation: An application using firm-level patent data. *Journal of Environmental Economics and Management*, *72*, 15–37.

Pahle, M., Fan, L., and Schill, W.P. 2011. How emission certificate allocations distort fossil investments: The german example. *Energy Policy*, 39(4): 1975–1987.

Parry, I. W. H., W. A. Pizer and C. Fischer. 2003. How Large Are the Welfare Gains from Technological Innovation Induced by Environmental Policies? Journal of Regulatory Economics 23(3): 237–255.

Pasurka, C. 2008. Perspectives on pollution abatement and competitiveness: Theory, data, and analyses. *Review of Environmental Economics and Policy*, 2(2): 194-218.

Pauliuk, S., Neuhoff, L., Owen, A., and Wood, R. 2016. Quantifying impacts of Consumption based charge for carbon intensive materials on products. *DIW Berlin Discussion Paper N.1570*.

Peters, G. P., Minx, J. C., Weber, C. L., & Edenhofer, O. 2011. Growth in emission transfers via international trade from 1990 to 2008. *Proceedings of the National Academy of Sciences*, 108(21): 8903–8908.

Popp, D. 2002. Induced innovation and energy prices. *The American Economic Review*, 92(1): 160-180.

Popp, D. (2003). Pollution control innovations and the Clean Air Act of 1990. *Journal of Policy Analysis and Management*, *22*(4), 641–660.

Popp, D., R. Newell, and A. Jaffe. 2010. Energy, the Environment, and Technological Change. *Handbook of the Economics of Innovation*, 2: 873-937.

Popp, D. and R. Newell. 2012. Where does energy R&D come from? Examining crowding out from energy R&D. *Energy Economics*, 34(4): 980-991.

Porter, M., E. and C. van der Linde.1995. Toward a New Conception of the Environment-Competitiveness Relationship. *The Journal of Economic Perspectives*, 9(4): 97–118.

Raspiller, S. and N. Riedinger. 2008. Do environmental regulations influence the location behavior of French firms? *Land Economics*, 84(3): 382-39.

Ryan, S. P., 2012. The costs of environmental regulation in a concentrated industry. *Econometrica*, 80(3), pp.1019-1061.

Rexhäuser, S. and C. Rammer. 2014. Environmental Innovations and Firm Profitability: Unmasking the Porter Hypothesis. *Environmental and Resource Economics*, 57: 145-167.

Rubini, L. and Jegou, I. 2012. Who'll Stop the Rain? Allocating Emissions Allowances for Free: Environmental Policy, Economics, and WTO Subsidy Law. *Transnational Environmental Law*, 1(02): 325–354.

Sato, M. and Dechezleprêtre, A. 2015. Asymmetric industrial energy prices and international trade. Energy Economics, 1(52):S130-141.

Sato, M., Neuhoff, K., Graichen, V., Schumacher, K., & F. Matthes, 2014. Sectors under scrutiny: Evaluation of indicators to assess the risk of carbon leakage in the UK and germany. *Environmental and Resource Economics*, 60(1): 99–124.

Sato, M., Singer, G., D. Dussaux, and S. Lovo. 2014. International and sectoral variation in energy prices 1995-2011: how does it relate to emissions policy stringency? Working Paper, Grantham Research Institute on Climate Change and the Environment.

Simpson, R. D. (2014). Do regulators overestimate the costs of regulation? *Journal of Benefit-Cost Analysis*, *5*(2).

Taylor, M. R. (2012). Innovation under cap-and-trade programs. *Proceedings of the National Academy of Sciences* , *109* (13), 4804–4809.

Taylor, M., S. and B. R. Copeland. 2004. Trade, growth, and the environment. *Journal of Economic Literature*, 4(1): 7-71.

Wagner, U., J. and C. D. Timmins. 2009. Agglomeration effects in foreign direct investment and the pollution haven hypothesis. *Environmental and Resource Economics*, 43(2): 231-256.

Walker, W., R. 2013. The transitional costs of sectoral reallocation: Evidence from the clean air act and the workforce. *The Quarterly Journal of Economics*, 128,(4): 1787-1835.

Xing, Y. and Kolstad, C. D. 2002. Do lax environmental regulations attract foreign investment? *Environmental and Resource Economics*, 21(1): 1–22.

Yamazaki, A., 2015. Jobs and Climate Policy: Evidence from British Columbia's Revenue-Neutral. Working paper