CROSS-BORDER, POLICY-INDUCED INNOVATION IN CLEAN TECHNOLOGIES

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ABSTRACT OF THE DISSERTATION

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As governments around the world attempt to curtail the harmful impacts of climate change, climate and environmental policies are becoming more ubiquitous and increasingly more stringent. Some policies encourage switching to less polluting forms of energy production, such as clean technologies, while other policies take aim at the most polluting industries. Still other policies are intent on tackling energy efficiency, and thus energy star and similar programs are also a common feature of climate policies. The underlying presumption is that the strongest policies will both induce innovation and encourage rapid and widespread switching to these new technologies. The umderlying question of how and to what degree climate policies are able to induce innovation and diffusion of clean technologies warrants substantial research, and indeed is the fundamental reason for this present research.

This dissertation starts by analyzing "The Porter Hypothesis" (PH), which theorizes that competitive firms properly attuned to environmental policies should respond in innovative ways, increasing their competitiveness and resulting in a "win-win" scenario. This has become an influential theory for climate technology innovation. The PH is widely discussed in the Induced Technological Change (ITC) literature dealing with climate technologies induced in part by climate policies. Yet the majority of this research, in particular ITC literature exploring such inducement effects, is strictly confined to domestic analysis; that is, the question of domestic policies inducing or not inducing domestic firms or innovators. The fact that inducement effects are not explored across borders represents a major gap in the literature and this is a problem because climate technologies are evidently quite globally dispersed. For the most part, ITC models are largely unable to account for a "foreign" Porter effect. A cross-border PH might beg the question of whether a nation's competitiveness increases in response to its domestic, *in addition to foreign*, environmental policies. Of course data limitations and the young age of the clean energy industry, coupled with its complicated global markets, might also account for this shortcoming in the literature. Nevertheless, the Porter Hypothesis conceptualized as operating across borders should open a new area of research into global but differentiated climate policies, and their potentially strong impacts on innovators, regardless of origin.

The second paper in this dissertation empirically tests a dynamic, multi-country Porter Hypothesis by regressing patents in several clean technologies over foreign environmental policies. In this paper, a sample of 32 countries over 16 years is used to understand the extent to which an international Porter Hypothesis exists, if indeed such an effect does. This extends beyond most of the empirical research by focusing on foreign policies and the impact these have on domestic innovators. The influence of foreign environmental policy stringency is proxied by weighting the average foreign EPS (environmental policy indicator from OECD) and its explanatory power for patenting in clean energy technologies (with patent rates as a proxy for innovation rates). The goal is to explore the magnitude of the foreign policy effect on home-country innovation in clean energy technologies together and taken separately. Properly constructed policy, as the "Porter Hypothesis" suggests, may lead to higher profits through innovative product development. Therefore, the question of whether countries are induced by foreign government's environmental policies has important ramifications for domestic and global climate policy-makers.

The final paper of this dissertation relies on institutional theory as a lens to understand cross-border, policy-induced innovations in environmental technologies. Using a sample of 32 countries, including the OECD countries and the BRICS, this article implies an important relationship between environmental policies and institutional quality. In particular, institutional distance between foreign environmental policies and domestic innovations is found to be significant. This finding benefits from a gravity model, which uses a formula to take the distance between institutional proxies, in order to understand the "institutional distance", or the distance between a home and foreign

institutions. Environmental technologies, in particular solar and wind energy, experience foreign policy pulls in different ways: for the former, “frontier” foreign policies “pull” innovations at home while for the latter, institutional “distance” between foreign policy leader and domestic innovator appears most significant.

Acknowledgements

Thanks to some very important people in my life, I’ve been able to reach this level of education. I am well aware that the majority of people throughout the world will never even have the chance to obtain a PhD. Before anything, I must thank my family who has supported me through the Masters and the PhD. I’m very fortunate to have a caring and generous family. Most of all, I am grateful for my mom. She’s not only given me the liberty to choose what it is that I want to do with my life, but she’s also been my biggest fan and constant supporter.

Two other women are pivotal to this dissertation and research. Elena Verdolini, a senior research at FEEM, for some reason accepted my inquiry to come research in Milan with her in early 2017. Through her mentorship and attention to quantitative detail, I was able to go from ‘0’ to ‘1’ in terms of what quantitative research in climate technologies actually entails. That leap reinvigorated within me an inchoate attraction to quantitative analysis, and I’m indebted to her selfless sharing of her limited time. Indeed, there is much work to be done in this field, and I very much look forward to collaborating with Elena in the future.

I cannot say enough good things about Gabriela Kuetting, my dissertation chair. In the middle of my dissertation program I was feeling, as I assume most PhD students do, a bit of regret and loss. Regret because it now seemed nearly ten years of education has gotten me absolutely nowhere; loss because of all the lost time (and money) from proceeding down this (sometimes quite miserable) path. Yet, when I met Gabriela, that all changed. Clearly our research interests aligned, but it was more than that. She imbued me with a sense of confidence and an awareness of the importance of both my experiences and my tacit knowledge in climate policy. The feelings of regret, of course, came back during the research and writing process here, but she was always there to say you’re on the right path, just keep pushing a little bit more. Consequently, writing a book with her was one of the most amazing things I’ve done in my life, and somehow seemed so easy.

Lastly, my hat goes off to the two gentlemen on my dissertation committee: Dr. Ajay Gaur and Dr. Jun Xiang. As the figurative ‘quantitative pillars’ of my dissertation, these two men consistently showed patience in the face of a tenacious and passionate, but an utterly disorganized researcher (me). I am indebted to their innate sense of how to deal with a lost PhD student trying to find his way: point towards where the solutions are and encourage the student to keep re-working over their methods until they arrive at a satisfactory conclusion, all the while knowing there will always be more work left to be done.

I have to thank FEEM (Fondazione Eni Enrico Mattei) in Milano for hosting me while I carried out the research for this dissertation, as well as the Grantham Climate Institute at the Imperial College and London School of Economics, in London. Finally, thanks to Rutgers University. The school has supported me financially and scholastically since 2013.

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Paper III

Preface

The motivation for this dissertation is largely due to being an American researcher trapped between two worlds. In Denmark and throughout Europe, I worked as a renewable energy lobbyist and climate diplomat, with the inevitable and dreadful return to the U.S. where I usually faced the same questions and confrontations: Do you really think Climate Policy is needed? Is Climate really an issue when there are more immediate issues such as economy? Is Climate Change real?

Meanwhile, each time I returned to Europe, I was confronted with further guilt-inducing questioning: Why do your policy-makers not believe in climate change? How is the US, such a technologically superior country in so many respects, failing to encourage innovation of technology for cleantech? And eventually I always faced a similar proclamation from a well-meaning European: You better go back to the US and help sort the mess out.

In time, I heeded to that advice after tiring of the polemic: while in Europe I felt I was helping build stronger climate policy, returning to the US always seemed to negate any gains due to the polarizing political climate. The decision to pursue this PhD therefore embodied these double lives I've led, defending climate policy in the US and spearheading climate policy in Europe. Thankfully, this dissertation has indeed served to mend the disaggregated parts of my inner-being. Ideally, it also serves to mend the disparate policies and tendencies on either side of the Atlantic.

Climate policy is at once local and global, domestic and federal, immediate and transcendent. For example if, at the local level, all citizens cut their energy use by 90% (including companies), we would overnight reach the goals set forth in the UNFCCC Paris agreement. At the other extreme if the UN, WTO, and other global institutions were capable of outlawing products at the heart of global emissions inducing climate change (i.e. fossil fuel production and consumption), we would solve climate change overnight. But the immediate needs of citizens coupled with intrinsic difficulties of forming and enforcing global rules, renders climate policy a transcendent and at times distant goal, to be solved by future generations.

The impasse is both predictable and unfortunate. At minimum, changes to our production of energy are required in order to avoid a laundry list of pollution problems, let alone the elephant in the room (climate change). How did I come to research innovation in clean technology? Technology is expected to surpass lethargic policy. For me, the elephant in the room became clear as I understood policies were rapidly losing efficacy, and in some severe cases, the policies themselves were actually only exacerbating the predominance of conventional energy industries (for example, “clean emissions” often leads to “cleaner natural gas” installations; “clean coal” is promulgated as a ramp to the cleaner future). I realized global and local needed to play a part in this movement. Perhaps more important, businesses both large and small needed to be drawn in. Indeed I started to realize, in addition to many others working in the field of climate policy, that firms could become a vital part of the process if they were able to innovate and market “green” products. Business, innovation, and technology, if adequately applied to climate technologies, is the only way to “leapfrog” because technologies advance societies at rate of several magnitudes faster than any government or policy could ever hope to. Technologies don’t necessarily await government approval so much as they await widespread adoption by citizens (the local), and the latter often determines their continued existence and thus alters the social landscape.

To take one example, the companies founded or run by Elon Musk are miraculous because of the variegated industries he’s helped to transform (phonebook, money, cars, energy, space). Each time he has thought about a widespread assumption, identified a possible and plausible solution, and then quickly scaled up to deliver the solution to market. Innovations in technologies coupled with social components allow Musk to build such world-changing companies. What is interesting about his story, from an institutional perspective, is that he emigrated to America from South Africa because something in the U.S. existed which did not exist in South Africa, and was key to the success of all his companies: institutions which would support his ideas, finance his new technologies and projects, and protect his inventions. These institutional features of the U.S. are without a doubt largely responsible for the success of his companies. The point is that technological innovations, especially for climate technologies, are very important, but institutions and policies still matter, a lot.

The story of Silicon Valley has many elements to it, most of which are usually overlooked in favor of only technological sophistication. For example historical, institutional, cultural and finally, economic factors all make the Valley a continually innovative epicenter of the modern world. First, there is the culture of gold-diggers: early American settlers came from all over the country to seek out gold in the San Francisco Bay area; riches were made and lost overnight in the 19th century. Second, some of the greatest Universities in the world are located in the Bay Area: Berkeley, Stanford, University of San Francisco, San Francisco State University, University of California San Francisco, San Jose State University. Third, the silicon revolution, the technologies underlying modern computers, began there. Last, due in large part to the cultural and historical past, venture capital is ubiquitous in the Bay Area. All of these features are unique to this area and, unfortunately, cannot be replicated anywhere else in the world. But there exists an underlying policy and institutional element to this story, and it is the primary reason the Bay Area continues to attract the most inspirational, innovative people and companies. The natural outcome of those people on the ground is technological and social innovations.

The reason I mention this short history is because this dissertation opens up the “black box” of clean energy technology innovations. Ironically, the boom and bust of cleantech has already occurred in the Bay Area, most likely due to return of capital being just a bit too long-term for the VC firms in that area, and in part due to the false assumption software development is a similar industry to hardware technology development. Inside this “black box” of cleantech innovation, many different elements are at play. Indeed, unpacking the cleantech innovation system in the Valley might make up a large part of my future commercial endeavors.

The cleantech technological paradigm (to borrow a term first used by Dosi, 1984), and indeed it is a paradigm, is poised to be one of the most fascinating technological stories of the 21st century. In comparison, perhaps only the rapid development of airplanes in the early 20th century to prepare countries for war, share the same or similar features. I say this because it is at once global and local: people and countries throughout the world are building policies and supportive institutions to face off against this enormous challenge. For example in 2000, renewable energy policies numbered in the teens with Germany and Denmark leading. Today (2018), there are literally thousands of renewable energy and cleantech policies in 280 countries throughout the world. Packed into the text of these policies is the explicit assumption that technological innovation is the most important element of climate change mitigation.

If climate policy is becoming globally widespread, while at the same time the UNFCCC appears to be losing ground in terms of building a successful global policy, the idea occurred to me that companies might be responding innovatively to climate policies outside of their own country. Admittedly, the most obvious example I saw was the response to European country demands for solar energy technology, met by China, South Korea, and Japan. Until recently these three countries had, relatively speaking, quite weak policies supporting solar and renewable energy technologies, yet they now produce nearly 70% of the world's solar tech. Another example, explained to me in detail while living in Denmark, is that the Danish wind energy industry only became so dominant because of favorable policies in California-after Reagan removed subsidies for wind in California, the Danish government was forced to build perhaps the world's' first cleantech industrial policy, to ensure its domestic wind firms did not collapse. Therefore, even in the earliest days of the renewable energy industry, foreign policies were inducing firms in other countries to innovate and export.

Yet, in the induced technological change literature for climate technologies, these stylized facts are entirely overlooked. Indeed, there is a dearth of cross-country studies, and the ones that do attempt to explore the global nature of climate technologies appear to focus only on the diffusion of such technologies, the assumption being that the most developed countries develop technologies that are then transferred to developing world. While this might still be true, very little analysis is done on *why* these technologies are being diffused so rapidly. On the other hand, and in contrast to the assumption that developed countries produce all new cleantech, it is almost as likely today for a developing country to transfer such technology to the developed world (Popp, 2012). Indeed, our older assumptions on technology development, and globally dispersed policy-inducement effects, need to be reconstituted for the clean energy technology industry (Aghion et al., 2012).

I. Introduction

This dissertation is comprised of three papers, each building on the previous one. The first paper is a qualitative analysis of the literature on Induced Technological Change and the Porter Hypothesis. The second paper delivers an empirical analysis of a cross-border, international Porter Hypothesis with a strong focus on foreign environmental policies and their inducement effects. The final paper focuses on institutional quality, “institutional distance”, and distance to the “environmental policy frontier”.

Paper I

Only three decades ago the concept of environmental policy inducing firms to innovate, and in some cases increasing their profits in response to such policies, was considered nonsense. Within the neo-classical economic lens environmental regulations, because these were invariably understood as increasing costs to firms, were seen to inevitably harm firm profits. This implicated firm innovation as well. But now, thanks to the Porter Hypothesis and ample empirical research, quite often the opposite is found in the literature. These findings are applicable to both firms and countries alike, the former appearing to adopt via innovative solutions, while the latter responding in kind by ratcheting up environmental policy stringency and partially advancing domestic firms competitiveness in doing so. Although the idea of environmental policy-induced innovation does not start with Porter (see also Ashford & Cummings, 1985), the most well-known concept is the Porter Hypothesis. The PH created such as stir because, at the time, very little empirical evidence existed to show firms benefited from stringent environmental regulations. It also seems to contradict basic economic theory, specifically that costs to firms hurt their bottom line.

The reason I chose to use the PH as a starting point for this research is because it fits neatly into a cross-border concept for policy-induced innovations in climate technologies. Surprisingly, only a few empirical studies exist for foreign policy-induced innovation in climate technologies even though Dr. Porter is considered a trade economist and an expert on international competitiveness (see, for example: Porter, 1990). It is therefore a bit strange that much of the empirical literature using the PH is restricted to domestic inducement effects only; this is the same for climate policy induced-technological change (ITC) literature. Yet, in comparison to strictly domestic approaches, Porter and van der Linde (1995) implore us to look beyond national borders:

> Internationally competitive industries seem to be much better able to innovate in response to environmental regulation than industries that were uncompetitive to begin with, but no study measuring the effects of environmental regulation on industry competitiveness has taken initial competitiveness into account (Porter & van der Linde, 1995: 108).

It is now an interesting time to unpack an “international” Porter Hypothesis as global trade in clean technologies continues to increase, while climate policies are ever more transnationally constructed. This includes the addition of a dynamic-international PH, or the potential impact of aggregate (“global) and independent (domestic) climate policies might have on firm innovation for climate technologies. Indeed as Porter, and later Porter and Esty (2005), openly call for, “more research might focus on the competitiveness across nations” for climate technologies (Ambec et al., 2011). Ultimately, a primary outcome of this research could be to shed light on the cross-country climate policy inducements of various clean technologies: “In addition, the widely discussed Porter Hypothesis is helpful in deriving a hypothesis on the innovation effects’ relative strength of domestic *and foreign-demand* pull policies (my italics added; Peters et al., 2012: 42).

To be sure, a fair amount of studies have already looked at isolated cases whereby environmental policy induced or deterred innovation. These have provided fertile grounds to undertake the present research. But it is now important to have a deeper look at the effect of different policies on innovation, caused at least in part by *foreign demand pull policies*, both globally and locally: “future research might distinguish among command-and-control, performance-based, and market-based instruments to determine whether the form of regulation has an impact on these findings” (Ambec et al., 2011: 16) (also see the reviews in Etsy 2001 and Ederington et al., 2010). The PH shifted the debate in a big way, but now it is time to better encompass government and institutional capacities (Norberg-Bohm, 2001) into a new, dynamic Porter Hypothesis. This paper answers the calls of previous researchers to provide a new approach to cross-border innovations in climate technologies.

Paper II

The inspiration for the second paper of this dissertation comes from the observation that climate technologies are produced in many different countries and exported throughout the world. It is also motivated by a fascinating story I heard while working in Denmark. Interestingly, although the Danes are now seen as policy and technology leaders for climate change, it was not always the case, and indeed the catalyst first came from policies abroad. The enormous scaling up of the Danish wind energy is at first induced by California environmental policies many decades ago; the government increased its policy stringency only *after* the California policies were removed (i.e. foreign policy inducement effect). Because Senator Reagan sought to remove all wind energy subsidies, the Danes now boast the most sophisticated wind companies in the world.

Following eco-evolutionary theorists as in the first paper, it seems reasonable to ask if multinational firms "producing CCMTs must accurately assess the global market, and by doing so may in fact be responding to both domestic and foreign policies" (Kemp, Rip & Schot, 2001: 93). This burning question is crucially important because it is "now widely acknowledged that technological change can substantially reduce the costs of stabilizing atmospheric concentrations of greenhouse gases" (Verdolini & Galeotti, 2011: 31). And since climate technologies are now understood as globally dispersed (Dechezleprêtre et al., 2008), it is becoming ever more critical to better understand the cross-border effects of policy on innovative trends. Indeed, there is a large gap in the empirical literature in this area, especially empirical models (Wiesenthal et al. 2012; Buchner et al. 2011).

After establishing the PH as a lens to examine cross-border in the first paper, the second explores inducement of climate technology innovations. I empirically test foreign induced clean technology innovations by building a foreign environmental policy variable, weighted geographically. Following the literature, I decide to use patents as a signifier of innovation, and thus as the dependent variable. Even though the drawbacks of such a measure are widely discussed (Griliches, 1990), patents remain an important empirical measure, especially with global data because they are relatively commensurable across many nations. Yet the decision to use patents as the dependent variable immediately excludes 80% of the world, since patents are mainly concentrated in only OECD countries and the BRIICS. This is not really a concern, however, because climate technologies are concentrated in the top 10-15 countries (Lanjouw & Mody, 1996). But future research should take this data constraint into consideration.

The next matter of business is to determine what variable should represent "environmental policy". Since I am looking at cross-border inducement effects on CCMT innovations, the variable must be standardized across all countries in the dataset. Several options exist, including Yale's EPI, WEF's EPI (now merged), PACE, other emissions, PMR. I decide to use the OECD's EPS for three reasons. First, the OECD's EPS offers the best time-series index; others, such as WEF's cover only several years. Second, their EPS is constructed to deal specifically with policies I assume should directly induce climate technologies. While others, such as the EPI, incorporate broad environmental policies dealing with water and soil pollution, for example, the OECD's EPS deals with subsidies for renewable energies, taxes on fossil fuels, and the like. In other words, the latter deals primarily with clean energy technologies. Third, the EPS constructed by the

OECD is built on seven key components, which are delivered in three sub categories: overall EPS; market-EPS, and non-market EPS. This allows me to test individual hypotheses dealing with different clean technologies.

What does Porter mean by “initial competitiveness”? This is where my controls come in: research and development per GDP, methane emissions from energy production; science and technology journals, GHG emissions, knowledge stock, ICT technology imports and exports. The kinds of skills and knowledge individuals and their organizations acquire will shape evolving perceptions about opportunities and hence choices that will incrementally alter institutions. This paper is quite progressive and, although it does not offer overwhelming evidence of a *dynamic Porter Hypothesis*, it does open up an entirely new area of research.

Paper III

The United Kingdom’s ascent to most powerful country in the world during the 17th century is in large part due to open and transparent governance as well as strong governmental institutions (Robinson & Acemoğlu, 2012). With transparency came policies directly benefiting trade and commerce. Strong judiciary principles enforced new policies, which in turn supported commerce and trade. British merchants gained power through trade, creating a feedback effect precipitating in more demands from the crown (ibid). In turn, Britain imparted its institutional norms and theories of governance on other territories, including India, Singapore, and Hong Kong--norms that persist to this day. Indeed, their adept rule of India through institutional organization, powered by only several hundred soldiers yet still able to control millions of people (Guha, 1997), is still considered an institutional wonder even to this day.

Today, institutions play a large part in shaping and regulating global commerce. Standards across many countries allow multinational corporations to exploit differences in currencies to avoid suffering big losses when their main trading partners are experiencing deflationary pressures. Opening up to global trade requires federal governments to take, at times, painstaking steps to assure foreign businesses their country is worth doing business with. The smooth functioning of this ecosystem requires that multinational corporations monitor foreign political and economic landscapes to decide if and when a foreign country is worth exploiting for commercial gain. It is an intertwined system, beholden to a great variety of differentiated institutions that “encompass a set of common habits, routines and shared concepts use by humans in repetitive situations [...] Institutional set-ups and capacities are determined by their spatial, socio-cultural and historical specificity” (Wieczorek & Hekkert, 2012: 77).

Consequently, institutions initiating these changes on the relative price of climate change mitigation technologies play a large role in defining the marketplace. Decreasing the cost of clean technologies is typically considered a success of climate policy, while this relative decrease in price allows innovations to spread more rapidly. Likewise, climate policy institutions introduce and refine territory for firms to innovate and trade their clean technologies. This applies to both global climate policy, for example the co-development mechanism (CDM) under Kyoto which expedited the transfer of climate technologies, as well as to domestic policies that encourage investments in certain regions at specific times. Therefore, the neoclassical assumption that institutions do not matter, and "if they exist they play no independent role" (North, 1993: 64), appears to be less convincing for empirical research on climate policy and its induced effect on clean technology innovation. The neoclassical model does not capture induced innovations very well, because "New technological possibilities must compete on an uneven playing ground, in which established technologies and development routines are already ingrained in organizations" (Weyant, 1999: 24). In this type of environment, innovations can be expected and indeed are perhaps the only way new technologies can supplant older, polluting technologies.

The 21st century began with a unique institutional event for climate policy, The Kyoto Protocol, although now it is considered somewhat of a failure (Barnett, 2003). Kyoto's enforcement began in 2005, but truly only lasted 7 years and was plagued with "institutional sclerosis" nearly the entire time (Oberthür & Gehring, 2011). Several components of the UNFCCC agreement soon landed in virtual obscurity, including global emissions trading (ET) and Joint implementation; however the third pillar of Kyoto, the Co-Development Mechanism or CDM, is considered a partial success (Laing, Sato, Grubb, & Comberti, 2013). This is interesting because the CDM is the only pillar focused almost exclusively on technological innovations and diffusions. One primary goal for the Co-Development Mechanism (CDM) is to transfer climate and environmental technologies. The reason it is considered only a partial success is because, while environmental technologies were seen as transferred (Dechezleprêtre et al., 2008), the technologies were often vintage and more aligned with the much older Montreal Protocol. Furthermore, a large portion of such technology transfer only went to China, meaning the "global" policy was simply a bilateral policy in the end. Nevertheless, the CDM showed global climate institutions could work.

Where institutional theorists and neoclassical economic theory agrees, I think, is in the concept of competition. By both accounts, competition is good because it "forces organizations to continually invest in skills and knowledge to survive" (North, 1990). Evidently, the separation of institutions from organizations is crucial if one is to get a handle on the dynamics of institutional change (North, 1990). In merging the conceptual and empirical approaches delivered in the first two papers, the final paper explores the questions more deeply in light of institutional dynamics.

By using the lens of Institutions (North, 1990) and competitive reaction to policies (Porter, 1992), I can construct an internationally dynamic approach to environmental policy and induced technology innovation dependent, principally, on home country institutional capacity but also on institutional distances. In other words, home country firms might innovate in clean technologies in response to foreign environmental policies to stay competitive if they are sure their home institutions will support this endeavor. By the same token, the foreign "target" whereby the environmental policies exist must also have strong and transparent institutions, otherwise the home firm will not believe its innovation is able to be exported and sold on a foreign market. One key issue I must consider, however, is the difference in these two institutions, home and foreign. Indeed, this consideration encompasses most of what the final paper is about.

In addition, the final paper offers closure to the initial ideas that sparked the research interest for this dissertation. Pinning down what we actually mean when we use the word “institutions” is certainly difficult. Vaguely defined usage in the literature is rampant and can be particularly devastating for researchers. Yet, I think the general framework put forward by North (1990) continues to hold sway. Even if we are unable to fully define what we mean by institutions, in regard to a particular avenue of research, we should still consider these very important, especially in a global political economy context. I believe this is evident for climate policies as well as for innovation of new technologies. Thus, the focus on institutions in the final paper is well placed.

Specifically, the technique employed establishes a global political economy model for international climate policy induced innovations. This is accomplished by way of creating an institutional distance variable under the hypothesis that institutional distance can be used as a weight on the foreign climate policy-inducing impact of home country. In other words, if a foreign country has strong environmental policies, a domestic country is expected to be induced only to the extent the difference between the two countries institutions is not too large. Otherwise, if the institutional distance is indeed very large as per the gravity model (that is, closer to “1”), I expect little to no foreign climate policy inducement effects on innovation. Lastly, and to check for robustness, this effect is explored not with institutional distance but with environmental policy distance to the frontier climate policy leader. Using a slightly different approach, but still using a gravity model, I construct the environmental policy frontier variable to measure the distance a home country is to the leading environmental policy country in the sample. These findings are strong and suggest that a global political economy index for clean energy technology innovation, diffusion, and trade represents a promising new area of research.

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Chapter II: Might Global Political Economy Approaches Supersede Pure Economic Approaches to a Global Porter Hypothesis?

Abstract: The Porter Hypothesis theorizes that competitive firms, properly attuned to environmental policies, should respond in innovative ways, thereby increasing their competitiveness and resulting in a "win-win" scenario for businesses and the environment. While initially, empirical support for the Porter Hypothesis (PH) was scant, more recently a large body of literature finds evidence in its favor. Yet most of these are either case studies or empirical investigations confined to only one or several countries. This paper first identifies some of the difficulties induced technological innovation theorists face by taking a purely economic, and sometimes by definition a static, approach to the Porter Hypothesis. Specifically, the principle weakness in purely economic approaches in ITC literature plays out the constricting of a "foreign" Porter effect. This might be one reason that, up to now, ITC and PH researchers do not fully conceptualize a cross-border, foreign policy-induced innovation inducement effect for clean energy technologies.

Keywords: Porter Hypothesis; Induced Technological Innovation; Green/Environmental Technology; Clean Energy Technology; Innovation; R&D

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Introduction: Global Induced Innovation Effects

The Danish wind energy industry is an oft-cited example of how a country may, through certain steering environmental policies, guide a renewable energy industry from infancy to global domination. Likewise, the Chinese solar industry represents one of the most rapid technological advances, in any industry in any country, the world has ever witnessed. While Denmark is a tiny Scandinavian country with some of the most stringent environmental policies in the world (now), China is by far the world's most populous country with a relatively weak environmental record. Though wind and solar are together the most well-known renewable energies, in particular for policy makers, they're characteristically quite different. The differences between wind and solar might even be as large as the political and economic differences between Denmark and China.

Yet in both countries the rapid ascent to creating the world's most highly valued and highly innovative renewable energy companies is quite similar. What, we may ask, do these two countries share in common aside from dominance in the renewable energy landscape? As I argue, following eco-evolutionary theorists (Kemp, Rip & Schot et al.), Denmark and China perhaps share only the common intuition to respond to foreign environmental policies. While induced environmental innovation economists using the Porter Hypothesis are able to show how environmental policies induce innovation, there clearly exists a gap in the literature on cross-country inducement effects (Ambec et al., 2011). Why? That is the crux of this chapter.

The Porter Hypothesis

Porter views pollution essentially as “wasted resources” (Porter, 1991; see also Ashford, 1993). Environmental regulation often exposes wasted resources otherwise invisible to firms and spurs them to find innovative solutions (Porter & van der Linde, 1995; Ashford & Heaton, 1983; Rothwell, 1992). By “assuming away innovation benefits” (Porter and van der Linde, 1995: 108) researchers using strictly economic methods inevitably conclude that environmental policy stringency invariably raises costs on firms and therefore harms their competitiveness. But the Porter Hypothesis implores us to take a different perspective, broadly built on the idea of innovation as a potentially significant form of advancing solutions. Said another way, if analysis expands to include internationally competitive firms, environmental regulations can just as easily drive a firm to become more competitive and innovate. Thus, regulations on polluting firms’ emissions need not invariably harm firms, especially multinational ones that are paying particularly close attention to policies of many different countries.

In this paper, I present a novel reconceptualization of the Porter Hypothesis in an international, global political economy context (Newell, 2008). This *dynamic* model implies international environmental policies impact innovations in climate change mitigation technologies (a smaller subset of environmental technologies) (Dasgupta et al., 2015). In a hyper-globalized world where policy-spillovers, knowledge-spillovers, and innovation-spillovers are commonplace, it should also be the case that environmental policy-spillovers between countries are normal. Accordingly, it is expected that products and technologies frequently cross over into other industries, while simultaneously investors look abroad for ideas to develop new products (Fagerberg, 2004).

Framework

Going beyond the purely domestic policy inducement effects on innovation in firms in response to market incentives (narrow PH), and building on theoretical literature of weak and strong PH, I propose here a *dynamic PH* is a key feature of the global cleantech technological paradigm. Therefore, going further, I add to the three definitions offered by Jaffe & Palmer (1997) (*weak, narrow, strong*) to include a *dynamic* international Porter Hypothesis: *dynamic* international PH refers to *innovative domestic response to environmental policies from abroad* (Walz, Schleich & Ragwitz, 2011; Sijm et al., 2004; Glachant & Dechezleprêtre, 2014; Peters, Schneider, Griesshaber & Hoffman, 2012; Kneller & Manderson, 2012). I borrow the concept of dynamic innovations across borderers from Mulder and Soete (1991), who find empirical evidence for a link between technological competitiveness and trade performance in a variety of different sectors: “from such a *dynamic* perspective, it is not surprising that the relationship between technology, trade, and growth is at the center of analysis” (Mulder & Soete, 1991: 251) (this also enlightens the variables selected in the following chapters). Further, and stemming also from business innovation theory, is the idea that if competition from abroad, or “learning-by-exporting” (Grossman & Helpman, 1991), is seen to sometimes increase productivity (i.e. strong PH), might this also apply to environmental policy “competition” from abroad? These ideas are at the heart of my reconceptualization of the Porter Hypothesis as a dynamic, cross-border theory.

This reconceptualization of PH is supported by evolutionary economics innovation researchers (including Dosi, Rosenberg, Nelson, Freeman), as well as the systems of innovation approach generally speaking (Lundvall, 1988; von Hippel, 1986; Malerba, 2002), and national innovation systems concepts more specifically (Lundvall, 2017). Systems of innovation goes beyond classical economic approaches by harkening back to institutions, their strength of home markets for “testing” new innovative exports, and likewise the central importance of a nation's regulatory regime in shaping the innovation system. As such, the innovation system is defined as dynamic and not linear; linear being apropos to static, economic approaches. Importantly with this new approach, technology-push (innovation-induced) and demand pull (regulation-induced) are seen as two sides of the same coin, with a more general focus on knowledge accumulation effects (Lundvall, 1988; Mowery & Rosenberg, 1989). As such, the *dynamic* PH aligns closely with a “systems of innovation” approach (Freeman, 1989; Nelson, 1989; Malerba 2002; Nelson, 1993; Lundvall, 1985; Lundvall et al., 1988), I believe a dynamic international Porter Effect might empirically present itself (Ambec & Barla, 2006), if properly reconstructed with these characteristics in mind. Indeed, the Porter Hypothesis is already shown to operate across borders, in the form of “foreign-demand pull policies” (Peters et al., 2012) for solar energy and foreign effects of policy on inducing wind energy innovation at home (Glachant & Dechezleprêtre, 2014).

1. Essential Background: Innovation and Policy-Induced Innovation

Innovation theory is primarily an outgrowth of Schumpeter's’ seminal works over seven decades ago (Schumpeter, 1934; Schumpeter, 1942). Instead of supposing companies and their constraints based on expenses operated in a strictly linear fashion, he introduced the idea that companies can and do innovate as a dynamic reaction to market forces. Such innovation leads to countrywide or worldwide technological change (Dosi, 1982). Further, companies not innovating are expected to fall at the mercy of innovative firms. This is the oft-cited “creative destruction” of innovative industries (Schumpeter, 1942).

Technological change, according to Schumpeter (1942), proceeds in three stages: (1) birth of an idea; (2) commercially viable product development (i.e. “innovation”); (3) diffusion, or consumer’s choice to use the new product. Notice this conceptualization of innovation is based solely on firm and company action, not at all to do with government policy. In fact only after 1945 did the “Bush Report” (Bush, 1945) openly draw in government policy to induce innovation: “The huge success of science in supplying practical results during World War II in one sense supplied its own legitimation for science [...] as a source of innovation” (Etzkowitz & Leydesdorff, 2000: 116). Government policy aimed at inducing innovation most likely requires revised economic methods to properly detect innovative responses of industry.

The first two stages of Schumpeter’s technological change--invention and innovation--are normally embodied in simply one variable: “Research and Development” (Dosi, 1982). Meanwhile the third stage, diffusion, is notoriously difficult to measure and incorporate into empirical research on climate technologies even though it is critical to the development of these same technologies (Popp, 2011). Equally, all stages are affected by regulations, incentives, and subsidies (ibid). Later in this paper it should become clearer how price and R&D variables to understand firm innovation in climate technologies might not be up to the task of a dynamic investigation of the Porter Hypothesis (Ambec & Barla, 2006).

Induced technological change (ITC) is a direct outgrowth of the three stages of Schumpeter's theory of technological change, but with a strong emphasis on price inducement effects (Hicks, 1932; Goulder & Schneider, 1999; Jaffe, Newell & Stavins, 2002). Generally speaking, ITC models take either one of two forms: (1) cost-function models; or, (2) top-down macro analysis or empirical studies (Weyant & Olavson, 1999). A recurring theme in this paper will be to highlight the dependence on "price" as the principal explanatory variable for induced innovation. For that reason, there is an explicit focus on cost-function models of induced innovation and the Porter Hypothesis. In contrast to ITC researchers, Eco-evolutionary researchers place greater emphasis on policies and expected future markets resulting from carefully constructed environmental policies. This results in more concerted focus on innovative outputs. "In the evolutionary view, the chance of making creative innovative combinations is reinforced by a number of activities: stimulation of attractive future perspectives [...] institutional facilitation, education, knowledge exchange, and [...] niche experiments" (Loorbach & Kemp, 2008: 162). Notice a pronounced focus on institutions, knowledge, and experimentation for innovations within this theoretical approach.

Public policies are theoretically able to induce one or several of the following: (1) birth of an idea; (2) commercially viable product; (3) diffusion of the new product to the public (Kemp, 1997). As yet, a cross-fertilization of eco-evolutionary theory and induced-innovation in climate technologies does not truly exist. Recall (1) and (2) are often combined into one variable, Research and Development (R&D). Therefore, a more broad way to conceptualize induced innovation is to imagine policies catalyzing R&D, which in turn leads to innovation and diffusion of new technologies. This is the manner by which most ITC economists conceptualize policy inducements. It allows more straightforward economic interpretation because in this way they are able to convert policy into a direct effect on prices, which in turn is assumed to induce firms to innovate. As mentioned above, however, diffusion is, in terms of analysis, very difficult to pin down. Luckily for climate technologies we are able to employ novel methods of patent families to understand how quickly new innovations are becoming globally valuable (discussed in the following paper). In sum one possible solution, not typically taken by economists, lies in eco-evolutionary approaches.

1.1 Rate and Direction of Innovations

In evolutionary economics literature, induced innovation is delineated into two subsets: rate of innovation and direction of innovation. Some consider these two sides of the same coin (Lundvall & Archibugi, 2001; Geels, 2006). Rate of innovation is simply the increase (or decrease) of innovative activities over time in respect to the previous time period. An example is the rapid rate of computer technology innovation experienced by Japan in the 1970s and 1980s, induced in large part by domestic industrial policies, but certainly in response to foreign demand for computer technologies as well. Alternatively, the direction of innovation involves technological trajectories, path dependencies, and the overall “technological paradigm” (Dosi, 1984). An example of direction of innovation is seen in VCR and DVD being, for a time, dominant video technologies. New trajectories might open up entirely new industries, and the rates of these new directions are usually unknown beforehand.

Technological trajectories embodies the idea that technology becomes, in a way, “locked-in” (Unruh, 2000), and as such develops along a semi-predictable future pathway. Meanwhile path dependencies refer to the history of specific technologies and the many different iterations of technologies leading to a very specific, resultant technology. Finally, the technological paradigm expands on these two previous ideas to understand where technologies are headed and where they came from (Dosi, 1984). In other words, what are the stylized facts giving rise to new technologies? (Dosi, Pavitt & Soete, 1990). Answering this question is important, especially for climate policy, because it might show the extent to which climate policies actually drive firms to innovate in Climate Change Mitigation Technologies (CCMTs).

Policy induced innovation researchers must pay particularly close attention in defining Schumpeter’s innovation stages and, in tandem, which part of the technological paradigm they are intent on examining (Freeman, 1994). For example, rates of innovation can be induced by targeted government R&D and subsidies (Nemet, 2009). Increased rates of innovation might also arise out of government military requirements, a salient example being the U.S. postwar years (Mowery & Rosenberg, 1993). Contrarily policies inducing a change in direction of innovation might require product standards or strict technological mandates (Jaffe et al., 2003; Acemoglu et al., 2009; Popp, 2010). What makes these delineations more difficult is the fact that, from a National Innovation Systems (NIS) perspective, government policies can and does influence both rate and direction of technological change (Freeman, 1995). This is often referred to as “The chain-link model”, where both supply push and demand pull are analyzed in relation to scientific knowledge, and is an important contribution to NIS literature (Kline & Rosenberg, 1986). The perspective on innovation as a process of interaction between producers and users may be seen as introducing the micro- foundation for evolutionary theories embodying such a chain-link model (Lundvall 1985).

Indeed, that is precisely the motive behind carefully constructed environmental policies: to influence a change in an industry in order to decrease environmental damage caused by that industry. Or, to induce firms to innovate in environmental technologies capable of emitting less noxious pollutants which otherwise would not be invented in absence of such policy. Likewise, this is where Porter and van der Linde (1995) stand conventional economics on its head (Ambec et al., 2011) by pointing out that innovations result from stringent environmental policies, leading to increased competitiveness, and therefore such policies *do not necessarily increase costs for properly attuned firms*. The PH claims, in contrast to most economists, that induced change in industry behavior can and often does confer competitive advantage, especially in globally dispersed multinational firms. Internationally competitive industries seem to be much better able to innovate in response to environmental regulation than industries that were uncompetitive to begin with, but no study measuring the effects of environmental regulation on industry competitiveness “has taken initial competitiveness into account” (Porter & van der Linde, 1995: 108).

In almost distinct contrast, most induced-innovation economists continue to understand environmental policy as strictly a cost. This is evidently a static approach based on prices, and can only force innovation into the model. Also, a global perspective on variegated inducement effects is nearly impossible with such an approach. “Thus, by taking a specific technology as a starting point, the technological system approach cuts through both the geographical and the sectoral dimensions. Take for example the development and diffusion of solar cells: this depends on technological progress made in research institutes and universities all over the world” (Hekkert et al., 2007: 419). In terms of pollution caused by energy production and use, environmental policies aim to decrease harmful emissions from conventional energy. Simultaneously these policies encourage a shift towards more efficient and non-emitting clean energy technologies. Thus, environmental policies related to climate change specifically target *rates and directions* of innovations in production, storage, and consumption of energy technologies of firms. If the PH is correct by any measurable degree, a “win-win” situation emerges whereby society gains by a cleaner climate and firms gain by becoming more competitive by creating and marketing new clean technologies (Kanerva et al., 2009: 12).

1.2 The Porter Hypothesis and Induced Technological Innovation: Same Coin?

As discussed above, Porter (1991) proposes environmental regulations, if properly designed, do not always hinder firms but in fact might spur them to innovate. In contrast, it is typically assumed by most economists (and still is) that all environmental regulations damage firm profits (Ambec & Barla, 2006). What is perhaps overlooked, especially from a macroeconomic point of view, is that the Porter Hypothesis (PH) is sometimes misconceived to imply that all environmental policies induce positive innovations in firms. However, this is not the formulation Porter had in mind:

> [We are not] asserting that *any strict* environmental regulation will inevitably lead to innovation [...] Instead, we believe that if regulations are properly crafted and companies *are attuned to the possibilities,* then innovation to minimize and even offset the cost of compliance is likely in many circumstances (Porter & van der Linde, 1995: 110).

Notice, in particular, the PH does not rest entirely on price-inducement effects on firm innovation. This salient point is of critical importance. Companies *attuned to the possibilities,* rather than implying all companies benefit from innovation, implies instead that only companies cognizant of how their own innovative responses to policies can be turned into a positive benefit will participate in this win-win situation. Therefore the PH does not, as many mistakenly claim, mean all environmentally stringent policies induce innovative efforts in firms. Likewise, we should not expect a price inducement effect to represent an acceptable approach if the PH is used as a lens for analysis. In short, firms can actually benefit from properly crafted environmental regulations that are more stringent (or imposed earlier) than those faced by their competitors in other countries. “By stimulating innovation, strict environmental regulations can actually enhance competitiveness” (Porter & van der Linde, 1995: 98). How might researchers go about exploring these important questions on competitiveness and innovation in environmental technologies?

The Porter Hypothesis has gathered enormous empirical evidence over the past 20 years. Earlier empirical research mostly cautioned against Porter's predictions (Jaffe, 1995; Walley & Whitehead, 1995) but more research suggests otherwise (Bosetti et al., 2014; Ambec et al., 2011; Carraro et al. 2010; Popp et al. 2010; Lanoie et al., 2011). The obvious result is that a variety of studies are able to demonstrate the positive innovation outputs in reaction to properly constructed environmental policies (narrow PH). Finding a positive innovation effect from environmental policies is critical to climate policy, because technologies for the environment will play a salient role in combating climate change (Verdolini & Galeotti, 2011; Johnstone et al., 2010). The importance lies in the implication that climate policies might be able to offer a "double dividend" (Hoffman, 2000), or "win-win" (Reinhardt, 2000), by catalyzing one or all of Schumpeter's innovation vectors into action to produce and diffuse new climate change mitigation technologies (Albino et al., 2014; Harman & Cowan, 2009). In sum, climate technologies will be critical for stabilizing greenhouse gases in the atmosphere (Albino et al., 2014; Hoffert et al., 2002), and therefore Schumpeter's innovation vectors are increasingly important for examining the role climate policy has on effectuating firm innovation for these technologies.

1.3 Three Divisions of the Porter Hypothesis

How might properly designed environmental regulations "induce" innovative responses in firms? Porter and van der Linde specify how their theory unfolds in five key steps: (1) regulation alerts firms to resource inefficiencies; (2) information gathering becomes more precise and raises awareness of the issue; (3) regulation reduces uncertainty; (4) regulation creates pressure motivating innovation and progress; (5) environmental regulations ensure a level playing field, for example all firms within the same industry must adhere to the same rules. In terms of innovation in environmental technologies specifically, rather than innovation broadly within regulated industries, how are we to begin analysis?

An important contribution to the literature is made by Jaffe and Palmer (1997) who divide the PH into three different versions: *weak, strong, and narrow.* This allows for a more adequate investigation into the PH because researchers are then able to isolate specific technological, price, or other measurable firm effects from variegated environmental policies (Ambec et al., 2013). Although the empirical strength of such a delineation of PH into three different vectors should be evident, the literature largely fails to properly account for this division. As we shall see below, even though ITC theorists and economists prefer the narrow version because it most closely resembles static economic approaches (i.e. market and price mechanisms largely lead to innovation), these researchers frequently frame studies around either the weak or strong versions of the PH. This might significantly alter their results and slightly diminishes credibility of such empirical studies. Furthermore, it effectively closes the door on an international (*dynamic*) Porter Effect.

The weak PH implies regulation induces innovation in firms, yet whether the innovation is positive or negative remains unknown. In other words, environmental regulation causes some kind of innovative response. This is also most closely associated with the idea of induced technological innovation first formulated by Hicks (1932) because it imposes a price change-inducement effect causing firms to spend on R&D in hopes of innovating. ITC is a demand-pull theory implying certain policies induce innovation in certain firms, and thus ITC is considered part of the weak version of the PH (Franco, 2013). Demand pull, in contrast to technology push, refers to a market demanding a certain innovation leading firms to initiate search and development for that market need. But demand pull is known to rely "too heavily on a neoclassical economic framework" (Rosenberg, 1976: 96), while the Porter Hypothesis is embedded more naturally in a systems of innovation approach embodying both demand pull and technology-push approach. Carefully constructed environmental policies indeed account for demand-pull and technology-push, the latter supported in the form of subsidies for R&D for private firms carrying out environmental innovation or by directed R&D at public institutions (Jaffe et al., 2005). Lanoie et al. (2011) add even stronger metrics by defining the weak version frame as a firm's innovation choices (proxied by R&D expenditures) and a narrower version to signify environmental regulations affect productivity of a firm (Lanoie et al., 2011).

On the other hand, the strong PH implies that such innovations indeed increase firm competitiveness while environmental policy directly leads to “positive innovations” (Ambec et al., 2013). In other words, the policy in question causes all regulated firms to innovate and make a handsome profit from doing so, thus leading to increases to productivity. Needless to say, evidence for the strong PH is scant (Rubashkina, Galeotti & Verdolini, 2015; De Vries, & Withagen, 2005), although as more dynamic approaches are incorporated, the strong PH is gaining ground. After all, as Schumpeter states, there will be creative destruction in innovative industries and thus we should not expect all firms to innovate and survive. Likewise, it becomes inherently difficult to identify exactly which firms are regulated by the new policy because of global value chains and globalized production methods.

Finally the narrow PH postulates that market policies should induce adequate innovation and overall competitiveness in firms (Lanoie et al., 2011). More clearly stated, carefully calibrated environmental policies will have the effect of inducing innovation in firms able to carry out such innovation in environmental technologies. Therefore, some firms will innovate in response to environmental policy and flourish, while other firms will succumb to creative destruction *a la Schumpeter*. It is worth reiterating here an additional caveat: both weak and narrow PH are not expected to induce positive innovation in all firms, only those firms most attuned to environmental policies (Porter & van der Linde, 1995). Below is a summary of the literature using the Porter Hypothesis to understand the innovative inducement effects of various climate policies, delineated among the three components introduced by Jaffe and Palmer (1997).

Table 1: Brief Summary of literature on Porter Hypothesis

Author(s)	Data	Porter strong	Porter narrow	Porter weak
Walley & Whitehead (1994)	Large Companies, always a cost	No	No	No
Jaffe & Stavins (1995)	find scant evidence for strong PH (looking at productivity increases from EPS).	No	No	Yes/No
Lanjouw and Modi (1996)	Patents Germany, Japan and the US	No	Yes	Yes
Jaffe and Palmer (1997)	Patents and R&D US Manufacturers	No	No	Yes (for patenting only)
Brunnermeier & Cohen (1998)	Environmental regulation positively impacts environmental patents at sector level	No	Yes	No (patents)
Xepapadeas, A., & de Zeeuw (1999)	Productivity in capital stock and machines	No	No	Yes
Berman and Bui (2001)	Productivity Los Angeles Refineries	Yes	No	No
Jaffe & Lerner (2001)	environmental policy stringency leads to specific energy innovation	No	Yes	No

Alpay et al. (2002)	Productivity Mexico and the US Manufacturers	No	Yes Mexico/ No US	No
Brunnermeier and Cohen (2003)	Green Patents US Manufacturers PACE/No Regulations	No	Yes	No
Murty (2003)	Productivity Indian Enterprises	Yes	No	No
Popp (2003)	186 plants in the U.S. from 1972 to 1997	Yes	Yes	No
Filbeck & Gorman (2004)	24 U.S. electrical Impact of environmental regulation	No	No	No
De Vries & Withagen (2005)	Green Patents in OECD countries	No	Yes	Yes
Gupta & Goldar (2005)	17 Indian Pulp and Paper	No	No	No
Popp (2006)	Green Patents Germany, Japan and the US	No	Yes	No
Lanoie et al. (2008)	Productivity Quebec	No	*Yes (internatio nal)	No
Rutquist (2009)	Productivity 48 US manufacturers (but sub-sectors variability)	No	No	No
Carrión-Flores and Innes (2010)	Green Patents 127 US Manufacturers Support	No	Yes	No
Johnstone et al. (2010)	Green Patents 25 countries Support	Yes/No	Yes	Yes

Rexhäuser & Ramer (2010)	Productivity German enterprises	No	No	No
Greenstone (2010)	Productivity USA Manufacturers	No	No	No, Ozone and particles/Yes CO
Rübbelke & Weiss (2011)	Rübbelke, D. T., & Weiss,	No	No	Yes
Lee et al. (2011)	Green Patents US enterprises	No	Yes	Yes
Lanoie et al. (2011)	Patents 7 OECD countries	No	Yes	Yes
Kneller & Manderson (2012)	R&D UK Manufacturers R&D	No	No	Yes
Costantini & Mazzanti (2012)	Exports EU-15 countries	No	No	No/Yes
De Santis (2012)	Exports EU-15 countries treatments: Kyoto, Montreal, cause change	No	No	No ER/Yes
Johnstone et al. (2012)	77 countries, patents, WEF survey data as proxy for EPS.	No	Yes	Yes
Aguirre and Ibikunle (2014)	found no significant positive influence of policies on RE growth.	No	No	Yes/No
Nesta et al. (2014)	Renewables policies in competitive markets	No	No	Yes
Sauvage (2014)	Exports OECD countries Support in Env. goods	No	Yes	No

Groba (2014)	Exports 21 OECD countries	No	Support in Env. sector	No
Rubashkina et al. (2015)	Patents and R&D in 17 EU countries	Yes Support in patents/No support in R&D	No	No
Lindman & Soderholm (2016)	wind industry in the EU	No	Yes	No

2. Empirical Investigations of PH: For and Against

Literature surveys of empirical PH approaches are given by several researchers (Lanoie et al., 2011; Ambec et al., 2011; Ambec & Barla, 2006; Ambec & Lanoie, 2008). I do not intend to offer an extensive literature review of the PH here, only enough evidence to support my contention that price-inducement methods, and consequently the bulk of economic ITC models for climate technology, encounter some difficulties in capturing interindustry, and likewise cross-country, Porter Effects. The Porter Hypothesis evidently causes a renewed interest in induced innovation from environmental technologies (Howes, Skea & Whelan, 2013). In general, a key finding is environmental policies can and do induce firms to innovate in a variety of environmental innovations (Rennings, 2000; Jaffe et al., 2002; Bosetti et al., 2014): “virtually all climate-economy models [i.e. economic modeling predictions] find that climate change policies induce an increase in the pace of carbon-saving technical change” (Bosetti et al., 2014: 39). Evidence for weak (Lanoie et al., 2011; Rubashkina et al., 2015; Lanoie et al., 2011;), narrow (De Vries, & Withagen, 2005) and even strong PH (Ambec & Barla, 2002) is found in the empirical literature.

In particular, Brunnermeier and Cohen (2003) find a positive correlation between pollution abatement policies and firm-level patenting and, hence, innovation. But their analysis is confined to the U.S. manufacturing industry, which says very little about the extent to which policies directly induced positive environmental innovations to flourish (narrow or strong Porter). In the same vein Taylor et al. (2005) explore innovative effects of the 1970 Clean Air Act (U.S.) and find a surge in patenting in Sulphur-Dioxide control devices several years after the policies. Again, their analysis involves domestic policy and end-of-pipe innovations and as such does not give sufficient evidence of point-of-source innovations from policies for climate mitigation, even though in that time the technological responses were considered quite important. Likewise Hamamoto (2006) find pollution control expenditures correlate with R&D expenditures in firms while stringency of regulation also affects total factor productivity. These are important examples of earlier literature finding evidence of the Porter Hypothesis, even though the research is confined mainly to the *weak* Porter or otherwise focused on end-of-pipe, or reactive, technologies.

2.1 Countering Porter

The Porter Hypothesis is not without strong critique. This paper is not intended to provide an exhaustive survey of the literature on the PH, including research in support and against its predictions, but rather to suggest the predominant methods and variables used in the literature clearly have difficulty in detecting and explaining foreign environmental policy effects on innovation at home.

Jaffe et al. (1995) find no statistical evidence environmental policies induce patenting, the latter representing their chosen proxy for innovation. One primary critique of Jaffe et al. (1995) is their data is cross-sectional (meaning it examines only one point in time) (Ambec et al., 2011). Subject to cross-sectional constraints, it becomes nearly impossible to pin down induced innovation effects. Perhaps with a longer time lag for patents, they might have seen innovation effects predicted by Porter. Investment, R&D, and new product development can often be a lengthy process. Jaffe et al. do find, however, evidence of new investment in environmental technologies as a result of such policies. This in fact suggests a weak PH exists.

Following Jaffe et al. researchers begin to investigate R&D and investment responses to environmental policies, and subsequently assume these are innovative inputs. The assumption R&D or prices account for induced innovation in firms invariably leads to ambiguous results, depending on individual assumptions of the different studies. For example while Newell, Jaffe, and Stavins (2002) find induced innovation in energy efficiency technologies, Nordhaus (2004) finds an entirely different result. Aguirre and Ibikunle (2014) also find no evidence of PH, but there focus is mostly on taxes as a proxy for environmental stringency. Clearly, choice of proxies leads to differentiated findings in the literature.

What is most surprising is the finding by Lanjouw in Mody (1996) in favor of the PH. Consequently, this is the first empirical research to clearly show the Porter Hypothesis has merit. Indeed, each and every paper hence cites this seminal paper. One shortcoming of their study, discussed in detail below, is the misguided assumption pollution abatement costs (PACE) should be used as a proxy for environmental policy stringency; indeed Porter does not say all environmental policies might induce firms, just well guided policy (Gillingham et al., 2008). Furthermore, Porter does not contend abatement costs as representative of well-constructed environmental policy, they could just as easily be due to vintage capital equipment costs (Ambec & Barla, 2006; Ambec et al., 2011).

The perhaps misguided central importance of the R&D variable leads predominantly only to the weak PH. But at the same time, many models confuse the weak and narrow, and therefore look at only one industry while expecting exactly the same industry to respond to a distinct set of environmental policies, or simply one policy. One error here is looking for strong or weak Porter Effects, but using a narrow Porter approach. Others do not properly account for a longer time series. Analysis of environmental policy, inherently a long and iterative process, should not be restricted to one point in time (Brunel & Levinson, 2013). Interestingly, it appears what Jaffe and Stavins (1995) needed was a proper delineation of the PH, which Jaffe and Palmer promptly create in 1997.

In sum, most of the research countering PH does not take into account for a central tenet of the theory: environmental policy does not harm competitiveness in all firms and all industries and indeed can even induce positive innovation offsets. Many studies simply fail to account for time and as such do not build lags and delayed capital expenditures into the models (Ambec et al., 2011). Or, studies examine the effects of command and control regulations (typically using PACE) while the PH is more likely to be detected with incentive/market based regulations (Ambec & Barla, 2006). Failing to account for these nuances, the bulk of the PH investigations fall back on well-known price-inducement approaches. Indeed, a static interpretation of the PH will likely fail to encompass the dynamic effects of technological change in climate technologies (Grubb, 1997: 163). “Apart from conceptual problems with this “strong” interpretation, evidence for it is difficult to find from published data. Therefore, Jaffe and Palmer only try to establish a relationship between stringency and innovation. Innovation is measured in two ways: industry-wide R&D expenditures (a route we will discuss no further) and patents” (De Vries, & Withagen, 2005: 5).

Even though Jaffe and Palmer (1997) and Brunnermeier and Cohen (2013) understand environmental policy is a “dynamic process”, they insist on using static models. They simply fail to account for a dynamic, or perhaps cross-border, Porter-effect. Likewise their lag structures, or allowing time for innovation “offsets” to be developed and patented, leave much to be desired. A reasonable estimate for detecting PH effects of policy on patenting, for example, is between three to six years not 1-3 years as these studies assume (Jaffe & Palmer, 1997; Brunnermeier & Cohen, 2013; Johnstone et al., 2010). Many studies such as these already assume a linear innovation process whereby R&D responds to policy and such R&D theoretically leads to innovations (patenting); it is interesting that these studies tend to lag R&D several years, on average, but do not additionally lag patenting (which is assumed to result from R&D, and thus occur only afterwards). "While the PH is in essence a dynamic hypothesis, most empirical research use empirical specification with a very simple dynamic structure or none at all (Ambec & Barla, 2006: 53). In the following section, I'll begin to introduce empirical support for the PH, but continue to highlight some methodological issues in the analysis.

2.2 Empirical Support for PH

Perhaps the most detailed, collective analysis of weak, narrow, and strong PH is carried out by Lanoie et al. (2011). Using survey data and econometric methods they are able to find strong evidence for the weak and narrow PH, but not for the strong version (which is expected because the strong version implies all firms will respond positively). Notably, their proxy for induced innovation is determined by increased R&D spending after environmental policies are implemented; in other words, they continue to employ linear economic approaches embedded in price-inducement effects.

As such, and in line with the narrow PH, they find evidence that less prescriptive "standards" provide more incentive for innovation. In other words, environmental "market" policies enable firms to seek out their own unique and innovative solutions, which often results in more innovative solutions. This result is important because it stands in contrast to earlier examinations of energy efficiency innovation that find standards play a more critical role in innovation for energy efficiency products (Newell et al., 1998; Popp, 2006). One issue is that standards are found to induce innovation in energy efficiency technologies (Newell, Jaffe & Stavins, 1999) but are not directly comparable, in terms of PH analysis, with other industries such as clean energy technologies. We might suggest PH investigations should not only be separated by narrow, weak, and strong, but consequently also between innovations in clean energy innovation and energy efficiency innovation (energy demand-side, and energy supply-side).

A paper by De Vries and Withagen (2005) stands out as one of the first approaches to not employ PACE as a proxy for environmental stringency. They test the weak PH across several countries in Europe and North America (making their approach dynamic as defined here). Importantly, their environmental policy proxy employs a method to build a robust composite indicator that even includes dummies for international climate agreements. The seminal paper by Johnstone, Hascic and Popp (2010) follows this approach to examine 25 OECD countries in all renewable energies (dynamic and semi-complex because renewable energies can sometimes be considered one industry and other times not). I suggest a dynamic complex PH extension of Johnstone et al. (2010) to include a more robust composite indicator for environmental policy, building on recent research conducted by Nesta (2014) and Nicoli & Vona (2014).

The strongest example of a true dynamic-complex PH is conducted by Constantini and Crespi (2008). They look at strong PH in 20 OECD countries. And, while they do use PACE, they build a composite policy variable to include Kyoto Protocol ratification. This approach is unique because it considers the expected future market of clean technologies as a result of international climate agreements. In a separate study, Costantini and Mazzanti (2012) carry out a similar approach, but rely more heavily on PACE even though environmental taxes are also factored into their model. Although their approach is dynamic, the results are weakened because of the continued reliance as PACE. Lastly, Albrizio et al. (2014) investigate 17 OECD countries using the strong PH (dynamic here) and indeed find productivity increases as a result of environmental policy stringency (proxied by pollution intensity and total factor productivity). Taken together, these approaches carve out important avenues in the literature, and although now the weaknesses of PACE are well known (Rubashkina et al., 2015), these aforementioned studies sufficiently opened up the dynamic Porter Hypothesis.

Rubashkina, Galeotti and Verdolini (2015) introduce one of the first truly dynamic international, empirical PH studies. They look at weak and strong PH across European countries, and find evidence in favor of weak while their results are somewhat inconclusive for the strong PH. One drawback of this study is in following with misguided literature relying on PACE as environmental stringency indicator. PACE serves as a weak environmental policy indicator (Galeotti, Salini & Verdolini, 2017), especially concerning the PH (Ambec et al., 2011). Many previous studies address weak

PH in terms of environmental regulations effect on clean energy technologies, while the strong PH involves a more detailed analysis of impacts on competitiveness in several industries (Rubashkina et al., 2015). Clearly a major gap, discussed in great detail here, is the dynamic effect of the PH able to incorporate knowledge and policy pressure from abroad, or outside the normal boundaries considered (Mazzanti et al., 2014); that is one main goal of eco-evolutionary theories (ibid). Taxes as a form of environmental stringency are rarely tested empirically, with the exception of Franco (2013), Leiter et al. (2011) and Nesta (2014). Franco (2013) confirms evidence in favor of both strong and weak PH, which is interesting because of the ambiguous results given from using PACE as EP stringency. Nesta (2014) indeed uses taxes as only one element of his Principal Component Analysis forming a composite environmental policy stringency.

Finally, a recent paper attributed innovation in environmental technologies to downstream environmental stringency, in other words taxes imposed for emissions and energy production (Franco & Marin, 2017). While they find some evidence for the strong PH, in the form of increases to productivity only with specific sector regulations, they do not find a distinct correlation to increased patenting. Suffice to say, this is favorable evidence for the PH because PH predicts not all firms will react innovatively. Some may innovate, while others may increase productivity-it is too strict to define the PH as needing to incorporate both innovation output and increased productivity. Perhaps the most interesting finding is a strong PH effect for expected regulation. But caution should be taken in this finding since they continue to use PACE for environmental stringency proxy.

2.3 Have scholars simply overlooked an international PH interpretation?

The first truly cross-country dynamic study is carried out by De Vries and Withagen (2005). It is considered dynamic and semi-complex because it looks into Porter effects across countries and in the renewable energy industry (the renewable energy is comprised of several partially related sectors). A second, more recent example of a pertinent cross-country study is that of Johnstone et al. (2010), who address the effect of many different policy tools on the innovative performance of the main renewable technologies (solar, wind, geothermal, ocean, biomass and waste) in 15 OECD countries over the 1978–2003 period.

Consequently, what is not deeply analyzed in the literature is the possible inducement of foreign environmental policies, even though foreign policies in general are known to influence the decision of firms, in particular multinational firms (Porter, 1991). For the most part only diffusion of environmental technologies across countries is examined (Schumpeter's third stage). For example the diffusion of climate technologies are explored in detail by Dechezleprêtre (2008), Popp (2011), and Philibert (2004). It is shown how Kyoto’s co-development mechanism (CDM), an aspect of global climate policy meant to increase collaboration and knowledge spillovers of cleantech, did indeed support diffusion of clean technologies. However, it remains unclear if Schumpeter’s first two stages of innovation (invention and development) are affected positively by the CDM. Meanwhile, policy inducement across countries (Schumpeter stages one and two) is confined to the automobile industry (Hascic et al., 2008; Dechezleprêtre et al., 2015) and sometimes the energy efficiency industries (Newell et al., 1997; Popp, 2003; Gillingham et al., 2008). Vast evidence is found in favor of a dynamic foreign Porter Effect in the auto industry and to some degree in the energy efficiency industry. As stated above, although it is also found in energy efficiency, caution should be taken in comparing these findings with findings for the clean energy industry. The same caution might be taken with direct comparisons of ITC in autos with clean energy technology.

2.4 R&D as an overused variable and the failure to account for properly attuned environmental policy

Due to both the ubiquity of clean technologies and the persistence of national environmental policies (Popp, 2010), in addition to the increasing collaboration on global agreements (Ragwitz et al., 2009), a formidable question emerges: Does the Porter Hypothesis hold internationally? In other words, do foreign country’s environmental policies induce innovation in domestic firms? In attempting to answer this question, substantially new information on the design and effects of environmental policies is possible.

In order to approach the question, however, it is first worth evaluating the PH and ITC literature to understand why this question is not adequately examined. One reason, I think, is economists conflate weak PH with narrow PH, and vice versa. Another reason, similarly, is economists fail to break out from strictly price-induced innovation responses of firms. This restricts analysis to mainly R&D in private industry, under the assumption that private industry is usually responsible for the bulk of all innovations. But, as pointed out by Ambec et al. (2013), environmental policy frequently subsidizes public R&D and technological innovation; thus, “highly uncertain” (Freeman, 1982), such specialized, perhaps policy-induced, technological innovations are not easily correlated with R&D expenditures. Because R&D can typically only be modeled alongside technology-push innovations (ibid), the models do not properly account for “both sides of the coin.” Accordingly, an over-reliance on private R&D evidently does not capture public R&D. While the general assumption that most innovations come from private industry might indeed be correct (Teece, 1986; Freeman & Soete, 1997), the PH calls for a more nuanced examination because climate and environmental policy clearly alters the R&D landscape (for example, offering R&D subsidies and grants). Finally, R&D does not account for “serendipity in innovation” because it is still couched in a linear innovation model (de Vries & Withagen, 2005).

Government policy inducing R&D and diffusion of climate technologies is an instrumental factor of induced environmental innovation that must not be overlooked (Jänicke & Lindemann, 2010; Flanagan, Uyarra & Laranja, 2011). Furthermore government policy, if it is supported by strong institutions, creates a narrative whereby price inducement effects on innovation are demoted to only one aspect of the policy-induced innovation paradigm. A dynamic model is apparently needed to deal explicitly with dynamic environmental policies (Grubler, 2010; Geels, 2006; Etzkowitz & Leydesdorff, 2000; Ambec & Barla, 2006).

2.5 The Dynamic International Porter Effect

Looking beyond only price inducements, a dynamic PH model might also account for various spillovers: knowledge spillovers, technology spillovers, and even policy spillovers. If these spillovers are ignored or not properly accounted for, the rate of innovation will inevitably be underestimated, or models will overestimate returns to R&D if public and private investments are not disaggregated (Olavson & Weyant, 1999; Ambec & Barla, 2006). In other words, spillovers are of primary importance for PH analysis, and classical economic models built with only price effects do not properly account for dynamic effects of innovation and policy. Even integrating "knowledge stocks" (Popp, 2006; Hascic et al., 2009) does not remedy this problem. Actually, it is sometimes magnified because knowledge spillovers are assumed to have a stronger effect than is suggested by evolutionary economics (tacit and codified knowledge is inherently difficult to transfer, and thus does not spillover easily). Subsequently, the former misuse the Porter Hypothesis. Indeed, the proxies now used in the literature are usually crude and possibly misleading (Ambec & Barla, 2006). Most importantly, in relation to the approach here, only a handful of researchers are effectively able to account for a cross-country Porter Effect. There are some exceptions of course, including Schleich et al.

(2016), Ravi (1999), Constantini and Crespi (2008), Jänicke and Jacob (2004), Constantini and Crespi (2013).

3. On the different conceptual approaches to Climate Technology

Induced Technological Change (ITC) is the favored terminology for economists examining innovation effects of environmental policy. The different flavors of ITC are not properly delineated in the literature, in contrast to the three different PH (Jaffe & Palmer, 1997), so we are left to generalize. Broadly, induced technological change from the point of view of economists, “implies that when energy prices rise, the characteristic "energy efficiency" of items on the capital goods menu should improve faster than it otherwise would” (Newell, Jaffe & Stavins, 1998: 2). In other words, increases to firm’s expenses cause them to fund R&D to look for innovative solutions in order to mitigate the new costs.

3.1 Induced Technological Change, Economic Views of PH

Thus induced innovation conceptualizes R&D as a firm's or industry's reaction to a perceived increase in prices. The former theoretically leads to innovation to mitigate the impact of price increase (Hicks, 1932, Binswanger & Ruttan, 1978; Acemoglu, 2002). To be clear, this rendering relies almost exclusively on direction of innovation and not on rate of innovation. This means firms innovate in the direction of more efficient products using less energy in response to energy prices. The stylized definition fits neatly in with an economic approach to PH. It implies prices and expenses, in other words "invisible" market forces, are responsible for catalyzing firm investments in R&D and, subsequently, are the main catalyst innovations. Immediately, this precludes analysis of rates of innovations, while later it is evident how such an interpretation does not properly account for direction on innovations as well.

In this view, prices alone coordinate economic choices, including demand, supply, investment in capital and outlays on R&D. The static interpretation does not easily fit into the PH, as articulated by Porter and van der Linde (1995). Meanwhile, new data and dynamic approaches now allow us to properly examine the effects of climate policy with sufficient lag to account for the innovation system, allowing expectations of future regulation as a driver of innovation (Mazzanti et al., 2014). Indeed, even the very first innovations in electricity during the late 19th century were not in response to price changes but rather expected cost advantages--in other words, the expectation of a growing market, surreptitiously supported by guiding government policy (Gijs Mom, 2012).

Another issue with price inducements for innovation is the ambiguous distinction between pollution control technologies and energy efficiency technologies. The latter “will diffuse even without environmental policy in place, as they offer users the opportunity of cost savings” because firms always try to reduce their energy costs (Popp., 2010). Meanwhile pollution control technology, a relic of command-and-control regulations, appears to be responsible for leading many researchers to use PACE (pollution abatement cost expenditures) as a proxy for environmental policy. However, pollution control technologies are usually provided by firms outside of polluting industries (OECD, 2001: 35; Milliman & Prince, 1989) , so it does not really make sense to incorporate such industries in technological change models for environmental policy. In similar vein, many economic models rely almost exclusively on (PACE) as a primary determinant of innovativeness of firms in response to strict policy. However, a number of studies reveal PACE is at best a partial proxy for environmental regulation (Johnstone et al., 2010; Galeotti et al., 2017; Ambec et al., 2011; Vona & Nicoli, 2013; Franco & Marin, 2017). Thus both prices and PACE appear to be weak variables used widely in PH ITC literature.

While energy-price increases historically are responsible for altering the direction of clean energy innovation (Jacobsson & Bergek, 2004), more recently the opposite is mostly found (ibid; Dechezleprêtre et al., 2011; Kemp, 1997). Due to the oil embargo in the 1970s (which significantly increased energy prices) firms and governments responded by directing innovation towards cleaner and alternative energy. But since the early 1990s, energy prices are found not to significantly affect R&D or diffusion of climate technologies (Dechezleprêtre et al., 2011). Instead, government climate policies are understood to play the greatest role in influencing innovation in new energy technologies (ibid).

Thus, since the 1990s conventional energy prices have detached from their previous umbilical to innovation in clean technologies. Stated more clearly, while in the 1970s and 1980s energy price correlated well with increased R&D and innovation in clean energy technologies, since the 1990s global innovation in clean energy technologies is found not to be directly tied to conventional energy prices. Instead, induced innovation is seen to come almost exclusively from environmental policies rather than prices. ITC theorists using these assumptions keep climate technology innovation inside a black box (Rosenberg, 1972; Rosenberg, 1982; Nathan, 1982) by assuming technical change automatically results from investments in R&D (Weyant & Olavson, 1999).

This static interpretation of innovation presumed to follow the “price inducement->firm R&D-> innovative output” is quite often a mischaracterization of innovative firm response (Kline & Rosenberg, 1986). Instead of being inside a black box, innovations evolve and the cycle of policy to firm response and innovation, with feedbacks and spillovers, follows a dynamic cycle. Thus, projects to design new energy products or processes are classified as “research” while “learning-by-doing is not.” (Jaffe et al., 2005). Thus another critical variable is often overlooked: learning and knowledge capital. Without sufficient research capacity and supportive institutions, a country with strong environmental policy but no Porter effect might simply be due to weak institutions. An example is Greece, with quite strict environmental policies but relatively weak institutions and therefore not many environmental innovations or regulatory oversight of pollution. Institutions are therefore seen as critical in this respect (Dosi, Pavitt & Soete, 1990; Carlsson, 1997; Mazzanti et al. 2017)

3.2 Economic Black-Box Thinking

The benefit to economists of conceptualizing induced innovation as a direct response to increased (energy) prices allows their favored variable "price" and secondarily "expenses" to take center stage. This leads to a more straightforward, or static, interpretation of the theory as a neoclassical economic problem. The neoclassical interpretation assumes prices guide markets, while innovation arises out of firm's response to prices; in short, a market-pull. As we shall see below, the PH is not a static theory (by definition) and as such suffers major setbacks if interpreted through the lens of neoclassical economics. This is in large part due to abstracting away variables such as institutional capacity or government policy changes, which invariably affect rates of innovation (Glass & Saggi, 2002; Helpman, 1993; Taylor, 2009) especially in clean technologies which are evidently highly receptive to government subsidies.

Economics, for instance, has traditionally primarily dealt with the allocation of resources to innovation (in competition with other ends) and its economic effects, while the innovation process itself has been more or less treated as a “black box”. What happens within this “box” has been left to scholars from other disciplines (Fagerberg, 2004: 4).

ITC researchers evidently focus almost exclusively on “resources to innovation”. Or, they focus on one of three modeling techniques: cost-function, macro, or empirical (Weyant & Olavson, 1999). As such, they are guilty of leaving environmental innovations inside the black box. Apparently, neoclassical economic models are unable to avoid considering as a primary variable R&D as the most important input for innovative output (the latter mostly measured by patent counts).

A related issue develops from this line of reasoning. The insistence on looking at climate innovations as coming from either one of two schools: the demand-induced (market/policy), or technology-pushed. Meanwhile both systems, if employed independently, continue to keep innovation inside the black box. Whereas the supply school focuses on R&D as a primary variable going into the innovation system, in turn giving rise to innovations coming out of the black box, the demand school begins from the top and works down, i.e. demand changes will produce positive benefits at the bottom (Lundvall, Dosi, Freeman, 1988). As a result of these shortcomings, neither school is able to formulate a generally adaptable hypothesis for the PH, but only one that functions within very specific parameters (ibid).

3.3 The Neoclassical Lens Pervades Induced Innovation and Narrow Porter

The neoclassical economic lens appears to account for the lack of literature on international/dynamic Porter effect. In a closed system (i.e., a domestic economy) dependent on rational actors (responsive firms) whom theoretically respond immediately to the market, at best only the weak PH can be tested. This lens can merely ask whether some firms innovate in response to policy. The narrow PH cannot, as it were, be used to accurately examine induced innovation from policy in this context even though it often is.

With these models, some will inevitably find a strong positive innovative response in select firms or industries while others will find a weak or negative innovative response. Yet these apparent differences should not be used to discount the Porter Hypothesis because they are merely the outcome of researchers investigating different industries or, more methodologically, employing quite different proxies and variables. A neoclassical model is therefore ill-suited to investigate a strong PH or narrow PH because, respectively, there is no way to understand the innovative responses of all firms to one domestic environmental policy.

The major oversight of neoclassical investigations of PH, and hence the majority of ITC researcher studies involving some form of a narrow PH, becomes immediately clear: a serious constraint on the proper detection of foreign inducement effects. Studies based largely on price-inducement effects have no way of incorporating foreign policy elements because it is nearly impossible to predict the price effects of foreign environmental policy upon domestic innovation. Yet it is well known internationally competitive firms can be expected to react to environmental market policies in foreign countries (Kemp, Rip & Schot, 2001; Porter & van der Linde, 1995). Meanwhile economists continue to force the interpretation of results into a narrow PH because they expect price effects to exclusively induce innovation. While economists are quick to point out the shortcomings of Malthusian-type rapid depletion of the world's resources as wrong due to overlooking the effect of innovation, they at the same time seem to not apply this thinking to environmental policies whether at home or abroad (Porter & van der Linde, 1995). Consequently, little notice is taken for environmental policies inducing innovation in the industry they are examining (so-called "endogenizing" innovation), although some have recently attempted to endogenize innovation with varying results (Gillingham et al., 2008).

Two misalignments in research can be identified using a strictly economic approach to analyzing induced innovation and the PH: (1) the narrow PH (market-induced) is used to investigate what is properly a weak PH question (because economists typically look at only one industry at a time); (2) second, most studies are confined only to domestic firms' innovative responses while it is well known multinational corporations, at least in terms of patenting, are the most capable of producing innovations in response to variegated policies from around the world (Dosi et al., 1990). Regulation-induced price changes cannot be confined to simply one country if we are looking at innovation in climate change mitigation technologies (CCMTs) (Kemp, Rip & Schot, 2001). The latter are indeed globally dispersed throughout the global value chain

(Dechezleprêtre et al., 2016), or in other words CCMTs are globally "saturated" (Helm et al., 2014). This means innovations in CCMTs are taking place around the world. Deductive reasoning leads to a the finding that if environmental technologies are now unhinged from energy prices, the expansive innovative effects must be in some part due to various environmental policies in different countries.

Lastly, price effects inducing innovation do not properly allow for "serendipity in innovation" (van den Bergh et al., 2006). Although innovation is often defined as a calculated, long-term process firms embark on, sudden innovations also occur quite frequently. While prices of energy might continue to induce firms to innovate in energy efficiency products (Popp, 2010; Newell et al., 2002), this is to be expected because firms have in-built incentive to do so; price increases on energy will not automatically result in sudden innovations. It may take time to innovate in energy efficiency in response to energy price increases anyway.

Meanwhile, a more concerted focus on institutions and policies is able to encompass niche inventions and serendipitous discovery. Carefully constructed policy might seek to effectively change future expectations of environmental policy stringency, leading more firms to participate in the innovative discovery process. But it is important to remember serendipity in innovation does not mean any firm is able to quickly respond, and in an innovative fashion. The firm must first set up an ecosystem able to incorporate dynamic new ideas. For example, even developing niche (Kemp, 1997) technologies away from the technological frontier can foster radical innovations (van den Bergh et al., 2006). The natural assumption is that some firms respond innovatively while others do not; the response is not necessarily due to increasing prices, but rather to a well-orchestrated response to tightening environmental policies.

In contrast, price inducement requires the following assumption: innovation in environmental technologies occurs in regulated firms only *after regulation induces a price change,* which gives rise to R&D and only later, to new innovations. This assumption is based on a rather simplified understanding of innovation as a linear process, invariably leading to analysis using static models. These static models are often guilty of following a "deterministic model of technical change" that only weakly resembles the effect of policy on innovation rates (Weyant, 1999).

Indeed, it is remarkable economists are so quick to dismiss the failure of "Limits to Growth" theorists (Malthus; Meadow & Meadows, 1972; Ehrlich, 1968) to properly account for innovation and at the same time these same economists are unable to articulate how CCMT prices, innovations, and "offsets" clearly are induced by properly constructed environmental policies (Porter & van der Linde, 1995: 115). To at once dismiss "Limits to Growth" while also dismissing innovation induced by properly designed and regulated environmental policy is conceptually and theoretically duplicitous.

4. Evolutionary Economics and the Porter Hypothesis

Meanwhile the evolutionary school (Nelson & Winter, 1982; Dosi, 1984; Dosi, Pavitt & Soete, 1988) approach technological change and inducement effects in an entirely different manner. Evolutionary economists, in contrast to induced innovation theorists using price-models, do not assume spillovers are representative of market failures, or that prices are responsible for inducing different types of innovations. Instead of seeing economics as driving technologies, evolutionary economists theorize technologies drive economic development. With that conceptualization, the assumption of technology spillovers is already an assumed part of the technological innovation system. In contrast to technology, according to evolutionary researchers, knowledge (both tacit and codified) is not easily "spilled over". This last point is quite often ignored in the scant literature on cross-border innovation in CCMTs and often ignored in other research with the exception of Popp (2002; 2003; 2006), who effectively models knowledge spillovers into induced technological change from climate and environmental policy.

Innovation might not be “fully responsive” to economic stimuli and occurs within certain patterns and constraints (Dosi, 1988; Malerba, 2002; Malerba & Orsenigo, 1997). The linear model is deterministic, assuming a “one-way flow of information, ideas and solutions from basic science [...] through the market to consumers” (Williams and Edge 1996: 3). But the evolutionary model is dynamic. Therefore innovation is an iterative and interactive process not linear as assumed by price/R&D/innovation models (Freeman, 1982; Weyant & Olavson, 1999). However, as discussed above, most models for the PH or ITC rely on the antiquated premise of price/R&D/innovation as the primary drivers for innovative responses to policies. Evidently, remaining fixated on price-induced innovation continues to frame the debate incorrectly, and as such wrongly supports a “static view of environmental regulation [...] where firms have already made their cost-minimizing choices” (Porter & van der Linde, 1995: 97).

Clearly, induced technological change models are begging for more input from evolutionary economics. Apparently neoclassical models impose such a strong bias that the idea of induced technological change, which is itself partly extrapolated from evolutionary economics, continues to be embedded in the neoclassical economic frame. It is therefore critical to make a clear distinction between neoclassical and evolutionary approaches to induced innovation because most studies only differ in their choice of assumptions (Rennings, 2000: 324). Whereas neoclassical approaches implies "methodological individualism", the evolutionary approach assumes serendipity of innovations, knowledge and technology spillovers (ibid).

In sum, the evolutionary economics literature has a lot to offer researchers on innovation induced from climate policies. Eco-evolutionary researchers, discussed in detail below, appear to incorporate the views of evolutionary economists better than neoclassical economists in ITC for CCMTs field. Unlike ITC economists, eco-evolutionary theorists are also better able to incorporate cross- border policy effects and spillovers, and indeed focus more prominently on the broader effects of policy on innovation as opposed to policy induced price changes. Accordingly, eco-evolutionary theorists might offer the best interpretation and empirical modeling of the Porter Hypothesis.

4.1 Merging Eco-evolutionary and evolutionary economics for Dynamic Porter

Both evolutionary economists and the eco-evolutionary school are highly cognizant of the potential for different spillovers, even though order of importance is different. For example, evolutionary economists find technology spillovers to be a primary feature of the global technological innovation system, while eco-evolutionary researchers tend to focus more on knowledge spillovers. I introduce a rather novel conceptualization here: *Environmental Policy Spillovers*.

Spillovers are sometimes used to account for the observation of induced innovation from foreign countries (Galeotti & Verdolini, 2011). Foreign spillovers come in several forms, all related deeply to the technological paradigm: knowledge spillovers, technological spillovers, and innovation spillovers. Foreign knowledge spillovers of energy technologies is an example of the dynamic forces at work in the global CCMT industry (Buonanno et al., 2003; Galeotti & Verdolini, 2011; Grubler, 2010). Foreign knowledge spillovers means, literally, knowledge of new technologies is “spilled” over, through any number of human ways, into the home country. But knowledge takes many different forms: know what, know why, know-how and know who (Lundvall & Johnson, 1994). Being able to make proper distinctions among these different conceptions in knowledge allow researchers to effectively branch away from classical economics (ibid). Indeed “devotees” of evolutionary economics would most likely argue innovation in environmental technologies involves dynamic changes in systems which go way beyond simply prices (Grubler, 2010). ITC researchers stop short of embodying technical change by insisting on using equilibrium models, or production models based on prices, but technological change in climate innovation is known to be highly contingent on path dependence (Dosi, 1984) and existing “capital stocks” rather than purely knowledge stocks (Grubler, 2010).

Yet this disposition is misguided. PH refers to pollution as market failure, and frankly wasted firm resources. The PH does not explicitly state that technological spillovers are wasted resources; indeed evolutionary researchers understand technological spillovers are simply part of doing business (see Dosi, Pavitt, Soete, 1988). That firms underinvest in clean technologies because they are perhaps waiting to capture other firm's technology (Mohr, 2002) is a reasonable assumption in some industries. This assumption simply does not hold for CCMTs. But knowledge spillovers should not be confused with technological spillovers. Knowledge and technology are very different aspects of the technological system. Knowledge, technology, and innovation spillovers can perhaps be considered one coherent unit of the national innovation system (Kozluk and Zipperer, 2015): as a consequence, the national innovation systems with better absorptive capacities and stronger technological pasts, are able to absorb better this codified knowledge which passes over borders.

Although an abundance of research is now available examining various aspects of the PH, these continue to have difficulty mending evolutionary economics with induced international environmental policy. This is interesting because the former calls exactly for such mending: evolutionary economics predicts multinational firms are the most capable at innovating in new technologies and likewise respond best to variegated policies in different countries (Ambec & Barla, 2006). Where the international PH is introduced it is either abstractly through "Trade Theory" or inductively (Porter & van der Linde, 1995) through variables integrated into the models (such as international spillovers).

4.2 Summing up the Eco-Evolutionary Approach to a Dynamic PH

Eco-evolutionary theorists understand climate technology innovation as a longer, more dynamic process. In contrast to climate economists positioned firmly in neoclassical models, eco-evolutionary theorists align more closely with evolutionary or behavioral economists. Subsequently, the latter might help to improve research related to the Porter Hypothesis, in particular investigations into foreign environmental policy spillovers and innovative effects at home (Rosenstein, 2001)

While evolutionary economists are mostly responsible for formulating modern innovation theory on the heels of Schumpeter, followed by evolutionary economists led by Nelson and Winter (1982), eco-evolutionary theorists are credited with providing support for concepts such as PH, and indeed ITC for CCMTs. The latter are more equipped to "open up the black box" of climate technology innovation. Eco-evolutionary theorists are led by Kemp, Rip, Schot, and Smith. Later carbon lock-in (Unruh, 2000; Berkhout, 2003), like technological lock-ins (Dosi et al., 1990), is a prime example of eco-evolutionary theorists borrowing from evolutionary economists (see Dosi's technological paradigm, leading to lock-in technologies). Carbon lock-in refers to the risk that poorly designed climate policies might further support the production of conventional energies rather than, *a la PH*, inducing firms to respond innovatively with new environmental technologies. Carbon lock-in policies fail either in not effectively inducing the rate or direction of clean energy innovation. As such it is closely related to the chain-link model, which embodies both technology-push and demand-pull (Lundvall, 2017).

Although eco-evolutionary theorists closely mirror evolutionary economists, the former differ in one critical aspect: they place much higher emphasis on the institutional component of innovation and transition of technologies. Also important to note is that many studies incorporating emissions policies and emissions “trading” are most likely encouraging “carbon lock-in” (Unruh, 2000) technologies because emissions policies quite clearly encourage more natural gas exploration and exploitation. Thus, studies with a strictly technological approach reliant on emissions policies cannot truly employ a Porter approach. Indeed, I argue such policies are certainly not carefully constructed and lead to carbon lock-in. Climate technology innovation, on the other hand, rather than being end of pipe or dodging emissions policies is highly dependent on institutions. In parallel, institutions also form the backbone of a well-functioning national innovation system.

> What is needed [for] alternative energy technologies [...] [is an] understanding [of] change in complex technology systems [...] our approach differs from the more cognitive technology approach of Nelson and Winter (1977; 1982) and Dosi (1982; 1988) by looking at the real technical, economic and organizational potentialities and characteristics of technology, and the way in which institutions (economic, social and political) shape and limit economic decisions and technological choice (Kemp, 1997: 294).

In other words, eco-evolutionary theorists follow evolutionary economists but focus more on policy and institutional variables. This approach more readily allows various spillovers, including policy spillovers, to explain innovation in climate technologies. In this eco-evolutionary approach, powerful actors (lobbyists) are incorporated but their influence in technological development is muted because of the various other effects incorporated into the model (bounded rationality, exogenous influences) (Schot, 1998). As such it is a quasi-evolutionary theory (ibid).

Hence eco-evolutionary theorists emphasize institutional shaping and structuring of climate technology innovation, development and deployment. They show how government policies clearly alter the decisions of actors within the innovation system (Hekkert, 2011). In a sense, the eco-evolutionary lens draws in all three phases of Schumpeter's innovation system: invention, innovation, and diffusion. The understanding that climate technologies are quite new and in many ways still developing technologically, but at the same time integral to solving global climate issues, seems to be wrongly abstracted away from climate economists looking narrowly at price-induced innovation. As it were, climate economists are unable to fully incorporate a PH model looking at the cross-border effects of domestic climate and energy policies.

Another advantage of focusing on institutional components is the ability to embody a co-evolution of policies and technologies. This means, more explicitly, a focus on the socioeconomic interactions influencing the rate and direction of technological change for the climate (Kemp, 1997; Rip & Kemp, 1998; Van den Bergh & Bruinsma, 2008). In this manner, eco-evolutionary theorists are able to allow for serendipitous and niche innovations. As the name implies, niche inventions are able to slowly edge out frontier innovations over time. Thus niche inventions are quite related to "serendipity of innovation". New niche technologies often cause bifurcations, different from Dosi's path dependencies, which are unexpected innovations stemming from various industries, indeed sometimes not the industry regulated by environmental policies at all (Kemp, 1997).

In sum, eco-transition approaches attempt to re-establish the fundamental role institutions play in green technology development, much as earlier national innovation systems theorists (Lundvall et al.) sought to bring back the importance of institutions to economics because strong institutions allow innovations to flourish. Institutions are not static, but instead quite dynamic and morphing over time (Roland, 2003). In this way, eco-evolutionary approaches closely align with the formal Porter Hypothesis: regulation has the effect of pointing out to firms, quite blatantly, that their pollution is a "wasted resource"; firms capable of responding are expected to innovate and survive, while those incapable of innovating will be destroyed (Schumpeter, 1942).

4.3 Primary gaps From PH lens, what are these approaches missing?

The tendency to misconstrue this aspect of the PH is common outside the eco-evolutionary realm. Instead of developing models to analyze a weak or narrow PH with the expectation of producing results in line with weak or narrow, researchers expend too much effort on applying *weak* PH approaches and expecting *narrow or strong* PH results. Going further, some approaches might be better suited to finding *dynamic* (cross-border) PH results, if indeed this be approached in a conceptually sound manner.

As a result the economic lens, with explicit focus only on prices, costs, and R&D effectively crowds out meaningful interpretation of the PH within an evolutionary lens. Evolutionary economists cite knowledge spillovers as critical for technological innovation systems and national innovation systems alike. Indeed some go as far as to claim knowledge is the most important resource for firms (Dosi, 1984). Yet "Despite the potential for technological spillovers in the energy-intensive industries, most of the models used in the analysis of spillovers of climate policies lack an endogenous representation of technological change for these industries” (Sijm et al., 2004: 20). More clearly stated, climate technology spillovers from foreign countries and firms are missed because most models do not account for innovation within the very industry they are attempting to research. For the reasons enumerated above, it is quite surprising why foreign-induced policy innovation for green technologies is not more widely researched. Three stylized facts quite clearly point to the existence of this phenomenon: one from Porter and van der Linde and the other two from eco-evolutionary theorists.

5. Conclusion

The literature on cross-border or international environmental policy inducement effects on innovation leads to lengthy debate in the literature over the past two decades. Still, much work is yet to be undertaken. Central to this debate is the role of carefully designed environmental policy and the mirrored importance of sound institutional apparatus to support and enforce such policies. The question of whether global climate institutions and policies induce such innovation is and will continue to be vaguely understood. What is more clear are the importance of developing policies in the context of the Porter Hypothesis and global innovation. The weak and narrow PH are hypothesized here to be at work in the international realm, meaning stringency of a country's environmental policy may induce foreign technology innovation to satisfy foreign market demand. The latter is itself the result of targeted government environmental policy to create a strong clean energy industry. Consequently, a country that does not itself have the strongest environmental policies may, as it were, become a clean energy technological leader. This is probably the most likely case for China. On the other side of the coin, a country with very strong environmental policies is able to induce varied innovators to supply increasing demand for these technologies, with the expectation learning-by-using environmental products will inevitably increase innovative offsets to policy leader.

I identify gaps in the literature which, if pursued in future research, might be able to find both qualitative and quantitative evidence of the PH at work. In terms of the latter, the magnitude of such effect should be of utmost importance for global and federal policy-makers. Meanwhile, qualitative research might continue to follow (Rip, Kemp, and Schot) in evolutionary transitions to eco-economy. The PH shifted the debate in a big way, but now it is time to better encompass government and institutional capacities (Norberg-Bohm, 2001) into a new, dynamic Porter Hypothesis. Many of the international innovation effects pointed out in this paper (global policy leads to domestic policy changes; multinational companies respond to foreign policies; innovation is strengthened by participation in foreign markets; foreign direct investment in/out encourages more innovation) are already well known in the evolutionary economics literature.

Chapter II: Works Cited

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Chapter III: Induced Innovation in Clean Energy Technologies from Foreign Environmental Policy Stringency?

Abstract: This paper takes a global political economy approach to induced innovation in clean energy technologies. This extends beyond most of the empirical research focusing primarily on domestic policies, with the exception of cross-national studies confined to the European Union. The influence of foreign environmental policy stringency is proxied by weighting the average foreign EPS (environmental policy indicator from OECD) while patents in clean technologies are employed as a proxy for innovation. The goal is to explore the magnitude of the foreign policy effect on home-country innovation in clean energy technologies. Properly constructed policy, as the "Porter Hypothesis" suggests, may lead to higher profits through innovative product development. The question of whether countries are induced by foreign government's environmental policies has important ramifications for domestic and global climate policy-makers.

Keywords: dynamic innovation; ITC; cross-border climate policy; CCMTs; Environmental Technologies; Porter Hypothesis; UNFCCC; World Bank; ETS

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I. Introduction: Induced Technological Change in Climate Technologies

Clean energy technologies are evidently central to global efforts to curb climate change and related emissions from conventional energy sources (Hoffert et al., 2002; Stern, 2006; Panwar et al., 2011; Edenhofer et al., 2011). Previous literature addresses induced technological change (ITC) in renewable or clean energy technologies in one of two ways: (1.) as demand-pull of the market for clean energies inducing firms to innovate, (i.e. from policy creating demand), or (2.) as technology-push, or innovation in cleantech due to increasing returns to scale from innovative capacity of firms, (i.e. the innovation is induced by rapid technological change) (Ashford, 1985; Milliman & Prince, 1989).

While the induced technological change literature rests on Hicks (1932), and later evolutionary growth theorists (such as Romer, 1990), more recently it is hinged on the Porter Hypothesis (Porter, 1991; Porter & van der Linde, 1995). Three forms of the Porter Hypothesis are defined by Jaffe & Palmer (1997): *narrow*, *weak* and *strong*. With ITC, the main concern is with the *narrow* version, which postulates that firms being regulated by environmental regulations will respond in a positive way by innovating and benefiting from new innovations. Indeed, Lanoie et al. (2008; 2011), as well as Ambec et al. (2013) find strong evidence for this phenomena. In this way, the PH somewhat mirrors an evolutionary approach to eco-transitions (Nill & Kemp, 2009) in that long-term innovative output figures prominently in the models.

Instead of asking whether domestic environmental policy induces innovation domestically (Lanjouw & Mody, 1996), or if technology simply pushes technological change only domestically (Jaffe & Palmer, 1997; Newell, 1997), I ask how do foreign environmental policies induce innovation at home? What is unique about this approach is that it combines both the market-demand (pull) and technological-supply (push) conceptualizations (Nemet, 2009). In this way, I propose a dynamic, *narrow* version of the Porter Hypothesis. I assume clean energy technologies are actively traded and their innovative development quite globally dispersed (Dechezleprêtre et al., 2008). This position also assumes high rates of diffusion, but does not rest on the principle that diffusion represents the predominant way by which renewable energies are shared and transferred. Another main assumption is actors across borders are able to receive policy signals and react innovatively.

The empirical literature is replete with studies focused on the effect of domestic policies on domestic innovation in environmental technologies (Dechezleprêtre et al., 2011; Nemet, 2009; Popp et al., 2010). Yet, the effect of foreign policies is scarcely looked at (Popp, 2011), even though many models find participation in global climate agreements, such as the Kyoto Protocol, show significant correlation with innovation (Johnstone et al., 2010). As such, there exists no foreign policy-induced innovation in the empirical literature on climate technologies. Only a handful of very recent studies attempt to explore this phenomenon (Peters et al., 2012; Dechezleprêtre & Glachant, 2014; Nesta et al., 2014). This is surprising since, even as far back as the late 1970s, strong renewable energy policy in California induced innovation in Danish wind energy firms (Karnøe & Garud, 2012); likewise it is well known that Asian solar technologies currently dominate the world market even in spite of relatively weak market-oriented environmental policies in China, Japan and South Korea (Nykvist & Nilsson, 2015). Moreover, even lesser developed countries such as Turkey or Mexico are increasingly developing clean technologies (Popp, 2006b), which calls for a greater understanding of these dynamic, cross-border inducement effects and globally dispersed innovations (Dechezleprêtre et al., 2011). Countries "catching" up to the clean energy technology frontier innovate for specific reasons which are still poorly understood using conventional theories.

While supply side technology-push theorist (Peters et al., 2012; Nemet, 2009) have demonstrated that foreign inducement effects exist for environmental policy, their assumption is that these effects occur through knowledge spillovers rather than foreign environmental policy spillovers. Knowledge spillovers are similarly disembodied into technology spillovers and dependent on absorptive capacity (Schmidt, 2010). In contrast, I assume knowledge spillovers and knowledge-stock--that is, existing knowledge in specific technologies accumulated over time--are endogenously determined by the global environmental-policy induced innovation system (Weyant & Olavson, 1999). In other words, knowledge spillovers are not a cause of environmental technology diffusions, but rather the effect of variegated environmental policy stringency, the latter the cause of inducing innovations. I argue, therefore, that knowledge spillovers are actually an effect of foreign environmental policies. This calls for a re-examination of the effect of foreign policies on domestic innovations.

The empirical literature on induced innovation in environmental technologies has not, to my knowledge, yet explored the hypothesis that foreign environmental *policies* induce innovations at home. While various spillover effects are explored, including knowledge and technological spillovers, perhaps the most visible spillovers, i.e. policies, are seldom examined. In other words, why not understand foreign policies as pulling (inducing) innovators in climate technologies? Furthermore, as the induced innovation literature for energy innovation remains mostly the remit of economists, institutional dynamics are not yet adequately incorporated into the models.[1] To the same point, models focused on the importance of policies aimed at creating future markets, (i.e. renewable energy feed-in-tariffs), are largely subsumed under the economic straightjacket (Rosenstein, 2001) of "price-induced" effects of policy (Jaffe et al., 2003; Nordhaus, 2002); meanwhile, technological transitions are not confined to *current prices* but rather *future expectations of the market, including prices and penetration.* Therefore, the examination of prices is misleading. We need a better understanding of technological innovations from policies which, even though known affect prices, actually bear the brunt

[1] Explored in more detail in a subsequent article, where I examine the effects of foreign EPS with stronger domestic institutions, including a weighted average for the governance indicators as done with the EPS-foreign: "Institutional distance is a recently developed construct in strategic management literature that captures the differences between the institutional environments of two countries (Kostova, 1999)" (Gaur & Lu, 2007: 87).

of the change. Policies and institutions, rather than mere prices and perceived costs, are certainly more important in terms of inducements in clean technologies.

2. Foreign Environmental Policy-Induced Technological Change in Clean Energies

2.1 Porter and ITC

The Porter Hypothesis (Porter & van der Linde, 1995) represents an important departure for the present research, because it is the first widely recognized theory able to account for positive responses to environmental policies. Before the Porter Hypothesis (PH), environmental policies were assumed to negatively affect firm profits for the simple reason that the costs of compliance added otherwise additional costs for firm operations (Ambec et al., 2013). Note, this assumption is still largely shared with ITC modelers. Likewise, it was assumed environmental policies limited firm competitiveness, both at home and abroad. Yet, the PH proposed firms could just as easily return additional profit *despite, and indeed perhaps due to,* increased environmental stringency. The PH marks an important point of departure for this present research because it accounts for dynamic competitiveness of firms across countries in response to variegated environmental policies.

A broad outgrowth of the PH is found in the literature on environmental technology innovation induced by environmental policy (Ambec & Barla, 2006; Lanoie et al., 2011; Dechezleprêtre & Sato, 2017). Stated another way, while PH opened up the "black box" of environmental innovations (Jaffe et al., 2003), induced technological change (ITC) from environmental policies roundly reconstructed and repackaged the black box to understand precisely what innovative effects existed. The induced technological change (ITC) literature for climate and environmental technologies mostly focuses on specific technological effects from one or several distinct policy actions (Gillingham et al., 2008; Popp, 2002; 2006; Kerr & Newell, 2003). This represents one primary limitation of ITC literature: its analysis can only integrate one policy at a time, typically confined to one sector, and rarely across countries. But climate policies, being naturally constructed with global results in mind, induce changes across sectors and countries alike.

While some seminal studies explore multiple countries (Lanjouw and Mody, 1996; Newell, 1997; Jaffe et al., 1997), these are limited by the fact that the countries under investigation (U.S., Germany, Japan) are not so different technologically speaking

(Branstetter, 2001), and only one or a few policies are considered. These types of studies are referred to as the *weak* Porter Hypothesis (Jaffe & Palmer, 1997; see previous paper I). Meanwhile the *strong* PH implies an investigation across multiple policies and countries, while the *narrow* PH supports an in-depth look at one sector but across many years or countries. Indeed, many tests of the weak version of the Porter Hypothesis exist, for example: Popp, 2003; Johnstone, Hascic and Popp, 2010; Lanoie et al., 2011. Lanoie (2008) is one of the few studies to look at the PH *weak and strong* with time-series data/model. Their findings are important because they expose the dynamics that exist across countries.

Before Lanoie (2008), empirical research is typically restricted to cross-sectional, rather than time-series, quantitative analysis. This reveals two further limitations of ITC: first, it is quite difficult to understand induced effects from climate policy only looking at a snapshot, due to the fact that technologies take time to develop and diffuse and, second, it is nearly impossible to pick up the cross-border effects of climate policies if only one or several years are examined (because cross-country diffusion typically takes longer as compared to strictly domestic diffusions). Taken together, then, the primary gaps in the empirical literature are the following: (1) a time-series, or longitudinal study of policy-induced clean technology innovation across many countries; (2) a focus specifically on the effects of foreign, rather than domestic, climate and renewable energy policies. In exposing this large gap in the literature, this paper aims to uncover the potential cross-border policy-induced innovation in environmental technologies.

2.2 ITC Foreign, Auto Industry

Of the few investigations into the effects of *foreign policy innovation inducement*, only the automobile industry is explored (Hascic et al., 2008; Oltra & Saint Jean, 2009; Lee et al., 2011; Gerard & Lave, 2005; Aghion et al., 2016). Indeed, these earlier cross-border studies influenced this present research inquiry. A rich body of literature explores the impact of U.S. regulation on automobile emissions and the rapid response of foreign car manufacturers (Pakes et al., 1993; Kerr & Newell, 2003; Aghion et al., 2016). The most prominent and obvious case is the Japanese and German auto industry's response to U.S. environmental policy, including stricter emissions and the catalytic converter (Aghion et al., 2016). Yet, the responses are not restricted to only Germany and Japan; if it were only restricted to these two countries, we might be tempted to say these induced innovations natural arise out of the common factor of being the world's top three innovating countries.

Indeed, the effects of foreign policy are felt in countries beyond Germany and Japan. For example, Medhi (2008) demonstrates the Korean response to U.S. and Japanese environmental policy in equipping their newly designed vehicles in *anticipation of regulatory stringency* (Ashford et al., 1979). Anticipatory innovation (ibid) is also explored by Taylor et al. (2005). Indeed, the premonition that regulations will soon change prompts a technological search (Nelson & Rosenberg, 1993). Presumably, multinational corporations operating in different domestic environments, each composed of their own unique environmental regulations, are wise to develop new technologies suitably designed to meet emerging regulatory requirements. Interestingly in 1997, the year Kyoto occurs, a number of new clean technologies are patented (Johnstone et al., 2010; Helm et al., 2014), signifying that the phenomena of ‘anticipatory innovations’ indeed did occur. That firms not only respond to foreign environmental policies, but also respond ahead of such policies is quite remarkable, especially in countries outside the Royal Patent Family (so-named because nearly 70% of the top innovations are patented in Germany, U.S., and Japan). These general findings are confirmed by Lee et al. (2011) who find government intervention certainly impacts the pace of change in environmental technology, in particular firms’ reactions to foreign environmental policies.

2.3 Foreign Spillovers: Knowledge, Technology, Policy?

Other notable examinations of foreign effects focus on foreign knowledge spillovers. Earlier, business innovation theorists, including Dosi, Soete, Nelson and Cantwell, show innovation is embodied in technology and knowledge; the former is represented by both codified and tacit knowledge. If technology is easily codified, it is easily transferred; on the other hand, if tacit knowledge is needed in order to employ a specific technology, it is very difficult to transfer. Therefore looking at knowledge spillovers across borders, although perhaps a point of departure for foreign-inducement effects, should be done with extreme caution. It is certainly rare for tacit knowledge and capabilities to easily diffuse across borders (Cantwell & Santangelo, 1999).

Verdolini and Galeotti (2011) test whether knowledge spillovers from foreign innovations influence domestic energy Research and Development (R&D). This is a notable foray into spillovers for climate technologies. It begs the question of whether foreign policies directed at energy R&D might spillover, and in turn lead to innovations initiated from abroad. They perform a sophisticated analysis incorporating technological distance index (Jaffe, 1986), forward citations count as a proxy for technological development (MacGarvie, 1996), as well as a parameter for diffusion (Peri, 2005). Their approach is informed by the concept of how trade influences the international *flow of ideas* (Coe & Helpman, 1995), sometimes buttressed by common language and culture (Kneller, 2002; Peri, 2005). One key finding is that a “10% increase in foreign knowledge stock is associated with a 9.4% increase in domestic innovation [...] [and] both policy expenditures as well as the presence of policy targeting energy efficiency have a positive and significant effects on innovation’’ (Verdolini & Galeotti, 2011: 132). Yet, their focus remains on the change in R&D investments, a favored variable of economists (Mulder & Soete, 1991). Quite often R&D is used as a proxy for innovation because it represents the principal input for innovation. However, we must remember R&D is an *input not an output*. Although it is often correlated to patents (Pavitt, 1983), and from a dynamic point of view they are often considered two sides of the same coin (Dosi, Pavitt & Soete, 1990), patents evidently reveal output-oriented innovations and are preferable to R&D.

Perhaps the most important outcome from Verdolini and Galotti (2011), for the purposes of the present research, is they are able to show that increases in foreign knowledge have a *larger impact* on domestic R&D than increases in domestic knowledge. This finding is remarkable because it shows the critical importance of foreign knowledge within the clean energy innovation system. Indeed, this also begs the question of whether a dynamic, cross-border effect is happening; in other words, a *dynamic Porter Effect* (previous paper). I build on this research by partially embodying foreign knowledge into foreign environmental policies, represented by knowledge stocks. In constructing knowledge stocks, which are essentially aggregated patents per country per year with a decay rate, Galotti and Verdolini (2011) find increases in foreign knowledge have a larger impact on domestic R&D than increases in domestic knowledge. They also find knowledge sharing is more contingent upon technological distance between two countries than geographical distance.

To be sure, Arrow's conception of knowledge (1962) combined with Griliches "appropriability of ideas" (1979), continue to play an integral role in clean energy innovation literature. For example international knowledge spillovers, perhaps first formally incorporated in ITC literature for environmental policy by Buonanno et al. (2003), figure prominently in the literature along with the impact of international knowledge flows on R&D (Fiorese et al., 2013; Bosetti et al., 2009). In line with Cohen and Levinthal (1989) and Griliches (1979), I argue that the cost of appropriating clean energy technologies are still quite high and thus "spillovers of codifiable information are an incentive (and not a disincentive) to in-house technological development" (Cantwell, 1994: 52). This would then imply policy spillovers, rather than technological or knowledge spillovers, might account for the majority of induced innovation in clean technologies. This feature, policy spillovers, is hypothesized to play a particularly salient role to the inputs of the cleantech innovation system.

A natural extension of the research, therefore, is to understand better "how knowledge flows across countries and technologies as evidenced by patent citations" in clean technologies (Braun et al., 2010: 24). The present approach thus relies on the assumption foreign countries know quite well the foreign environmental policies being enacted abroad, and hence respond dynamically to these policies without simply waiting for technology transfers. Evidently spillovers in clean technologies (i.e. technology spillovers) are evidently much higher than for dirty technologies (Dechezleprêtre et al. 2014), which leads to the need for a somewhat different approach to understanding the cleantech industry, in particular its variegated policies and policy spillovers and how those affect innovations.

2.4 Empirical Examinations of the foreign policy effect

Dechezleprêtre and Glachant (2014) are among the first to assess the foreign policy inducement effects of clean technologies, although they confine their analysis to only wind energy (implying a *narrow* PH). They ask whether foreign or domestic environmental policies are more responsible for inducing innovation in wind technologies and find, surprisingly, that after controlling for the *size* of the foreign market for wind energy, the impact of foreign policies are twice as high as domestic policies. Certainly this finding deserves further consideration, if only for the impact foreign policies might have on domestic clean technology innovations.

In a similar approach, Peters et al. (2012) look at various foreign policies and their inducement effect on a narrow cleantech sector, solar energy (again, a *narrow* PH). Interestingly, they find a much smaller effect for solar-PV as compared to Dechezleprêtre and Glachant (2014). Using a panel study across 15 OECD countries between 1978 and 2005, Peters et al. find domestic and foreign *demand-pull* policies indeed influence solar technology development. What is more, they find country-level innovation spillovers are almost entirely due to demand-pull policies in general (i.e. induced technological change). This broadly signifies evidence of foreign ITC and, more specifically, the *narrow* PH at work. There is one major difference between solar and wind technologies which is important here: solar technologies are much smaller and relate closely to computer industries in terms of technological sophistication; meanwhile, wind technologies are normally much larger and locally customized. Solar-PV should lend itself to much higher foreign inducement effects due to its close technological relatedness to ICT industry and its light weight; it is already quite geographically dispersed in terms of production. Still, due to the much smaller nature of PV, it can be assumed that foreign inducement effects should be stronger. Yet Peters et al. actually find a much smaller foreign inducement effect for solar in comparison to the much larger foreign effect found by Dechezleprêtre and Glachant.

This is why it is quite interesting Peters et al. find a smaller foreign-induced effect for solar energy technologies. However, it is important to expose two primary gaps in their study: the sole focus on only one solar technology (solar PV), and the time constraint (up to 2005). We know solar PV represents only one part of the overall clean energy sector, while we also know only *after* 2005 does solar technology begin to experience enormous rates of innovation, in many different countries, and especially for various kinds of solar technologies.

Finally, Blind (2012) points towards the idea of lagging and leading environmental policy countries. With his conceptualization, lagging countries that take part of UNFCCC agreements are required to invest more money and resources to catch up to frontier members (frontier here refers to countries with the most stringent environmental policies). Yet, this is true only to the extent the "global" climate policies informed by the UNFCCC are legitimate and enforceable: "if the outcome of such international negotiations is more a minimal compromise the pressure to innovate will be reduced" (Blind, 2012: 10). This is particularly true for non-OECD countries, which is one reason I choose to include rather than ignore BRICS in this present study. Note many previous studies exploring cross-border Porter effects only look at OECD countries (Ambec & Barla, 2006), thus this represents another departure I take here.

2.5 Plugging the Research Gap: My Departure

I take as starting point that both knowledge spillovers and technological spillovers are an integral part of the global clean energy innovation system. I then seek to understand the more complex, cross-border effect of policy spillovers. Clean energies are susceptible to high rates of technology spillover (Dechezleprêtre et al., 2013), due in no small part to their ubiquitous demand, which itself is largely the result of variegated climate policies. While it is clear that foreign regulations certainly impact domestic innovation, especially considering how globally dispersed environmental technologies are (ibid), it is quite astonishing to see that the influence of foreign regulations can indeed be *stronger* than domestic environmental regulations (Hascic et al., 2012; Dechezleprêtre & Glachant, 2014). Therefore, the focus on only domestic effects of environmental policy on environmental innovation ignores the fact that environmental policies might also promote innovation in foreign countries (Kozluk and Zipperer, 2015; Dechezleprêtre et al., 2013; Dechezleprêtre and Glachant, 2014). This is the major research gap I explore.

Confronted with growing evidence of the *foreign policy-inducement* effect, we are faced with the question of why there exists very little empirical investigation into foreign environmental policy inducing innovation in clean energy technologies. Clearly, the Chinese are now dominant solar technology exporters capturing nearly half the global market (de la Tour et al., 2011); but, more crucially, they export nearly 98% of all their solar energy production (ibid), implying their solar innovations are most likely induced from strict environmental policies abroad. This might be partly explained by China’s industrial policy (Popp, 2012), but that still leaves us with the same question: does this not imply a foreign inducement effect? Indeed, India as well is fast becoming a dependable supplier of both wind and solar power equipment to foreign countries (Sawhney & Kahn, 2011), indicating induced innovation from abroad occurs there as well since India continues to have poor environmental and climate policies.

As discussed above, these first attempts to empirically examine induced innovation for environmental technologies are case-specific, country-specific, or industry-specific. As such, they mainly look at the *weak* version of the PH, and only domestic policy influence on domestic innovation. *Strong* or *narrow* versions of PH are not really explored, and very few empirical studies look at foreign inducement effects. The foreign ITC, or foreign *narrow* PH, are not explored but for several exceptions (Dechezleprêtre and Glachant, 2014; Peters et al., 2012 *for clean energy*; Pakes et al., 1993; Kerr & Newell, 2003; Aghion et al., 2016 *for automobiles*).

As I propose here, country-level tightening of environmental policies might also result in innovative effects not only in the domestic country, but also in firms abroad that are “properly attuned to the possibilities” (Porter & van der Linde, 1995: 24). The extent to which Kyoto and the UNFCCC processes play a part in these foreign inducement effects, for example by easing communication among countries and promoting technology transfer, is a difficult question. Still it is worth mentioning that, in countries that signed and ratified Kyoto, increased patenting in environmental technologies is found (Rubbelke & Weiss, 2011). But going being (ibid), we need to remember to ask what initiates changes to R&D, namely what kinds of policies are catalyzing foreign and domestic firms to seek new innovations in environmental technologies: "[it is] the most important message for modelers to recognize the severe limitations of using deterministic, aggregate R&D functions [...] A big first step in addressing this concern is to model fossil fuel-based and alternative energy technologies individually" (Weyant, 1999: 25). Indeed clean technologies, a technology whose prices are both directly and indirectly influenced by foreign and domestic environmental policies, should not be modeled with the same innovation models used for other industries, even those used to model conventional energy technology innovations.

In sum, I examine a large gap in the literature, contextually represented by the importance of international political economy regimes and the innovative development of clean energy technologies, which is surprisingly not satisfactorily examined in the literature (Hall & Helmers, 2010: 24). Thus, my focus for foreign inducement effects is not on knowledge spillovers but policy spillovers. This might also be conceptually approached as "foreign policy pull" rather than domestic policy pull. In comparison to previous empirical research, largely confined to OECD or EU countries (De Vries and Withagen, 2005; Constantini and Crespi, 2008; Johnstone et al., 2010), I look at overall competitiveness and innovation across many developed and developing countries. This approach accounts for the potential opportunity costs of environmental regulation and induced innovations. It is also the approach more in line with how Porter and van der Linde (1995) logically trace out their ideas of induced innovation from environmental policies (*dynamic Porter Hypothesis*). Foreign EPS influence shows that the frontier stringent country does not suffer, in a competitive sense, because it induces more investment, FDI, and export into its country, and later is able to export technologically sophisticated clean technology innovations.

3. Data and Empirical Modeling Strategy

To be sure, this paper is not the first to model the potential impact foreign environmental policies have on domestic innovators. For example, a paper by Buonanno et al. (2003) is among the first to model foreign knowledge spillovers, under the assumption knowledge is spilled-over and thus seen as inducing domestic innovations that were catalyzed by foreign innovators. Yet, researchers appear to stop short of conceptualizing how these policy spillovers might directly influence domestic innovators (Pizer & Popp, 2008), exposing a gap in the literature. Similar to Buonanno et al. (2003), Popp et al. (2007) investigate innovations in the paper industry and find foreign consumer pressures are able to induce innovation at home; thus firms innovate in response to changes in foreign demand (in this case, pollution of water from paper manufacturing). Environmental policies change demand at home, and thus we should also expect foreign innovators to take note of increases to environmental policies of foreign countries. Coming closer to testing that hypothesis, Walz (2007) uses exports as a proxy for foreign regulation to understand how wind technologies react to foreign markets and policies. He finds exports in wind energy technology correlate with foreign environmental policy. Indeed, this is one of the strongest findings in the literature concerning foreign induced innovation in clean technologies.

Several previous studies might have been remiss in focusing too much on emissions and related polluting industries. Yet it seems somewhat paradoxical why innovation rates in clean technologies should be induced in firms which are not innovative in the first place. In contrast to many previous studies that attempt to find innovation in the industries directly affected by environmental regulations, I do not expect polluting industries to innovate in clean technologies regardless of strength of environmental policy. Policies are often designed in a way which forms a pre-designated focus on polluting industries (Martin et al., 2012; Millman & Price, 1989), but finding that these industries do not react in innovative ways says little about the functioning of the clean technology innovation system, as other companies outside of the polluting industries often deliver important innovations (Kemp, 2000). Indeed, it is more likely that innovations come from non-polluters, in terms of climate technologies (ibid).

Accordingly, researchers sometimes fall into the self-defeating assumption that polluting industries should respond by innovating in clean energy technologies. In other words, environmental policies that target certain industries are expected to, in a linear manner, induce those same firms to innovate out of their polluting technological paradigms. This linear conceptualization is far too simplified in today's global economy, where technologies quite readily permeate across national borders, which theoretically should lead to an abundance of cross-sectoral and cross-border inducements, especially in environmental technologies. Linear innovations in clean technologies harkens back to the days when environmental policies were still in their infancy (during the 1980s, for example), whereby command-and-control policies often led polluting industries to find and make use of end-of-pipe innovations (Popp, 2006). In contrast, today an enormous amount of market-based environmental policies are understood to be inducing an equally large amount of point-of-source innovations in clean technologies (Johnstone et al., 2010). Point-of-source innovations, such as clean energy rather than scrubbers on smokestacks (the latter considered end-of-pipe), are much more easily diffused across national borders. These fundamental changes to environmental technologies, in step with environmental policies, in terms of both their expansiveness and ubiquity as well as their respective magnitude, call for renewed research into cross-border policy induced innovations in clean technologies.

This impels the present investigation to take several key departures from the literature. For example, even though other researchers employ energy prices as an inducement driver for clean tech innovation, I elect not to use this '"statistically sound" (Popp, 2002) variable. First, energy prices are no longer seen as drivers of innovation in environmental technologies: energy prices have, since the early 2000s, largely been decoupled from environmental innovations, signaling that environmental innovations are now driven by policies rather than competing energies (Dechezleprêtre et al., 2011). While in the 1980s conventional energy price increases correlated strongly with increases to innovation in clean technologies, this phenomenon no longer exists (ibid). On the other side of the coin, energy price changes are now often the *result* of environmental policy, for example by making some energies either less or more expensive to conform with climate and emissions policies. Furthermore, energy prices across countries are simply not comparable (Dechezleprêtre & Sato, 2014), which also detracts from prices serving as a key variable in multi-country studies. For example, though Spain and Germany employed similar renewable energy policies in the mid-2000s (namely, feed-in-tariffs), Germany's prices increased significantly while in Spain the increase was modest (Couture, & Gagnon, 2010). At the same time, both countries experienced rapid innovation in renewable energy technologies (wind in Spain, solar in Germany) (Frondel et al., 2010). This implies different policies induce different kinds of innovations, and also leads to the question of how policies across countries induce niche technological solutions in cleantech.

3.1 Modeling Strategy and Research Question

The models I use are based upon a global political economy conceptualization of the *narrow and weak* versions of the Porter Hypothesis, discussed in detail in the previous paper. This means I explore certain individual technologies within the basket of clean technologies (*narrow PH*) while modeling inducement effects from abroad, and across different countries (both *narrow* and *dynamic*). Specifically, the research question is framed as the following: *Does foreign environmental policy stringency induce innovation in clean energy technologies domestically?*

To approach this question, I follow Lanoie et al. (2011), who are able to find evidence for both *narrow* and *weak* PH, but not *strong* (see previous paper for detailed discussion). Due to the finding that environmental policy stringency induces innovations in the "eco-innovation chain" (Kanerva et al., 2009), I am inclined to find a proxy for environmental policy stringency. After looking into various environmental policy variables (including Yale, WEF), I elect to use the environmental policy stringency (EPS) from the OECD for two primary reasons: (1.) it provides the longest time horizon; and, (2.) it is almost exclusively focused on *clean technology policies* rather than the much more general *environmental technologies*, the latter consisting of over 700 different patent classifications. In addition, the EPS has stood up to empirical testing for statistical consistency, both in regards to similar indicators as well as balanced across countries (Botta & Kozluk, 2014). The other indicators (Yale, WEF) cover anything along the spectrum from deforestation to plastic consumption. Being the primary explanatory variable, however, I am limited to the countries the OECD-EPS covers. Susceptibility to data availability problems is not a unique problem in this research field (Knill et al., 2012). This limitation is acceptable, however, because most of the innovations come from OECD countries, at least innovations we can measure in terms of patenting or R&D, and the OECD EPS includes BRICS as well.

3.2 Modeling specifications

I regress innovation rates on environmental policy at home and abroad, institutional quality, knowledge stock, and several control variables.[2] A time-series, cross-sectional model (1996-2011) is constructed to understand the change in rates of innovation in clean technologies over time, as this might be induced by policies. Rates of innovation are proxied by clean technology patents divided by total patents, in contrast to taking simply the count of patents per country per year, a departure from some of the previous literature. Fixed Country Effects are employed with the following assumptions: (1) predictor variables might be biased by one country; and, (2) there may indeed be

[2] Note: This model is not as rigorous as other related studies. The object is to point in the direction of future research towards the idea of foreign-induced clean energy innovation. It therefore represents an exploratory foray into the relatively small field of foreign policy inducement and foreign policy spillovers.

correlation between the error term and the predictors. As such, FE removes this effect; (3) FE keeps effects that do not vary over time, per country, unique to that country only (Torres-Reyna, 2009).

A reduced form equation specifies the model

Y_it=f(∑ EPSF_jt ,EPS_it, GOV_it, Z_it)

- *Where Y is produced in RTA form, and represents innovation in clean energy technologies divided by total patents in country i, time t*
- *EPSf is environmental policy stringency of all foreign countries, weighted by geographical distance (OECD)*
- *EPS is environmental policy stringency in domestic (own) country i, time t*
- *GOV is institutional quality, proxied by World-Bank Governance Indicators*
- *And Z represents a vector of country-specific control variables*
- *Country-Specific Controls: emissions from conventional energy (as % of country's total emissions); knowledge stock (patents of CET, with decay); R&D per GDP, renewable energy output (as % of total energy output), fossil-fuel consumption (as % of total energy consumption), high-tech exports, science and technology journals, methane emissions from energy production.*

3.3 Theoretical underpinning

I discuss the operationalization of these variables in detail below. Broadly speaking, the dependent variable is the innovation output in clean energy technologies. The main explanatory variable is environmental policy stringency in foreign countries, the effect of which is estimated conditional on all other controls, including domestic EPS. Lastly, another explanatory variable of interest is institutional quality because, without strong domestic institutions, foreign environmental policies are not expected to cause noticeable domestic inducement effects. This is conceptually in line with the Aalborg theory of national innovation systems (Lundvall et al., 2001), with the caveat that knowledge-stock might also reveal the strength of the NIS. As such, I assume each country's national innovation system follows a neo-Schumpeterian trajectory wherein home production responds to demands of the international market, and the importance of institutions factors prominently into home capacity to innovate. Although important, I am not able to carry out in-depth analysis of all potential "bridging institutions" (ibid) in this paper. In the following paper, "Institutional Quality and Environmental Policy Inducements", these questions are explored in greater detail.

Patents as a proxy of innovation: Literature

Using patents as a dependent variable to explain rates and directions of innovation is widely accepted in innovation theory. Patents have social value (Trajtenberg, 1990) and also are an economic indicator (Griliches, 1990). R&D spillovers are prevalent in high technology sectors (Griliches, 1991), of which patents represent public knowledge. Environmental regulation (EPS) is shown to increase patenting in environmental technologies (Brunnermeier & Cohen, 1998; de Vries & Withagen, 2005; Popp, 2006; Johnstone, Hascic and Popp, 2008; Johnstone et al., 2010; Jaffe and Palmer, 1997; Lanjouw and Mody, 1996), which is often a positive consequence of such regulation (Porter & van der Linde, 1995). Indeed, the finding of positive innovation offsets in environmental technologies is central to the Porter Hypothesis. Due to the intrinsic value of patents this is interpreted to mean innovation occurs if patenting rates increase over time.

At the national level, patents represent a statistically sound way to measure a country's macroeconomic capabilities in terms of innovative change (Patel & Pavitt, 1987; Griliches, 1990; Schmoch, 2008). A country's innovativeness is sometimes proxied by the breadth and depth of their patenting, controlled by strength of endogenous intellectual property protection. Despite some major drawbacks (Griliches, 1990; Cohen & Levin, 1989; Dosi, 1988), patents remain among the best research metrics for determining policy-induced innovation (Rajamani, 2007; Abbot, 2008; Holdren, 2006; Mandel, 2005; Kemp, 2008; Archibugi, 1992; Hagedoorn & Cloodt, 2003). These data contain an enormous wealth of information and a "window into technical knowledge" (Christensen & Raynor, 2013). In this paper, I intend to investigate the technical knowledge of different country-level cleantech innovation systems which, as patents show precisely what technology is patented, in particular by providing a description of the technology, who and where patented, these data are especially well-suited for these type of investigations (Griliches, 1990; Popp, 2006, Khramova et al., 2013).

Patent data specifications including lags and families

The patent data is collected from the OECD-stat website. The OECD uses an algorithm to extract data from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office (EPO). As PATSTAT patents are considered the strongest for determining technological specialization (van Zeebroeck et al., 2006), extracting these data match well with the hypotheses here. International Patent Classification (IPC) symbols and simple keywords were used to identify relevant records in the databases. Furthermore, IPC symbols have the advantage of being language-independent and generally assigned to patent applications in a uniform manner across different countries (WIPO, 2014). The data extracted from the OECD are able to be conditioned to reflect the “priority date”, which is the date of initial filing of the invention, regardless of the family size. This is important for my purposes since I can easily adjust the lags and ensure uniformity across countries (Haščič & Migotto, 2015). Priority date also shows inventive performance while accurately reflecting timing of patents, and due to these features is the most recommended way to carry out patent statistical analysis (Harhoff et al., 1999). Among other important quantitative data, patents also contain: (1) technical description of the invention (claims class; prior art; patent references); (2) development and ownership of the invention (list of inventors and location; applicant is inventor in the U.S.); and (3) history of the application (application/patent number; priority number; priority date; date of filing; date of publication; list of designation; date of refusal or withdrawal; date of grant) (OECD, *Patent Statistics Manual* 2009: 24).

Time lags of technological innovation for environmental technologies is found to average 2 years for domestic inducements (Lanjouw & Mody, 1996; Cincera, 1997). Lags in patenting are very important for understanding inducements for climate technologies, in particular “sudden changes in policy or carbon taxes, developments following upon major innovations, or in the exploitation of spillovers” (Weyant, 1999: 25), and factor as a very critical consideration in the construction of these types of models. The literature is clear on the specification of integrating well thought out lag structures into environmental innovation models (Brunnermeier & Cohen, 2003, Hamamoto, 2006; Johnstone et al., 2010; Martinez, 2010; Popp et al., 2011). Although I am inclined to follow the literature (i.e. lags of between one and three years for clean tech innovation inducements), I leave open the possibility that some clean technologies might take as long as five years to respond to policy (Brunnermeier & Cohen, 2003). In particular, policies from abroad might exhibit longer time lags since diffusion of policies across borders is expected to slow down the induced innovation response time (Nesta et al., 2014 ; Vona et al., 2013). This is particularly important when "institutional accommodation" (Nelson, 1993) presides over important latent variables, rendering more time needed for innovations to disperse (explored in detail in the subsequent paper). A further benefit of the OECD data is its built-in patent family specifications. Patent families are patents filed in more than one jurisdiction, with greater patent families typically revealing a stronger global invention. Accordingly, both patent lags and patent families are carefully accounted for in the models below. The dependent variable properly accounts for all of these critical features, and is constructed according to the specifications detailed below, replete with descriptive statistics of the different dependents taken according to the models.

The dependent takes this specific form: **ϕYt-x**
Where ϕ represents the family (between "1" and "4")
Where ***x*** *represents* ***lag*** (between "2" and "5" years)
Where **t** *represents the year aligned with all other variables (except k-stock)*
Where **Y** *represents CETs, or specific technology in question, over all patents*

Descriptive statistics of the dependent variables, replete with different lag structures and families, are provided below.

Table 1: Descriptive statistics of dependent variables (in RCA form, logged). Note: in this paper, only Clean Energy Technologies (cets) are used in the analysis. The number following "y" signifies size of patent family, while the number following the technology signifies the number of years lagged.

Variable	Obs	Mean	Std. Dev.	Min	Max
y1solar2	**512**	**-5.431073**	**0.950714**	**-8.04347**	**-2.685805**
y2solar2	**512**	**-5.182885**	**1.013309**	**-8.628771**	**-2.159869**
y3solar2	**512**	**-5.043969**	**1.077605**	**-8.288794**	**-1.575881**
y2solar4	**512**	**-5.305127**	**1.02751**	**-8.628771**	**-1.909543**
y1renewable energies2	**512**	**-4.716351**	**0.9375776**	**-7.438587**	**-2.014427**
y2renewable energies2	**512**	**-4.656371**	**1.009511**	**-8.628771**	**-1.922105**
y1cleantechnologies2	**512**	**-4.494253**	**0.8047077**	**-6.944859**	**-1.993912**
y2 cleantechnologies 2	**512**	**-4.360501**	**0.8448872**	**-6.943605**	**-1.910317**
y1wind2	**512**	**-5.928612**	**1.191055**	**-10.2718**	**-2.113511**
y2wind2	**512**	**-4.866023**	**1.429932**	**-9.681203**	**-1.466722**
y2wind3	**512**	**-4.917513**	**1.478349**	**-9.681203**	**-1.466722**
y2wind4	**512**	**-4.95819**	**1.523211**	**-9.681203**	**-1.216395**

3.4 Explanatory Variables (Zit)

Environmental Policy Stringency EPSf_jt and *EPS_it*

- Statistically sound index with positive correlation with GDP, and negative with CO2 emissions (which is what we would expect in an EPS focused on emissions and energy generation).
- Correlates well with other widely accepted environmental policy indicators, indicating the OECD EPS is fundamentally sound in reflecting environmental policies across countries and years.

The OECD's Environmental Policy Stringency Index (EPS) (Botta & Kozluk, 2014) spans many years and includes most OECD countries along with the BRIICS.[3] Further, the EPS index explicitly deals with emissions policies, renewable energies and energy production. Policy stringency regulating the energy industry, and thus aimed at inducing change from conventional energy to clean energy, is precisely the policies I theorize should induce innovation from abroad; in comparison, policies aimed at reducing emissions most likely constrain inducement effects to domestic innovators, as these are both touch-and-go, and offer little to innovators aside from compliance cost reductions. A subsequent benefit to the OECD EPS is it lends well to manipulation, including creation of dummy variables for market policies and normalization of the index over time (Vona & Nicolli, 2013). For example, Galeotti et al. (2017) normalize the indicator (0-10) over 19 OECD countries from 1995-2009, to show how environmental policy lowers energy intensity, with the conclusion that energy-saving innovations are deployed. Similarly,

[3] Brazil, Russia, India, Indonesia, China, South Africa

Albrizio et al. (2014) show how multifactor productivity growth is the result of stringent EPS. Further, other researchers divide the EPS into market and non-market, under the expectation that market policies induce innovation more (Nicolli & Vona, 2013). I follow the latter in order to understand more clearly if foreign market policies have a stronger effect on domestic innovation or non-market. However, one minor caution remains: the OECD-EPS places feed-in-tariffs under market policies, while others such as Johnstone et al. (2010) consider FIT a non-market environmental policy. Therefore, it is important to note here that eps-market includes feed-in-tariffs in this paper.

Market and non-market policies are shown to induce both the rate and direction of innovations (Johnstone et al., 2010). This means, put more simply, clean technologies are innovated more rapidly as well as into a "cleaner" direction thanks to differentiated environmental policies, i.e. feed-in-tariffs, subsidies, and emissions taxes. With this in mind, therefore, I rely on an aggregate environmental policy stringency indicator embodying all these specific environmental policy characteristics. In this manner, I explore the overall conclusions in previous literature that "market" policies more effectively drive innovation in clean technologies. Importantly, dummies may be created for feed-in-tariffs (FITs), which are technologically-specific policies, most often considered direct subsidies aimed at inducing installations of either wind or solar (or both). This allows for a more comprehensive understanding of the direct price impacts, and potential innovation inducements, of FITs. This feature of FITs is particularly salient if these indeed induce *innovation* domestically or from abroad.

With these specifications, I am able to understand if such policies actually induce technological change rather than merely speeding up *installations* of wind and solar. If installations are crowding out innovations, there is reason to reevaluate the strength of certain policies, since installations do not imply innovations. This is also a primary reason why I elect not to use installed capacity of renewable energies as a primary variable. Installed capacity of incumbent clean technologies, rather than being a signifier of innovation, might actually represent the exact opposite: *stalled innovation*, or wider installation of merely vintage clean technologies. By the same token, if environmental policies induce innovations abroad but only installations domestically, a more serious examination of environmental policies directed at clean technology is certainly warranted. Thus the policy implications of this research are quite evident.

Nevertheless, this approach is left with some limitations. Environmental Policy Stringency (not the index) takes on varying characteristics over countries and over time, including: (1) stringency over time; (2) predictability or uncertainty; (3) flexibility; and, (4) incidence (Johnstone, Hašcic & Kalamova, 2010). For my purposes, I am concerned with foreign environmental policy stringency over time (point 1), although in the model predictability and uncertainty are accounted for. Lastly, flexibility and incidence are tested via the disaggregation of the EPS into market (flexibility) and non-market (incidence).

Foreign Environmental Policy Stringency (EPS-f)

Having determined OECD's EPS is most suitable here, I then build the *foreign EPS*. To construct foreign environmental policy, a three-step process is used. Please see appendix for calculations. In brief, the foreign EPS is calculated by first calculating each foreign country's EPS divided (weighted) by distance to home country, then taking the sum (mean) of all these bilateral calculations. Thus, *epsf* is the mean of all bilateral foreign EPS of *country **j** in year **t***, weighted by individual distances between domestic and foreign country. The logic here is that I expect, for example, European nations to induce other European nations more than countries in North America. Another specification is the distance weighting, which uses CEPII's (Head & Meyer, 2002) distance based on most populous region within a country; this implies Russia, for example, is closer to Europe than it is to Asia as most of its cities are located in the West. This is in line with the literature on the importance of distance in absorbing high technology innovations from abroad (Dosi, 1984: 6; Jaffe, 1986). I employ precisely the same method to construct both EPSf-market and EPSf-non-market variables (in order to separately examine the inducement effects of market and non-market environmental policies). In sum, I follow closely Johnstone et al. (2008) as well as Constantini and Crespi (2008) in constructing composite indicators for clean energy policy. But, whereas their indicators focus on domestic policies only, mine focus on foreign policies.

Institutional Quality and Country Innovative Capacity (IQit)

Institutions are absolutely critical for innovation systems (North, 1990), not least because they allow knowledge to grow and create new resources, but also due to the role institutions play in maintaining economic order (Johnson, 1992, 1988; Freeman, 1992; Lundvall, 1992; Nelson, 1993). Evidently, Institutional foundations are pivotal in formulating country's environmental performance objectives:

> the preliminary evidence developed here suggests that countries would benefit environmentally from an emphasis on *developing the rule of law, eliminating corruption, and strengthening their governance structures* (Esty & Porter, 2005).

It is here I feel a large contribution to the literature is needed. Indeed, the following paper largely is based on this research gap ("Institutions and Cross-Border Climate Technology Inducements"), and there continues to be a lot to be done to more deeply explore this area of research.

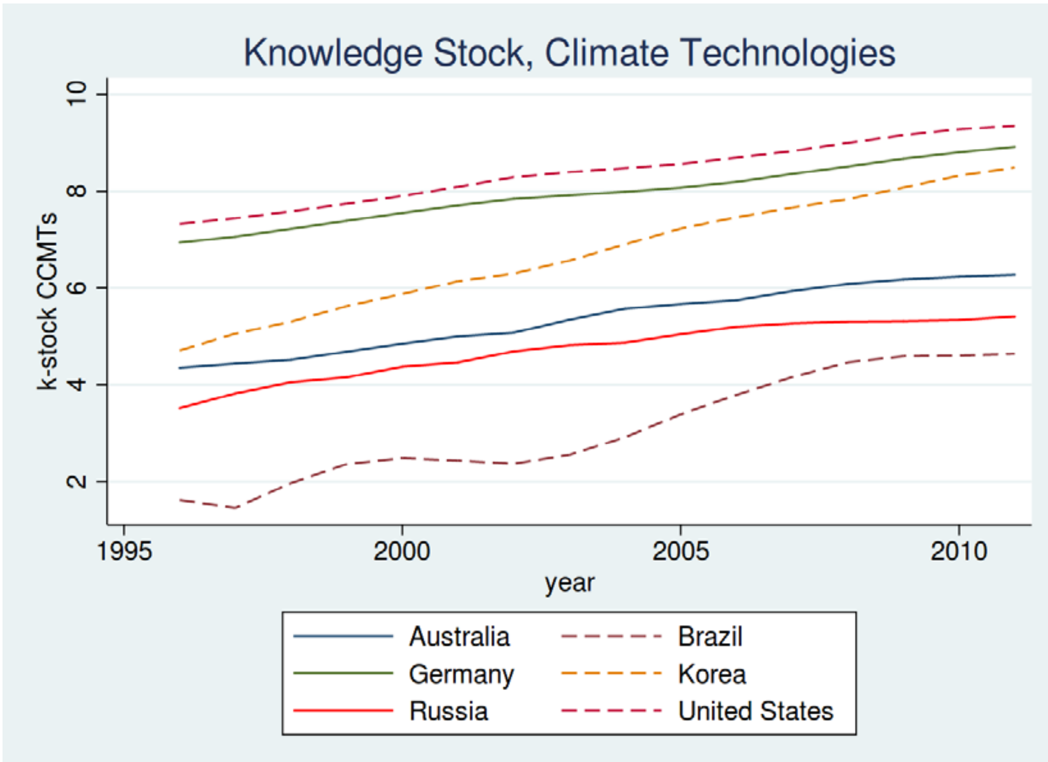
Patenting also tends to follow from strong institutional capacity (Jensen et al., 2007; Teece, 1986). As such, using patents as the dependent variable, institutional quality is a naturally well suited as a control variable. Note, institutional quality is largely overlooked in models employing neoclassical economic methods. To my knowledge, only several papers adequately add such a variable into their models, including: Johnstone et al., 2010; Dasgupta et al., 2016; Verdolini & Galeotti, 2014. Several seminal papers have explored the connection that exists among institutions and patenting for green technologies (Constantini & Crespi, 2009; Kemp, 2009; Kemp, 1997), but I reserve more detailed exploration of these methods for the subsequent paper. Below is a statistical description of the institutional variables, which are given as couples as suggested by Langbein and Knack (2010) (for desciptive statistics of World Bank Pairs, see the Appendix). In the analysis I employ between 2 different WB-pairs: Voice/Accountability-Government/Effectiveness (VAGE) is the first pair; Political/Stability-Rule/Law (PSRL) is the second pair. I use these pairs for their presumed closeness to the institutional components related to potential to absorb foreign EPS (that is, environmental policy spillovers). The nice feature of this is I can also proxy for the domestic country's ability to innovate, market, and export new CETs in response to foreign demand. Second, I choose pairs that are found not to autocorrelate and take their mean, a method suggested by Langbein and Knack (2010) and used with moderate success in the literature (ibid; Easterly et al., 2002). This convention is reflected in the "wb" pairs listed above.

Knowledge Stock

Following business innovation literature (Dosi, Pavitt, Soete, 1990) and, later, induced climate technology literature (Popp, 2002; 2006a; 2006b; 2008), I create a control variable "knowledge-stock" (*k-stock*) *for country **i** in time **t*** with respect to each separate technology class and each individual patent family. This convention assumes technology is both an input and an output of the innovation system (Dosi, Pavitt, Soete, 1990). Dosi (1984) emphasizes the outsized role played by knowledge in innovation systems and technological development, and for this reason literature on innovation in technologies typically includes this type of variable.

Several different techniques for creating k-stock exist in the literature, applicable to different aims of the models. Investigating wind technology innovation, Ek and Soderholm (2010) construct knowledge stocks according to R&D expenditures, and take an annuity. Yet for the present research, as I'm concerned more with innovations than costs, I follow Popp (2006; 2010) and take a decay rate over time. Below is a graph depicting a sample of six country's knowledge stocks over time (1996-2011).

Graph 1: Knowledge stocks proxied by patenting in climate technologies, with a decay rate over time (1995-2011, select countries).



The knowledge stock in each technology represents the technological competence of a country in the specified clean energy field; for that reason it exposes parts of the national innovation system favorable towards creating new technologies in the same or related fields (Vona et al., 2012). This ensures that inducement effects and innovative output do not simply vanish in subsequent years, and also assumes knowledge builds upon past innovations (Caballero & Jaffe, 1993; Nordhaus, 2002). As stated above, *K-stock* is calculated with a decay rate over time. Details for this calculation are found in the appendix.

Control Variables

The control variables follow the induced technological change literature, in particular ITC for climate technologies whenever possible. If deviations from the literature are made, these are explicitly reasoned and stated. Below is a summary of the main control variables, including the literature followed and their statistical data.

I break with the ITC literature by not including R&D as a primary input to environmental innovation. It might seem rhetorical to include R&D inputs (explanatory variable) along with patent outputs into a model for ITC for CETs because indeed they show “different aspects of the same process of industrial innovation” (Dosi et al., 1990: 44). But, in fact, focusing on R&D investments while incorporating technological spillovers into a dynamic model (Mohr & Sengupta, 2002; Greaker, 2003), invariably leads to the conclusion that firms under-invest in clean technologies in industries where technological spillovers are high. In other words, R&D does not paint a very positive innovation picture for clean technologies, thus it might be more satisfactory to find an alternative variable. As I am following the Porter Hypothesis, it is important to consider internationally competitive firms’ expectations and decisions (Porter & van der Linde, 1995: 108). R&D provides data on “magnitude” of environmental policy stringency (assumption) (Johnstone et al., 2010: 10), while patents provide strength and consistency of innovation over time, and as such the latter more properly expose firms’ reactions to variegated climate policies in terms of innovation output. In similar vein, high tech exports (htx) and fossil fuel consumption (as a percentage of total energy consumption) are primary control variables in the first set of models because these features play a particularly salient role in determining a country's ability to export cleantech, and endogenous usage of energy, respectively. It is expected that, since clean technologies are considered advanced technology, high tech exports will be significant across the models. Further, if fossil fuel consumption is increasing in a country over time, I do not expect that country to be innovating in clean technologies. Meanwhile, other control variables are added to the second set of models including methane emissions from energy, no2 emissions from energy, and science and technology journals per 1000 researchers.

Dummy Variables

Following the environmental policy-induced innovation literature (Popp et al., 2011; Johnstone et al., 2010; Horback, 2008), several dummy variables are created. The dummies for feed-in-tariffs are set to “1” if a country has either a solar or wind FIT law in a certain year, per country, and “0” otherwise. The same is followed individually for solar or wind. In the following paper, Johnstone provides the FIT data already constructed as dummies, however this paper simply uses the FIT data provided by the OECD website. Lastly, the Kyoto dummy takes a 1 if Kyoto is signed and ratified before July of that year (Johnstone et al., 2010) (See appendix).

Log Transformation of the Variables

The variables are transformed by taking the log in order to avoid spurious skews in the data. First, due to the variance in the countries covered in the data, in terms of their innovative capacity, the data do not provide smooth curves as needed for our statistical analysis. Further, following (Peters et al., 2012; Greening et al., 2000; Constantini & Mazzanti, 2012), log-linear form allows us, *ex-poste*, to understand the elasticities of innovations as an output in regards to the multiple regression independent variables (Newell et al., 1999; Popp, 2006; Popp et al., 2011). This means we can interpret independent variable coefficients as percent increases or decreases, thus allowing the model output to provide elasticities as in Popp (2002). Popp (2002) and Aghion et al. (2011) use log(green/all patents) as dependent variable. Using this form also reduces sensitivity to outliers in the data, while allowing easy interpretation through elasticities (Popp, 2010; Furman, Porter, & Stern, 2002; Furman & Hayes, 2004).

4. Hypotheses and Econometric Specifications

Hypothesis: *Environmental Policy Stringency in foreign countries induces innovation in clean energy technologies domestically.*

The Exploratory Story

I started by looking at CETs together as one unit (Wind, Solar, 3 high tech storage, marine, hydro, and geothermal). I found some influence of foreign policies, and slightly more inducement effects with domestic policies, and ask: are inducements coming from market or non-market foreign EPS? I also pose the question: do different lags have anything to do with inducements? And how are different technologies affected by different lag structures?

Hypothesis to test:

1. Domestic Environmental Policy Stringency induces domestic innovation in Clean Energy Technologies (CETs). (Models I, II, III)

2. Foreign Environmental Policy Stringency induces domestic innovation in Clean Energy Technologies (CETs). (Models I, II, III)
3. Foreign market policies account for the bulk of inducements in CETs (Models I, II, III)

Econometric Specification

- The analysis employs time-series cross-sectional techniques to regress the impact of our explanatory variables on the dependent variable, innovation output.

5. Results and Discussion

5.1 Models 1-3 : Foreign and Domestic EPS are significant

I started by examining a sample of Clean Energy Technologies (CETs) defined as traditional renewable energy technologies (wind, solar, geothermal, hydro, marine) plus storage technologies. Storage technologies, which enable renewable energies by storing energy as “the sun doesn’t shine or the wind doesn’t blow” are important considerations for policy-inducements and are relatively under-explored in the literature. I tested the environmental policy-induced innovation effects from foreign environmental policies (EPS-f) and controlled for domestic environmental policies (eps). Three different models were tested using Stata (xi: xtreg i.country, fe robust). See appendix for details on the

Stata “do” file coding for these tests. The different models all look at CETs family of two (meaning the CET is patented in two jurisdictions), with the difference being the time-lag: either 2, 3, or 4 years’ time lag is employed for the dependent variable.

- **Model 1:** CETs lag 2 years, eps foreign market, eps market; vector of controls: world bank political stability and regulatory quality, k-stock, renewable energy output as a percentage of total energy, high tech exports, fossil fuel consumption as percentage of total energy, and R&D per GDP.
- **Model 2:** same as model 1 with lag of 3 years for CETs.
- **Model 3:** same as model 1 with lag of 4 years for CETs

Table 2: Description of models 1-3

Model	Dependent	Main Exp. Var	Vars	Main controls
1	CETs	epsfm	epsm	reout, wb_psrq
2	CETs	epsfm	epsm	reout, wb_psrq
3	CETs	epsfm	epsm	reout, wb_psrq

Table 3: Main Models 1-3 (CETs) regression results, with different lag structures. Note, in parenthesis describes the variable immediately above, with intersects.

VARIABLES	**y2cets2**	**y2cets3**	**y2cets4**
epsfm	0.874**	0.939**	0.933**
(epsF-market)	-0.388	-0.407	-0.434
epsmark	0.0013	0.0675	0.167***
(eps-market)	-0.0524	-0.055	-0.0586
wb_psrq	-0.433**	-0.513***	-0.363*
(institutional quality)	-0.172	-0.181	-0.192
kcets2log	0.238***	0.180**	0.0703
(knowledge stock)	-0.0672	-0.0704	-0.0751
reout	-0.0536	-0.0766*	-0.0687
(*renewables output*)	-0.0387	-0.0406	-0.0433
htx	0.0576*	0.103***	0.0844**
(high-tech exports)	-0.0322	-0.0338	-0.036
ffcon	-0.458***	-0.391***	-0.333***

(fossil fuel consumption)	-0.112	-0.117	-0.125
rddgdp	-0.00636	-0.0123	0.0187
(r&d / gdp)	-0.0221	-0.0232	-0.0248
Constant	1.656	1.718	1.339
	-2.006	-2.104	-2.242
Observations	512	512	512
R-squared	0.468	0.353	0.208
Number of country	32	32	32

I found that, surprisingly, EPS foreign market policies are indeed significant across all models (up to 5 percent significance). Meanwhile, EPS market (domestic) is only significant in CETs lag 4 years. While others found foreign policies to be significant (Peters et al., 2014), I found foreign policies to be more significant than even domestic policy stringency. Institutional quality (wb_psrq) is significant across all models (wb_psrq), with 4 year lag only at 10 percent. Interestingly, however, this variable exhibits a negative coefficient. The following paper will unpack this result in more detail. Knowledge-stock is significant at the 1 percent level in the first model, at the 5 percent level in the second model, and not at all in the third model with lag of four years. High tech exports, as a percentage of total exports, exhibit varying significance across all models; meanwhile fossil fuel consumption, as a percentage of total energy consumption, are also significant across all models. Vona and Nicolli (2013) suggest foreign inducements might require five years or more in order to be accurately detected, therefore future research should focus on exploring better ways to acquire longer time-series data, perhaps by compressing each year down to quarters if at all possible in order to gain more data points. Unfortunately, due to both data and technological constraints on innovation in CETs, with innovations really only beginning in the late 1990s, it is very difficult to build these types of specifications into the models.

Summary of Key Findings

Clean energy technologies are induced by both foreign and domestic environmental policy stringency, which is suggested by previous literature but only in terms of domestic inducements (Constantini & Crespi, 2009; Blind, 2012; Vona & Nicolli, 2012; Glachant & Dechezleprêtre, 2014; Peters et al., 2013). The results here are some of the first to empirically test a cross-border Porter inducement for environmental technologies and, due in part to data constraints that certainly limit the strength of these models, this certainly warrants more research in the future. Generally speaking, another key finding is that both market and nonmarket policies induce innovations, both for foreign and domestic innovators. This particular finding is in line with Carraro et al. (2010), Popp et al. (2010), and more recently, Dasgupta et al. (2016), even though these researchers mostly attribute this to knowledge spillovers rather than foreign policy inducements.

For foreign EPS, market based policies are typically stronger than non-market (i.e. *epsfm* is reported above as it shows stronger results as compared to *epsf-nonmarket*). This might indicate market-based environmental policies are better in terms of inducing innovation in Clean Energy Technologies (Albrizio et al., 2014; Johnstone et al., 2010), either at home or abroad, but more research needs to be done in this direction to understand the role of market and nonmarket inducements, especially across borders. It would seem, intuitively, that market policies should induce foreign innovators while non-market policies might cater more to domestic innovators, as market policies offer more of a carrot to reward innovators regardless of geographical location, while non-market policies seem to favor domestic innovators as they are less transparent and do not offer subsidies or financial rewards. Perhaps, due in part to the fact that foreign innovators are more likely to supply market policies with clean technologies, market policies are consistently found to induce innovations more than non-market policies.

Institutional quality variables (wb_vage or wb_psrq) end up being significant across all models, regardless of lag or patent family, or even dependent variable technologies considered. Yet, interestingly, their coefficients are always *negative*. This confirms the theory that technological change is treated as being induced by institutional change (Koppel, 1995; Kawagoe et al., 1985), but the fact that the institutional variable is always negative is an important issue to explore in the following paper.

The positive "knowledge stock" coefficients confirm what is found in previous literature, in other words innovation is an "additive" effort (David, 1992; Caballero & Jaffe, 1993). Countries and firms that have innovated in certain technology areas in the past are thus expected to continue innovating along technological trajectories. As expected, high-tech exports (htx) always shows a positive coefficient and significant effect because advanced technologies are embodied in CETs. Overall, these findings are significant. They show, generally speaking, that CETs are being exported to meet foreign demand, the latter increasing as EPS increases. Lastly, the implicit focus on lags is evidently very important for analysis of ITC or PH and may well have been overlooked in many previous studies (Lankoski, 2010; Ambec et al., 2013; Lanoie et al., 2008). More research should be done in this direction with particular focus on certain technologies, longer lag structures, and more concerted statistical analysis.

5.5 Cautions and Limitations

One additional complication for empirical analysis is the potential of reverse causality; that is, the extent to which the stringency of environmental policies is driven by productivity growth, causing practical problems for estimation such as biased estimates (Gray, 1987). This means, broadly speaking, that although policy might induce innovations in the beginning, over time the innovative rates of countries determines the ratcheting up of stringency as government acts to support a growing technological market. Another implication of this is that, while an initial environmental policy “shock” might significantly induce innovations at the start, later ratcheting up of EPS might only have minimal inducement effects (Johnstone et al., 2010). Indeed, some findings point towards the EU emissions trading scheme as evidence of just such as shock. As economic growth can spur demand for environmental quality, sometimes referred to as the environmental Kuznets curve, stricter environmental laws might be a response of policy makers to this increasing demand. On the other hand, the marginal effect of the tightening may be smaller if environmental policies are already stringent (Johnstone et al., 2010), similar to the idea discussed above.

Some caution should be taken in interpreting the results of the dependent variable as a ratio (RTA). Despite the perceived benefits or using RTA to look at innovative differences across countries, there is a concern if too many zeros are found in the data (OECD, 2009), indicating that some countries lag far behind the frontier innovating countries. Indeed, I was forced to drop Indonesia from the analysis due to precisely this reason. This is one reason why more robust models in this subject area are typically confined to only OECD countries. Similarly, in the case a country has only one patent in a certain CET sector during the year, I encountered a problem since I have taken the log of the ratio. For these reasons, I add “1” to all countries and all sectors (to arrive at minimum two or one patents per year per technology).

Finally, I was confronted by the central issue of cross-border measurement dissimilarities: adding an international dimension can increase the variation both across policies and across outcomes which, although sometimes providing for a richer sample, is still cause for concern especially when interpreting results. This could possibly reduce the need for a longer time series. For example, European Nations’ maintain very low variation in EPS, while the addition of BRICS increased EPS variation across countries significantly. The high degree of convergence on a number of renewable energy policies in the EU, for example, and the slight divergence of other countries, could cause some modelling issues. Therefore, the use of country-specific effects may perhaps correlate with time and eps effects, further confusing the data analysis. For further limitations concerning fixed effects and time-series modelling, see the appendix. Finally, the existence of patent data does not in fact imply that environmental innovations have been adopted (Popp 2012; Lanjouw et al. 1998), and therefore we must caution against treating rates of patenting as strictly implying rates of innovation. This is the million dollar question separating commercialization of innovations and research into innovation, diffusion, and technological change.

5.6 Robustness checks

Looking at the R-squared, all models are relatively strong. Yet one issue in particular is worrying, and a common concern in the literature: there is the potential that predictor variables are in linear relation to other predictor variables, causing standard errors to be inflated unnecessarily (Bentler & Chou, 1987). The main detrimental outcome that unfolds is unstable coefficient estimates (ibid). Due to the fact that environmental policy is so closely related to institutional qualities, and also to patent protection, this remains a key concern. Thus, I am not able to entirely rule out linear relations. Another issue that arises is endogeneity. This is a well-known concern in the ITC literature, and there are several ways to approach this problem. Country-level innovation trends in CETs certainly are susceptible to a variety of factors which are unable to be included in this model; this is reflected in the moderate R-squared values (mostly under .500). Estimation results might reflect this bias and indeed EPS might be partly responsible for such bias because, for example, of convergence in EPS in European countries, in addition to their geographical closeness (which might only be significant for large technologies such as wind or large hydro). Geographic proximity of EU countries, which mostly account for the strongest environmental regimes, might certainly skew the results (see, for example, Carley, 2009; Marques et al. 2010). Statistical analysis of “national systems”, in this case the clean technology innovation system, also faces some major limitations. Soete (1980) first cautioned against longitudinal comparisons of different country-level innovation systems, due in large part to their very different patent and property protection regimes. Suffice it to say that, "in sectors as different as whaling and plastics, strong correlations have been found between the location of R&D, patents and innovations (Basberg, 1982; Freeman, 1963)" (Pavit, Dosi & Soete, 1990: 46). Even with these limitations and caveats, the results here are strong, and more research needs to be conducted in this area.

6. Conclusions

I have thus established a connection between foreign environmental policy stringency (*epsf*) and innovation in clean technologies. Unlike the scant empirical investigations in previous research, confined mostly to OECD or EU countries (De Vries and Withagen, 2005; Constantini and Crespi, 2008; Johnstone et al., 2010), I look at overall competitiveness and innovation, which are indicators for the "foreign" induced *dynamic* PH. This *dynamic* approach accounts for the potential opportunity costs of environmental regulation and induced innovations. The models explored here seem to closely resemble the Porter Hypothesis, since their original conceptualization relies on underlying features of trade theory, and articulates how frontier policy countries might in fact benefit domestic innovators. Foreign EPS influence shows that the frontier stringent country does not suffer, in a competitive sense, because it induces more investment, FDI, and export into its country. Later, policy stringent countries are able to export these technologies as other countries ratchet up their own domestic EPS. Finally, this paper implies that frontier EPS countries may benefit by attracting foreign innovators which, in turn, increases the competitiveness of home clean tech industries by incorporating a large variety of innovations from home and foreign markets. This is critical component of the national innovation system for environmental technologies.

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Chapter IV: Institutional Distance and the Diffusion of Clean Technologies

Abstract: This chapter employs institutional theory as a lens to better understand cross-border, policy-induced innovations in environmental technologies. I propose the global diffusion of climate technologies is dependent on home and foreign country's institutional *strengths and a specific combination of environmental policies. Using a sample of 32 countries, including the OECD countries and the BRICS, this article implies an important relationship between environmental policies and institutional quality. In particular, institutional distances are found to play an important role in the extent to which foreign policies might induce domestic innovators. Similarly, distance to environmental policy frontier countries also is found to correlate with the potential effects of foreign policy inducements. These investigations benefit from a gravity model, which uses a formula to take the distance between institutional proxies. Further, using this gravity model, foreign environmental policies are shown to have an inducement effect on domestic clean technology innovation to the extent institutional distance is not too large. Environmental technologies, in particular solar and wind energy, experience foreign policy pulls in different ways: for the former, "frontier" foreign policies "pull" innovations at home while for the latter, institutional "distance" between foreign policy leader and domestic innovator appears most significant.*

Keywords: gravity model; cleantech; climate technologies; unfccc; induced innovation; institutional distance; kyoto protocol; Montreal protocol.

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Introduction: Institutions and Environmental Policies

In this chapter, I investigate the institutional dynamics integral to the inducement and diffusion of new clean technology innovations. I hypothesize that such innovations are induced from both domestic and foreign environmental policies, and those effects vary according to distances. Distances here refers to gravity distances between institutions of different countries (De Groot et al., 2004; Baltagi et al., 2003; Jansen et al., 2004). With a gravity model, distance between the institutions of two countries is calculated according to the distance between institutional proxies. Thus formulated, if institutional distance between two countries is too large, their respective foreign environmental policies are not expected to induce innovations from abroad.

Along similar conceptual lines, I create an “environmental policy frontier” variable, with the expectation that a country at the environmental policy frontier “pulls” foreign innovators intent on supplying a foreign market with more stringent policies than their own. Countries in a sense play “catch-up” both on technological and policy fronts. The frontier countries tend to exhibit strong pulls from innovators from variegated countries around the world, to the extent that the latter have strong enough institutions to enable innovators and exporters. Therefore, the distance between the institutions in leading policy countries and technological supplier countries largely determines this phenomenon. It is assumed policy leaders already are imbued with strong institutions. Indeed, this is an important departure from previous literature which predominantly looks only at domestic policy inducements (Lanjouw & Mody, 1996; Jaffe & Palmer, 1997), and virtually none employ a gravity-inspired model with institutional quality as a main focus.

Therefore, the present research brings together induced technological change (ITC) and institutional theory (North, 1991; Kostova, 1999; Scott, 1995). The induced technological change literature (ITC) (Jaffe et al., 2003), however, mainly follows the conventions of neoclassical economics. This is in part due to the fact that the neoclassical "story builds on an implicit set of assumptions that are derived from the rationality postulate of economic theory" (North, 1991: 10), and are thus constrained to the neoclassical "strait-jacket" (Buchanan, 1987). Yet, institutions are needed to support environmental policies; the latter, according to induced technological change theory, is understood to support the invention and diffusion of climate and environmental technologies in general.

Therefore I argue that, holding other things constant (including country and year fixed effects), institutional quality distance between countries (gravity) and environmental policy distance to frontier country, will affect the rate of innovation in clean technologies induced by both foreign and domestic policies. That rate seems to be at least partly driven by frontier policy countries, themselves well positioned to capture the competitive benefits of stringent environmental policies (Porter & van der Linde, 1995). Institutional distance means the difference in institutional environments between two countries, and the gravity measure is computed between 0 and 1 (Kostova, 1999; Gaur & Lu, 2007). Meanwhile, environmental policy distance is a new measure introduced in this paper to measure the distance a country is to the “frontier” policy country, with frontier country set to “.001”, while the country with the weakest environmental policy is closer to “1.0” (therefore the measure is computed using the same gravity formula).

Though variegated environmental policies often yield vastly different environmental innovation outcomes (Johnstone et al., 2010; Johnstone & Hascic, 2010; Tobey, 1990; Lanoie et al., 2011), by building the current model using strictly environmental policies and institutional-quality indicators, I intend to explore in greater detail the interesting inducement effects observed over the last few decades. I focus on technological innovations in clean technologies because, at heart of all climate policy, is the idea that new technologies must be created and deployed, and at a rapid rate (Polzin et al., 2015; Verdolini & Galeotti, 2011), to displace the global fossil fuel industry, the latter evidently causing a broad array of climate and pollution problems (Schot & RIp, 1997; Wüstenhagen & Menichetti, 2012: IPCC, 2014; Foxon & Pearson, 2007; Schleich, 2009). Indeed, governments are interested in “best practice for environmental policymaking (Bennett, 1991; Busch et al., 2003), and […] the role of pioneers seems to be more important than the creation of policy innovations [diffused] from pioneer countries to the rest of the world” (Jänicke & Jacob, 2004: 42).

This diffusion by imitation is an important mechanism for global clean technologies. In other words, the rate of innovation for clean technologies ostensibly represents the most critical core to successful climate policy and regulative support. That rate appears to be determined at least in part by policy distance to “frontier” country and institutional distance as calculated by the gravity model.

While a large body of literature explores the induced innovations from climate and environmental policies (Jaffe et al., 2003; Johnstone et al., 2010; Popp et al., 2011), both empirically and theoretically (Jänicke & Jacob, 2004), there are very few studies looking at cross-border inducements. What is more, even those that do explore the cross-border effects do not fully account for institutional quality, institutional distance, or the potential interaction of these two variables with environmental policies. This is despite the fact that climate policies are increasingly more global in scope in almost every dimension: emissions, technologies, policies and social impacts. Therefore, the present research goes beyond the seminal work by Johnstone et al. (2010) and Popp et al. (2010) by taking an explicit cross-border approach, and resting on the implicit assumption that environmental policies are hinged on institutions, as well as institutional distance. While the idea is first empirically tested by Johnstone and Hascic (2009), their models are not developed further in this regard. The model I deploy goes beyond earlier empirical research on the subject by distinguishing between “capacity, as a relative stable condition of action, and its utilization which leads to the subjective and situational aspect of environmental policy” (Jänicke, 1997: 8). The environmental capacity of a country, in this perspective, is constituted by the strength, competence and configuration of the governmental and non-governmental proponents of environmental protection and the specific cognitive-informational, political-institutional and economic-technological framework conditions (ibid).

Furthermore, though some seminal investigations are evidently critical in bringing these ideas to the fore (Newell, 1997; Popp, 2002; Popp, 2006; Johnstone et al., 2010; Popp, 2010), the analysis warrants updating and expanding for three key reasons. First, clean technologies have experienced rapid technological innovation since 2005 (BNEF, 2017), yet most of the previous literature, due in part to data constraints, only explores these issues up to about 2009 (Johnstone et al., 2010). Second, mainly as result of the pace of innovations, costs of clean technologies fallen precipitously over the past decade. This calls for a renewed examination of innovation in clean technology because rapidly falling costs is a strong indicator that innovations are occurring at equally rapid rates, and policies must be in some way responsible for these declining cost curves. Finally, an array of different policies and schemes are tried and revised in the two decades since the introduction of Kyoto Protocol (1997). Much has been learned by policy-makers over this time period while perhaps even more is learned by firms and innovators, evidenced by sharp increases to knowledge stock for climate technologies (Dechezleprêtre et al., 2014), which is a measure capturing tacit knowledge of a firm or country. The majority of this research employs patent data as a proxy for innovations, a convention that I follow here. One caveat is patents add a data and time constraint due to the fact that patent data should be lagged to reflect the time it takes for R&D, invention, and eventually deployment or diffusion of new technologies. For all these reasons, (the timing, the cross-border effects, along with concerted focus on institutional quality indicators), this current research is well placed to exploit several key gaps in the literature.

The first paper in this dissertation discusses the potential benefits of using the Porter Hypothesis in a cross-country perspective, opening up the proposition that a foreign country's environmental policy to induce climate technology innovation at home. A similar re-conceptualization of induced technological change is explored in Ambec et al. (2011) as well as Lanoie et al. (2008), but the weakness is these investigations are merely cross-sectional; innovation in technologies should be studied with time-series, especially when examining climate policies, which naturally are structured to induced changes into the distant future(Angrist & Pischke, 2008). Indeed some have gone as far as defining innovation within the temporal changes of institutional dynamics: "We define the pace of institutionalization as the length of time taken for an innovation to become diffused throughout an organizational level" (Lawrence et al., 2001: 627). The second paper in this dissertation empirically tests the hypothesis that foreign country environmental policy induces innovation in clean technologies, with country-specific and time variant controls. The results of the second paper indicate that inducement effects indeed exist from home and foreign policy, although the effect of home policies appears much stronger across all technologies apart from solar. This final paper builds on the previous findings and begins to explain variegated impacts of the foreign inducement effect, in particular the importance of institutional quality on both home and foreign countries. I am able to parse out this variegated effect using a gravity model for institutional distance and a gravity-inspired model for distance to "frontier" country environmental policy. Indeed, the construction of these two variables is novel and an important contribution to the extant literature.

1. Globally Dispersed Climate Innovation

Institutions are understood to play an important role in development and transfer of climate change mitigation technologies (Dechezleprêtre, Glachant & Ménière, 2008). Climate policies have sprung up in a number of countries, supported by domestic and global institutions (UNFCCC; World Bank; OECD), and the former encourage a wide variety of innovations in climate change mitigation technologies (CCMTs). CCMTs have crossed borders to meet demand of environmental policy-stringent countries, with innovative responses stemming from a large variety of firms in several dozen key countries. They've been encouraged to diffuse to less-stringent, or lesser developed countries, through certain UNFCCC policies (Haščič & Johnstone, 2011), but it is clear the innovation and diffusion of these technologies lies mostly within OECD countries (Haščič et al., 2011). Empirical evidence shows that weak intellectual property protection results in less technology transfers, and tech transfer also depends heavily on technological capacity of receiving countries as opposed to innovating (exporting) countries (Ockwell et al., 2010). What this indicates is, not only do we have to pay close attention to institutional distances between countries, but also the institutional capacity of a receiving country. The ability of a country to absorb spillovers, including technological, knowledge, and policy spillovers, is ultimately determined by its domestic-institutional capacity. Further, a variety of spillovers are seen as increasing the rate of climate technology diffusion (Verdolini & Galeotti, 2011; Voigt et al., 2014).Yet, I suggest the diffusion of climate technologies is still somewhat poorly understood, due in large part to the lack of awareness of institutional components, in addition to the high likelihood of cross-border inducements partially determined by these same institutional features. Why do CCMTs diffuse? What is causing the push?[4] What is causing the pull? These are some of the key questions addressed in this paper.

[4] A prominent role is played by technology push factors (Schumpeter, 1943; Schmookler, 1966; Horbach et al., 2012) in determining how innovations spread. Technology push implies innovations themselves drive dispersion and diffusions, rather than policy or price inducements 'pulling'. This is another reason to incorporate knowledge stock to capture previous innovation experience. Knowledge stock is expected to have a positive influence on the innovation capacity because innovators can "stand on the shoulders of the giants" (Caballero and Jaffe, 1993; Rubashkina, Galeotti, Verdolini, 2015).)

While evidence of environmental policies inducing innovations is detected in the seminal paper by Lanjouw and Mody (1996), followed closely by Newell (1997) and Popp (2002), these earlier studies largely fail to account for institutional quality, instead relying on a proxy for environmental policy to somehow represent both institutions and policy stringency. The favored proxy for environmental policy stringency, at least in earlier studies (Dechezleprêtre & Sato, 2017), is Pollution Abatement Costs (PACE). This proxy is now known to be highly problematic, especially as a main explanatory variable (ibid; Sato et al., 2015b; Brunel & Levinson, 2013). In principal, PACE varies too widely across industries and countries, and therefore is only a good proxy for cross-sectional investigations. Meanwhile, policies and institutions change over time, and innovations are determined by a special mix of these forces. A certain combination of these endogenous features—e.g., stringent environmental policies coupled with strong and stable institutions, therefore, should be expected to induce innovations in the home country, in contrast *to ex post*, industry-sourced, PACE data.

Therefore I hypothesize that, in line with the Porter Hypothesis (Porter and van der Linde, 1995), the probability of foreign innovators entering the market of a country closer to the environmental policy frontier will increase as foreign environmental policies are ratcheted up in countries with strong institutions. In this respect, on the other hand, laggard countries increasingly innovate to meet frontier countries' demands, according to stricter environmental policy, until their own country can successfully "catch-up" to the environmental policy frontier, the latter constrained by its own domestic institutions. As such a “frontier” country, if its institutions are of sufficient quality, might very well define the global clean technology innovation frontier, to borrow a concept discussed in Fagerberg and Verspagen (2002), by pulling any number of innovators from “laggard” policy countries.

1.1 Institutions and the Dispersion of Clean Technologies

At the heart of climate change policy is innovation and diffusion of clean technologies. Reducing and eventually eliminating emissions by way of driving innovation in clean technologies will be the most important industrial policy of the 21st century (Aghion, 2011). But climate policies, along with innovations and diffusions of climate technologies, require strong and stable institutions. This is particularly true if imported technologies are needed to meet new policies. Some recent papers have begun to explore an empirical approach to climate technology innovations in response to climate policies and focus on a wide variety of political factors (Fischer & Newell, 2008; Gillingham et al., 2008; Dasgupta et al., 2016; Nicolli & Vona, 2012), with varied focus on political and institutional dynamics (Fredriksson et al., 2004). What these papers seem to be getting at, however, is a new approach able to incorporate institutions and trade in clean technologies, is needed.

Technological innovations, including clean technologies, are not constrained to linear technological development. Indeed, according to Schumpeter (1939), innovations are not rational and follow no predetermined set of constraints. The assumption of rationality in business decisions works only within the confines of familiar and vintage industries, the latter usually sidelined by new innovations. Immediately after the introduction of new innovations, a key feature of neoclassical economic models, namely bounded rationality, is rendered irrelevant (Weyant & Olavson, 1999; Rosenberg, 1994). To the extent that technological change (ITC) models continue to rely almost exclusively on general equilibrium models, these suffer by not embodying institutional and policy variables (Weyant & Olavson, 1999). Taking into account these complicated features of the cleantech innovation paradigm, an institutional approach to understanding induced innovations might more easily account for rapid advancements in clean technologies experienced over the past two decades.

Institutions are composed of three pillars: regulative, normative, and cognitive (Scott, 1995; Hoffman, 1999; Gaur & Lu, 2007). The regulative pillar embodies rules and monitoring (Scott, 1995). Climate policies set renewable energy targets, supported by feed-in-tariffs, R&D credits, and emissions restrictions to achieve these targets, and therefore characteristically reside well within the regulative pillar. Indeed, firm's varied responses to climate policies represent a central aspect of this pillar (Hoffman, 1999: 33). The normative pillar is referred to as the "rule-of-thumb" (ibid) and is important for establishing environmental policies in first place. What lies in the normative pillar, with respect to these policies, are country-specific variations such as intellectual property protection, GDP per capita, and emissions. Accordingly, these are accounted for in the control variables. Meanwhile, the cognitive pillar is captured in some of the dummy variables including the year a country entered Kyoto Protocol and its UNFCCC cooperation index. One important finding in the literature is the effect Kyoto appears to have on patenting which, according to Popp et al. (2010), is seen as leading to new investment in knowledge production for renewable energies, resulting in novel innovations. Interestingly, and something that comes up in the results section below, this effect is much weaker for wind technologies. Importantly, however, Popp et al. (2010) suggests that ratification of Kyoto serves as a signal of “the menu of policies to come” (Popp et al., 2010: 658). Indeed, I use Kyoto as a dummy variable as well as experiment with several UNFCCC cooperation proxies for precisely these reasons.

1.2 Cross-border inducements

Dechezleprêtre et al. (2015) and Hascic et al. (2008, 2010) examine cross-border effects of “clean-tech” innovation in automobiles. Both studies confirm that firms react to regulatory stringency in foreign countries, at least for “cleaner” automobile technologies in response to stringent emissions policies. The evidence is found by comparing the difference in regulations of home and foreign country next to patents (as the dependent variable). Moreover, Dechezleprêtre et al. (2015) consider the distinction among “regulatory followers and frontrunners”, under the assumption frontrunners will induce foreign innovators. Some countries lead while others follow. The regulatory frontrunner should be expected to have, at a minimum, a slight technological advantage (measured by patents) because it will be the first country to react to new policy (as a home country is expected to know best and quickest the impacts of its own policies). Meanwhile the regulatory "laggards", at least at the beginning of the time series, react to foreign country front-runners until, in future time, their domestic policy closes the regulatory gap:

> In fact, once we control for regulatory distance, absolute regulatory stringency in potential destination countries of technology inflows ceases to matter. A possible explanation for the role of regulator distance is that regulation-driven demand for [Environmental Technologies] is more likely to be supplied by foreign innovators where these countries have already innovated compliance technologies in response to similar standards (Dechezleprêtre et al., 2015: 254).

This stylized approach aligns well with the Porter Hypothesis in that the PH predicts that stricter environmental regulations will benefit the home country by giving it a technological advantage, precipitating in the "pioneer" home country exporting technologies to laggard countries. "Pioneer countries in environmental policy are highly competitive [...] The causal relation can be in both directions [but] the hypothesis of a contradiction between competitiveness and a demanding environmental policy can be rejected" (Jänicke and Jacob, 2004: 31). In other words, evidence exists to show competitiveness and strength of environmental policy are correlated, but no evidence is found for environmental policy harming a country's competitiveness. What is more, in terms of environmental technologies, increased stringency of environmental policies appears to rise in tandem to a country's competitiveness in these same technologies (ibid). Going further, Dechezleprêtre et al. contend that the environmental policy frontier country even has an advantage in comparison to a country very near to the environmental policy frontier. A critical departure they make is to bring to the fore the importance of "regulatory distance between sending and receiving countries, i.e. the gap between regulatory standards in *[country] i and j*” (Dechezleprêtre et al., 2015: 246). As such, they find “regulatory distance” is paramount in cross-border environmental technology flows; in other words, the gravity model of distance in institutions is a critical component of cross-border policy-induced clean technology innovations.

Similar analysis concerning frontier-country policy driving diffusion of clean technologies is delivered by Rubashkina et al. (2015), but with more emphasis on spillovers. “[There is a] link between total factor productivity gains in the “catching-up” country with the extent of innovation and knowledge spillovers [in the] most advanced country” (Rubashkina et al., 2015: 296). More precisely, this means catching up countries benefit immensely from an ability to absorb key spillovers, including knowledge, technology, and innovation spillovers. Likewise Constantini and Crespi (2008), Constantini and Mazzanti (2012), and Constantini et al. (2017) suggest a *dynamic Porter-like* effect (Constantini & Mazzanti, 2012) driving global cleantech innovation and diffusion. These models are among the few incorporating a gravity variable in induced technological innovations in environmental technologies. A more stylized approach might employ an institutional gravity model to explore cross-border spillovers and inducements. In particular, it is important to understand how “catching up”, then leveling off reflects a laggard countries’ ability to innovate in this technology area (Aghion et al., 2005; Aghion et al., 2001).

1.3 Gravity Modelling

Some recent empirical studies explore the phenomena of increased preponderance of clean technology exports correlated to variegated foreign policies (Constantini & Mazzanti, 2012; Constantini & Crespi, 2008; Verdolini & Galeotti, 2011. Helpful in this analysis are gravity models based in trade theory, the latter becoming very complicated if using neoclassical models (Deardorff, 2011; Jansen et al., 2004). For example, gravity models are successfully deployed by Constantini and Mazzanti (2012) to understand the extent to which countries export climate technologies based on foreign climate policies. Their model relies on bilateral export flows of clean technologies, including energy-saving technologies, and is confined to OECD countries only based on the assumption that the majority of climate policies and environmental technologies are found in developed countries. The findings reveal that, indeed, international competitiveness in environmental technology innovation is determined in part by environmental policies from both domestic and foreign sources. These findings are confirmed by similar investigations (Verdolini & Galeotti, 2011).

Indeed, both Constantini and Mazzanti (2012) and Rubashkina et al. (2015), find “Porter-like” effects on an international level. In other words, environmental policies are found to induce home and foreign firms to innovate in response to policies. For example, Constantini and Mazzanti (2012) attempt to uncover both strong and weak versions of the Porter Hypothesis (see paper I of this dissertation), and reject their hypothesis of the presence of PH with the model using aggregated exports while accepting their hypothesis in the model with strictly environmental goods exports. Therefore a strong Porter

Hypothesis, meaning environmental policy inducing positive innovations in many different sectors, is not observed. However, these do confirm the weak version of the PH, or positive innovation offsets for some sectors. Most importantly, for the purposes of this present research, cross-border inducement effects are evidenced by the empirical literature.

Meanwhile Sauvage (2014) finds strong evidence for a cross-border Porter-like effect by teasing out country-level competence in distinctive environmental technologies. What is novel about the approach is the use of “Revealed Comparative Advantage” (RCA), which is able to more clearly delineate among similar but quite different climate technologies. He shows an increase in the value of environmental goods exports of 40% between the years 2007-2011, far above the same measure for total exports in all other sectors (thus adding importance to a gravity model here). During this same time (2000-2010), OECD countries augmented their respective environmental policies. This implies that exports of new innovations are in some way in response to foreign policies. Sauvage seeks to understand specific competencies in environmental technologies, therefore distinguishing his approach beyond employing simply patent count models (Johnstone et al., 2010; Popp et al., 2011), the latter unable to account for rates of innovation. By using RCA, or specific sector patents divided by total country patents, he uncovers more detailed empirical findings for distinct environmental technologies. For example, he finds solar panels accounted for 18% of total world exports in environmental goods between 2007-2011. This is astonishing since, according to the OECD, environmental technologies include over 700 different technologies. Therefore this research clearly goes beyond other researchers exploring the environmental policy inducement effects on the large subset of environment technologies.

De Santis (2012) research is situated somewhere between the aforementioned explorations into cross-border climate policy inducements, although his findings are somewhat inconclusive until after adding global climate policy variables. By employing a gravity model and exploring specific CCMTs, this study is able to explore, in depth, the extent to which various domestic, regional and global climate agreements serve to induce a variety of technological innovations. To be sure, De Santis finds environmental policies have a negative impact on bilateral trade in European countries, meaning these countries tend to be malaffected by trade in environmental products, evidenced by the gravity model. Yet this effect is reversed once UNFCCC agreements, including the Kyoto and Montreal Protocols, are integrated into the model. It seems, after controlling for multilateral climate policy agreements, the gravity model for environmental policy distances becomes significant. I account for this finding by incorporating the Kyoto Protocol and UNFCCC Cooperation as dummy variables in some models. De Santis findings emphasize the importance of global climate institutions and the potential role these play in inducing cooperation and clean technology diffusions.

In similar vein, an explicit gravity model for solar technology components induced by international policies is employed by Groba (2014), with positive PH findings, specifically for the narrow version of the Porter Hypothesis. Groba's analysis on

21 OECD countries uses PPML estimation to understand how renewable energy policies and trade restrictions impact solar component exports (captured by controlling for high technology exports in my models). The findings clearly demonstrate that, in countries that introduce stringent environmental policies earlier, if buttressed by institutional support in the form of lower trade restrictions, benefit from foreign solar innovations.

Nevertheless, the findings of researchers discussed above are slightly inconclusive and display high variation in terms of the extent to which a cross-border, Porter-like technological inducement effect occurs. In general, “market” policies appear to induce foreign innovators while solar, and to some extent biofuels, are found to be impacted most (Johnstone et al., 2010). Broadly speaking, large gaps in the literature exist including, in particular, more adequate integration of institutional variables into modelling cross-border induced innovations. There is of course one major caveat here: institutional change oftentimes is a much slower process than policy change, let alone technological change (Dosi, 1984); the former thus experiences low variability, adding to modelling difficulties. Therefore, it might take a very long time for a country in the sample to reach the regulatory-institutional frontier. But how can we really predict when the leveling off might occur and why? This is the critical problem. A final problem is the novelty of gravity models, which are still somewhat untested in the literature. However, gravity models have slowly “been established as a major instrument for analyzing trade flows and explaining effects of related trade agreements” (Kepaptsoglou et al., 2010: 10).

In the following section, I turn to discuss where exactly I intend on filling these research gaps.

1.4 Filling the Gap: The Role of Institutional Quality in Innovation and Diffusion of Technologies

Hascic and Johnstone (2009) along with Dechezleprêtre et al. (2015) conceptualize flows of environmental technologies from laggard to frontier countries as an increasing trend in tandem with decreases in regulatory distance (or institutional quality distance). This can be interpreted as meaning laggard countries will eventually overtake the dynamic PH Effect as the laggard country catches up to the frontier. I empirically test for this effect, paying particularly close attention to institutional variables. As stated above, while Johnstone et al. (2010) and others (Popp et al., 2011; Lanjouw & Mody, 1996) look at the effect of domestic environmental policies on domestic innovation (strong or narrow PH), only several researchers explore international effects of environmental policy stringency on globally-induced innovators. Gravity models using variables such as trade, export/import and distance, are increasingly seen as useful for cross-country comparisons These models prove resilient in showing a cross-border Porter-effect (Ambec et al., 2011). This model is also expected to demonstrate an inverse, U-shaped effect as countries at medium distance to the frontier experience the greatest pull from foreign policies.

Another strong feature of gravity models is their ability to contend with variation in policies and technologies across countries. In contrast, ITC models or case studies do not typically explore the effect of differentiated policies across countries, most likely because gravity-like effects are too difficult to incorporate into neoclassical models (Deardorff, 2011). In order to formulate a cross-border (dynamic) Porter Effect, I turn to Porter directly. Although Porter and van der Linde (1995) implicitly draw upon institutional components involved in inducing environmental innovations, only later does Porter conceive of institutions taking a more formal role:

> Environmental performance is hypothesized to result from two broad sets of independent variables. One set, which we term the environmental regulatory regime, is comprised of measures of various aspects of a country's environmental regulatory system including standards, implementation and enforcement mechanisms, and associated institutions. These variables capture regulatory elements that directly affect pollution control and natural resource management (Esty & Porter, 2005: 80).

This represents a concrete starting point for the present research, and directly leads to the selection of explanatory variables. Due in part to the fact that a number of empirical studies, even if using the gravity model, still fail to properly account for institutional variables, it is evident the dynamic, cross-border Porter Effect has not been deeply explored in the empirical literature. If institutional variables are more effectively accounted for, a stronger cross-border inducement model can be created.

2. Theory and Hypothesis

Institutions have a special capacity to either increase or decrease the cost of markets because they influence transactional costs (North, 1990: 58). The fact that institutions can change relative and shadow prices (Fullerton & Metcalf, 2001) makes it even stranger that induced technological change models often neglect to properly account for an institutional variable. Institutions provide the rules for the game (North, 1990), and as such should not be summarily dismissed in these models. If a government, for example, is to guarantee a certain subsidy for wind technology development, this makes the marginal cost of building a wind farm go down, and thus the investment becomes more attractive. Note that the institutional structure is the first principle actor and catalyst in this example not, as it were, the firms or the market. Continuing this example, this new environmental subsidy likewise encourages innovators to deliver new technology at either less cost or higher efficiency to the subsidized market. Clean technology fits neatly into institutional theory because the former is obviously still heavily dependent on government support. Further, institutional theory, in a geopolitical context, effectively clarifies the dynamic global interactions of climate policies and environmental technologies. In countries where policies and institutions are weak, environmental technologies are prohibitively expensive; at the other end of the spectrum, the market for CCMTs in environmental frontier countries such as Denmark creates long-term demand for clean technology innovations. Such countries are able to stabilize the market, in turn providing a space for innovators to sell their technologies regardless of whether they are foreign or local; this is what can be coined the *environmental policy frontier*.

2.1 Institutions and a U-Shaped Effect

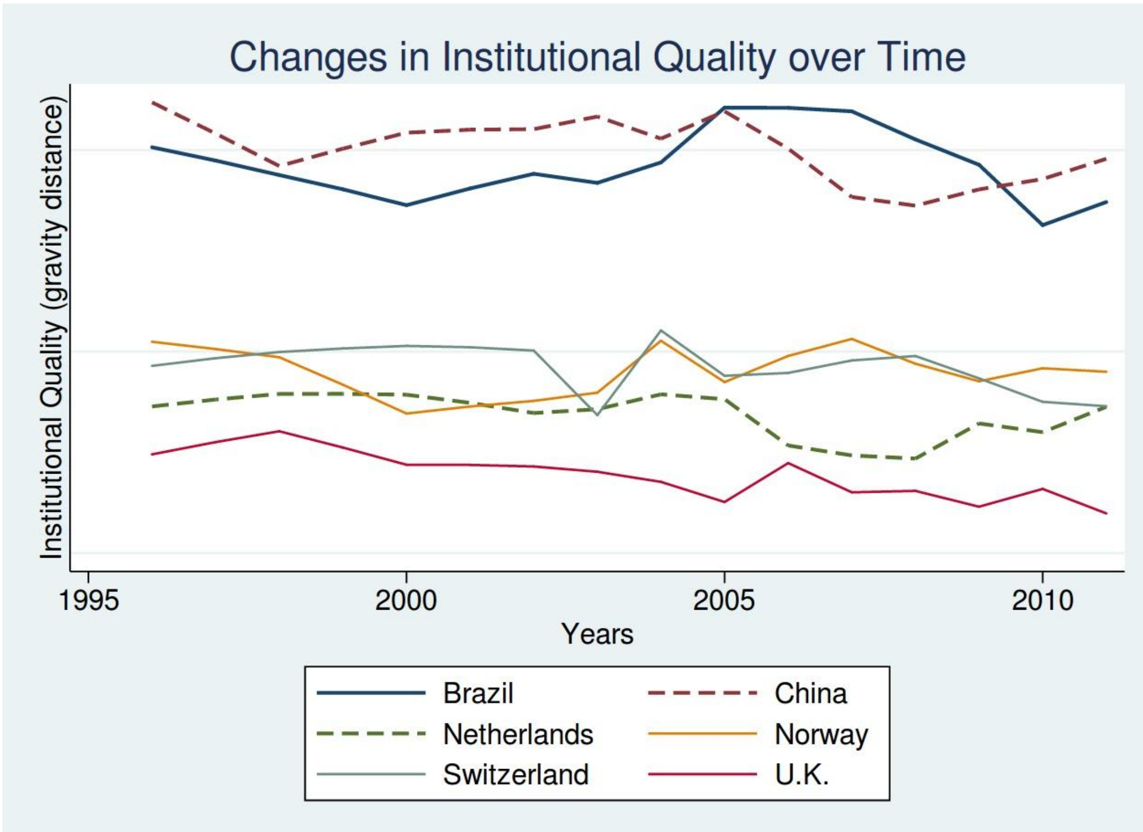
Institutional stability is a key component of environmental regulation (Volkery et al., 2006; Janicke & Jacob, 2004; Sauter, 2014). Such stability leads to “maximizing behavior of economic organizations [and] [...] the resultant demand for investment in knowledge of all kinds [..] the stock of knowledge, and the institutional framework; and incremental alteration of the informal constraints” (North, 1990: 78). These features are evidently crucial to the smooth functioning of the environmental policy system. The very success of such policies is hinged squarely on institutional pillars.

This novel approach for understanding the cross-country impacts of environmental policy on technological innovation is an important contribution to the extant literature. Specifically, one critical departure I take is predicting an inverse U-shaped effect among the distance to the policy frontier in respect to institutions, and foreign policy pulling innovations. That is, laggard policy countries but with medium institutional distance, are expected to experience a dynamic Porter-effect until a certain point. The inflection point occurs once the laggard country has successfully caught up in terms of either policy or technology (each factor itself determined in part by institutional quality); after a certain point of time, an inflection point is reached whereby domestic innovation in clean technologies begins inducing more rapid strengthening of domestic environmental policies (Johnstone, 2015).

Therefore, once the frontier is near, the cross-border effects are expected to diminish. Meanwhile, if institutions take a more central role in the model, I predict, we shall see a catching up only to a certain point, and then a leveling off (Aghion, 2016), because countries that completely mirror each other on both an institutional and policy level are not expected to have strong cross-border policy inducement effects even if their trade in high-tech goods continues to increase. In other words, I expect to see a decrease in foreign-policy inducement effects as country policies and institutions equalize (in the European countries, for example, I expect decreasing foreign policy pull). Indeed, we may be on the cusp of an entirely new form of industrial policy (Aghion, 2011; Aghion, 2016), contingent largely on state support of clean technology innovations. Such industrial policy would be predicted to support a rapidly emerging cleantech industry, the latter meeting the needs of various countries throughout the world. This appears evident in China's enormous push into solar energy production, but it is still largely based on institutional capacities while the technological frontiers are being defined by foreign policy leaders.

2.2 Country ability to absorb foreign policies and technologies

The ability of a country to absorb foreign policies, and thus experience policy-inducements from foreign environmental policies, is determined in part by a certain set of institutional qualities. I shall call these institutional factors *"IQ-1a"*, representing *country i* (policy-absorbing-country). This is because the hypothesis is based on the idea that a country is able to experience induced innovation in climate technologies to the extent its institutions are above a certain threshold: "Hence context indirectly (but perhaps importantly) determines environmental performance" (Porter & Esty, 2005: 80). Home institutional quality also relates to absorptive capacity and, indeed, some combination of institutional quality and technological past, or "knowledge-stock" (Popp, 2002), is representative of a country's ability to absorb foreign spillovers. Such spillovers may come in the form of policy, technology, R&D or knowledge. Here my focus is on policy because it seems policy spillovers are largely overlooked, and I expect foreign policies to influence rates of innovation domestically. Thus, I contend that foreign policy spillovers are determined at least in part by home-country absorptive capacity, in addition to institutional distance.



Graph 1: Institutional quality, proxied by World Bank Governance indicators, in select countries from 1995-2010.

Absorptive capacities are explored in several ways relating to knowledge, cultures, technological sophistication, and other country-specific characteristics. The policy-absorbing, innovating *country i*, is also expected to have at least some degree of technological knowledge proxied by “knowledge-stock” (Popp, 2002), which refers to “the stock of patents [and is] a good proxy for local absorptive capabilities, which previous research has shown are critical for the diffusion of advanced technologies” (Dechezleprêtre et al., 2015: 250). Therefore, a special combination of institutional quality, home institutions, and environmental technology knowledge imbues firms in *country i* with an opportunity to develop new clean technologies for export to frontier policy countries. This approach is theoretically similar to Lichtenthaler & Lichtenthaler (2009) who combine knowledge, absorptive capacity, and dynamic capabilities between firms to produce a 'capability-based' framework for an 'open innovation processes'.

I do not model knowledge or technology spillovers directly, although they are carefully accounted for in the control variables. This is critical because "when modelling induced technological change for CCMTs, spillovers need to be clearly articulated and kept as simple as possible" (Weyant & Olavson, 1999: 6). Buonanno et al. (2003) are among the first to explore cross-country climate policy effects, but rely on a neo-classical economic approach. As such, they are not able to properly assess policy spillovers. Understanding spillovers is key to foreign policy-induced technological change and cross-border cleantech innovations. Even though "disembodied" knowledge spillovers are frequently used to conceptualize innovations as benefiting from R&D (Romer, 1990), a conception which sidelines lesser developed countries with less capacity for R&D, I elect not to follow this convention as it is often considered more of an input to innovation rather than an innovative output.

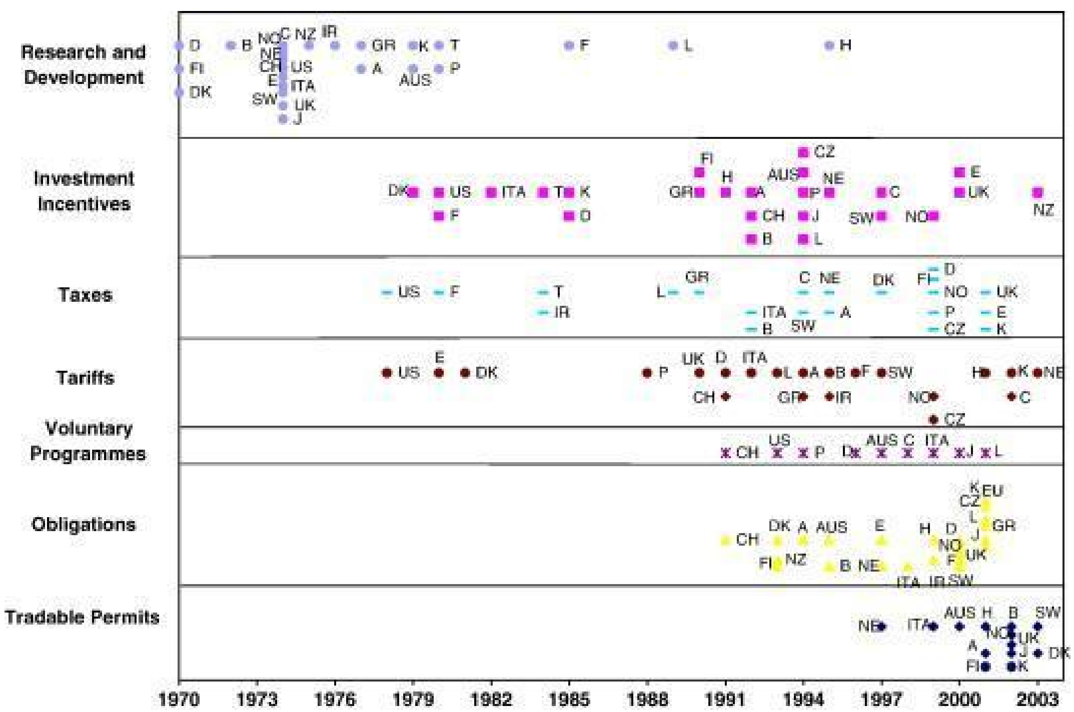
2.3 Distances and Institutions

Meanwhile, the regulatory-institutional strength of the frontier country's environmental policies determines, first of all, its potential to induce domestic innovators (*narrow PH*) and, second, its potential to draw in technological innovators from foreign countries that are policy laggards (dynamic, cross-border PH). In other words, the frontier country pulls foreign countries and firms, in particular those countries at medium distance, which are attempting to rapidly catch up to the frontier. The approach is similar to Berry et al. (2010), although their distance variables evidently take into account a much more comprehensive index. The gravity pulling effect can be visualized as a gravitational field, and therefore a gravity model suits the investigation quite well.

Likewise, in order for firms to “believe” a foreign country’s environmental policies are sufficiently stable to export to foreign frontier policy countries, the frontier country is expected to embody a certain degree of institutional qualities, in addition to a high degree of openness to trade; this feature is supported by the distance between *country i and j* institutions, and the latter is expected to be close enough for the gravity effect to exert a pulling force. However, if the distance between respective country institutions is simply too large, for example, foreign environmental policies are not expected to represent any gravitational pull. I shall refer to this second institutional variable as *”wb_grav”*. *Wb_grav* specifically refers to the calculated institutional distance between laggard and leader countries; it can be more easily thought of as representing the institutional components supporting foreign environmental policies, in terms of both their perception, quality, and attractiveness to foreign innovators. Therefore, environmental policies in home and foreign countries as well as institutions in home and foreign countries, interact in a dynamic way to create a clean technology paradigm (borrowing a definition from Dosi, 1984). The extent to which this paradigm demonstrates foreign policy pulling innovations in clean technologies is referred to here as the *dynamic* Porter Hypothesis. Geographical distance continues to play an important part in cross-country comparisons (De Groot et al., 2004) and is not completely abandoned here; I have maintained the geographical component within the foreign environmental policy variable.

2.4 Climate and Environmental Policy

Effective environmental policy requires not only strong institutional support in the form of government effectiveness, but also consistency and accountability. Stability of policies over time is sometimes even more important than the introduction of environmental policies (Johnstone & Hascic, 2009), which further underscores the importance of strong institutions, both theoretically and empirically. This is why it is no secret that the countries with the strongest institutional framework have historically advanced the most stringent environmental policies; by the same token, these policies are largely effective, in comparison to countries with much less institutionally capable governments. Governments provide regulatory-institutional support for environmental policies in a number of ways, which are well represented in the OECD's Environmental Stringency Index. Specifically, environmental policies directed at moving countries away from conventional energies and towards more cleaner production of energy include: direct taxes on GHGs (CO2, NOx, SOx, diesel); trading of CO2, renewable energy credits (RECs), energy efficiency certificates (EEC) and other tax/rebate and promotional schemes; subsidies or feed-in-tariffs. All of these policies, if domestic institutions are at a certain level, temporarily drive the cost of clean technologies down. Below is a chart depicting the various clean energy policies introduced over the past three decades in select OECD countries. Notice, some countries maintain policies over time, even if instruments are changed, while others drop out.



Graph 2: The evolution of Climate Policies over three decades in OECD Countries (Popp et al., 2010)

Consequently, the policy variables used by seminal researchers align very closely with OECD's Environmental Policy Stringency (EPS) (Botta & Kozluk, 2014). Popp et al. (2011) confirm the importance of these policies and their inducement effect on investments, installments and innovations in clean technologies. They identify six key policy variables are primarily responsible for inducing innovation including R&D, investment incentives (grants, low-interest loans), tax incentives (e.g., accelerated depreciation), tariff incentives (e.g., feed-in tariffs), voluntary programs, obligations, and tradable certificates. All of the critical policies identified by Popp et al. are captured by the EPS index (Botta & Kozluk, 2014; Albrizio et al., 2014). As seen in the policies chart above, there is a clear movement away from taxes and tariffs and towards obligations and tradable permits, even though the latter are shown not to induce innovations in newer technologies, but rather incumbent technologies (Johnstone et al., 2010). This important distinction, inducing incumbent technologies rather than new and innovative technologies, also represents a pivotal area of research to explore because innovation in clean technologies implies drawing in new technologies rather than relying on older, perhaps outdated, technologies for climate mitigation.

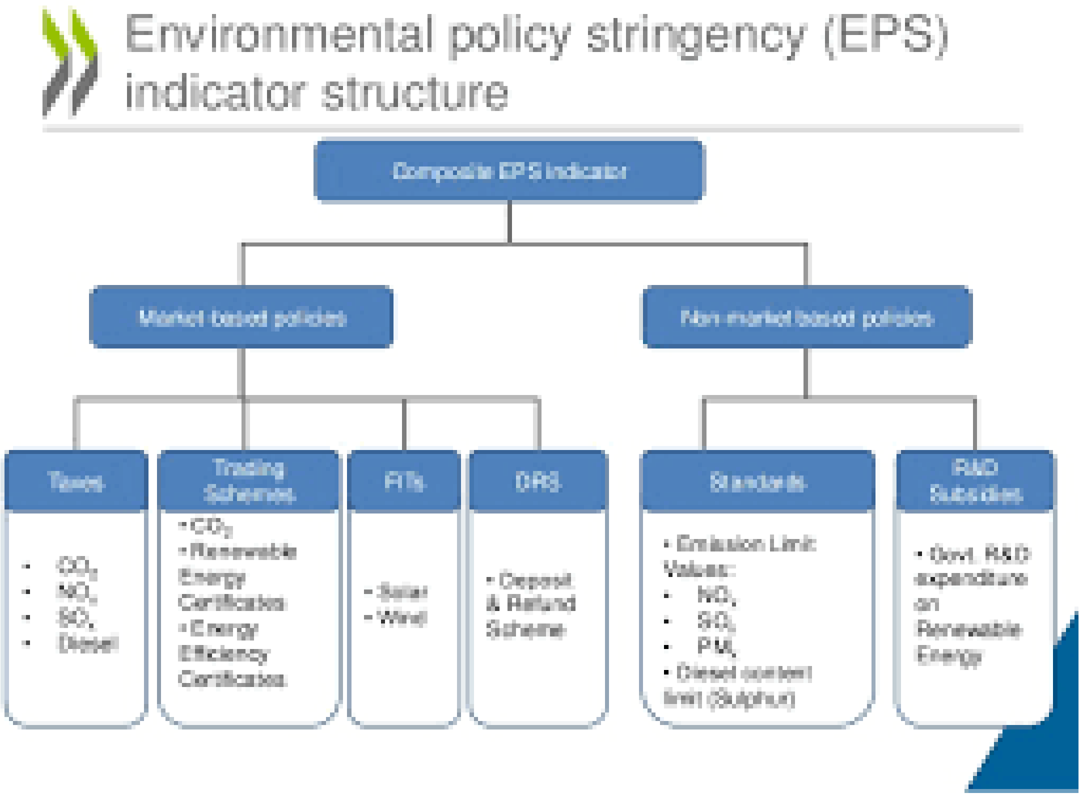


Table 1: OECD'S Environmental Policy Stringency Index (Botta & Kozluk, 2014)

The index deals specifically with policies to counter GHG emissions and encourage renewable energy investment and innovation. The EPS has three key features which make it stand out against comparable indicators: (1) Unlike Etsy and Porter's index which is confined to only a handful of years, the OECD EPS covers over two decades of data, which allows time-series models to be constructed (Sauter, 2014); (2) the OECD EPS is disaggregated into "non-market" and "market" policies, which allows interesting empirically testing of different types of government policies; (3) the OECD EPS is empirically consistent in the literature in terms of its correlation to other environmental indexes (Albrizio et al., 2011; Lanoie et al., 2011). As the present study is restricted to innovation in clean technologies, rather than the broader climate mitigation technologies CCMTs, the OECD EPS, which is primarily composed of renewable energy and emissions policies, represents a strong starting point for both foreign and domestic climate policy analysis. As mentioned above, although earlier studies of climate technology innovations employ emissions data to proxy for stringency (PACE) (Jaffe & Palmer, 1997), this approach is not taken here because I am not concerned with emissions, *per se*, but rather with the relationship between regulatory-institutional environmental policies and induced innovations.

The extant literature suggests any combination of the policies elucidated above can have a significant inducement effect on clean technologies, with either a short (t< 2 years) or long lag (3<t<10 years), or even no lag at all (de Serres et al., 2010; Albino et al., 2014). The timing of lags is important for the model. Greater than two years from “policy to patent” (Shadlen, 2009) is considered a feature of “strong” patents, because it indicates a patent might have been sought in another jurisdiction. Meanwhile, the strongest patents are innovations patented in two or more jurisdictions (Harhoff et al., 2003). This also indicates a technology has diffused across countries (Popp, 2006; Jaffe & Trajtenberg, 2002). As such, by looking at only patent families of two and greater, I home in on innovations which are both diffused across countries and represent more important innovations, contingent on institutional qualities.

2.5 Hypotheses to test

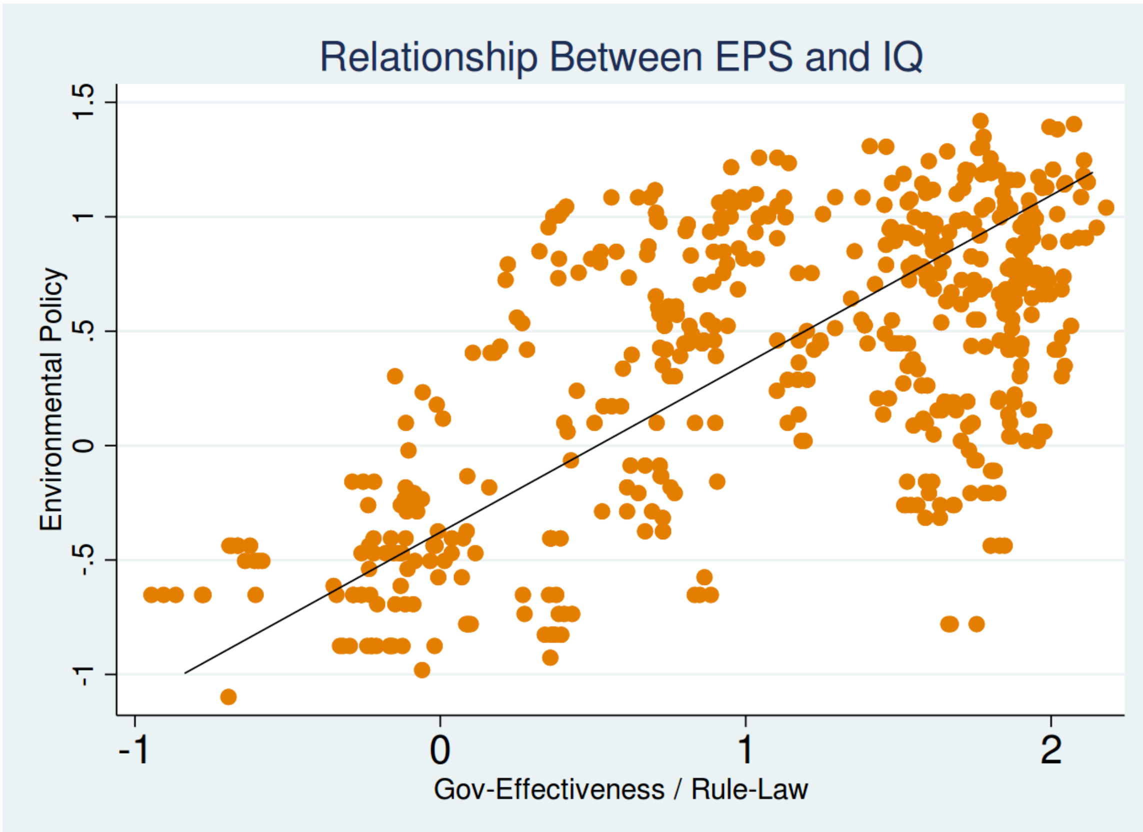
Taking into consideration the foreign policy inducement effects, coupled with institutional distance, I propose to find an inverted U-shaped relationship between foreign environmental policies and innovation in clean technologies. A similar proposal is put forward by Kalamova and Johnstone (2011) who predict an inverse U-shape relationship should exist between foreign environmental policy and foreign direct investment. Likewise, Sauter (2014) finds a significant positive correlation between the OECD's EPS and RCA of environmental technologies, presumed to indicate stringency of environmental policy in home country are found to benefit by way of exporting to "catch-up" countries as the latter approach the policy frontier (Sauter, 2014: 30). I follow this approach but expand on it by investigating a longer time series and adding BRICS into the country sample.

Over time, the laggard country is expected to slowly introduce its own stronger policy, somewhat resembling the stringency of the frontier country. This becomes more likely as its technological sophistication improves, in terms of satisfying the needs of climate policies. In other words, a country that introduced policy in *time t* might have been exporting clean technologies to the frontier country already, the latter having introduced strong policies at *time t-5*. Yet in *time t+5*, the laggard country will have experienced five years of increasingly stringent domestic policies, and should slowly be looking inward to meet demand as it approaches the regulatory-institutional frontier. Indeed, this seems to be the case for both China and India, countries that have very recently begun to supply clean technologies to meet domestic energy needs *only after* first exporting their technology to environmental policy frontier countries. But before I can explore this main hypothesis in detail, I establish the case for the importance of institutional quality: specifically, I need to find out to what extent environmental policy depends on institutions.

First, I look at the extent to which environmental policies are dependent on institutions. The first hypothesis is confined to only domestic effects.

Hypothesis 1a: Strength and consistency of environmental policy depends to a large extent on the quality of its domestic institutions (regulative, normative).

Two graphs depicting this relationship point towards the fact that institutions certainly impact the extent to which environmental policies are carried out and supported. The first, below, suggest a strong relationship between the World Bank Governance Indicators (IQ-1A) and the OECD-EPS.

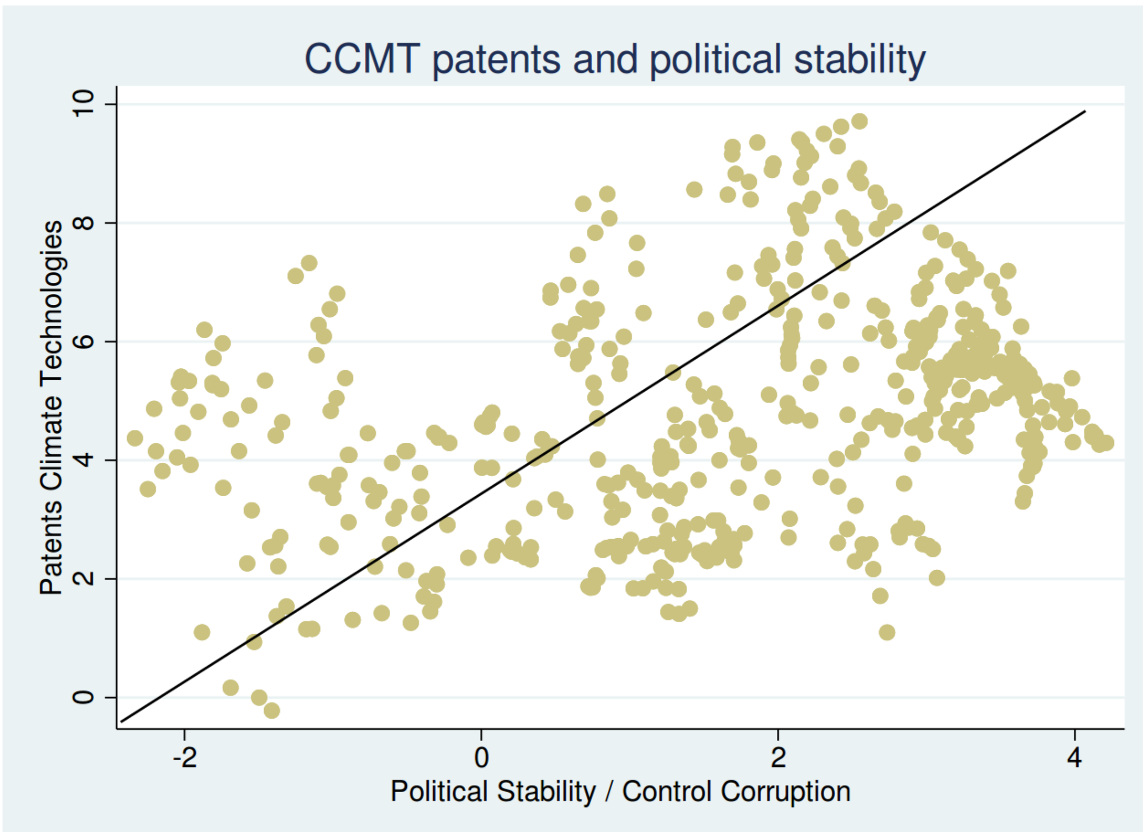


Graph 3: The conglomeration of points around the goodness of fit line for IQ-1A (Government Effectiveness / Rule of Law) and the relationship with EPS (logged), indicates there is a very strong relationship here**.**

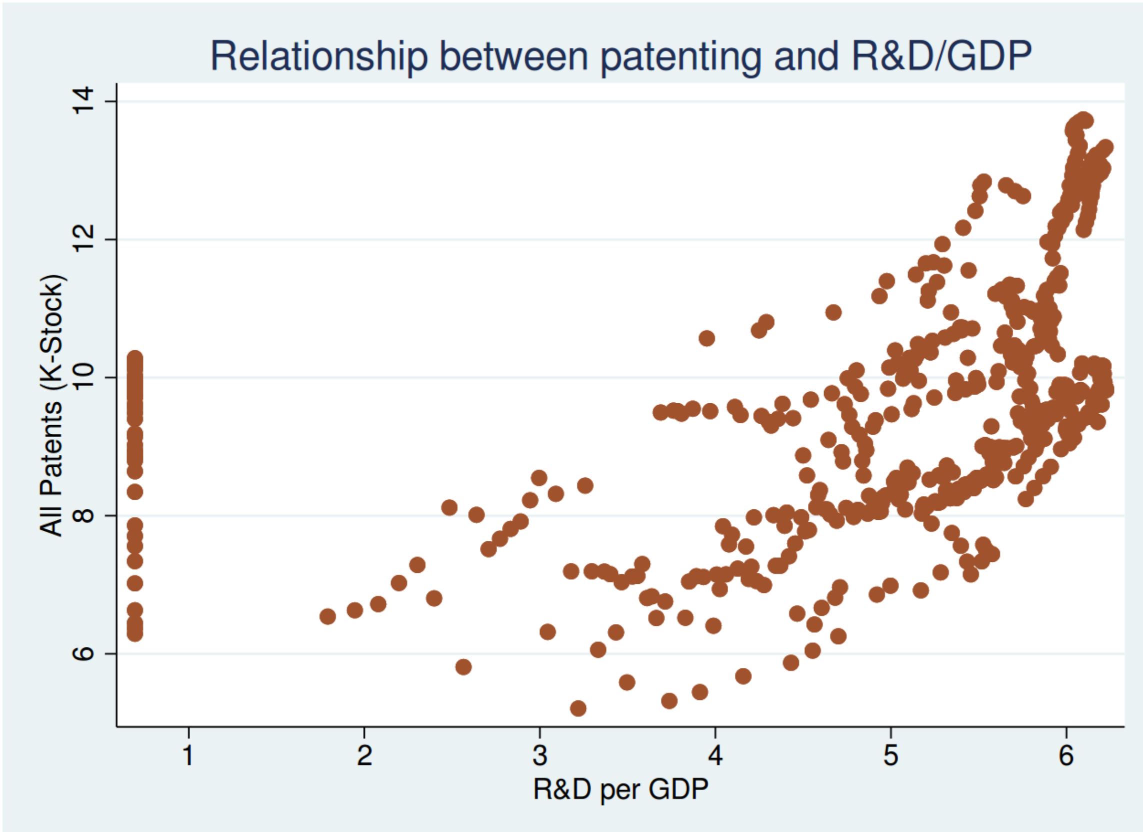
Next, I need to explore the relationship between climate technology innovation and institutional quality. This leads to the second hypothesis:

Hypothesis 1b: Innovations in Climate Technologies are dependent on strong environmental policies and on institutional quality, research and development from public and private sources, and participation in high technology industries (htx and ict).

This hypothesis, similar to the previous one, is based on the expectation that strong domestic institutions leads to innovation in clean technologies induced by domestic climate policies.



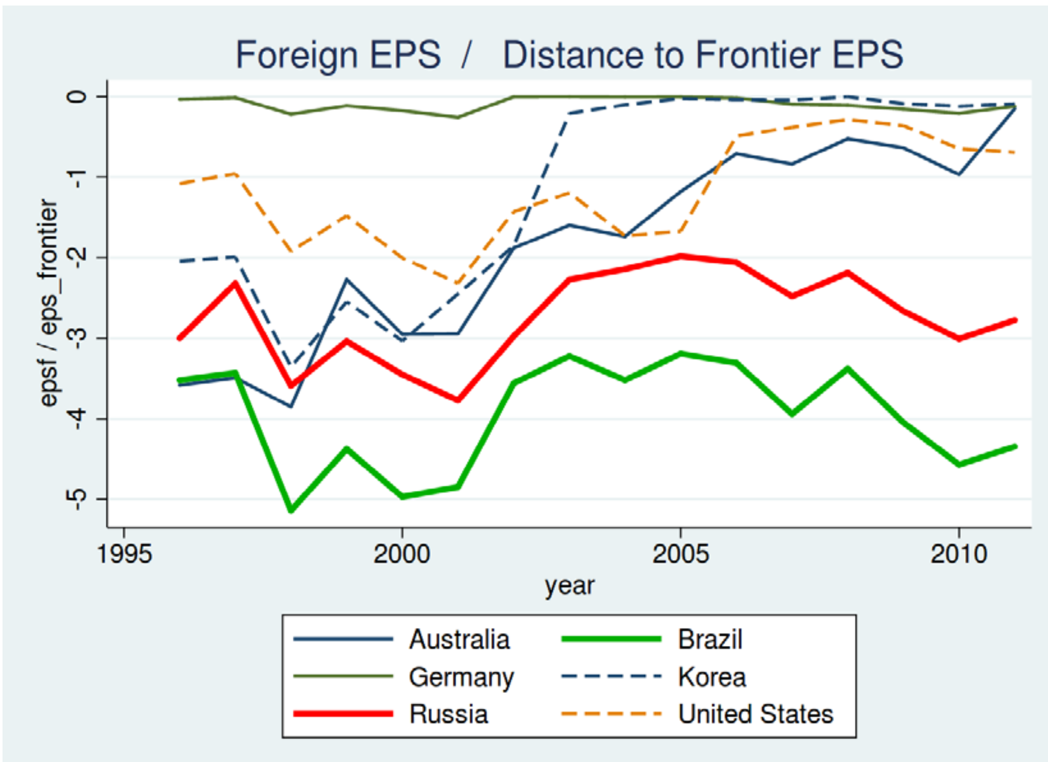
Graph 4: Here it is clear there is a strong relationship between IQ-1A (Political Stability / Control of Corruption) and patenting in Climate Change Mitigation Technologies (CCMTs).



Graph 5: Similar to the previous graph, a relationship is found for knowledge stock and R&D.

Frontier environmental policy countries might be capable of inducing foreign innovators. The foreign innovator does not, therefore, need to reside in a country with strong environmental policies, but only needs to reside in a country capable of providing institutional support for invention and diffusion (export) of new technologies. South Korea represents an interesting example since, up until about 2009, it had relatively weak domestic climate policy but was one of the world's top solar technology exporters. Interestingly, the quality and stability of its institutions are well known, and presumably contributed to their export success in clean technologies.

Hypothesis 2a: Innovation in clean technologies is dependent on institutional distance (weighted gravity), domestic institutional strengths, and domestic environmental policies.



Graph 6: Foreign environmental policy divided by distance to the environmental policy frontier, from 1996-2011.

Here notice foreign EPS converges for OECD countries, while Russia and Brazil ascend until 2005 (the year Kyoto begins enforcement), then begin to descend again. This graph demonstrates how distance to the frontier policy country, interacting with foreign environmental policies, is able to reveal how countries closer to the frontier are not expected to be induced as much as countries at medium distance. More plainly, Australia, Germany, and the US are experience a cancelling out effect due to quite similar institutions and environmental policies, exhibited by the convergence after 2010. The objective of this graph is to lead to the next several hypotheses which deal specifically with the foreign frontier policy country pulling innovators from abroad.

There exists a positive interaction between Regulative distance (EPS frontier) and a country's innovative efforts in clean technologies. In contrast, normative institutional distance (*wb_grav*), if it is too large, prevents foreign policy inducement effects because these normative attributes are not readily exploited; global agreements under the UNFCCC are unable to account for these normative distances. This leads to the following hypothesis:

Hypothesis 2b: Innovation in clean technologies is dependent on institutional distance and proximity (geographical distance) to frontier environmental policy country (or countries).

While Kalamova and Johnstone (2011) predict a flow from developed countries to laggard environmental policies, my concept involves laggard country policy innovating to satisfy technology needs of frontier environmental policy countries. In this sense, at least in the beginning of the “pull”, the arrow is reversed in respect to the concept put forward by Kalamova and Johnstone. I predict this reversal is determined in part by closeness of two countries institutions, but also the extent to which a country has caught up to the environmental policy frontier. This might certainly be the case as laggard countries experience “learning-by-exporting” (Crespi et al., 2008). More concretely, with institutional proximity being quite small, I expect foreign environmental policies’ inducement effect to remain low; meanwhile, as institutional distance becomes moderate, I expect strong effects of foreign policy inducing innovations at home; finally, beyond a certain point, if institutional distance is too large, little to no foreign policy inducements are expected. Clearly, these expectations paint a picture of an inverse U-shaped relationship among these variables. Because geographical proximity might play a more central role in the absence of institutional proximity (Boschma, 2005), I do not drop the geographical component of the foreign EPS variable. More concretely, this means if two countries happen to have widely different institutional capacity, but still border one another, I still expect a foreign-policy inducement effect. Conversely, because institutional proximity (*wbgrav*) is found to operate over long distances, even in the absence of geographical proximity, accounting for the institutional variable within a gravity-pull context remains critical to the cross-border inducement effects (Ponds et al., 2007: 425).

Hypothesis 3a: Inducements of clean technology innovations from innovative source country i to recipient country j increases as the regulatory distance between the two countries becomes smaller, but levels off at a certain point when both regulatory distance and distance to the environmental policy frontier converge.

This hypothesis draws on the "flow" of clean technologies put forth by Dechezleprêtre et al. (2015). Over time, institutional or regulatory distance and environmental policies are subject to change. An inflection point is therefore expected to occur around the time this change happens. The inflection point, in terms of the foreign-policy inducement effect, is expected when a country's own environmental policy reaches a certain level of stringency. Beyond a certain point, we should not expect a strong foreign-inducement effect. Likewise, if countries are too similar both institutionally and in terms of environmental policies (the European Union, for example), the effect of foreign policy inducement is expected to decrease, even though exports in clean technologies could increase simply due to competitive advantages.

Hypothesis 3b: Innovation in clean technologies, pulled/induced from foreign environmental policies, experiences the highest inducements at medium institutional distance. If countries are either too close or too far, in terms of institutional gravity, the effects diminish. In other words, there is an inverse U-Shaped phenomenon predicted to occur for institutional distance and foreign-induced innovation in clean technologies.

Now I turn to the following section, which describes the data sources, variable construction, and econometric models employed to explore these hypotheses.

3. Data and Methods

The sample includes 27 OECD countries and the BRICS (Brazil, Russia, India, China, South Africa). The country sample is the same for both ‘foreign’ innovators and ‘frontier’ policy countries. The time period under investigation spans from 1996 through 2011, due to both data limitations on upper and lower bounds, as well as the fact that cleantech innovations truly only begin in the late 1990s for the lower bound. The full sample before collapsing the IQ and EPS-foreign variables, because bilateral analysis is carried out for the institutional distances, includes 15872 observations (32 countries * 16 years * 31 countries). The final time-series panel, following computation of bilateral (gravity) variables, includes 512 observations (32 countries * 16 years).

The 32 countries in the sample provide sufficient empirical data since innovation in clean technologies is over 90% confined to these countries, at least as far as patenting and R&D are concerned (Aguirre & Ibikunle, 2014; Johnstone et al., 2010; Popp et al., 2011; Polzin et al., 2015). Yet, the inclusion of BRIICS also allows for wider variance to estimate the effects of institutional distance on the impact of global or regional environmental policy, and avoids selective sampling. It is also becoming more evident BRICS are able to account for their own environmental innovations (Acemoglu et al., 2014) and not simply waiting for "off-the-shelf" developed-country technology transfers (Popp, 2011). I test my hypothesis on a sample of 2 broad technology baskets ("cleantech" and "renewable energy tech"), and more narrowly on wind and solar. Several lags are experimented with, the most consistent lag effects turn out to be between two or four years.

3.1 Dependent variable

I employ revealed comparative advantage (RCA) for the dependent variable, as it is a consistent indicator used in business innovation field (Laursen, 2015). The construction of this variable is as follows: patents in clean technologies are divided by patents in all technologies, per country per year. The convenient feature of this approach is that it allows to easily interpolate between different patent families (1-4 jurisdictions) and with different time lags (2-5 years) (Peters et al., 2012). By using patents as a dependent variable for climate technology studies, I follow a surfeit of previous literature (Jaffe & Palmer, 1997; Lanjouw & Mody, 996; Brunnermeier & Cohen, 2003; de Vries & Wittengenhen, 2005; Johnstone et al., 2010; Lanoie et al., 2011). The natural log of patents are taken in all models to deal with the fact that patenting in CCMTs is not smooth over time (Jaffe & Palmer, 2007; Rubbelke & Wiese, 2011). Before taking the log, I add "1" to all patents in order to deal with zeroes in the data. Using the RCA and taking the log of the dependent variable is an acceptable method, according to Allison and Waterman (2004), "because the model is based on a regression decomposition of the over dispersion parameter rather than the usual regression decomposition of the mean" (Allison & Waterman, 2004: 264). However, to test for robustness and align the models more closely with the extant literature, I also take patents as count variable rather than RCA for the final models (the results of these regressions are reported in the appendix).

3.2 Explanatory variables

(1) Institutional quality of home country: *IQ-1a (wb_pscc or wb_gerl)* (Best indicators, taking the average of two since they are all highly correlated to each other (Easterly et al.,2002) are: RLCC, RQCC, RQRL, GECC, GERL; GERYQ, PSCC, PSRL, PSRQ (Langbein & Knack, 2010);
(2) Institutional quality distance (Gravity): (*wbgrav)* Institutional distance is calculated using Carpenter and Choi (2016) formula:
    (a) GRAVITYijt = [(Zait - Zbjt)^2)/varijt)/H_it, where Gravity is the indicator desired, Za is foreign country institutional quality, Zb is domestic country Institutional quality, var refers to the covariance between the two variables, and H represents the amount of years in the time-series.
    (b) Gravity ijt = ((wb_gerl_foriegn-wb_gerl_dom)^2)/covariance / 16 years) and renders an index between 0 and 1, the latter meaning the highest IQ distance;
(3) Domestic Environmental policy (market, non-market, and total): *epsln*
(4) Foreign Environmental policy (weighted by geographical distance is computed in the previous paper using CEPII geographical distances (Mayer & Zignago, 2006).
(5) Frontier EPS: Calculated by awarding leading country in year t with ".0001", then calculating bilateral gravity for each country in each year. *(eps_frontier)*
(6) EPSvar is computed using EPSf environmental weighted by institutional distance (appendix, experimental).

Table 2: Environmental policy variables descriptive statistics *Must add to this table wbg, eps_frontier, epsvar*

Variable	Obs	Mean	Std. Dev.	Min	Max
Epsln (log)	512	0.3548374	0.6306091	-1.098612	1.419084
epsmark	512	1.180859	0.8449724	0	3.983333
epsnonmark	512	2.222168	1.210261	0.5	5.5
Epsf (log)	512	-3.774188	0.9629146	-6.109894	-2.257848
Epsfm (log)	512	-4.146791	0.988909	-6.570312	-2.536066
Epsfn (log)	512	-3.506313	0.9517319	-5.795828	-2.040427

3.3 Controls

As discussed previously, renewable energy output and emissions of methane from energy are important domestic country controls. If countries are world leaders in methane emissions from energy, we should not expect much foreign policy inducement or spillover, nor any domestic policy inducements in clean technologies. All controls are logged, unless they are already given as percentages. Consistent with other studies, I also employ the following controls:

(1) Renewable Energy as a percentage of total energy;
(2) Consumption of fossil fuels;
(3) Information-Communication Technology Exports;
(4) Information-Communication Technology Imports;
(5) Research and Development Expenditures per GDP;
(6) Science and Technology Journals per capita (omitted in final analysis);

(7) Methane emissions from energy production

Kyoto and Cross-Border Control Variables:

(1) Parks' Intellectual Property Index
(2) UN Cooperation Indexes (CI)
  (a) Reporting CI
  (b) Financing CI
  (c) UNFCCC-CI
  (d) Kyoto CI
  (e) ETS CI

Feed-in-Tariffs (Johnstone et al., 2011):

(1) Wind, solar (pv), ocean, geothermal, biomass, waste, small hydro

Table 3: Control Variables and literature followed

Variable	Obs	Mean	Std. Dev.	Min	Max	Lit Followed
Renewable energy percentage	512	5.3301	1.036908	0.6931472	6.378426	Bayer et al., 2013
Fossil fuel consumption	512	5.4202	0.9735652	0.6931472	6.386879	Newell et al., 1999; Popp, 2002; Lichtenberg, 1986
ICT exports	512	3.9933	2.062178	0.6931472	6.059123	Lall, 2000
ICT imports	512	3.9676	2.059424	0.6931472	6.056784	Lall, 2000

RDD per GDP	512	4.9048	1.494998	0.6931472	6.226537	Popp, 2002; OECD, 2001; OECD, 2009
Science and Technology Journals/1000 researchers	512	5.4301	0.9317295	1.098612	6.386879	
Methane emission from energy	512	4.3492	1.936649	0.6931472	6.139884	Sachs et al., 1995; Gennaioli and Tavoni, 2011

3.4 Dummies

Finally, following the literature (Popp et al., 2011; Johnstone et al., 2010; Horback, 2008), several dummy variables are created. Feed-in-tariff controls are sourced from Nick Johnstone's private database at the OECD, and is in line with previous researchers (Lanoie et al., 2011; Peters et al., 2012; von Stein, 2008; Baettig, Dieter & Imboden, 2008; Grunewalk & Martinez-Zarzoso, 2009). The dummies for feed-in-tariffs are set to "1" if a country has either a solar or wind FIT law in a certain year, per country, and "0" otherwise. The same protocol is followed individually for solar or wind. The Kyoto dummy takes a "1" if Kyoto is signed and ratified before July of that year (Johnstone et al., 2010). Kyoto certainly has an impact on clean technology innovations, even though it appears not to be as strong for wind energies (ibid; Popp et al., 2011). More than anything, Kyoto serves as a policy signal of the potential stringent policies to come from the country level (ibid). As can be seen in the chart below, the dummies are very evenly distributed across all observations. (add, Johnstone et al.: FIT target/policy dummy).

3.5 Methods: Estimation framework

I use a log-log specification for the model, following Jaffe and Palmer (1997), Verdolini and Galeotti (2011), and Fankhauser & McDermott (2014), among other related researchers. One important difference, though, is my dependent variable, which is not count as in previous authors but RCA (Revealed Comparative Advantage, as stipulated above). The purpose for this is because I am looking at the rate of innovation and how this depends on, among other things, institutional quality, as opposed to looking only at increasing count of patents.

In stata, the following commands are used:

Xi: xtreg , fixed effects model (within regression estimator) (following Allison and Waterman, 2004; Allison, 2009; Bertrand et al., 2004; Blundell et al., 1995; Hausman et al., 1984). Although this model relies on strong exogeneity assumptions for explanatory variables (Blundell et al., 1995: 334), it is the best fit for the present analysis. I am assuming, in other words, there is little to no heteroskedasticity across the variables, even though there very well could be.

3.6 Models

Table 4: Description of models 1-6

Mode l	Dependent	Main Exp. Var	Vars	Hypothesis?
1	Environmental policy stringency (EPS)	Institutional Quality	High-tech exports, R&D	1a
2	EPS (market or non market)	Institutional Quality	High-tech exports, R&D	1b
3	All Clean Energy Technologies	EPS (non market)	EPS	2a
4	All Clean Energy Technologies	Institutional Quality (gravity distance)	EPS	2b
5	Solar/Wind patents	Institutional Quality (gravity distance)	EPS (foreign)	3a
6	Solar/Wind patents	Institutional Quality (gravity distance)	EPS (foreign)	3b

- Models 1/2: The effect of institutional and country-specific variables on environmental regulatory stringency (Verdolini & Galeotti, 2011)
- Models 3/4: The effect of institutional quality distance, proximity to EPS-frontier, on rate of innovation in clean technologies. Uses results from first models to predict 10 percent increase in EPS results in percent increase.
- Model 5/6: The inflection model specification: Due to the increasing rather than decreasing effect of EPS and IQ gravity variables. Uses empirical framework from first two stages to understand the more nuanced effects of foreign policy, distances, and innovation.

First the data is cleaned and a series of tests are done to ensure the dataset conforms with previous literature. This includes running analysis on the impact of

GDP/capita on environmental policies, suggested by Porter and Esty (2004). I find a significant correlation among these two variables. A regression is run with EPS as dependent with R&D per GDP as the only independent. The correlations are very strong, suggesting that environmental policies depend in large part on wealth of a country. As I add on explanatory variables, the correlations remain strong, suggesting that EPS is highly dependent on several country-specific variables including R&D intensity, institutional capacity, and intellectual property protection (IPP). I note to be cautious of heteroskedasticity in more complex models involving EPS and these variables.

The Models:

The effect of institutional and country-specific variables on environmental regulatory stringency (Verdolini & Galeotti, 2011)

$$EPS_{j,t}=(IQ_{jt},Z_{jt}) \quad \textbf{(1a)}$$

Where EPS refers to the OECD's EPS, in *country i year t*, while IQ refers to institutional quality of home country (IQ-1a), and Z are the controls specified.

$$EPS_{j,t}=(IQ_{jt},Z_{jt}) \quad \textbf{(1b)}$$

Therefore, in accordance with the second hypothesis, I add several more variables including ICT exports and imports to control for the fact that domestic innovation might be entirely dependent on the amount of resources a country has to invest in the technology, as well as a historical sophistication in cutting edge technologies. I must be cautious here and properly lag variables to avoid spurious correlation among technology controls (ICT) and the dependent variable as a high-tech as well (Hall & Helmers, 2013; Pizer & Popp, 2008; Horbach, 2008; Dechezleprêtre et al.,2015; Stimson, 1985). (In the robustness tests, various lag structures are deployed, and the results remain strong, indicating that spurious correlations are not an issue). The results of the first two models, with R-squared value above .700, indicate that institutions are extremely important for environmental policies. I then use the results from the first two models to predict 10 percent increase in EPS results in at least a 2 percent increase in institutional quality. Establishing the importance of regulatory variables for environmental policies, I turn to the gravity models. These explicitly extrapolate the underlying effects of foreign policy after considering gravity distances and represent the central focus of this chapter..

$$CTinno_{it} = (IQ1a_{j,t-x}, IQ2b_{i,t-x,} EPS_{j,t-x}, Z_{i,t-x}) \quad \textbf{(2a)}$$

Where *CT-inno* refers to innovation in home country, *IQ-1a* refers to institutional quality of home country (to support innovations), *IQ-2b* (*wbgrav*) is institutional-quality-distance of foreign country (this distance determining the extent to which *epsf* is able to "pull"), EPS is environmental policy of foreign countries, weighted geographically, and reduced to mean value in *year t*, and Z is a string of *country i*-specific controls. A very similar approach is taken by Hascic and Johnstone (2009) who regress patents of clean technologies on environmental policies (stringent and flexible), total patents, and a series of controls. The difference here is, as opposed to separating among policy stringency and policy flexibility (ibid), I elect to differentiate between foreign and domestic environmental policies, including foreign and domestic institutional components. In this sense, I am able to go beyond both Constantini and Mazzanti (2012) and Johnstone and Hascic (2009) by distinguishing between different policy instruments (i.e. market/non-market; market-FITs, market-trading, etc.), and of course from domestic and foreign gravity sources.

The same form is used as in (2a):

$$CTinno_{it} = (IQ1a_{j,t-x}, IQ2b_{i,t-x,} EPS_{j,t-x}, Z_{i,t-x}) \quad \textbf{(2b)}$$

Here, a similar model is run, with EPS being replaced simply with distance to the frontier, rather than weighted mean distance to frontier. Note, again IQ-2b (*wbgov*) represents gravity distance between institutional proxies of home and foreign country.

Baseline model specifications for Hypothesis 3 is as follows:

$$CTinno_{it} = (IQ1a_{j,t-x}, IQ2b_{i,t-x,} EPS_{j,t-x}, Z_{i,t-x}) \quad \textbf{(3a)}$$

Where CTinno refers to clean energy technology innovations, as in (2b), with the addition of more control variables.

Due to the fact that wind and solar appear to be causing the most pull, these technologies are further extracted from the model into the following:

$$WIND_{it} = (IQ1a_{j,t-x}, IQ2b_{i,t-x,} EPS_{f,t-x}, Z_{i,t-x}) \quad \textbf{(3b)}$$

In this model, the tests are run with only wind technologies in the dependent. Others have found weak cross-border inducement effects for wind, and the null hypothesis here is foreign EPS has no effect on innovation in wind at home.

$$SOLAR_{it} = (IQ1a_{j,t-x}, IQ2b_{i,t-x,} EPS_{f,t-x}, Z_{i,t-x}) \quad \textbf{(3b)}$$

In this model, the tests are run with only solar technologies in the dependent, under the assumption solar is most responsive to foreign environmental policies, in particular feed-in-tariffs (FITs). All variables and controls are manipulated using a logarithmic transformation (Feldman & Florida, 1994; Pakes & Griliches, 1984), consistent with other climate policy induced literature (Johnstone et al., 2012; Lindman & Soderholm, 2016; Verdolini & Galotti, 2011).

4. Main Findings, Results, and Tests for Robustness

The hypotheses were tested using a sample of 32 countries over a seventeen year period (1996-2011). As previously mentioned, the time-series represents a very interesting period in terms of both environmental policy and innovation in clean technologies. Therefore my main aim, to explore induced innovation dependent strongly on institutional quality variables, is well represented by the sample. I tested my hypothesis using several regressions with the 2 main models. The first two models are nearly identical, while the only difference in models 2-6 is the dependent variables which takes larger, then smaller subsets of climate technologies: Clean Technologies (renewable energies plus storage tech); renewable energies (solar, wind, geothermal, hydro, marine, tidal, without storage); solar technologies (solar pv, solar thermal, and solar hybrid); and wind (all wind components, onshore and offshore).

The first model tests the strengths of the variables and exposes potential homogeneity, the latter giving caution as to the construction of further models. The homogeneity is serially dealt with by adding different lag structures to the explanatory variables. The next models test independent gravity variables on the dependent, patents. The last set of regressions aims to understand an inverse U-shaped effect of foreign policies on domestic innovations.

4.1 Main Findings

Hypothesis 1a: Strength and consistency of environmental policy depends to a large extent on the quality of its domestic institutions (regulative, normative

Looking at *EPS* as the dependent variable, with explanatory variables *IQ-1a* (home institutional quality), *rddgdp* (R&D per GDP) and *renewp* (renewable energy as a percentage of total energy use), I find r-squared of nearly .700. Alternative tests of this hypothesis are found in the appendix, with equally strong results.

Hypothesis 1b: Innovations in Climate Technologies are dependent on Strong environmental policies and on institutional quality, research and development from public and private sources, and participation in information-communications-technology sectors.

Going further than (1a), I then add other variables such as *ict_im* (information communication technologies imports) and *meth* (methane emission from energy production). Although *ICT-im* is not significant in the main model, it appears significant for *EPS-nonmarket* (see appendix). In this baseline model, Clean energy technologies are used as the dependent, with *IQ-1a*, *EPS*, *rddgdp*, and *reout* (renewable energy output) as explanatory variables. This model shows, indeed, the variables I have chosen are consistently significant across most models.

Hypothesis 2a: Innovation in clean technologies is dependent on institutional distance (weighted gravity) to the environmental policy frontier country (weighted gravity and geographically).

Null Hypothesis: Institutional distance impacts foreign policy inducements for clean technologies.

I fail to reject the null hypothesis that institutional distance impacts foreign policy inducements for clean technologies. Although institutional distance does appear to correlate highly with a country's domestic EPS, it is not significant in cross-border effects in any of the models. But there appears to be something going on with solar and wind technologies, as the comparison across solar, wind, RETs, and CETs (as dependents), turns out different results.

Hypothesis 2b: Innovation in clean technologies is dependent on institutional distance and proximity (geographical distance) to frontier environmental policy country (or countries).

Null Hypothesis; Institutional distance in conjunction with geographically-weighted foreign EPS, impacts innovation in clean technologies.

Alternate Hypothesis 2: Solar Technology Innovation (foreign induced) is dependent on institutional distance while wind Innovation (foreign induced) depends only on gravity distance to the frontier environmental policy country.

The findings here are quite interesting, and categorically different comparing wind and solar technologies. Whereas solar technologies are induced dependent on institutional distance, the same cannot be found for wind.. Meanwhile, wind technologies correlate strongly with the EPS-frontier variable, meaning the closer a country is to the leading EPS country, in terms of gravity modelling (proximity here not referring to geographical), the more it is expected to innovate in wind technologies. Conversely, no such correlation exists for solar technologies. Solar technology innovation, instead, appears to depend on institutional quality distance between countries.

Table 5: Summary of findings from Hypothesis 2

Dep Var\dist_var	*Institutional quality (gravity distance)*	EPS (distance to frontier country)	interaction/both
Clean Energy Technologies (all CETs)		x	x
Renewable Energy Technologies (RETs)	x		
Solar	x		x
Wind		x	

This could imply several research outcomes. Most likely, as other researchers have found, solar technologies are much more globally dispersed in terms of both inducements, trade, and competitiveness. On the other hand, this points to the fact that wind technologies are much more localized and perhaps have reached their height of their innovativeness.

Hypothesis 3a: Inducements of clean technology innovations from innovative source country i to recipient country j increases as the regulatory distance between the two countries becomes smaller, but levels off at a certain point when both regulatory distance and distance to the environmental policy frontier converge

Although the data seems to indicate this is the case, there is no way to test it empirically since I do not have access to export data. I leave this hypothesis for future research. However, running some regressions with top innovating countries, then summarily running the same regressions with hypothetical “medium” distance countries, interesting results are found (reported in the appendix). In short, it appears medium distance countries are almost exclusively pulled by foreign environmental policies, which makes sense since their own domestic policies are incredibly weak. Meanwhile, the effect for leader countries needs more research.

Hypothesis 3b: Innovation in clean technologies, pulled/induced from foreign environmental policies, experiences the highest inducements at medium institutional distance. If countries are either too close or too far, in terms of institutional gravity, the effects diminish. In other words, there is an inverse U-Shaped phenomenon predicted to occur for institutional distance and foreign-induced innovation in clean technologies.

This is also indicated by the “curvilinear” graph (located in the appendix) but was not tested empirically. A potential way to test for this, is to run a series of regressions taking only countries at “medium” average distance. Further, the gravity variable for institutions might be removed only leaving the “frontier policy” variable in place. In the appendix, several graphs show the exploratory phase of this research, including parsing out only

BRICS, and also only large countries (both BRICS and OECD countries). An inverse U is found for EPS (distance to frontier) predicting solar, but not much of a predictor for wind, as that line comes out straight even with quadratic prediction with confidence intervals.) .

Alternate Hypothesis 3c: Institutional distance between countries determines the extent to which foreign environmental policies induce innovations in clean technologies at home. Null: Institutional distance does not have an effect on CET innovation.

I fail to reject the null hypothesis for clean technologies in general. However, for solar technologies the institutional distance between countries appears significant in nearly all models (see appendix). Interestingly, wind technologies are not at all determined by institutional distances, but rather proximity to the EPS frontier. Indeed, due to the geographical constraints of wind technologies, we should expect foreign inducements to be more geographically constrained. And, in contrast, since we know institutional closeness works over long distances (geographically speaking), the failure to reject alternative hypothesis 3 for wind makes sense from a theoretical perspective.

4.2 Summary of findings

Although strong evidence for some of the hypotheses above is not found, we need to recall the objective of creating the *wbgov* variable in the first place. It is not created to indicate regulatory strengths are the cause of foreign policy innovation inducements. Rather, the *wbgov* variable is created under the proposition that if institutional quality is *at a sufficient level*, foreign environmental policies will have an impact on the innovative capacity of home innovators. This means institutional quality simply determines if and how, rather than why, foreign policies might induce domestic innovators. In terms of this reading, the results are very strong: many of the models show high levels of significance for the gravity variables (*wbgrav* and *eps_frontier*). Therefore, the present research has opened up an important new area for future investigations.

I first found that increased stringency of foreign environmental policies results in an inducement effect on domestic innovators. These findings, consistent with hypothesis (2a/2b), indicate institutional distance between innovating country and recipient country is statistically significant in determining whether or not a foreign policy has any inducement, or pulling effect. This is consistent with the findings of Dechezleprêtre and Glachant (2014), Peters et al. (2014), and Dechezleprêtre et al. (2015). I have likewise found foreign policies indeed do pull innovators from abroad, if institutional quality is fully accounted for. Moreover, I found wind and solar technologies respond differently (as well as CETs and RETs); whereas the former is statistically significant for environmental policy frontier (eps_frontier), the latter is not. And vice versa: solar technologies appear to be dependent on institutional quality distance (*wbgrav*). This result is surprising for solar, since the common conception is that China innovates the most in solar energy, but clearly its institutions are somewhat weak; however, this finding is not inconsistent with my hypothesis as I predicted countries at “medium” IQ distance will experience the most foreign policy pull. The results also confirm Kim and Kim (2015) who find, for mature clean technologies such as wind, international markets might affect domestic R&D more than solar, and wind thus increases imports and exports as a result of similarity to frontier policies.

These findings also confirm that EPS depends on several country-specific variables, the most important of which are R&D per GDP and institutional quality (Models 1/2). Second, armed with the previous finding of EPS composed of primarily IQ components, innovations in clean technologies are seen as dependent on home institutions (*IQ_1a*) interacting with home climate policies (*eps, epsmarket, epsnonmarket*), as well as foreign policies (*EPSf*) interacting with institutional gravity variable (*wbgrav*). As I expected, a variety of environmental policies (local, foreign, global), in conjunction with country institutional qualities, appear to exert inducement effects for innovation in clean technologies.

Table 6: Regression results models 1-2 (EPS dependent)

VARIABLES	**Environmental Policies**	**Market Environmental Policies**	**Non-market environmental policies**
Institutional Quality (gravity distance)	0.465***	0.343**	0.587***
(inst. Qual.)	-0.134	-0.156	-0.189
R&D/GDP	-0.0478***	-0.0426**	-0.0530**

	-0.0171	-0.02	-0.0242
ICT imports	-0.03	0.0327	-0.0928***
	-0.0244	-0.0285	-0.0345
ICT exports	0.147***	0.144***	0.150***
	-0.0341	-0.0398	-0.0481
Fossil Fuel Consumption	-0.131	-0.0927	-0.169
	-0.0841	-0.0981	-0.119
Constant	1.474***	0.947*	2.001***
	-0.488	-0.569	-0.688
Observations	512	512	512
R-squared	0.721	0.544	0.659
Number of country	32	32	32
Country FE	YES	YES	YES
Year FE	YES	YES	YES

The regression results of models one and two deliver strong evidence environmental policy stringency, both market and non-market, is explained by the vector of independent variables I have chosen for these models. Institutional quality is significant across all models, as well as ICT exports. Interestingly, R&D per GDP is significant but the coefficients are all negative.

Table 7: Regression Results Models 3-4 (CETs dependent)

VARIABLES	Clean Energy Technologies (lag 2, family 2)	Renewable Energy Technologies (lag 2, family 2)

EPS (gravity distance to frontier country)	0.0019	-0.265
	-0.221	-0.249
Institutional Quality (gravity distance)	0.148***	0.152**
	-0.0555	-0.0626
ICT imports	0.00256	-0.00337
	-0.0316	-0.0356
Knowledge stock	6.94e-05*	0.000158***
	-4.18E-05	-4.72E-05
R&D / GDP	-0.0223	-0.0251
	-0.0222	-0.025
Feed-in-tariffs (wind)	-0.00477***	-0.00573***
	-0.00179	-0.00202
Feed-in-tariffs (solar-pv)	0.000803	0.00167
	-0.00127	-0.00143
Constant	-5.095***	-5.311***
	-0.262	-0.296
Observations	512	512
R-squared	0.457	0.481
Number of country	32	32

The regression results of models three and four show clearly how the gravity variable for institutional quality figures in prominently for clean energy technologies as well as the smaller subset, renewable energy technologies. Wind feed in tariffs are significant but solar FITs are not, while knowledge stock is significant at the 90% and 99%, respectively.

Table 8: Regression results Models 5-6 (solar / wind depend)

VARIABLES	Solar Technologies (lag 2, family 2)	Wind Technologies (lag 2, family 2)
Institutional Quality (gravity distance)	0.139**	0.0218
	-0.0625	-0.0668
EPS (gravity distance to frontier country)	1.561***	2.053***
	-.374	-.674
EPS (foreign)	-2.156***	1.790**
	-0.825	-0.881
Renewable Energy Output (% total energy)	-0.0758*	-0.0879*
	-0.0446	-0.0476
R&D/GDP	-0.0818***	-0.0625**
	-0.0261	-0.0278
Methane emissions (from energy)	0.151***	0.164***
	-0.0444	-0.0475
Feed-in-tariff (dummy)	0.115	0.12
	-0.085	-0.0908
Kyoto Protocol (dummy)	-0.222*	0.0975
	-0.133	-0.142

Institutional Quality (home country)	-0.428*	-0.517*
	-0.247	-0.265
EPS (home country)	0.386***	0.307***
	-0.0728	-0.0781
Constant	-15.17***	2.456
	-3.508	-3.746
Observations	512	512
R-squared	0.412	0.326
Number of country	32	32

It is evident here, institutional distance does not factor into wind technologies, while it does for solar. What is more, the statistical significance of the IQ gravity combined with foreign EPS (at the 95%, and 99% levels respectively), exceeds the same correlation for domestic IQ and domestic EPS (90% and 99%, respectively) in models 3 and 4 above. Foreign environmental policies (EPS, foreign) are significant up to 95 percent for wind technologies and up to 99 percent for solar technologies, however the latter shows a negative coefficient. This implies foreign environmental policies are inducing innovation at home in clean technologies, and the negative coefficient for solar technologies might only be because it is in fact over correlated. Meanwhile, as predicted, gravity IQ does not matter at all for wind technologies; that is, institutional qualities between countries are not seen as affecting the foreign inducement of technologies, even though distance between two countries environmental policies is significant to 99 percent. The effect of knowledge is significant across all models. Specifically, a 2% increase in knowledge results in a 37% increase in innovations. Ratifying Kyoto, and UNFCCC cooperation indexes are also significant, and after ratification innovation increases 14 % (reported in the appendix).

In sum, there seems to be a weaker relationship with solar and geographical distances, meaning actual distances do not matter for foreign inducement effects, while for wind a pattern begins to emerge with distance to the EPS frontier, suggesting technological spillovers are indeed present, while also suggesting gravity distance on the environmental policy variable factors as an important element in this model. This could certainly have to do with China's catching up in solar technologies, a country that mostly lags behind the institutional frontier. Likewise, wind typically needs to be adapted and customized to local regions, implying institutional closeness is more of an issue for cross-border wind technologies. Institutional differences should not be too large or else foreign innovators are not pulled strongly enough by frontier countries. As the institutional gap is closed, policy-inducements increase until a certain inflection point. Thereafter the effect becomes negative. This is probably because institutions and environmental policies align too closely to have any foreign policy effects anymore, or home country has achieved some degree of self-sufficiency in these technologies.

4.3 Tests for Robustness

I first checked the robustness using different classifications. I re-coded the patents, specifically by trying different patent families. I tried different lags, and did find some interesting results. I increased the weight of the Institutional Quality (gravity distance). I then tested the hypothesized relationships of the sample in terms of IQ and distance. I added different time lags to further explore the main variables, as well as traded several different controls and dummies in and out. Linear and square IQ variables were examined. I settled on natural log for all variables (except those already expressed in percentages such as renewable energy consumption). The results still hold. I used different EPS and IQ, and different lag structures. The findings remained robust, even with alternative models. I also looked at variance inflation factor values. They were in range, which suggested no multicollinearity issues were present. Furthermore, the explanatory variables are stable across all models, which also confirms multicollinearity is not an issue.

Caution should be taken before drawing any broad conclusions from this study. Principal among these is to take institutional quality as an indicator for environmental stringency: it is not. As the case of Germany and Greece shows, two countries with very similar environmental policies can have widely differing results in terms of clean tech innovation and deployment of new energy technologies. Thus, although some generalizations might be derived from this study, such as the finding that institutional distance shapes the impact of foreign environmental policy inducement effects, measuring the magnitude of inducement effects is still quite difficult. Furthermore, I have constricted this study to OECD plus BRICS, which is both too little and indeed too many countries for the sample. It is too little because there are clearly many more countries in the world, each with their own environmental policies and each encouraging foreign investment in different ways, in terms of clean technology. On the other hand, there are too many countries in the sample because the bottom half account for less than 5% of all clean technology innovations. Therefore, they are not really innovating in reaction to policies, but rather must import all their clean technologies if their institutions and policies are strong. Future studies should focus on the challenge many researchers in this field face in terms of finding a proper environmental policy index.

5. Discussion and Conclusion: What this all means for climate policy spillovers and institutional distances

This paper provides empirical evidence for a dynamic, international Porter Hypothesis, or an induced innovation effect from foreign environmental policies, after accounting for institutional distances and regulatory control variables. New econometric evidence is presented here on the nexus between environmental regulation and competitiveness, as captured by innovation activity and productivity, shedding light on the well-known Porter Hypothesis in both its weak and its strong versions, as well as a novel dynamic version. The analysis is based on a panel of clean technologies across thirty-two OECD and BRICS countries over the period of 1996–2011. Only a few papers offer such a comprehensive analysis. Indeed this is among one of the first tests of a cross-border, Porter Hypothesis, at least empirically and across many countries, which is highly relevant to both policy-makers and technological innovators. Evidently, variegated effects of climate policies induce innovations across many countries. Global competitiveness determines the extent to which innovators provide demand for these technologies, and the constraints on these demands are accounted for by environmental policies coupled with regulatory instruments. Environmental policies are not domestically confined, and indeed spill across borders.

In this paper I have argued that, holding country and year effects constant, institutional quality distance and environmental policies, led by frontier countries, determine the rate of innovation in clean technologies. While this conceptualization is novel, it is steeped in the literature. Indeed, I have found this is a promising new area of research. One major reason these findings are so important is that environmental policies are increasingly becoming industrial policies (Aghion et al., 2011), and each nation presumably desires to meet these challenges in a way that takes advantage of its endogenous resources while also providing ecological offsets. For some nations, that may mean manufacturing clean technologies, while for others it may simply mean designing and licensing new innovations. Still for others, it may mean importing all of the technology, and beginning to innovate around the software which will invariably become so important for integrating clean technologies into the world's energy system. Either way, policy inducements are an important area of research for firms, governments, and meeting the challenges of climate change on a global scale. Are countries behind the environmental policy frontier being induced by foreign environmental policies? Beyond what point will these countries simply need to innovate in their own technologies. The causal change that potentially exists among foreign environmental policies and domestic innovations, in other words policy spillovers, represents a very novel and exciting area for future research.

Chapter IV Works Cited

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Chapter V: Conclusions and Future Research

This dissertation has brought together several very interesting areas of research. Climate change policies are slowly morphing to accommodate, and indeed induce, firms and innovators to create much-need environmental technologies. Even though a techno-scientific fix will not be able to, on its own, confront the threat of climate change and related, global problems, technology does have a very important role to play here.

Chapter II in this dissertation explored the well-known “Porter Hypothesis”. The idea that some environmental policies create a “win-win” situation whereby firms are encouraged to innovate and, in turn, create profitable innovations from such policies, receives considerable support in the empirical and theoretical literature. Some countries and firms able to quickly adapt to the multitude of environmental policies coming on line over the past several decades have indeed been very successful. This chapter sought to introduce a new dynamic Porter Hypothesis under the assumption firms, especially globally competitive firms, react to environmental policies stemming from a number of different countries. How governments construct industrial policies in the 21st century, keeping in mind how firms respond to environmental policies, is expected to become a pivotal research field.

The following chapter endeavors to empirically test the propositions put forth in the chapter II. This was a daunting undertaking. Environmental policies are so widespread, diverse, and extremely difficult to measure. Fortunately, researchers before me have carved out several avenues whereby such an exploration might begin. Although this paper does not provide great evidence of foreign environmental policies inducing domestic innovators, it does show this feature could be present in the clean technological paradigm. Importantly I found that, although all clean technologies in the sample do not respond to foreign policies, some actually do, even though domestic climate policies appear to induce stronger effects on innovation rates.

Finally the third paper introduces more detailed concepts of institutions and regulatory capacity, which is assumed to support both domestic and foreign environmental policies. For the former, it was expected institutions and domestic environmental policies correlate strongly, therefore leading one to believe the former is quite important for this field. Secondly, institutional capacity is expected to determine the extent to which a domestic country might be induced by foreign environmental policies. The findings for this empirical question were indeed very interesting. In particular, wind energy technology appears to be induced from foreign policies only if the country is close to the environmental policy frontier, i.e. their domestic policies are already quite strong. On the other hand, solar technologies are affected by institutional quality distance, and this effect appears to level off after countries approach the frontier.

In sum, this area of research is integral for climate policies in the 21st century. We need new technologies, and we also need to incorporate existing clean technologies into society. Different countries are capable of supplying differing sophistication of such technologies, yet all are important. One of the most important findings is that a country at the environmental policy frontier, that is-the country with the most stringent policies, might be exert a gravity force upon other countries both in terms of catching up with their own policies as well as in meeting the demand for new clean technologies. Indeed, if several key countries seriously augmented their environmental policy menus, the inducements to innovate in clean technologies is expected to increase precipitously. Therefore, a frontier policy country might drive the entire world to innovate more rapidly in clean technologies.

VI. Appendices

Chapter III Appendix

World Bank Governance Indicators:

1. Voice and accountability (VA) – measuring perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association and a free media.

2. Political stability and absence of violence (PS) – measuring perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including political violence and terrorism.

3. Government effectiveness (GE) – measuring the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies.

4. Regulatory quality (RQ) – measuring perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.

5. Rule of law (RL) – measuring perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, the police and the courts, as well as the likelihood of crime and violence.

6. Control of corruption (CC) – measuring perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of

corruption, as well as ‘capture’ of the state by elites and private interests.
(Thomas, 2010: 35)

Construction of the World Bank Indicators (include also the averaging)
World Bank Governance Indicators Specifications.
The World Bank Governance Indicators (WB) are used in the literature as a proxy for governance, accountability, control of corruption, regulatory compliance, and rule of law.

World Bank Governance Pairs, Descriptive Statistics

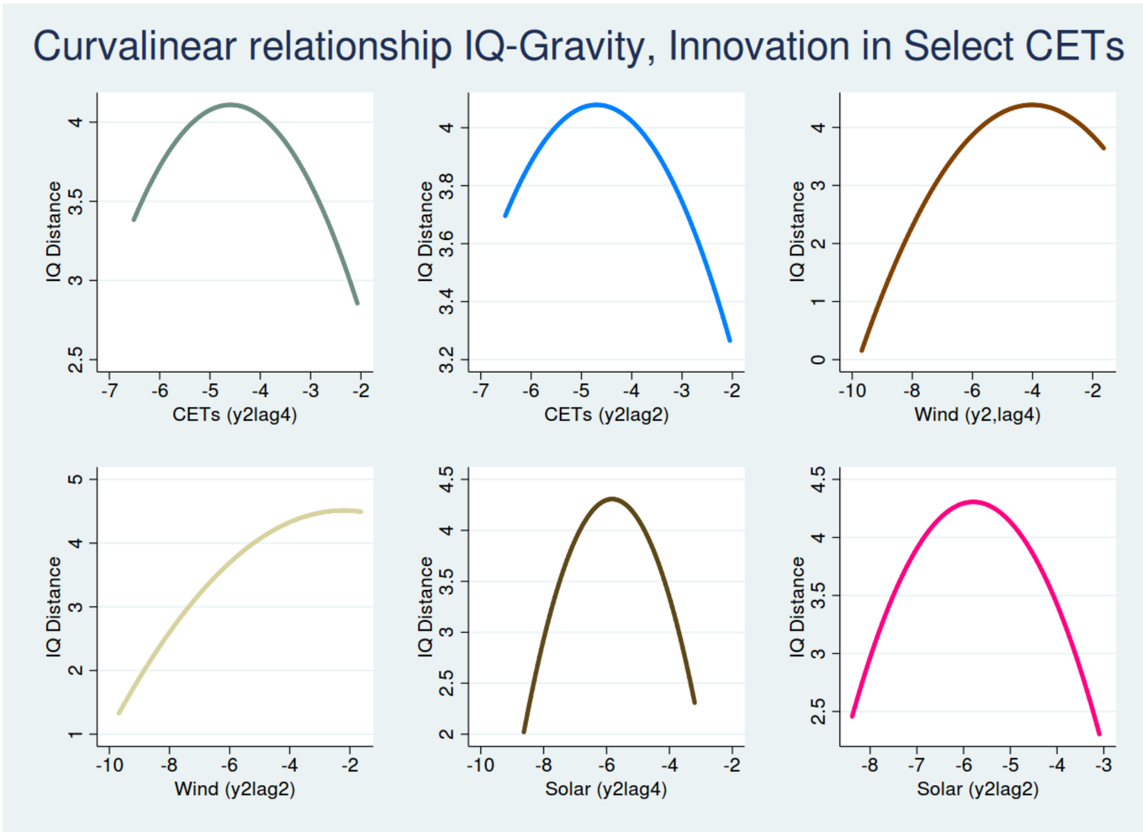
Variable	Obs	Mean	Std. Dev.	Min	Max
wb_psrq	**512**	**0.8032439**	**0.6692776**	**-0.9905735**	**1.870008**
wb_psge	**512**	**0.8582371**	**0.7283465**	**-1.091295**	**1.961967**
wb_vage	**512**	**1.058588**	**0.7113338**	**-0.8114977**	**2.085653**
wb_vacc	**512**	**1.0096**	**0.8146652**	**-1.13487**	**2.17058**
wb_pscc	**512**	**1.618497**	**1.656739**	**-2.334664**	**4.211385**
wb_varl	**512**	**0.987262**	**0.7417319**	**-1.119956**	**1.890017**
wb_psrl	**512**	**0.786911**	**0.7547746**	**-1.271799**	**1.811517**
wb_varq	**512**	**1.003595**	**0.6533203**	**-1.051101**	**1.840193**
wb_rqcc	**512**	**1.047057**	**0.7975124**	**-0.7407485**	**2.226142**
wb_rqrl	**512**	**1.024719**	**0.718274**	**-0.8452159**	**1.962296**

wb_gerq	**512**	**1.096045**	**0.6945371**	**-0.6647114**	**2.140303**
wb_gecc	**512**	**1.10205**	**0.8714742**	**-0.8512717**	**2.444537**
wb_gerl	**512**	**1.079712**	**0.7883953**	**-0.9459372**	**2.180692**
wb_rlcc	**512**	**1.030724**	**0.8930753**	**-1.021974**	**2.270184**

Favored World Bank Pairs

Chapter IV Appendix

Curvilinear relationships: all patents are logged and in RTA form (specific technology over all technologies, in country/year).



Graph 7: Curvilinear (inverse U-shaped) inducement of select clean technologies (y2cets2) dependent on institutional distances (*wbgrav*).

Alternate regressions:

Models 10-13: Solar patent family 2, lag 2, various *eps.*

VARIABLES	y2solar2	y2solar2	y2solar2	y2solar2
wb_gravity	0.144**	0.131**	0.143**	0.104*
	-0.0621	-0.0619	-0.0614	-0.0615
epsf	-0.658			
	-0.874			
eps	0.247***	0.288***	0.191***	0.613***

	-0.0718	-0.0681	-0.0714	-0.106
epsfm		0.883**		
		-0.438		
epsfn			-2.500***	
			-0.845	
eps_frontier				1.561***
				-0.374
Constant	-8.876**	-1.949	-15.89***	-6.787***
	-3.708	-2.072	-3.323	-0.32
Observations	512	512	512	512
R-squared	0.392	0.396	0.402	0.413
Number of country	32	32	32	32
Country FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Models 14-16: Solar family 4, lag 2, all controls and delineated EPS.

VARIABLES	y4solar2	y4solar2	y4solar2
wbgravity	-0.00573***	-0.00582***	-0.00558***
	-0.00154	-0.00154	-0.00154
noxlim_f	0.0891	0.0849	0.103
	-0.065	-0.0648	-0.0641
pmlim_f	0.149**	0.137*	0.145**
	-0.0719	-0.072	-0.071
soxlim_f	-0.124*	-0.122*	-0.105
	-0.0724	-0.0722	-0.0714
allfits	-0.210***	-0.205***	-0.183***

	-0.0463	-0.0462	-0.0463
sfits	0.165***	0.158***	0.147***
	-0.0403	-0.0403	-0.0407
epsrddsubs	0.108***	0.108***	0.101**
	-0.0411	-0.041	-0.0405
standards	0.0259	0.0404	-0.0115
	-0.201	-0.201	-0.199
co2tax_f	-0.00298	-0.000622	-0.000435
	-0.0549	-0.0548	-0.054
taxdiesl_f	-0.0288	-0.0281	-0.0278
	-0.0418	-0.0417	-0.0412
taxnox_f	-0.0398	-0.0435	-0.029
	-0.0325	-0.0325	-0.0324
taxsox_f	0.0434	0.0424	0.0343
	-0.0391	-0.039	-0.0389
eps_trad	0.0162	0.0137	0.0384
	-0.0466	-0.0465	-0.0469
rddgdp	-0.0467*	-0.0428	-0.0478*
	-0.0269	-0.0269	-0.0265
wb_dom_pscc	-0.00377	-0.00384	-0.00335
	-0.00371	-0.0037	-0.00365
htx		0.0718*	0.0973**
		-0.0382	-0.0383
reout			-0.106**
			-0.0494
meth			0.148***
			-0.0457

Constant	-4.900***	-5.310***	-5.625***
	-0.313	-0.381	-0.508
Observations	512	512	512
R-squared	0.408	0.413	0.432
Number of country	32	32	32
Country FE	YES	YES	YES

Models 17-19: Wind family 2, lag 2, extra models.

VARIABLES	y2wind2	y2wind2	y2wind4
htx	0.148***	0.148***	0.113***
	-0.037	-0.0371	-0.0396
k_cets2	0.000368***	0.000367***	0.000391***
	-5.03E-05	-5.03E-05	-5.37E-05
rddgdp	-0.0404	-0.0408	-0.0137
	-0.0261	-0.026	-0.0278
epsf	-0.649	-0.682	-0.184
	-0.921	-0.921	-0.985
epsln	0.175	0.289	1.348***
	-0.125	-0.288	-0.308
fit_w	-0.00621***	-0.00610***	-0.00577***
	-0.00149	-0.00146	-0.00156
renewp	-0.114**	-0.111**	-0.104*
	-0.0541	-0.0536	-0.0573
wb_gravity	-0.0132		
	-0.0633		
eps_frontier		0.279	2.053***

		-0.631	-0.674
Constant	-7.477*	-7.752*	-6.128
	-3.969	-3.957	-4.229
Observations	512	512	512
R-squared	0.419	0.42	0.281
Number of country	32	32	32

Models 20-23: Environmental policies from foreign countries strong across all models, while intellectual property protection and Kyoto Dummy also significant.

VARIABLES	y2re2	y2solar2	y2re2	y2solar2
wbgrav	0.403	0.322	0.482*	0.507*
	-0.263	-0.257	-0.272	-0.266
epsf	-2.841***	-4.162***	-2.873***	-4.328***
	-0.865	-0.87	-0.897	-0.91
htx	0.0987***	0.116***	0.105***	0.127***
	-0.0364	-0.0364	-0.0372	-0.0375
L.k_cets2	0.000203***	0.000281***	0.000257***	0.000354***
	-5.68E-05	-5.76E-05	-5.81E-05	-5.90E-05
rddgdp	-0.0168	-0.0348	-0.0395	-0.0618**
	-0.026	-0.026	-0.0266	-0.0268
epsln	-0.112	0.192	0.108	0.494*
	-0.27	-0.274	-0.275	-0.28
fit_w	-0.00238*		-0.00369**	
	-0.00143		-0.00146	
renewp	-0.0863	-0.0682	-0.143***	-0.125**

	-0.0542	-0.0543	-0.0553	-0.056
eps_frontier	-0.239	0.438	0.0521	0.88
	-0.577	-0.578	-0.594	-0.599
kyoto_dum	-0.269**	-0.258**		
	-0.123	-0.123		
kyoto_coop	-14.13	14		
	-17.71	-17.69		
park_ip	-0.470***	-0.538***		
	-0.0866	-0.0871		
fits_pv		-0.000399		-0.00181*
		-0.00102		-0.00104
unfccc_coop			-9.956	6.951
			-11.01	-11.09
Constant	-1.772	-25.37**	-4.885	-25.44***
	-11.75	-11.74	-9.657	-9.732
Observations	480	480	480	480
R-squared	0.561	0.533	0.525	0.487
Number of country	32	32	32	32