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Declaration in lieu of Oath

I declare that this thesis submitted for examination in consideration of the award of the PhD degree in Economics is my own work except where indicated by referencing, and that it has not been submitted, in whole or in part, in any previous application for a degree or other qualification anywhere else.

Where any of the content presented is the result of a collaborative research with a co-author, my contribution amounted to 65% of the paper.

To the best of my knowledge, this work does not breach copyright law.

Abstract

This thesis explores topics in environmental and resource economics and is composed of three independent empirical papers. In the **first paper (chapter 2)** I apply survival analysis on a sample of low and middle-income countries for the (1990-2012) period to show that fossil fuel dependence negatively affects the time leading to private sector investment in renewable energy projects, and that this effect is weaker with repeated previous investments. In addition, government deployment policies that aim to raise the share of clean energy generation play a positive role in earlier investment spells. The results have implications on the current investment trends in renewable energy technologies, especially in the light of increasing energy demand in developing countries. The **second paper (chapter 3)** examines the role of geographical proximity to other adopters of renewable energy technologies and its effect on domestic diffusion rates. We test whether this effect becomes more important given a large share of trade with adopters. Our results confirm the existence of a geographic spill-over effect on the intensity of adoption of renewable energy technologies. Moreover, this effect is stronger when intensive adopters of renewable energies are also important trading partners. The **third paper (chapter 4)** examines the relationship between adopting environmental management standard certificates (EMS) and resource efficiency in manufacturing small and medium enterprises (SMEs) in Vietnam for the (2011-2013) period. The results indicate that environmental certification leads to resource savings by about 2.3% holding other factors constant. Moreover, the paper highlights a number of determinants for environmental standard certificate adoption, where firm size, investment in new technology and engaging in selling products via e-trade are likely to be key variables in the decision to adopt certification.

Contents

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Any mistakes or inaccuracies are my sole responsibility

March 2019

Dalia Fadly

Chapter 1

Introduction

1.1 Background and Research Context

In the face of pressing economic and environmental challenges, national and international efforts to promote sustainable economic growth have accelerated in recent years. Investment in green technologies and innovations, in particular, are seen as key elements to achieve sustainable economic growth as they have the potential to decouple economic growth from natural resource depletion and environmental pollution. These technologies can increase resilience to environmental shocks and thus provide a route for realizing environmental targets while simultaneously encouraging economic diversification. However, large scale deployment of green technologies would require innovative approaches to finance, profitable business models and enabling institutional settings.

In environmental and resource economics, the definition of green technologies is very broad, which implies that governments face choices regarding the policies they promote in order to achieve their goals. The set of policies available to governments can be broadly subdivided into supply-side policies, that target production of clean energy (e.g. renewable energy sources such as wind, solar, biomass and hydro-power) and policies that promote the uptake of resource efficiency measures in consumption and production. Given that there are often costs associated with the adoption of such technologies and that there may be positive externalities associated with them, governments also provide fiscal incentives (e.g. subsidies, permits) to reduce the costs of adoption.

While green technologies are often associated with environmental outcomes, the economic rationale for such technologies goes beyond environmental outcomes. First, there are substantial positive externalities related to the adoption of such technologies. For example, there is a link between pollution, health and labour productivity. This means that the adoption of green technologies could indirectly impact those outcomes. Second, green technologies are expected to accelerate innovation investments which when widely adopted can shift the production frontier upwards and thus, knowledge spillover in the entire economy increases.

Given the importance of the adoption of green technologies in the process of transition to a green economy, this thesis aims to improve the understanding of the adoption of green technologies at both the macroeconomic (chapters 2 and 3) and microeconomic level (chapter 4). **Chapter 2** focuses on the key factors explaining private sector investments in renewable energy technologies in low and middle-income countries for the (1990-2012) period and focuses specifically on the role of fossil fuel dependence on the rate of clean energy transition. The topic contributes to policy discussions on challenges of transition to a low-carbon economy in fossil-dependent countries. **Chapter 3** focuses on the geographical pattern of renewable energy diffusion and empirically examines whether geographical proximity to an intensive adopter of renewable energy technologies accelerates the diffusion of renewable energies. It also tests whether this effect becomes more important given a large share of trade with adopters. The paper represents a step in establishing the proposed links between geography, international trade and technology transfer. **Chapter 4** examines the link between adopting environmental management standards certification (ems) and resource efficiency in manufacturing small and medium enterprises (SMEs) in Vietnam. The paper contributes to the debate of whether mandatory environmental management standards contribute to a win-win situation environmentally and economically in emerging countries, where high industrial growth rates and the inefficient technologies used by most SMEs provoke concerns about the waste of materials and fuels in resource intensive industries.

1.2 Thesis Outline

This section outlines the structure of the thesis, which consists of two single-authored papers (Chapters 2 and 4) and one co-authored paper (chapter 3). The following paragraphs highlight the main research question of each paper, data and methodology and the main contributions made.

1.2.1 Low-Carbon Transition: Private Sector Investment in Renewable Energy Projects in Developing Countries[1]

The transition to a low-carbon economy is often perceived as a purely environmental issue. However, it can be defended on the basis of its wider economic, social and environmental implications and is directly related to aspects including energy security, sustainable economic development, pollution and climate change. Projections of the current trends of global energy consumption suggest that, overall, energy consumption will continue to grow strongly in developing countries, especially in India and China (Olivier et al., 2016). Currently, available evidence suggests that this increase in demand is likely to be met by increasing energy supply from fossil-fuel sources like oil, coal and natural gas (IEA, 2014,2016). Escaping the phenomenon of "Carbon lock-in"[2] (Unruh, 2000) is a challenge which requires policy makers to address two core intertwined elements: first, scaling up finance for long term investment in climate-resilient infrastructure (e.g. efficiency in buildings, transport and energy) and second, shifting investments towards sustainable low-carbon alternatives (Olivier et al., 2016). The scale of the required energy sector investments to achieve Paris Climate Agreement goal is estimated to be around 3.5 trillion USD on average each year between 2016 and 2050, according to IEA (IEA, 2017). This suggests that a transition is unlikely to occur without the participation of the private sector.

To date, however, most of the literature investigating determinants of renewable energy investments has focused on developed countries. In addition to this, the link between fossil fuel dependence and private sector investment in renewable energies has not been explicitly

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[2] A term used to describe a path dependent phenomenon where institutional, behavioural, economic and political factors inhibit the development of low-carbon sources (Seto et al.,2016)

investigated. This paper applies discrete time, multiple spell survival model to a dataset of private participation in renewable energy projects in a sample of 134 developing and middle income countries for the 1990-2012 period. The paper examines the duration leading to private sector investment in renewable energy projects and how this is affected by the high dependence on fossil fuels.

This paper contributes to the literature in a number of ways. First, it focuses on the factors affecting the time at which private sector investments in renewable energy projects occur. Second, the paper tests the "carbon lock-in" hypothesis in which fossil fuel dependence deters private sector investment in the renewable energy sector. Third, I solely focus on developing and middle-income countries which remain understudied in the literature.

The results suggest that higher dependence on fossil fuels, in the form of fuel rents and higher fossil fuel consumption, lead to a lower hazard of investments in renewables. However, the negative effect becomes less pronounced with having investments in previous period. Consistent with literature, the results support the belief that a number of macroeconomic variables, such as higher oil prices, higher income per capita, and the implementation of domestic renewable energy policies, play an important role in increasing the hazard of private sector investment. The results are relevant in light of recent trends in international oil prices as they suggest two potential competing effects, with lower oil prices potentially delaying investments directly through higher fossil fuel consumption but positively affecting investment through lower fuel rents.

1.2.2 Geographical Proximity and Renewable Energy Diffusion: An Empirical Approach[3]

The reform of the energy landscape is central to achieving the sustainable development goals (SDGs) and it depends substantially on the successful adoption and diffusion of renewable energies across countries. To date, the literature on the diffusion of renewable energies has highlighted a number of important determinants such as income level, domestic energy consumption and availability of finance. However, the importance of geographical proximity in

[3]Published online on 22 February 2019. Fadly, D. and Fontes, F. (2019). Geographical proximity and renewable energy diffusion: an empirical approach. *Energy Policy*, 129, 422-435

explaining the observed diffusion patterns of renewable energies remains unexplored, despite the potential implications of spatial interrelationships in terms of capital accumulation and knowledge spill-over and therefore on long run economic growth. This co-authored paper examines three fundamental questions. First, it explores the importance of geographic proximity to adopters in explaining diffusion patterns of renewable energies. Second, we test whether this effect becomes more important given a large share of trade with adopters. Third, we investigate whether the importance of geographic proximity to diffusion patterns changes over time.

From a theoretical perspective, the policy innovation literature offers the horizontal or regional diffusion model, where policy choices of one country are shaped by the choices of others sharing similar circumstances through three main mechanisms: learning, imitation and competition (Daley, 2007; Dobbin et al., 2007; Mooney, 2001). Additionally, underlying environmental conditions such as climate change vulnerability, soil characteristics tend to be correlated across neighbouring countries, and thus being able to observe and learn from the adoption of renewable technologies and its success in a comparable environment is likely to increase the likelihood of adopting a new technology in the home country.

In examining the effect of geographical proximity to adopters on the diffusion of renewable energies, we constructed two indexes such that the intensity of technology adoption in one country is a function of (1) geographical proximity to an intensive adopter (distance index), and (2) higher bilateral trade flows (trade index). Our results highlight the fact that the scope of diffusion of renewable energy technologies across countries like other types of technology has a spatial aspect. In addition, stronger spillover effects occur when intensive adopters of renewable energies are also important trading partners, highlighting the relevance of trade links with technology adopters as a potential catalyst of the diffusion of renewable energies across countries.

The paper contributes to the larger literature on knowledge transfer and is a step in establishing the proposed links between geography, international trade and technology transfer. Given the importance of technology transfer in the economic growth process, technological interdependence between countries generated by spatial externalities is important in explaining convergence process between countries.

1.2.3 Greening Industry in Vietnam: Environmental Management and Resource Efficiency in SMEs

Among the various policy instruments available for managing environmental impacts is the implementation and certification of environmental management standards (EMS). These standards have been proposed as an innovative mechanism for enhancing the efficient use of resources and reducing the negative environmental externalities associated with manufacturing processes. Some countries have made it mandatory for polluting industries to obtain certification of satisfaction of environmental management standards, while in other countries the certification is a voluntary initiative of the firm. The debate of whether mandatory or voluntary environmental management standards contribute to a win-win situation environmentally and economically has been an issue of interest recently. For large-scale enterprises in industrialised countries, such win-win has been documented; but little is known about the effectiveness of this instrument in achieving resource efficiency in small and medium enterprises (SMEs), especially in emerging countries.

In Vietnam, high industrial growth rates and the inefficient technologies used by most SMEs raised concerns about the waste of materials and fuels in resource intensive industries. As a consequence, the law of Environmental Protection of 2005 required firms engaged in polluting activities to undergo an environmental impact assessment and upon compliance, obtain a certificate acknowledging satisfaction of national environmental standards. This paper fills a research gap by empirically testing whether the adoption of environmental standards certificates by small and medium enterprises in the manufacturing sector in Vietnam contributes to resource efficiency for the (2011-2013) period, where resource efficiency is measured by the aggregate consumption of water, fuel, and electricity per unit of output.

Although emerging research investigates the impact of ESC on various aspects of environmental and financial performance, there is scarcity of empirical research on whether certification affects resource efficiency in SMEs in an emerging country context. In addition, most studies are either qualitative or they do not account for the endogeneity of certification. In this paper, to examine the impact of adopting environmental standards certificate on resource efficiency, I use a balanced panel dataset for the years 2011 and 2013 of the Small and Medium Scale Manufacturing Enterprise (SME) survey, which comprises 1,333 firms distributed across 17 manufacturing sectors and 10 provinces. I estimate an instrumental variable model to control for the possible sources of endogeneity arising for the reverse causality between certificate adoption and resource efficiency.

The paper finds a number of determinants for EMS certificate adoption, where firm size, investment in new technology and engaging in selling products via e-trade are likely to be key variables in the decision to adopt certification. The result indicates that adopting environmental standards certificates among manufacturing SMEs in Vietnam contributed to higher aggregate resource efficiency during the 2011-2013 period, reflected by a lower use of electricity, fuel and water for each unit of output. The largest savings relate to electricity (3.25%) followed by fuel (2.68%) and water (2.2%). Additionally, certification was found to have a heterogeneous effect on the extent of resource saving depending on the type of manufacturing activity (i.e light industry versus heavy industry). With regards to the control variables, receiving government assistance, as well as investing in new machinery and using a higher share of raw material from households, contributed to efficiency in resource use.

The paper adds to the understanding of the role of environmental management standards on resource efficiency, which goes beyond conventional financial measures used in the literature, such as returns on assets, stock market returns and profit margins. The findings are not only relevant in the context of Vietnam, but also to a larger number of developing and emerging countries where SMEs account for the majority of enterprises and hence could have the largest environmental footprint in the country. In fact, for policy makers to successfully roll out the adoption of environmental certificates on a larger scale, not only technical assistance regarding implementation of certification is a must, but also better knowledge among business owners about the potential positive impacts of certificates on competitiveness. Ultimately, firm owners get to realize that environmental management standards are not only a business responsibility to protect the environment but also a business opportunity.

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Chapter 2

Low-Carbon Transition: Private Sector Investment in Renewable Energy Projects in Developing Countries

Abstract

Given the rapid population growth and subsequent increase in energy demand in developing countries, private sector investment in renewable energy projects is key for sustainable economic development. However, the current energy mix is still dependent on conventional fossil fuels. The paper examines the time duration to private sector investment in renewable energy projects and how the hazard rate is affected by dependence on fossil fuels. Using data on private sector participation in renewable energy projects in 134 developing and middle-income countries for the (1990-2012) period, this paper applies multiple failure time model. The results show significant negative effects of fossil fuel consumption and fuel rent on investment likelihood. Consistent with literature, a set of socio-economic variables, such as renewable energy policy and energy security concerns, play an important role in increasing the likelihood of private sector investment in renewable energy technologies. The findings of the paper resonate with concerns of the international community regarding the effect of fossil fuel dependence on the rate of adoption of renewable energy sources in developing countries

Key Words: Renewable Energy, Investment, Private Sector, Fossil Fuel, Survival Analysis

JEL classification: C41, O13, P48, Q42, Q50

2.1 Introduction

The transition to a low-carbon economy is often perceived as a purely environmental issue. However, it can be defended on the basis of its wider economic, social and environmental implications and is directly related to key issues of our time including energy security, sustainable economic development, pollution and climate change. Projections of the current trends of global energy consumption suggest that, overall, energy consumption will continue to grow strongly in developing and emerging countries, especially in India and China (Olivier et al., 2016). Currently, available evidence suggests that this increase in demand is likely to be met by increasing energy supply from fossil fuel sources like oil, coal and natural gas (IEA, 2014).

Dependence on fossil fuels can potentially "lock economies deeper into carbon-intensive technological systems and make them vulnerable to climate change" (OECD, 2015). It thus becomes a challenge to escape the phenomenon of "Carbon lock-in" (Unruh, 2000) which requires policy makers to address two core intertwined elements: first, scaling up finance for long term investment in climate-resilient infrastructure and second, shifting investments towards sustainable low-carbon alternatives (Olivier et al., 2016), especially by strengthening the policy commitment to renewable energy technologies. The scale of the required energy sector investments to achieve Paris Climate Agreement goal is estimated to be around 3.5 trillion USD on average each year between 2016 and 2050, according to IEA (IEA, 2017). The current pattern of public funding in renewables indicates that public investment is unlikely to supply more than 15% of the investment needed (IRENA, 2016). This suggests that an energy transition is unlikely to occur without the participation of the private sector, particularly in financially constrained developing economies.

In this regard, recent trends in the value of global new investments in the renewable energy sector, excluding hydro have increased by 2% in 2017 to reach 279.8 billion USD but still below the record set in 2015 (323.4 billion USD). Remarkably, in 2017 developing countries accounted for 63% of global investments, up from 54% in 2016 (FS-UNEP/BNEF, 2018) with much of this trend being attributable to investments in China, India and Brazil. Despite the general positive trend in investments, renewables have not been able to realise their potential in developing countries due to several barriers. Understanding these barriers, especially how dependence on fossil fuel can affect the rate of private sector investments in the renewable energy sector becomes an important issue from environmental and economic perspectives, and might have far reaching consequences for the scale of policy change required for a timely energy transition.

It has long been recognised that dependence on fossil fuel consumption not only leads to adverse environmental impacts, but also results in increased health risks and lower productivity caused by carbon dioxide emissions (Graff Zivin and Neidell, 2012). In addition, this dependence can undermine private sector investments in renewable energy sector through three main channels. Firstly, dependence on fossil fuel is likely to be associated with strong influence of polluting sectors' lobby groups and vested interest in the fossil fuel industry over environmental policy (Cadoret and Padovano, 2016; Damania and Fredriksson, 2000; Walker, 2000) and their power to oppose the adoption of policies related to diversifying the energy-mix (Ahmadov and Van der Borg, 2019; Neuhoff, 2005; Popp et al., 2011; Sovacool, 2009). Secondly, the generally low cost of operation of carbon intensive technologies lends them comparative advantage and, over time, reinforces institutional, behavioural and market factors that inhibit low-carbon objectives (Erickson et al., 2015; Unruh, 2000). Thirdly, the larger the scale of fossil fuel dependence or consumption, the higher will be the rates of return to continued use, and ultimately, the existing institutional system would reinforce this dependency even further (Erickson et al., 2015).

To date, however, most of the literature investigating the growth of renewable energy adoption has focused on developed countries and has typically considered (1) the determinants of adopting policies such as renewable portfolio standards (Cadoret and Padovano, 2016; Chandler, 2009; Pfeiffer and Mulder, 2013), or (2) the effectiveness of renewable energy policies (Carley, 2009; Vachon and Menz, 2006), or (3) the determinants of renewable energy growth (Aguirre and Ibikunle, 2014; Marques and Fuinhas, 2011; Marques et al., 2011; Sadorsky, 2009). However, the link between fossil fuel dependence and private sector investment in renewable energies has not been explicitly studied.

This paper contributes to the literature by testing for the carbon lock-in hypothesis in the renewable energy sector. Given the scale of future investment needs in developing and middle-income countries to achieve their 2030 energy-related emissions targets, and the leading role of the private sector in bridging 85% of the investment gap in RE sector (IRENA, 2016), it is important to understand the determinants of private sector investment and how the probability of investment evolves over time. Even more important from a sustainability perspective, is to understand how fossil fuel dependence affects the rate by which countries experience a relapse episode of investment projects. This is especially crucial in developing and emerging countries where a sustained inflow of private investment on renewable energies is needed in economies that are often dependent on fossil fuel production, use and exports.

In this context, success in achieving a country's energy transition is likely to depend on the length of the time (i.e. duration) it takes for private sector investment projects to occur and the likelihood of their recurrence. Although the methodology and the choice of the dependent variable are partially motivated by data availability and the structure of the database, using a hazard rate adds some new insights. First, the methodology measures the probability of receiving an investment in a given period, conditional on past history and control variables. This speaks to the important question of understanding when an investment occurs as well as what drives the probability of an investment. To my knowledge, the question of understanding the timing of an investment has not been explored before in the literature. Second, I am able to test if the lock-in effect becomes weaker in countries with repeated investment projects in earlier periods. This could point to a past investment leading to a weakening of lobby groups and vested interests in the fossil fuel industry, which could gradually pave the way for renewable energy transition. Third, by estimating the hazard rate of repeated investments, the results in the paper speak directly to changes in the probability of investment over time , which is likely to be linked, at least in part, to changes in the policy environment which could potentially enable/deter the renewable energy transition and attract/push away private sector investments.

In order to investigate this, I model the duration time to private sector investment using a multiple failure discrete-time model on a sample of 134 middle-income and developing countries for the 1990-2012 period. The results confirm the carbon lock-in hypothesis where higher dependence on fossil fuels, in the form of fuel rents and higher fossil fuel consumption, lead to a lower hazard of investments in renewable energy projects. These findings are consistent across vast majority of specifications. However, the negative effect becomes less pronounced with having investments in previous periods. Consistent with previous literature, the results support that a number of macroeconomic variables, such as higher oil prices, developed financial market, and domestic renewable energy policies, play an important role in increasing the likelihood of private sector investment. Higher inflation rates, however, tend to have a dampening effect. An important indirect channel of carbon lock-in is epitomised by the decrease in the marginal impact of regulatory quality on investment hazard in the presence of high fuel rent and fossil consumption.

The findings resonate with concerns of the international community regarding the effect of fossil fuel dependence on the rate of adoption of renewable energy sources in middle-income and developing countries. First, they highlight the importance of enabling renewable energy policies and access to finance in unlocking private investment potential. Secondly, the results on interactions between fuel dependence and spell order hint to a weaker effect of fuel dependence after a number of investment projects. Finally, the results are relevant in light of recent trends in international oil prices as they suggest two possible competing effects, with lower oil prices potentially delaying investments directly through higher fossil fuel consumption as oil gets more cost effective but positively affecting investment in oil exporting countries as it directly translates to lower fuel rents. The extent to which effect of these prevails and under which conditions is an area of future research.

The rest of the paper is organised as follows. Section 2 elaborates on the concept of lock-in and its link to fossil fuel. Literature review with a summary of some of the most important findings on determinants of investment or adoption of renewable energy technologies is presented in section 3. Section 4 describes the data and the methodology used. Section 5 presents the main results followed by a discussion. Finally, section 6 concludes.

2.2 The link between Fossil Fuel and lock-in

Despite promising recent trends, future growth in investments in the renewable energy sector faces several challenges. While investments in the renewable energy sector has increased substantially, around 70% of global energy supply is still derived from fossil fuels (IEA, 2014a) and this pattern is especially pronounced in the Middle East and North Africa region, where fossil fuels accounted for about 96% of the region's energy mix for electricity production in 2015 (World Bank, 2015). One of the barriers that has recently gained scholarly attention is the likely effect of carbon lock-in on renewable energy investments.

The term carbon lock-in centres on the idea that path dependent processes of economic, infrastructure, institutional and social conditions mutually reinforce each other to inhibit innovation and competitiveness of low carbon alternatives (Frantzeskaki and Loorbach, 2010; Seto et al., 2016). A prime source of lock-in is existing infrastructure of the energy system. The estimated locked-in emissions from already built or under construction infrastructure is 360 Gt CO_2 from 2011 to 2035, led by China, India and the Middle East region (IEA, 2013). In such circumstances, the introduction of new energy systems based on renewable sources would require replacements of the production system, causing capital investment to be obsolete (Kemp, 1994). In addition, the incompatibility of fossil fuel supporting infrastructure (e.g. pipelines, refineries) with other systems creates resistance for a technological shift due to higher costs of switching to a different energy system (Seto et al., 2016).

The consequences of gearing production patterns on carbon intensive sources are likely to be far more costly if a large scale transition away from fossil fuel does not occur in a well-managed way. According to the estimates of the International Energy Agency, delayed investment in low carbon infrastructure until 2020 will increase the cost of investment by four folds in the long term (through 2035)(IEA, 2013). On the policy front, Erickson et al. (2015) found that because coal fired power plants have low operating cost and long life span, a carbon price of 30 USD per tonne CO_2, is needed for replacement with low carbon alternatives. This price is much higher than the majority of carbon price worldwide, currently valued at 10 USD per tonne (World bank, 2017). Notably, this pose a global risk to lock-in and adds to the cost of achieving climate goals.

2.3 Determinants of Renewable Energy Investment

Literature on renewable energy sources covering developing and emerging countries is scant and has broadly focused on renewable policies' impact (Lewis and Wiser, 2007; Wang et al., 2010) and recently on the determinants of adopting renewable energy policies (Brunnschweiler, 2010; Pfeiffer and Mulder, 2013; Stadelmann and Castro, 2014). Eyraud et al. (2013) analyze determinants of green investments in 35 advanced and emerging countries, where green investments are defined as all types of energy-efficient and renewable energy technologies that contribute to cutting emissions as well as research and development expenditures (public and private) on green technologies. This paper is different however, in that, it explicitly models the time to investments; uses different proxies for fossil fuel dependency to test the carbon lock-in hypothesis; and includes a larger sample of developing countries. In addition, the definition of green investments is different, which will be discussed in section 4.

A number of socioeconomic, institutional, and energy market factors are key for the deployment of renewable energy technologies which have been considered in the literature. Under each factor, relevant variables are briefly discussed.

2.3.1 Socioeconomic variables

Income level and Macroeconomic Stability

Aguirre and Ibikunle (2014) and Sadorsky (2009) argue that due to the high cost of adopting renewable energy technologies (including costs of physical infrastructure and regulations); macroeconomic stability and high income levels play positive roles in adopting new technologies. Several authors confirm a positive and significant relationship between GDP per capita and the generation of renewable energy, as well as the likelihood to adopt renewable energy policies in emerging or developed countries (Carley, 2009; Chandler, 2009; Sadorsky, 2009; and Eyraud et al., 2013). Contrarily, some studies did not support this positive relationship as in Chang et al. (2009), and even a negative relationship between level of welfare and preference for traditional fuel sources to satisfy immediate energy needs was reported in Marques et al. (2011). A higher inflation rate is a sign of macroeconomic instability that dampens investment flows (Schneider and Frey, 1985).

H1.1 Higher GDP per capita and lower inflation rate increase the hazard rate.

Capital Markets

Access to finance is important to facilitate the deployment of long lead time projects like renewable energy investments with high upfront cost (Brunnschweiler, 2010) . However, a positive relationship is not always found in emerging economies. Pfeiffer and Mulder (2013) find that financial intermediation was insignificant in the deployment of non-hydro renewable energy in 108 developing countries for the 1980-2010 period.

H1.2 The higher the share of credit by banks (% GDP) to private sector, the higher investment hazard rate.

Market Size and Human Capital

Countries with high population growth rate face increasing demand for energy. The effect of market size and projected energy demand on renewables adoption was inconclusive as higher demand could be met by either consuming more fossil fuel (Aguirre and Ibikunle, 2014; Eyraud et al., 2013) or, by investing in alternative energy sources, such as renewable energy technologies. Investments in green technologies are also dependent on the level of human capital, which is needed to learn about the new technology and operate it effectively (Noorbakhsh et al., 2001).

H1.3 Larger population size and higher tertiary enrollment positively affect the hazard rate.

Carbon dioxide emissions

Several authors argue that higher CO_2 emissions have raised environmental concerns and public pressure to limit emissions, which consequently accelerated the diffusion of cleaner sources of energy (Sadorksy, 2009; Van Ruijven and Van Vuuren, 2009). Contrarily, others find that higher emission levels signal dependence on fossil fuels and public indifference about emissions (Romano and Scandurra, 2014; Marques and Fuinhas 2011,2011a), therefore less incentive to adopt renewable energy technologies.

H1.4 Carbon dioxide emissions have an ambiguous effect on the hazard rate of investment.

2.3.2 Energy Sector Variables

Fuel Prices

Fuel price volatility is likely to induce investment in non-fossil alternatives (Awerbuch and Sauter, 2006). Lower oil price, for instance, is likely to crowd out investments in renewable energy as oil becomes relatively cheaper. Chang et al. (2009) found that responses to a hike in fuel price differ by income level and, hence substitution to renewables is not always the outcome. The lack of a substitution effect was similarly found in Marques et al. (2010).

H2.1 Higher crude oil price increases the hazard rate of investment.

Energy Security

The pursuit of energy self sufficiency remains a key element in the face of reducing countries vulnerability to fuel price hikes. Advocates of renewable energy deployment posit that renwables adoption is likely to reduce fuel import since renewable energy generation is dependent on domestic sources (Gan et al., 2007; Johansson, 2013). However, the results of several studies which use the share of energy imports as a proxy for energy security was insignificant in explaining the observed pattern of renewable energy supply (Eyraud et al., 2013; Popp et al., 2011). *H2.2 A higher share of energy import increases the hazard rate*

Fossil Fuel Dependence

Although renewables are more sustainable and cleaner source of energy than fossil fuel, they are mostly considered as substitutes (Aguirre and Ibikunle, 2014). Thus, fossil abundance and the high share of fossil in electricity mix reduce concerns about adopting alternative energy sources (Marques et al., 2010). For example, Pfeiffer and Mulder (2013) find a negative association between high fossil fuel production and low share of renewable energy generation per capita in 108 developing countries. Ahmadov and Van der Borg (2019) estimate that a 10% increase in petroleum rents per capita is associated with a 1.1% reduction of production of renewable energy gigajoules per capita. Fuel dependence is generally associated with strong political and economic influence of lobby groups who are powerful enough to oppose deployment of renewables (Cragg et al., 2013; Popp et al., 2011).

H2.3 Fossil fuel dependence in the form of high fuel rent, high fossil consumption and higher share of electricity from oil sources decrease the hazard rate

2.3.3 Institutional Variables

Kyoto and domestic RE policies

various policies and support schemes to accelerate the share of electricity generation from renewable sources are adopted in developing countries. Generally, public policies are positively associated with higher of renewable energy adoption (Popp et al., 2011; Aguirre and Ibikunle,2014; Pfeiffer and Mulder, 2013; Carley, 2009; Stadelmann and Castro, 2014; Marques and Fuinhas,2012). Moreover, ratification of international environmental agreements are expected to signal countries' commitment to adopt low-carbon energy sources to cut emissions (Popp et al., 2011).

H3.1 Kyoto ratification and domestic RE policies have a positive effect on the hazard rate

2.3.4 Political Economy

In the context of environmental investment, Fredriksson and Ujhelyi (2005) find that institutional set up of the country matter for the type of environmental policy and for harnessing the power of lobby groups. The type of regime for example, can either permit or restrict the expression of environmental preferences and consequently on decisions to deploy renewables (Pastor and Hilt,1993; Farzin and Bond, 2006; Pfeiffer and Mulder, 2013). In general, it is widely perceived that democratic regimes offer a stable business-friendly environment through enforcement of rule of law and protection of property right. More importantly, checks and balances in democratic countries enhances incumbent governments to implement policies which balance between the interests of different groups in society (Feng, 2001).

H3.2 Democracy and regulatory quality increase the hazard rate

2.4 Data and Methodology

2.4.1 Data

Data on private sector investment in the renewable energy sector in developing countries is available from the World Bank Private Participation in Renewable Energy database. The database provides detailed project-level information of renewable energy investments involving a private sector financial disbursement for the 1990-2012 period. The dataset covers 134 low and middle- income countries (World Bank classification in 2012) from six different geographical regions[1]. According to the database, projects that satisfy the following criteria are included: a renewable energy infrastructure project, located in a developing country, at least 25% of capital is private participation (domestic or international), the financial closure has been reached, or 25% of construction has been completed, for pipeline projects, they are within two years of commissioning, and projects with at least 1 MW or 1 million USD.

The study period is dictated by data availability and spans 1990-2012. The analysed time period covers a number of important events related to global action on climate change which may affect investments in renewable energies in developing and emerging countries. These events include the Earth summit in 1992 (which led to the adoption of the United Nations Framework Convention on Climate Change (UNFCCC); the adoption of Kyoto protocol in 1997; the period where the clean development mechanism gained momentum as a tool to promote projects that limit emissions; and the financial crisis in 2008 followed by fluctuations in oil prices.

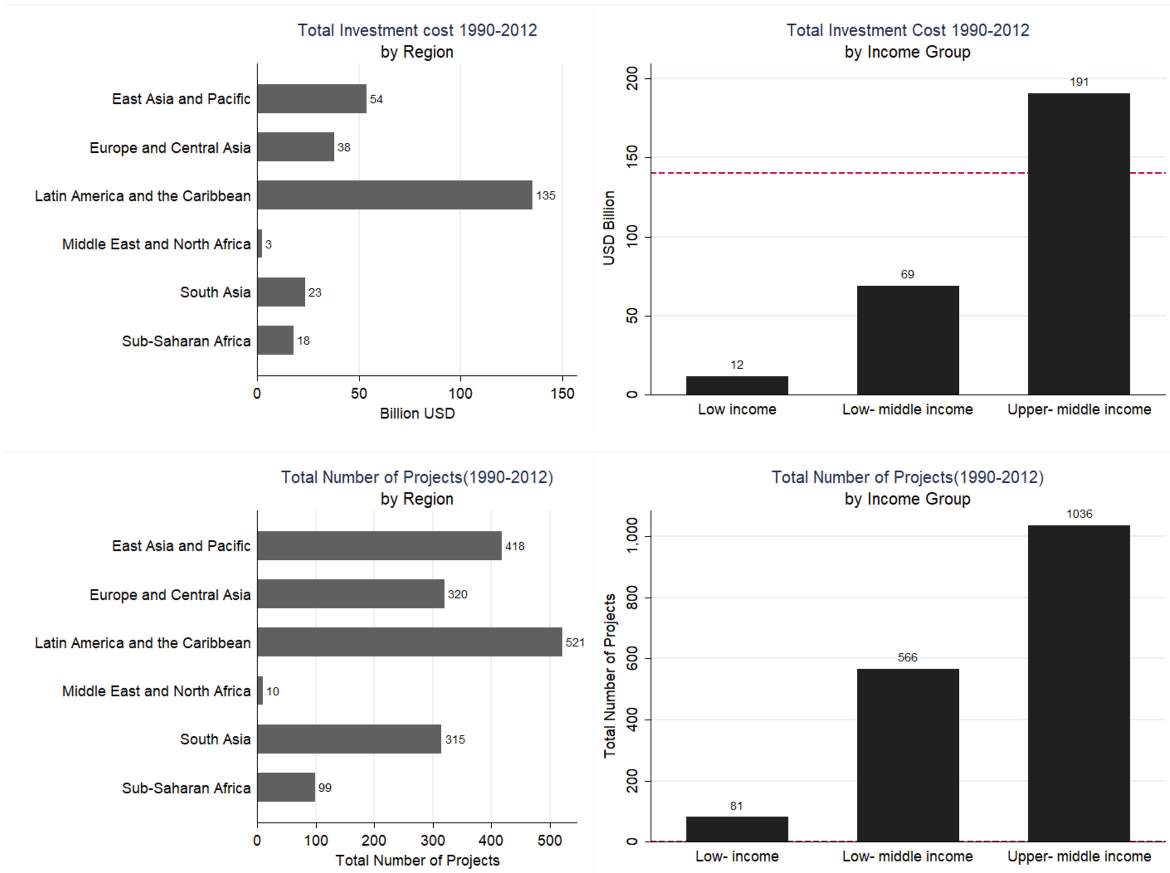
As figure 2.1 shows, there is heterogeneity in the volume of investment and the number of projects financed by the private sector across the different regions and across income levels. In terms of the number of projects, Latin America and the Caribbean (521 projects) and East Asia and Pacific (418 projects) accounted for the majority of the project. On the other hand, the Middle East and North Africa region only accounted for 10 projects.

The dependent variable is a binary variable taking the value of 1 for the year in which the country receives private sector investment and a value of 0 otherwise. A description of the

[1] The list of countries are in table A1

variables and data sources is provided in table 2.1 and summary statistics are in table 2.2.

Figure 2.1: Investment Profile by Region and Income Group (1990-2012)



Source: Author's Calculation based on The World Bank Private Participation in Renewable Energy projects Database. Last accessed December 2016.

Table 2.1: List of variables, definitions and sources

Variable	Definition	Source
Adopt	Dummy for the year of Private sector investment	World bank [1]
Investment Cost	Value of private sector investment (USD million)	World bank
Energy Variables		
Rent	Total natural resource rent excluding forest (% of GDP)	WDI
Fossil	Fossil fuel energy consumption (% of total)	WDI[2]
Oil price	Crude oil price (USD per barrel)	EIA[3]
Energy import	Energy imports, net (% of energy use)	WDI
Energy Intensity	Energy Intensity level of primary energy (MJ/2011 PPP GDP)	WDI
Electricity	Electricity Production from oil sources (% total)	WDI
Socioeconomic Variables		
GDPcapita	GDP per capita (constant 2010 USD)	WDI
Inflation	GDP deflator (annual %)	WDI
Credit	Domestic credit to private sector (% of GDP)	WDI
Population	Total population (Million)	WDI
Enrollment	School enrollment, tertiary (% Gross)	WDI
CO_2 emission	CO_2 emissions (metric tons per capita)	WDI
FDI	Foreign Direct Investment, net inflows (% of GDP)	WDI
Institutional Variables		
RE policy	Dummy variable for implementing RE policy	IEA/IRENA[4]
Kyoto	Kyoto Ratification dummy (1=yes, 0=No)	UNFCCC
Regulation	The Government's ability to formulate and implement sound policies and regulations that permit and promote private sector development. Scale ranges between approximately -2.5 (low) to 2.5 (high)	WGI[5]
PolityIV	Combined polity score. Scale ranges between -10 (strongly autocratic) to +10 (most democratic)	Marshall et al. (2011)

[1] Private participation in renewable energy database of the World bank. Last accessed: December 2016.

[2] World Bank Group's Development Indicators database.Last accessed: December 2016

[3] Energy Information Administration (EIA) Online database.

[4] The International Energy Agency and The International Renewable Energy Agency: Global Renewable Energy Policies and Measures Database. Policies are classified to three types: Economic incentive (e.g. feed-in tariff, tax credit), regulatory instrument (e.g. codes and standards, auditing) and policy support (e.g. strategic planning).

[5] World Governance Indicators database of the World Bank.

Table 2.2: Summary Statistics

Variables	N	Mean	Std. Dev.	Min	Max
Adopt (dummy)	3082	0.12	0.32	0.00	1.00
Rent (% GDP)	3082	4.78	11.5	0.00	73.34
Fossil Consumption (% of total)	2148	58.19	32.24	0.00	99.94
Oilprice (USD)	3082	42.70	31.43	12.76	111.60
RE policy (dummy)	3082	0.22	0.40	0.00	1.00
Kyoto (dummy)	3082	0.42	0.49	0.00	1.00
Co_2 emission (metric tons per capita)	2989	1.93	2.53	0.01	15.94
Energy import, net (% of energy use)	2063	-36.93	197.80	-1942.00	99.15
Electricity (% total)	2063	57.63	34.56	0.00	100.00
Energy intensity (MJ/$2011 PPP GDP)	2994	7.99	6.91	1.14	57.99
Inflation (annual %)	2907	63.75	653	-29.17	26762.02
Credit (% GDP)	2700	27.12	23.88	0.00	166.50
FDI, net inflow (% GDP)	2796	3.74	5.96	-19.77	103.34
Population (million)	3081	37.99	144.3	0.01	1351.70
School Enrollment, tertiary (Gross %)	1745	19.66	18.86	0.00	119.80
GDPcap (constant 2010 USD)	2917	2942	2740	115.80	14109
Regulatory quality (scale -2.5 -2.5)	1837	-0.49	0.72	-2.65	1.54
Polity IV (scale -10 to +10)	2696	1.71	6.24	-10.00	10.00

2.4.2 Methodology: Survival Analysis

This paper uses a multiple-spell survival analysis model to test the carbon lock-in hypothesis. Specifically, the objective is to identify the determinants of duration to private sector investment (hereafter defined as the event) and test whether fossil fuel dependence has an impact on the hazard of investment. The duration time (also known as survival time) for a given country measures the number of consecutive years until the first observed investment[2]; or the number of years between two different investments projects.

The duration to investment is formalised in terms of a hazard rate, which is the central concept of event history analysis (EHA) methods. It describes the risk a country incurs of having a duration end (also called spell) in a given period, conditional on the spell having lasted up to a certain point of time (Kiefer, 1988). In our case, repeated events discrete time models are used, as some countries experienced more than one event over the 1999-2012 time period. As a result, in our case, the hazard function for the i^{th} country is given by:

$$h_{ij}(t) = h_{0j}(t) exp(\beta_j^{'} X_{ij}(t)) \tag{2.1}$$

Where $h_{ij}(t)$ is the hazard of ending a duration for the j^{th} event at time t. $h_{0j}(t)$ is the baseline hazard, i.e the effect of time on the hazard. This formulation of the baseline hazard allows the hazard to vary as a function of time since the previous event (Prentice et al., 1981). $X_{ij}(t)$ is a set of time varying covariates and β is a vector of regression coefficients. A positive (negative) β value implies that an increase in $X_{ij}(t)$ is associated with an increase (decrease) in the hazard function (i.e. probability of witnessing an investment in period t). The dependent variable (hazard) is binary (0,1) and takes the value of one when an event is observed (i.e new investment project takes place) and zero otherwise.

[2]In the literature the occurrence of the event (i.e. occurrence of an investment) is known as "failure".

Non-Parametric Tests

A common first step in survival analysis is to conduct non-parametric tests by estimating the survival functions without a *priori* information on investment determinants for different sub-groups in the data. The non-parametric survival function is estimated using the Kaplan-Meier (KM) estimator[3]. The Wilcoxon and log rank tests[4] are then used to test whether the differences in survival time between two or more groups (e.g. low income vs. upper middle-income countries) is statistically significant or not. Under the null hypothesis, there is no difference in the survival rate for each of the groups.

To perform these tests, countries are classified to groups in two ways, depending on whether the characteristic we want to test is categorical or continuous. For categorical variables, the survival probability curve is estimated by the category/value of the categorical/binary variable (e.g. income group, signatory of Kyoto protocol). For continuous explanatory variables, the grouping is based on the mean value of the variable and two separate survival curves are estimated for countries with above- and below-mean values of this variable.

Parametric Specification

The parametric specification of duration time is the discrete time complementary log-log model (cloglog), represented by the equation below:

$$cloglog[h(t,X)] = log[-log(1-h_t(X))] = \gamma_t + \beta' X_{ij}(t) = \gamma_1 D_1 + \gamma_2 D_2 + \gamma_t D_t + \beta' X_{ij}(t) \tag{2.2}$$

Where $h(t,x)$ is the discrete time hazard rate for year t. $X_{ij}(t)$ is a set of time varying covariates. In our model, γ_t is the baseline hazard and consists of a set of dummy variables for the $t-1$ periods before the event occurs (Box-Steffensmeier and Jones, 2004). Using dummy variables is preferred as it does not impose a priori functional form for the baseline hazard

[3]The KM estimate measures the survival probability $S(t)$ past the previous failure time $t_{(f-1)}$ multiplied by the conditional probability of surviving past time t_f, given survival to at least time t_f (Kaplan and Meier, 1958).

[4]Both tests compare the observed and expected number of events for each group. The log-rank test is sensitive in detecting distributional differences which occur late in time, while the wilcoxon test tends to be statistically more powerful for detecting differences early in time (Martinez and Naranjo, 2010).

(Buckley and Westerland, 2004) and allows hazard functions to be determined by the elapsed amount of time (Petersen, 1995). In practice, it is possible that countries which did not receive investment for a long period of time may have a lower probability of the occurrence of an investment in the next period. This duration dependence is controlled by the dummy variables.

The Cloglog model was chosen as it is likely to perform better for a number of reasons given the specificities of time-to-event data. First, the data is characterised by censoring, which means that using OLS would be inappropriate. Second, the distribution of duration times is generally very different from a normal distribution (Cleves et al., 2008). Both OLS and the Tobit models assume a normal distribution and thus would be inappropriate[5]

In addition to this, if a time-to-event data is used as the dependent variable, only one corresponding value of the independent variable during the duration of the spell must be selected. This is problematic (especially for long spells) as it would force the research to treat time-varying covariates as fixed or omitting them altogether, which would be a misspecification (Cameron and Trivedi, 2005; Beck and Tucker, 1998), especially in cases where the contemporaneous value of the independent variable is likely to affect the probability of the event. Event history models, on the other hand, allow for time-varying independent variables (Allison, 2014). Third, the main issue regarding the probit and logit models for duration models is that do not account for differences in length of time countries were at risk of experiencing an event. In other words, they do not allow for a (non-constant) baseline hazard, which our Kaplan-Meier estimates (figure 2.2) suggest might be important. Finally, the Cox proportional hazard model is not used as it only looks at the time until the first event. In the dataset, there is more than one investment for certain countries. Ignoring or omitting these events would lead to a loss of information (Box-Steffensmeier and Jones, 2004).

The cloglog model was chosen as it can account for multiple spells, the inclusion of time-varying covariates, censoring, non-constant hazard rates and the non-normality of the distribution of the duration to an event. This is what makes this model appealing and why the class of survival analysis models have been increasingly applied to analyse time to adoption

[5]Cleves et al. (2008) note that OLS generally performs quite well when there are small deviations from normality. However, in the case of duration data, the distribution is often too different from a normal distribution. This is the case in our data (see Figure 2.5).

of environmental policies or green innovations (see for example Fredriksson and Gaston, 2000; Neumayer, 2002; Schaffer and Bernauer, 2014; Stadelmann and Castro, 2014).

2.5 Main Results

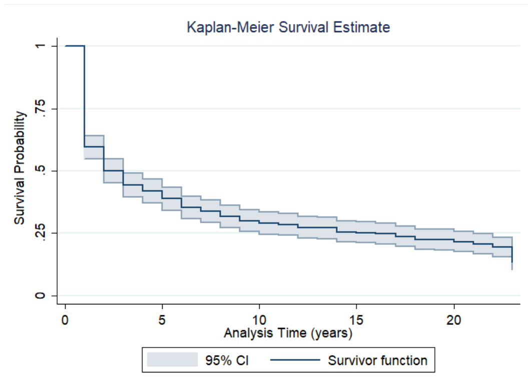
2.5.1 Non-Parametric Tests

The survival function of the Kaplan-Meier (KM) estimates shows a sharp significant decline in survival probabilities for early years as shown in figure 2.2 in panel (a) where fewer countries are at risk by 2012. Unsurprisingly, low income countries have higher survival probability than upper-middle income countries, indicating delayed investments (panel b) for this group of countries. Also, conditional on receiving at least one investment project, subsequent future investments (e.g. spell 2 and 3) are likely to occur in a shorter period of time (panel c). This result could be a reflection of a learning effect that is taking place with the first investment project and which acts to attract more investments in a shorter period of time.

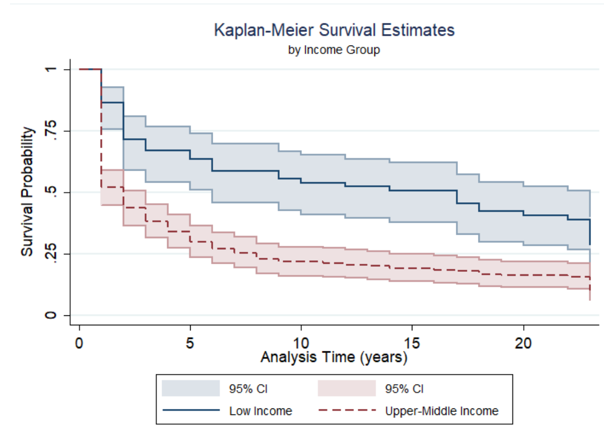
For the fossil fuel dependence; KM estimates for fossil fuel consumption are significantly different across the two groups (panel e). Contrary to expectation, countries with fossil fuel consumption levels above the mean value of 58% of total energy consumption would receive investments at an earlier time. However, the KM estimates for fuel rent are insignificant.

The Log-rank and Wilcoxon tests of equality of survival functions show significant differences for the survival rate for fuel rent and for fossil fuel consumption as shown in table 2.3 with longer mean survival time for countries with higher rent as a share of GDP. The table also indicates shorter mean duration time (i.e early investments) for countries with better access to credit, higher energy imports (i.e energy insecure) higher human capital and better institutional quality.

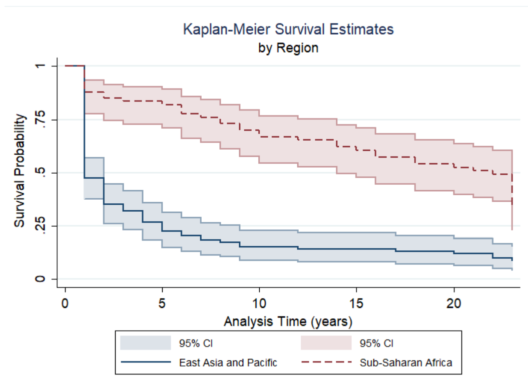
Figure 2.2: Kaplan-Meier Survival Estimates for private sector investment (1990-2012)



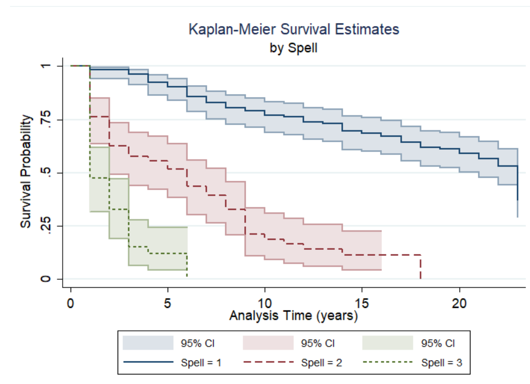
(a) KM Estimates



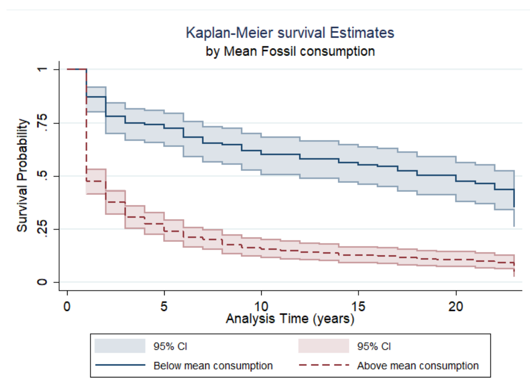
(b) KM Estimates by income groups



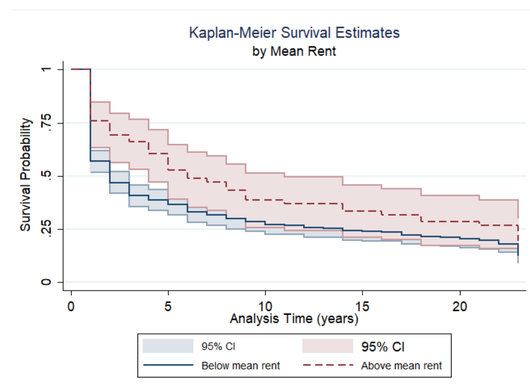
(c) KM estimates by regions



(d) KM estimates by Spell



(e) KM estimates by mean fossil fuel consumption



(f) KM estimates by mean fossil fuel rent

Notes: The survival plot shows how survival declines with time, or in other words, the probability by which a country does not receive investment at a given year. The upper and lower bounds are 95% confidence intervals.

Table 2.3: Non Parametric test of equality of survival functions and mean duration by explanatory variables

Variable	Log-rank	Wilcoxon	Mean duration (years)			
			Low	Lower-middle	Upper-middle	
Income group	21.71 (0.000)	28.40 (0.000)	18.3	8.7	7.3	
			EA	LA	MENA	SSA
Region	89.31 (0.000)	90.77 (0.000)	5.1	5.4	18.2	15.8
			No	Yes		
Kyoto (dummy)	160.93 (0.000)	132.64 (0.000)	13	2.7		
RE policy (dummy)	93.30 (0.000)	82.77(0.000)	13.82	2.87		
			Below Mean	Above Mean		
Rent (%GDP)	5.27 (0.022)	9.14 (0.002)	8.78	12.85		
Fossil consumption(% total)	93.50 (0.000)	94.18 (0.000)	22.2	5.35		
Inflation (% annual)	13.72 (0.000)	13.74 (0.000)	7.85	10.49		
Credit (% GDP)	60.17 (0.000)	54.81 (0.000)	13.46	4.28		
Population (million)	95.14 (0.000)	76.55 (0.000)	13.59	3.24		
Enrollment,tertiary (Gross %)	30.27 (0.000)	23.85 (0.000)	10.72	4.07		
GDP per Capita (constant 2010 USD)	18.14 (0.000)	14.44 (0.000)	11.29	5.85		
CO_2 emission (metric tons per capita)	7.56 (0.006)	9.81 (0.002)	10.07	6.45		
Energy import (% energy use)	17.01 (0.000)	28.16 (0.000)	12.48	5.65		
Energy Intensity	30.36 (0.000)	28.32 (0.000)	7.03	17.81		
Electricity generation (% oil sources)	0.08 (0.776)	4.13 (0.042)	6.55	6.51		
Regulatory Quality	22.42 (0.000)	21.16 (0.000)	8.13	2.45		
PolityIV	57.60 (0.000)	44.50 (0.000)	19.18	5.54		

Numbers in parentheses represent P-values. All numbers in the table were rounded to 3 decimal places. EA: East Asia and Pacific, LA: Latin America and Caribbean, MENA: Middle East and North Africa, SSA: Sub-Saharan Africa. The mean duration does not take into account censoring for each group according to each explanatory variable

2.5.2 Parametric Estimation Results

The main estimation results of the cloglog model is shown in table 2.4. The hazard rate of private investment differs depending on a number of factors, including spell length (time elapsed since the beginning of the spell), with negative spell length dummies indicating a decrease in the baseline hazard over time. The likelihood ratio test for temporal dependence indicates significance of the spell dummies for a better fit of the model. There is heterogeneity in the hazard rate among regions with the lowest hazard in Middle East and North Africa followed by Sub-Saharan Africa.

With respect to fossil fuel consumption and fuel rent; they have significant and negative effects on the hazard of private sector investment at 1% significance level, supporting the carbon lock-in hypothesis. Even after controlling for time, region fixed effects and socio-economic covariates as in model (7), the variables are still significant with a slightly more negative effect of rent. An alternative way to test for the role of fossil fuel dependence and the power of lobby groups is by using the share of electricity generated from oil sources, as in Carley (2009). The result of model (4) reinforces the proposition that the lack of diversity of energy sources can potentially increase lobby power of oil sector, delaying renewable investment (Hunag et al., 2007).

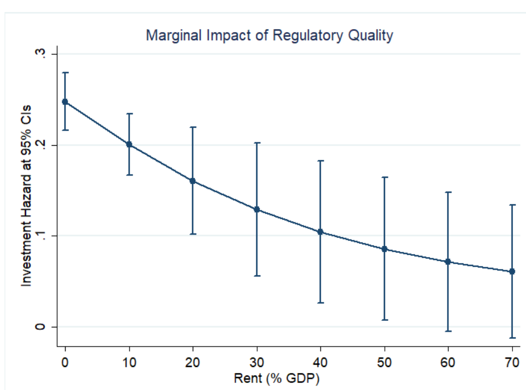
Energy security concerns proxied by the share of energy imports from total energy motivate investments in renewables as shown in model (5)[6]. This finding is in accordance with the arguments proposed for adopting alternative domestic energy sources to hedge against fuel price volatility and geopolitical factors in the long run (Gan et al., 2007). The presence of a substitution effect of renewables is evident in the positive and significant coefficient on crude oil price. Also, earlier investment projects tend to be driven by public policies as shown by the positive and significant coefficient on the renewable energy policy dummy, with an increase of investment likelihood between 0.57% and 0.65%, however, once more control variables are included (columns 6-9), policies become insignificant and negative. It is worth noting that ratification of international non-binding agreements like Kyoto does signal countries' commitment for an energy transition.

[6]Due to high correlation between energy imports and fuel rent, the latter variable is dropped from the model. Also in model 4, due to correlation between Co_2 emission per capita and fossil consumption, we estimated the model without the latter variable.

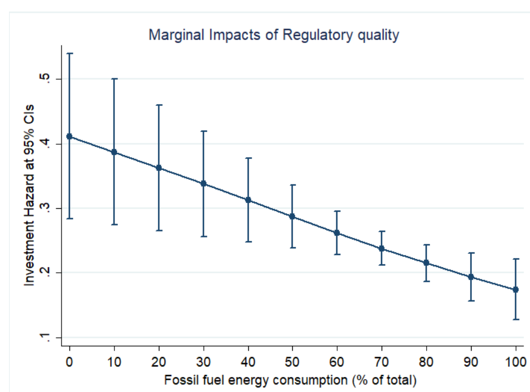
Contrary to the hypothesis that income level determines private sector investment in the renewables sector, the results do not support this hypothesis, similar to the finding of Aguirre and Ibikunle (2014). One explanation for this could be that upper middle income countries have a higher consumption level of traditional fossil fuel sources to maintain growth and standards of living (Marques et al., 2011). One aspect that consistently emerges from the results is the significance of credit and foreign direct investment inflows, which exhibit a positive and significant coefficient. Both variables signal a developed financial market and an enabling environment for private sector investments in general (Brunnschweiler, 2010). Energy demand proxied by population size shows a positive and significant effect on investment hazard at 1% significance level.

Institutional settings are argued to be main factors for private sector investment. Column (6) indicate that while democratic regimes do not have a significant effect on the hazard rate, higher regulatory quality plays a major role in attracting investments, with 0.84% increase in the hazard rate. The sample size in this estimation is smaller compared to other models due to missing data on regulatory quality and PolityIV variables. In order to test if the institutional setting in the presence of high fuel rent or high fossil consumption could be the mechanism leading to the carbon lock-in, marginal effects on investment hazard rate were estimated in Figure 2.3 using model (6).

Figure 2.3: Marginal Effect of Regulatory Quality on Investment Hazard (1990-2012)



(a) Marginal impacts at different levels of rent (% GDP)



(b) Marginal impacts at different levels of fossil fuel consumption(% total)

Notes: The line is the marginal impact of 1% increase in regulatory quality on investment hazard at different levels of rent (panel a) and fossil consumption(panel b). The upper and lower bounds are 95% confidence intervals. The graph is based on model (6) of table 2.4

The decrease of the marginal effect of regulatory quality on the hazard of investment at different levels of rent (panel a) and fossil consumption (panel b) show how fuel dependence could eventually crowd out private investments through a negative effect on institutional quality.

Exploring the extent to which carbon lock-in persists over time and over project's size is not only important from an academic perspective but can also have important policy implications. First, for the purpose of testing whether the negative effects of fossil fuel dependency changes with the frequency of prior investments projects, an interaction term between rent/fossil consumption and the number of spell (i.e. first investment, second investment, etc) is included interchangeably in the estimation in columns (8-9) of table 2.4. The result shows that the negative effects of fuel dependency are minimized conditional on having investment projects in the past, as the hazard rates on the interaction terms are positive and significant (for fossil consumption). Yet, the overall effect of both variables on investment hazard is still negative. From a public choice perspective, it is likely that vested interests of stakeholders and lobby groups in carbon intensive sectors are able to keep opposing regulations for the adoption of renewable energy technology up until the first investment occurs, after which the effect of lobby groups are weakened due to successful implementation of projects and learning effects.

Second, the effect of fossil fuel dependence on duration to investment could vary by project size. Therefore, based on the distribution of investment cost, a threshold of 500 million USD is used to identify large projects. The results of Table 2.5 indicate pronounced negative effects of fuel rent and fossil consumption on investment hazard rate, showing delayed duration to investment for large projects, in particular, compared to the main results estimations that do not differentiate between project size.

Table 2.4: Main Results - Hazard of Private Sector Investment in Renewable Energy Projects

	Dependent variable: Hazard of Private sector investment								
Variables	1	2	3	4	5	6	7	8	9
Spell 2-3	-1.183***	-1.217***	-1.194***	-0.755***	-0.775***	-0.123	-0.00502	-0.316	-0.320
	(0.180)	(0.186)	(0.183)	(0.199)	(0.207)	(0.253)	(0.233)	(0.226)	(0.236)
Spell 4-6	-1.774***	-1.799***	-1.749***	-1.295***	-1.298***	-0.688***	-0.622***	-0.529**	-0.483**
	(0.190)	(0.186)	(0.190)	(0.215)	(0.206)	(0.263)	(0.239)	(0.205)	(0.215)
Spell 7-9	-2.006***	-2.231***	-2.193***	-1.550***	-1.533***	-0.441	-0.176	-0.258	-0.172
	(0.239)	(0.254)	(0.257)	(0.268)	(0.270)	(0.329)	(0.295)	(0.290)	(0.297)
Spell 10-12	-2.586***	-2.558***	-2.547***	-1.921***	-1.913***	-1.096**	-0.729*	-0.946***	-0.870**
	(0.350)	(0.345)	(0.329)	(0.368)	(0.382)	(0.449)	(0.385)	(0.338)	(0.360)
Spell 13plus	-1.889***	-2.293***	-2.699***	-1.947***	-2.041***	-1.224***	-0.886***	-1.199***	-1.079***
	(0.169)	(0.165)	(0.184)	(0.240)	(0.237)	(0.276)	(0.289)	(0.292)	(0.296)
Rent (% GDP)		-0.0359***	-0.0391***	-0.0448***		-0.0124	-0.0380**	-0.0483***	-0.0317**
		(0.00625)	(0.00547)	(0.00807)		(0.0127)	(0.0190)	(0.0175)	(0.0128)
Fossil consumption (% of total)		-0.00480***	-0.0112***		-0.00584*	-0.0119**	-0.0191***	-0.0203***	-0.0183***
		(0.00178)	(0.00199)		(0.00345)	(0.00547)	(0.00670)	(0.00460)	(0.00424)
Kyoto (dummy)			0.547***	0.797***	0.494**	-0.203	0.161	0.411**	0.345*
			(0.128)	(0.171)	(0.201)	(0.328)	(0.391)	(0.191)	(0.181)
RE policy (dummy)			0.646***	0.578***	0.570***	-0.300	-0.0575	-0.107	-0.149
			(0.147)	(0.165)	(0.170)	(0.222)	(0.189)	(0.181)	(0.191)
Energy intensity (log)				-0.595***	-0.951***	-0.964***	-1.431***	-0.188***	-1.339***
				(0.131)	(0.231)	(0.232)	(0.219)	(0.0301)	(0.187)
Population (log)						0.581***	0.648***	0.631***	0.547***
						(0.0820)	(0.0833)	(0.0655)	(0.0631)
Inflation (annual %)						0.0111**	-0.00326	-0.00255	-0.00224
						(0.00553)	(0.00365)	(0.00333)	(0.00325)
Enrollment, tertiary (% gross)						0.0255***	0.0163***	0.0317***	0.0303***
						(0.00400)	(0.00603)	(0.00446)	(0.00480)
Credit (% of GDP)						0.0107***	0.0156***	0.0122***	0.0109***
						(0.00373)	(0.00373)	(0.00288)	(0.00314)
GDP per capita (log)						-0.589***	-0.211***	-0.153***	-0.288***
						(0.114)	(0.0690)	(0.0558)	(0.0549)
FDI, net inflows (% of GDP)							0.0656***	0.0786***	0.0747***
							(0.0174)	(0.0162)	(0.0162)
CO_2 emissions (log)				0.158					
				(0.0966)					
Electricity from oil sources (% of total)				-0.00360					
				(0.00322)					
Crude oil price (log)					0.228*	0.882***			
					(0.131)	(0.184)			
Energy imports, net (% of energy use)					0.00246***				
					(0.000578)				
PolityIV						0.0151			
						(0.0187)			
Regulatory Quality						0.845***			
						(0.168)			
Rent*spell								0.00552	
								(0.00594)	
Fossil*spell									0.000951**
									(0.000480)
Regions	✓						✓		
Observations	3,082	2,148	2,148	1,971	1,988	827	1,181	1,218	1,218
No. of Countries	134	115	115	89	89	93	100	100	100
Time FE	NO	NO	NO	NO	NO	NO	Yes	NO	NO
Log-likelihood	-923.42	-817.92	-779.05	-670.01	-697.00	-291.7	-348.2	-396	-395.6
Count R2	0.88	0.82	0.84	0.84	0.86	0.84	0.87	0.85	0.67
Wald Chi2	611.24***	681.86***	786.82***	[illegible]07.36***	583.14***	391.69***	1872.15***	490.92***	555.97***
AIC	0.606	0.768	0.734	0.691	0.695	0.749	0.666	0.678	0.675
Likelihood ratio test for temporal dependence	569.97***	621.00***	665.55***	179.78***	194.13***	26.03***	15.29***	25.14***	19.30***

*, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the country level. All numbers in the table were rounded to 3 decimal places.

Table 2.5: Main Results: Hazard of Private Sector Investment in Large Projects

	Dependent variable: Hazard of Private sector investment								
Variables	1	2	3	4	5	6	7	8	9
Spell 2-3	-2.403***	-2.296***	-2.163***	-1.261***	-1.410***	-0.940*	-1.122	-0.854*	-0.850*
	(0.319)	(0.349)	(0.345)	(0.329)	(0.330)	(0.547)	(0.771)	(0.455)	(0.443)
Spell 4-6	-2.900***	-2.935***	-2.723***	-1.741***	-1.687***	-0.790	-1.604**	-0.809*	-0.727*
	(0.381)	(0.437)	(0.435)	(0.476)	(0.460)	(0.523)	(0.751)	(0.417)	(0.422)
Spell 7-9	-2.593***	-2.838***	-2.718***	-1.737***	-1.518***	-0.511	-1.453	-0.516	-0.422
	(0.376)	(0.390)	(0.397)	(0.333)	(0.373)	(0.499)	(0.923)	(0.500)	(0.512)
Spell 10-12	-3.497***	-3.474***	-3.512***	-2.526***	-2.420***	-1.341**	-1.599	-1.190*	-1.088
	(0.591)	(0.593)	(0.591)	(0.618)	(0.623)	(0.678)	(1.132)	(0.671)	(0.678)
Spell 13plus	-2.340***	-2.655***	-3.408***	-2.416***	-2.744***	-0.962**	-0.675	-0.509	-0.411
	(0.241)	(0.186)	(0.234)	(0.308)	(0.321)	(0.396)	(0.466)	(0.439)	(0.454)
Rent (% GDP)		-0.0548***	-0.0550***	-0.0690***		-0.0234	-0.172***	-0.108***	-0.0530*
		(0.0135)	(0.0141)	(0.0209)		(0.0288)	(0.0524)	(0.0368)	(0.0273)
Fossil Consumption(% of total)		-0.0147***	-0.0258***		-0.0188***	-0.0356**	-0.0541***	-0.0438***	-0.0448***
		(0.00314)	(0.00356)		(0.00591)	(0.0142)	(0.0155)	(0.0130)	(0.0127)
Kyoto (dummy)			0.727***	1.105***	0.816**	-1.374***	-0.104	-0.0191	-0.0162
			(0.196)	(0.264)	(0.384)	(0.471)	(1.237)	(0.377)	(0.402)
RE policy (dummy)			1.224***	1.239***	1.308***	-0.261	0.627	0.226	0.182
			(0.261)	(0.310)	(0.374)	(0.434)	(0.435)	(0.381)	(0.382)
Energy intensity (log)				-1.266***	-1.839***	-2.103***	-1.902***	-2.338***	-2.319***
				(0.244)	(0.414)	(0.500)	(0.521)	(0.442)	(0.445)
Population (log)						1.008***	1.358***	1.040***	1.022***
						(0.189)	(0.208)	(0.177)	(0.170)
Inflation (annual %)						-0.00382	0.00355	-0.00117	-0.00122
						(0.0115)	(0.00272)	(0.00438)	(0.00416)
Enrollment, tertiary (% gross)						0.0539***	0.00889	0.0624***	0.0600***
						(0.0153)	(0.0143)	(0.0109)	(0.0110)
Credit (% of GDP)						0.0188***	0.0140**	0.0158***	0.0157***
						(0.00640)	(0.00705)	(0.00521)	(0.00522)
GDP per capita (log)						-0.894***	0.866*	-0.265***	-0.276***
						(0.272)	(0.510)	(0.0748)	(0.0766)
FDI, net inflows (% of GDP)						0.0500	0.0775***	0.0978**	0.0986**
						(0.0581)	(0.0300)	(0.0414)	(0.0396)
CO_2 emissions (log)				0.383**					
				(0.180)					
Electricity from oil sources (% of total)				-0.00880					
				(0.00596)					
Crude oil price (log)					0.469*	1.540***			
					(0.279)	(0.438)			
Energy imports, net (% of energy use)					0.00398***				
					(0.00107)				
polityIV						0.00213			
						(0.0242)			
Regulatory Quality						0.890**			
						(0.452)			
Rent*spell								0.0373*	
								(0.0203)	
Fossil*spell									0.00204*
									(0.00113)
Regions	✓						✓		
Observations	3,082	2,148	2,148	1,971	1,988	827	1,181	1,218	1,218
No. of Countries	134	115	115	89	89	93	100	100	100
Time FE	NO	NO	NO	NO	NO	NO	Yes	NO	NO
Log-likelihood	-381.66	-375.59	-346.24	-256.67	-254.86	-133.53	-108.76	-159.89	-161.78
Count R2	0.95	0.94	0.944	0.96	0.96	0.94	0.95	0.95	0.95
Wald Test	417.05***	427.73***	472.17***	433.48***	383.50***	509.54***	42784.36***	782.83***	732.95***

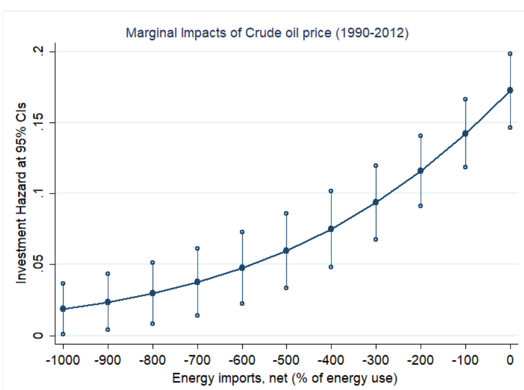
*, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the country level. All numbers in the table were rounded to 3 decimal places.

2.5.3 Further Results

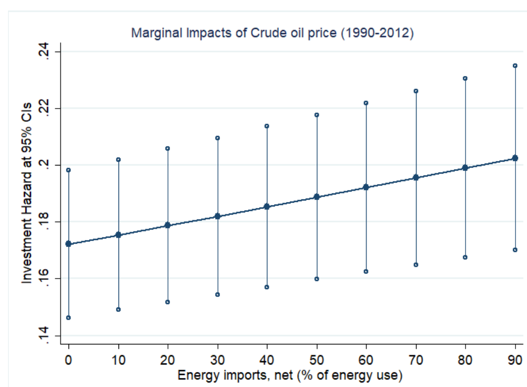
It can be argued that the effect of oil price increase is not uniform across countries; those who are major energy exporters tend to gain from a price hike and thus are less likely to consider alternative energy sources. Net energy importers on the other hand, face fiscal burdens as a result of higher fuel price and are thus more likely to consider adopting renewables. In order to disentangle the effect of oil price changes on investment hazard, two models are estimated using interactions of crude oil price (USD per barrel) with net energy imports variable, such that positive values indicate net energy imports and negative values indicate a net energy exporter.

As figure 2.4 shows, the predictive margins of crude oil price changes on investment hazards are slightly different between panel (a) for fuel exports and panel (b) for fuel imports, although the overall effect is a positive investment hazard in both cases. The probability of an investment spell in renewables in an energy importing country is higher compared an energy exporting country in the event of higher crude oil price. The result is intuitive as energy exporting countries stand to gain from higher oil prices and thus lower incentive to encourage investments in renewables.

Figure 2.4: Marginal Effect of Crude oil price (1990-2012)



(a) Marginal impacts at different levels of net energy imports (% energy use)



(b) Marginal impacts at different levels of net energy imports(% energy use)

Notes: The line is the marginal impact of 1% increase in crude oil price on investment hazard at the different levels of net energy imports (panel a) and net energy exports (panel b). The upper and lower bounds are 95% confidence intervals.

2.5.4 Robustness Checks

In order to check robustness of the results to different estimation methodology and sample size, this section presents 4 tests of robustness. First, to test if censoring can affect the results on the main coefficients, a sub-sample of 84 countries which had investment projects during the 1990-2012 period (i.e completed duration data) is included while censored observations are excluded. The results of table A2 indicate that censored data is not an issue since coefficients on rent and fossil consumption are statistically significant. However, according to the values of Akaike Information Criterion (AIC), the main model is a better fit since it has smaller AIC values (Cleves et al., 2008).

Second, to test if major recipients of renewable energy investments are not the ones driving the main results, estimations in table A3 exclude the top four receiving countries of private sector investment: China, India, Brazil and The Philippines. the main conclusions do not change. Third, as demonstrated by Buckley and Westerland (2004), failing to compute standard errors corrected for spatial and temporal dependence may lead to substantially different conclusions on estimators. Table A4 reports the estimated standard errors of coefficients when clustering on country, income group and on region in columns 1-3. Even when accounting for spatial dependence by assuming that the timing of private sector investment is serially correlated across income groups or regions, the significance of the main variables remains unchanged.

In terms of the alternative methodology, we use the monetary value of investments (USD) as the dependent variable instead of the dummy variable. Since there are 54 countries in the sample with no reported private sector investment, the two-part model is an appropriate approach to account for large observations of censored zeros[7](Belotti et al., 2015). This method specifies a model which accounts for a censoring mechanism using a probit model estimation given by equation 2.3 and a model for the outcome conditional on positive investment values (Cameron and Trivedi,2005).

$$Pr(Investment^d = 1 \mid X_{kt}) = Pr(Investment > 0 \mid X_{kt}) = \delta(\beta X_{kt} + \varepsilon_{kt}) \tag{2.3}$$

[7]I assume that those zero value of investment are true zero, however they could also be due to missing data on investment especially for low-income countries where data availability is limited

Where $Investment^d$ is a dummy variable equals to one if the investment value ($Investment$) is larger than zero, and zero otherwise.X_{kt} is a set of controls for k countries during time period t, δ is the standard normal distribution and ε_{kt} is the error term.

The second part involves an OLS regression of the parameters β that affect the expected value of investment conditional on positive investment values. The first column of table A5 reports the coefficient of the first part with a probit estimation and the second column reports the coefficients of OLS regression. The probability of investment and the amount of investment in USD conditional on any investment decrease with fuel rent and with fossil fuel consumption with 5% and 1% significance levels respectively. The marginal effect of fuel rent (% GDP) and fuel cosumption is decreased investment by approximately 5% and 2.4% respectively.

2.6 Conclusion

Given the heightened importance of renewable energy sources for developing and emerging countries for socio-economic, environmental and geopolitical grounds, a large scale energy transition away from traditional fuels is inevitable. A vibrant literature proposes several explanations for the determinants for varying levels of adoption of renewable energy technologies, but pays insufficient attention to the rate of private sector investments in RE sector and provides an incomplete account by overlooking the role of fossil fuel dependence in the extent and speed of energy transition in developing and emerging countries. This paper fills this gap and examines (1) how carbon lock-in affects the duration time to private sector investments across a sample of 134 developing and emerging countries for the 1990-2012 period, using multiple spell model for discrete time data, and (2) if the carbon lock-in persists given earlier investment projects.

The analysis presented in the paper takes a different angle to look at how developing and emerging countries are faring in energy transition by examining timings of private sector investments and exploring the underlying association between the duration time of investments and fossil fuel dependence. To my knowledge, this is the first study that tries to empirically test for the carbon lock-in effect on the hazard of investment using survival analysis. I show that higher fossil fuel consumption and fuel rent have a negative effect on the hazard rate of private sector investment, with more pronounced effects of fuel rent (% GDP). This suggests that the dependence on fossil fuels as a source of revenues in a given country is more of a deterrent to private sector investment in renewable energies than a country's dependence on fossil fuels for consumption. This is plausibly due to the interaction between three political economy factors strongly related to fuel rent than fossil fuel consumption as explained by Ahmadov and Van der Borg (2019); namely a lack of incentive for diversifying the energy mix, rent-seeking by politicians and rent-capture by vested interests.

I also find that the negative effect of fossil fuel dependence becomes smaller when there has already been a prior private sector investment in renewable energies in the country. However, despite this, the overall effect of fossil fuel dependence remains strongly negative. This could be interpreted in different ways. It could be due to (1) weakening of fossil fuel interest groups over time following successful projects, or (2) an initial successful project leading to a shift in attitude or in government policy, or (3) investors having experienced or witnessed a successful project in a country, being more willing to implement more projects, i.e a learning effect. In addition to this, I also find that fossil fuel dependence seems to have a larger negative effect on large projects (equal to or higher than 500 million USD) compared to smaller ones.

The paper also sheds light on the interaction between the different levels of fossil fuel dependence and regulatory quality. The results show that, at higher levels of fossil fuel consumption/rent, the presence of high regulatory quality does not necessarily accelerate investments, contrary to previous findings in the literature that point to a positive effect on deployment of RE technologies. Exploring further the relationship between institutions and the carbon lock-in effect and how it differs by type of investment (private versus public sector) is an area for future research. Within the broader literature on energy transition, the effects of socioeconomic and political variables corroborate other studies. For example, there is continued relevance of domestic renewable energy policies, energy security concerns, access to credit and ratification of Kyoto protocol as catalysts for early investment projects.

As mentioned in the analysis here, carbon lock-in effect will be reinforced in countries with no prior private sector investment experience. This implies that the first private sector investment is critical for catalysing further private investment, which is an important factor in order to enable a low-carbon future. For that to materialise in a timely manner, a development strategy is needed to manage a restructuring of the many sub-structures that make up the fossil fuel production system, i.e technical knowledge, workforce and infrastructure towards renewable energy investments while aligning countries' regulatory and investment frameworks with energy transition targets. For instance, a strategy focused on structured finance tools and government guarantees for low-carbon, climate-resilient infrastructure could provide investors with low risk and stable policy environment. Other complementary policies and measures could also be adopted to send appropriate price signals and incentives to change consumption pattern of fuels. For example, reducing fossil fuel subsidies, although a politically controversial topic in developing countries, could be effective.

2.7 Appendix

2.7.1 Tables

Table A1: List of countries in the analysis classified by income level (World Bank classification[1], 2012)

Low-income countries (USD 1,025 or less)				
Afghanistan	Chad	Guinea-Bisau	Malawi	Sierra Leone
Bangladesh	Comoros	Haiti	Mali	Somalia
Benin	Congo, Dem. Republic	Kenya	Mozambique	Tajikistan
Burkina Faso	Eritrea	Korea, Dem Rep.	Myanmar	Tanzania
Burundi	Ethiopia	Kyrgyz Republic	Nepal	Togo
Cambodia	Gambia	Liberia	Niger	Uganda
Central African Rep.	Guinea	Madagascar	Rwanda	Zimbabwe
Lower-middle-income countries (USD 1,026 to USD 4,035)				
Angola	Egypt, Arab Rep.	Kosovo	Papua New Guinea	Timor-Leste
Armenia	El Salvador	Lao PDR	Philippines	Tonga
Belize	Georgia	Lesotho	Samoa	Ukraine
Bhutan	Ghana	Mongolia	São Tomé and Principe	Uzbekistan
Bolivia	Guatemala	Mauritania	Senegal	Vanuatu
Cabo Verde	Guyana	Moldova	Solomon Islands	Vietnam
Cameroon	Honduras	Morocco	Sri Lanka	Yemen, Rep.
Congo, Rep.	India	Nicaragua	Syrian Arab Republic	Zambia
Côte d'Ivoire	Indonesia	Nigeria	Sudan	
Djibouti	Kiribati	Pakistan	Swaziland	
Upper-middle-income countries (USD 4,036 to USD 12,435)				
Albania	Costa Rica	Kazakhstan	Panama	Turkey
Algeria	Cuba	Lebanon	Paraguay	Turkmenistan
Argentina	Dominica	Libya	Peru	Tuvalu
Azerbaijan	Dominican Republic	Lithuania	Romania	Uruguay
Belarus	Ecuador	Macedonia, FYR	Russian Federation	
Bosnia and Herzegovina	Fiji	Malaysia	Serbia	
Botswana	Gabon	Maldives	South Africa	
Brazil	Grenada	Mauritius	St. Lucia	
Bulgaria	Iran, Islamic Rep.	Mexico	St. Vincent and the Grenadines	
Chile	Iraq	Montenegro	Suriname	
China	Jamaica	Namibia	Thailand	
Colombia	Jordan	Palau	Tunisia	

[1] For the 2012 fiscal year, low-income economies are defined as those with a GNI per capita, calculated using the World Bank Atlas method, of USD 1,025 or less in 2010; lower middle-income economies are those with a GNI per capita between USD 1,026 and USD 4,035; upper middle-income economies are those with a GNI per capita between USD 4,036 and USD 12,435.

Table A2: Robustness Check 1 - Private Sector investment in Renewable Energy projects in sub-sample

	Dependent variable: Hazard of investment								
Variables	1	2	3	4	5	6	7	8	9
Spell 2-3	-1.049***	-1.137***	-1.121***	-0.771***	-0.788***	-0.178	-0.0149	-0.383*	-0.336
	(0.182)	(0.187)	(0.185)	(0.200)	(0.209)	(0.246)	(0.231)	(0.224)	(0.235)
Spell 4-6	-1.534***	-1.641***	-1.609***	-1.285***	-1.278***	-0.744***	-0.674***	-0.573***	-0.473**
	(0.188)	(0.188)	(0.193)	(0.214)	(0.207)	(0.263)	(0.245)	(0.207)	(0.217)
Spell 7-9	-1.620***	-1.988***	-1.976***	-1.485***	-1.457***	-0.450	-0.131	-0.266	-0.138
	(0.233)	(0.250)	(0.256)	(0.256)	(0.264)	(0.325)	(0.285)	(0.284)	(0.300)
Spell 10-12	-2.075***	-2.221***	-2.236***	-1.762***	-1.739***	-1.089**	-0.568	-0.872**	-0.714**
	(0.349)	(0.339)	(0.323)	(0.363)	(0.379)	(0.467)	(0.363)	(0.344)	(0.354)
Spell 13plus	-1.048***	-1.610***	-1.956***	-1.486***	-1.502***	-0.812***	-0.473*	-0.777***	-0.558*
	(0.168)	(0.148)	(0.170)	(0.222)	(0.231)	(0.260)	(0.279)	(0.276)	(0.294)
Rent (% GDP)		-0.0325***	-0.0378***	-0.0409***		-0.00817	-0.0365**	-0.0493***	-0.0273**
		(0.00516)	(0.00500)	(0.00716)		(0.0114)	(0.0169)	(0.0160)	(0.0111)
Fossil consumption (% of total)		-0.00384**	-0.00954***		-0.00591*	-0.0127**	-0.0195***	-0.0209***	-0.0209***
		(0.00177)	(0.00199)		(0.00346)	(0.00521)	(0.00687)	(0.00432)	(0.00413)
Kyoto (dummy)			0.498***	0.653***	0.315*	-0.262	0.0468	0.332*	0.288
			(0.129)	(0.160)	(0.190)	(0.312)	(0.363)	(0.188)	(0.178)
RE policy (dummy)			0.542***	0.516***	0.509***	-0.272	-0.119	-0.0865	-0.157
			(0.149)	(0.154)	(0.163)	(0.227)	(0.190)	(0.184)	(0.191)
Energy intensity (log)					-0.892***	-0.934***	-1.412***	-1.280***	-1.176***
					(0.227)	(0.231)	(0.217)	(0.186)	(0.189)
Population (log)						0.528***	0.621***	0.571***	0.517***
						(0.0805)	(0.0818)	(0.0632)	(0.0643)
Inflation (annual %)						0.00857	-0.00304	-0.00303	-0.00273
						(0.00601)	(0.00352)	(0.00393)	(0.00328)
Enrollment, tertiary (% gross)						0.0217***	0.0142**	0.0270***	0.0227***
						(0.00394)	(0.00636)	(0.00429)	(0.00442)
Credit (% of GDP)						0.0109***	0.0161***	0.0125***	0.0115***
						(0.00371)	(0.00390)	(0.00285)	(0.00290)
GDP per capita (log)						-0.541***	-0.177**	-0.0979*	-0.113*
						(0.119)	(0.0775)	(0.0576)	(0.0581)
FDI, net inflow(% of GDP)							0.0583***	0.0696***	0.0678***
							(0.0179)	(0.0158)	(0.0152)
CO_2 emissions (log)				.096					
				(0.0983)					
Electricity from oil sources (% of total)				-0.00234					
				(0.00291)					
crude oil price (log)					0.262**	0.876***			
					(0.131)	(0.184)			
Energy imports, net (% of energy use)					0.00220***				
					(0.000489)				
polityIV						0.0171			
						(0.0192)			
Regulatory Quality						0.759***			
						(0.162)			
Rent*spell								0.00783	
								(0.00565)	
Fossil*spell									0.00111**
									(0.000460)
Region	✓						✓		
Observations	1,933	1,570	1,570	1,499	1,530	650	955	987	987
No. of Countries	84	76	76	67	68	67	72	72	72
Time FE	NO	NO	NO	NO	NO	NO	Yes	NO	NO
Log Likelihood	-723.167	-723.167	-693.343	-627.315	-632.371	-278.889	-332.922	-379.339	-376.541
Count R2	0.821	0.778	0.804	0.826	0.822	0.795	0.848	0.821	0.822
Wald Chi2	781.36***	781.36***	840.39***	541.22***	543.69***	337.55***	2301.05***	483.09***	592.85***
AIC	0.832	0.931	0.895	0.852	0.842	0.914	0.804	0.816	0.811

*, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the country level. All numbers in the table were rounded to 3 decimal places.

Table A3: Robustness Check 2 - Private Sector investment in Renewable Energy projects excluding Brazil, China, India and The Philippines

	Dependent variable: Hazard of Investment								
Variables	1	2	3	4	5	6	7	8	9
Spell 2-3	-1.205***	-1.176***	-1.188***	-0.556***	-0.580***	0.0502	0.260	-0.240	-0.235
	(0.196)	(0.205)	(0.204)	(0.204)	(0.216)	(0.263)	(0.257)	(0.241)	(0.244)
Spell 4-6	-1.765***	-1.698***	-1.682***	-0.998***	-1.017***	-0.549**	-0.401*	-0.484**	-0.454**
	(0.196)	(0.184)	(0.193)	(0.184)	(0.177)	(0.275)	(0.244)	(0.223)	(0.223)
Spell 7-9	-1.949***	-2.077***	-2.075***	-1.152***	-1.143***	-0.357	-0.188	-0.234	-0.185
	(0.237)	(0.246)	(0.254)	(0.223)	(0.225)	(0.334)	(0.357)	(0.299)	(0.303)
Spell 10-12	-2.529***	-2.400***	-2.421***	-1.528***	-1.513***	-0.984**	-0.404	-0.908***	-0.851**
	(0.350)	(0.340)	(0.327)	(0.336)	(0.353)	(0.477)	(0.429)	(0.344)	(0.352)
Spell 13plus	-1.838***	-2.174***	-2.601***	-1.613***	-1.722***	-1.226***	-0.799***	-1.205***	-1.121***
	(0.169)	(0.162)	(0.186)	(0.229)	(0.222)	(0.287)	(0.306)	(0.307)	(0.317)
Rent (% GDP)		-0.0329***	-0.0361***	-0.0395***		-0.00538	-0.0293*	-0.0369**	-0.0296**
		(0.00621)	(0.00561)	(0.00768)		(0.0104)	(0.0164)	(0.0175)	(0.0128)
Fossil consumption (% of total)		-0.00792***	-0.0137***		-0.00911**	-0.00743	-0.0136**	-0.0182***	-0.0183***
		(0.00158)	(0.00198)		(0.00371)	(0.00494)	(0.00603)	(0.00466)	(0.00458)
Kyoto (dummy)			0.539***	0.937***	0.436**	-0.626*	-0.0323	0.411*	0.394*
			(0.144)	(0.200)	(0.222)	(0.339)	(0.472)	(0.222)	(0.218)
RE policy (dummy)			0.622***	0.511***	0.506**	-0.201	-0.0415	-0.00909	-0.0269
			(0.169)	(0.196)	(0.207)	(0.225)	(0.207)	(0.197)	(0.199)
Energy intensity (log)				-0.819***	-1.321***	-0.934***	-1.275***	-1.260***	-1.215***
				(0.118)	(0.136)	(0.222)	(0.220)	(0.195)	(0.204)
Population (log)						0.440***	0.501***	0.538***	0.518***
						(0.0844)	(0.0783)	(0.0749)	(0.0758)
Inflation (annual %)						0.0122**	-0.00294	-0.00225	-0.00221
						(0.00534)	(0.00332)	(0.00282)	(0.00271)
Enrollment, tertiary (% gross)						0.0261***	0.0156**	0.0311***	0.0290***
						(0.00421)	(0.00643)	(0.00438)	(0.00454)
Credit (% of GDP)						0.00909**	0.0143***	0.0109***	0.0104***
						(0.00355)	(0.00415)	(0.00281)	(0.00275)
GDP per capita (log)						-0.721***	-0.197**	-0.152**	-0.159**
						(0.107)	(0.0787)	(0.0626)	(0.0650)
Foreign direct investment, net inflows (% of GDP)							0.0620***	0.0722***	0.0714***
							(0.0168)	(0.0162)	(0.0162)
CO_2 emissions (log)				0.139					
				(0.106)					
Electricity from oil sources (% of total)				-0.00476					
				(0.00321)					
Crude oil price (log)					0.363***	1.197***			
					(0.0822)	(0.179)			
Energy imports, net (% of energy use)					0.00233***				
					(0.000532)				
polityIV						0.0266			
						(0.0231)			
Regulatory Quality						0.834***			
						(0.150)			
Rent*spell								0.00273	
								(0.00800)	
Fossil*spell									0.000528
									(0.000536)
Region	✓						✓		
Observations	2,990	2,056	2,056	1,879	1,896	779	1,114	1,148	1,148
No. of Countries	130	111	111	85	85	89	96	96	96
Time FE	NO	NO	NO	NO	NO	NO	YES	NO	NO
Log Likelihood	-856.65	-741.66	-712.87	-587.55	-589.74	-274.89	-321.57	-372.53	-371.98
Count R2	0.896	0.845	0.845	0.880	0.884	0.846	0.879	0.856	0.854
Wald Chi2	600.58***	634.73***	730.75***	570.90***	552.08***	448.17***	1913.9***	549.17***	578.81***
AIC	0.580	0.728	0.702	0.637	0.634	0.752	0.658	0.679	0.678

*, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the country level. All numbers in the table were rounded to 3 decimal places.

Table A4: Robustness Check 3 - Estimation using different clusters

Hazard of Private Sector Investment				
		(1)	(2)	(3)
Variables	Coefficient	Cluster on country	Cluster on income	Cluster on region
Spell 2-3	-0.318	0.231	0.208	0.099
Spell 4-6	-0.564	0.197***	0.129***	0.221**
Spell 7-9	-0.260	0.272	0.268	0.298
Spell 10-12	-0.991	0.34***	0.177***	0.338***
Spell 13plus	-1.342	0.275***	0.116***	0.0891***
Rent (% GDP)	-0.0382	0.014***	0.007***	0.014***
Fossil consumption (% of total)	-0.0183	0.005***	0.002***	0.007***
Kyoto (dummy)	0.0109	0.247	0.336	0.090
RE policy (dummy)	-0.152	0.181	0.263	0.209
Crude oil price (log)	0.42	0.16***	0.0317***	0.132***
Energy intensity (log)	-1.447	0.181***	0.0237***	0.117***
Population (million)	0.615	0.072***	0.041***	0.058***
Inflation (annual %)	-0.00216	0.003	0.002	0.004
Enrollment, tertiary (% gross)	0.0341	0.005***	0.005***	0.003***
Credit (% of GDP)	0.0136	0.003***	0.001***	0.002***
GDP per capita (log)	-0.313	0.090***	0.021***	0.075***
FDI, net inflow (% of GDP)	0.0731	0.016***	0.009***	0.009***
No. of clusters		100	3	6
Log likelihood		-392.54		
Count R2		0.859		
AIC		0.672		

N=1,218. All numbers in the table were rounded to 3 decimal places.

*, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively.

Model estimated is cloglog. Asteriks denote statistical significance of the coefficient estimates for the given standard errors.

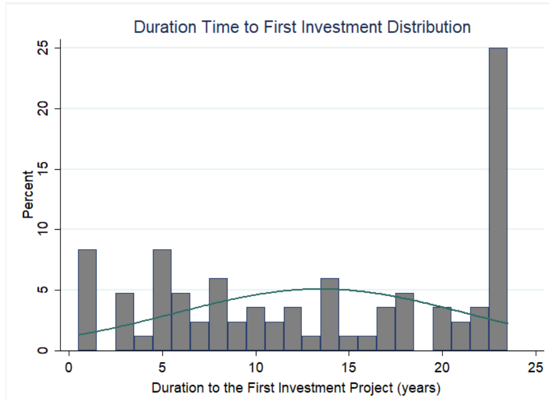
Table A5: Robustness Check 4 - Regression results using the two-parts model

	Dependent variable: Real Investment Cost per Capita (in logs)		
Variables	Probit	OLS	Margins
Rent	-0.0128	-0.0271**	-0.0504*
	(0.0194)	(0.0115)	(0.0301)
Fossil consumption	-0.0367***	-0.00748**	-0.0242***
	(0.00822)	(0.00359)	(0.00714)
Kyoto	-0.864***	-0.268	-0.726
	(0.334)	(0.292)	(0.466)
RE policy	-0.101	-0.164	-0.312
	(0.273)	(0.142)	(0.254)
Oil price (logs)	0.757***	0.358**	0.846***
	(0.246)	(0.161)	(0.276)
Enrollment	0.0247***	0.0103**	0.0253***
	(0.00853)	(0.00491)	(0.00903)
Credit	0.00588	-0.000721	0.000587
	(0.00411)	(0.00258)	(0.00432)
GDPcapita (logs)	0.674***	0.172	0.503**
	(0.190)	(0.118)	(0.231)
Intensity (logs)	-1.056**	-0.00126	-0.329
	(0.426)	(0.204)	(0.351)
Constant	-3.424*	-1.607	
	(1.800)	(1.113)	
Observations	223	223	223
Log likelihood	-78.171	-193.138	
R-squared	0.334	0.166	

*, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the country level. All numbers in the table were rounded to 3 decimal places.

2.7.2 Figures

Figure 2.5: Duration to Private Sector Investment



Notes: The figures are based on countries having private sector investments during 1990-2012. N=1,932

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Chapter 3

Geographical Proximity and Renewable Energy Diffusion: An Empirical Approach[1]

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Abstract

In an era where achieving both economic growth and environmental sustainability is paramount, the role of technology diffusion remains an important one. Recent literature explores the link between geographical proximity and the adoption and diffusion of climate change adaptation policies. However, it has generally focused on a restricted set of developed countries and focused on the diffusion of policy instrument rather than the outcome of the policies. In this paper, we argue that domestic intensity of adoption of renewable energy technologies is likely to be affected by the adoption pattern in neighbouring countries. Additionally, this effect is likely to be stronger when important trade partners are intensive adopters of renewable energies. To test these hypotheses, we construct an index that captures a distance-weighted measure of intensity of renewable energies in other countries and apply a fixed effects framework to a panel of up to 116 countries over the (1980-2012) period. Our results confirm the existence of a geographic spill-over effect on the intensity of adoption of renewable energy technologies. Moreover, this effect is stronger when intensive adopters of renewable energies are also important trading partners, highlighting the relevance of trade channel as a potential catalyst of the diffusion of renewable energies across countries.

Key Words: Renewable Energy, Trade, Geography, Policy adoption, Technology diffusion, Panel fixed effects

JEL classification: C23, O14, O33, F10, Q42, Q55

3.1 Introduction

It is now beyond dispute that the diffusion of new technologies is crucial in a number of ways. Different patterns in the diffusion of technologies have been shown to be an important determinant of total factor productivity (TFP) (Caselli and Coleman, 2001; Ertur and Koch, 2007; Jerzmanowski, 2007; Keller, 2010). Barriers to technology adoption is one of the key factors of differences in *per capita* income across countries (Parente and Prescott, 1994). Specifically, Comin and Hobijn (2010) find that variations in technology adoption can explain approximately 25% of cross-country income differences. Thus the geographic scope of technology diffusion across national borders can have important implications on national comparative advantages and long-run competitiveness (MacGarvie, 2005). Given their importance for economic growth, analyses of patterns of technological diffusion has attracted a lot of attention, with a number of technologies in areas such as telecommunications, transportation and industry being considered (Comin et al., 2012).

The role of clean technology diffusion in achieving both economic growth and environmental sustainability has continued to receive attention in international climate policy debates. The successful and widespread adoption and diffusion of renewable energy technologies are important factors in increasing the sustainability of the global energy landscape. In addition, there is a broad consensus that renewable energy (RE) technology transfer is associated with not only climate change mitigation and resilience efforts, but also with economic outcomes such as energy security and job creation (REN21, 2015). Recently, cross-country technological diffusion to achieve climate-related objectives has been important for the design of “climate clubs" (Vega and Mandel, 2018), which aim to increase gains from linkages and cooperation among a small group of countries. As such, understanding the drivers of diffusion of renewables appears as an important and timely question.

So far, the literature on the diffusion of renewable energy technologies has highlighted a number of important domestic and international determinants of adoption such as income level, domestic energy consumption, renewable energy policies and availability of finance (Aguirre and Ibikunle, 2014; Carley, 2009; Chandler, 2009; Pfeiffer and Mulder, 2013; Popp et al., 2011). The likelihood of adopting cleaner sources of energy depends both on domestic factors and on cross-country policy diffusion. This pattern of diffusion can be induced by competition, imitation or policy learning from neighbouring countries sharing similar geographic, socio-economic, cultural and political factors (Berry and Baybeck, 2005; Gray, 1973; Massey et al., 2014; Matisoff and Edwards, 2014; Shipan and Volden, 2008; Stadelmann and Castro, 2014; Walker, 1969). To date, some elements of the link between geographical proximity and the diffusion of policies fostering the adoption of clean technologies have been studied (Matisoff, 2008; Schaffer and Bernauer, 2014). However, the link between geographic proximity, trade and the intensity of adoption of renewable energy technologies has not been adequately examined. Understanding the spatial patterns of diffusion of green or climate-friendly technologies is not only important from an academic perspective but also from a policy perspective. In theory, there are reasons to believe that the spatial diffusion is more ambiguous in the case of renewable energies.

There are at least three possible reasons why geographical proximity is likely to be important in explaining the observed patterns in the diffusion of renewable energies. First, technologies typically emerge in a specific geographic location or initial markets and it is impossible for technologies to travel beyond their origin without knowledge spreading first. Bento et al. (2018) show that knowledge spillover in energy technologies from innovators to late adopters reduces the uncertainty period associated with new technology before mass commercialisation. A number of authors argue that repeated human interactions favour the diffusion of knowledge (Boschma, 2005; Portes and Rey, 2005; Lutz,1987) and it is believed that human interaction decays with distance (Audretsch and Feldman, 2004; Comin and Hobijn, 2004; Comin et al., 2012). As Von Hipple (1994) and Boschma (2005) illustrate, innovations with a higher degree of tacit knowledge, i.e not easily standardised, codified or transmitted via prototypes depend to a large extent on face to face interactions and communication, which are facilitated by geographical proximity. Even for codified knowledge, the assimilation process of new technology may still require tacit knowledge and thus, spatial closeness is an important factor (Howells, 2002).

A second channel is related to the risk and uncertainty associated with the adoption of a new policy. Being able to observe, exchange information and learn from the adoption process and its success in a comparable environment is likely to increase the likelihood of adopting the policy (Smith and Urpelainen, 2014). Since, in general, countries closer to each other tend to be more similar, witnessing the success of a policy in a nearby country may be a better indication of the domestic implications of the policy. In this sense, neighbouring countries can be seen as laboratories for policy experimentation (Dobbin et al., 2007; Matisoff, 2008). In the case of renewable energies (especially solar and wind), this is likely to be true as neighbouring countries may have a similar potential. Thirdly, adoption of renewable energy technologies has been found to be associated with positive socio-economic spillover effects, such as employment and investments. This implies that the adoption of these technologies may influence the decision to adopt in neighbouring areas as a result of competition for markets, especially if adopting countries are also main trading partners (Schaffer and Bernauer, 2014; Shipan and Volden, 2008).

However, in the case of renewable energies, the relationship is, at least in theory, more ambiguous for four main reasons. First, as mentioned in Ausubel at al. (1998) taking transportation as an example, the wheel represented an improvement compared to travelling by foot and motor cars also represented an improvement in terms of efficiency and time-saving compared to horses. In the case of renewable energies, while renewable energies are desirable from social and environmental perspectives, they may not always be the most economical option to increase electricity supply (especially in oil-rich countries). Moreover, certain renewable energies may also be associated to some specific challenges, such as intermittency and energy storage. Second, energy systems could be characterised by path dependence, where inferior technology can persist because of the lock-in effect resulting from factors such as public policy, rent seeking, and economies of scale (Verdolini and Galeotti, 2011; Unruh, 2000). Third, in the case of renewables, the feasibility of adopting renewable energies is often constrained by the natural endowment of the country. Fourth, since the diffusion of renewable energies is currently on-going, it is unclear whether the speed of diffusion of the renewables will conform to the often-observed S-shaped curve that characterises the speed of adoption of a technology over time.

Previous literature has mostly focused on developed countries (USA, EU, OECD) and on the diffusion of policy instruments rather than on outcomes (i.e electricity generation from renewable sources). To our knowledge, there was no previous attempt that investigates the spatial diffusion of intensity of renewable energy using a global sample and how this diffusion changes over time and with increased contact (through trade)with intensive adopters. In order to investigate this, we construct an index, similar to Comin et al. (2012), that captures a distance-weighted measure of intensity of renewable energies in other countries. We use a fixed effects estimator using a panel of 116 countries over the 1980-2012 period.

Our findings contribute to the literature on adoption of renewable energy technology and to our understanding of how geographical proximity plays a role in the diffusion process. Moreover, in the context of climate change mitigation and adaptation, the paper sheds light on how spatial patterns could shape convergence towards sustainability transitions across the globe. Our results highlight the fact that the scope of diffusion of renewable energy technologies like other types of technology has a spatial aspect. Spatial interdependence does matter in the process of technology adoption/diffusion. We find a positive and significant effect (at the 1% or 5% level) of geographical proximity to adopters on the diffusion of renewable energies. However, we do not find strong support for the hypothesis that this effect increases over time. The results also show that, in addition to a positive spatial diffusion of intensity of renewable energies, this effect is stronger when important trade partners are also intensive adopters of renewable energies. This highlights the relevance of trade links with adopters of renewables as a catalyst of the diffusion of renewable energies, especially in low-income countries.

The rest of the paper is structured as follows. In section 2, we briefly describe recent trends of renewable energy diffusion and the main literature findings on drivers of policy adoption and technology diffusion. Methodology and data are described in section 3. We present the estimation results followed by a discussion of our main findings in section 4. Finally, section 5 concludes.

3.2 Diffusion of Renewable Energy

3.2.1 Recent Trends of Renewable Energies: A brief overview

The number of people without access to electricity fell from 1.7 to 1.1 billion between 2000 and 2016 (IEA, 2017). Despite this, fuel and energy poverty remain important issues in a number of countries, where increases in energy prices lead to an increase in fuel poor households (Walker and Cass, 2007).

In recent years, however, renewable energies have become increasingly important in the energy landscape, with 34% of new connections being provided by renewable energy sources (IEA, 2017). In some countries renewable energy technologies are progressively replacing traditional carbon-intensive sources and investments in renewables have recently surpassed that of fossil fuel and nuclear power combined (REN21, 2018). In addition to this, they are also increasingly crucial to a wider range of environmental, social and economic goals. In a number of developing countries, low incomes often lead to a lack of access to cleaner fuels, perpetuating a dependency on polluting fuels (Pachauri et al., 2004), which have adverse effects on health and productivity (Ekholm et al., 2010; Pachauri and Spreng, 2011).

However, renewable energies are also seen as part of the solution for a number of reasons. First, the current trends in costs of renewable energies could enable countries to hedge against the variability and uncertainty of fossil fuel prices. Second, renewables could lead to an improvement in the access to affordable modern energy. Off-grid systems (e.g. solar home systems), in particular, could represent a solution for those households in areas that are hard-to-reach in the national grid (Barnes et al., 2011). Finally, a transition to cleaner fuels could also lead to health and productivity improvements, which could act as a catalyst for broader human development (Pachauri et al., 2004; Ekholm et al., 2010; Pachauri and Spreng, 2011).

The pattern of investments in the energy sector has also changed significantly in recent years. Renewable energy technologies emerged initially in a few number of developed countries who were engaged in research and development of new technologies. As pointed out by Dechezleprêtre et al. (2011), climate-friendly innovations remained mainly concentrated in OECD countries, especially in Japan, US, Germany and China, which accounted for 67% of the world inventions during the 2000-2005 period. More recently, middle-income countries such as China, Brazil and India, have invested heavily in renewable energies. According to a recent report, developing and emerging countries had higher levels of renewable energy investments in 2017 than developed countries, accounting for 63% of global total investment (REN21, 2018).

3.2.2 Policy Adoption and Technology Diffusion: Theoretical Framework and Empirical Evidence

Theoretical Background

In many respects, changes in adoption pattern for green technologies are likely to be similar to that of technology more generally (Allan et al., 2014; Stoneman and Diederen, 1994). To understand the way in which the diffusion process of innovations unfolds, several studies have examined technology adoption and policy diffusion from different perspectives; historical, behavioural, and economical (Hall, 2004). There is consensus that the adoption pattern of a technology or policy follows an S-shaped curve, which implies that no technology has been adopted by all potential users at the same time.

The S-shaped diffusion pattern is generally used to describe how a new technology is adopted at first by few users and then rapidly increases, until at some point, adoption rates fall as the number of remaining potential adopters decreases. Geroski (2000) presents three theoretical models and the channels that can provide an explanation to the observed S-shaped. In the "epidemic model", access to information about the technology and the interaction between adopters are the driver of the S-shape. The "probit" model is related to differences in the characteristics of adopters and potential adopters. These differences include taste, expected returns to adoption, and the relative cost of adoption. The third model, known as "legitimation and competition model", hypothesises that once a new technology becomes accepted, competition for resources and markets for goods and services using the new technology tend to diminish returns for early adopters. This consequently lowers expected returns by non-adopters and slows the rate of diffusion over time. It is worth emphasizing that these three types of theoretical models are not mutually exclusive.

In terms of mechanisms for policy innovation and diffusion, there are three main mechanisms identified in the literature. The first mechanism occurs through learning from peers, whereby a policy maker will observe and learn from experiences in neighbouring countries/regions. This mechanism has two main advantages. First, the effects of policies in neighbouring countries are policies perceived to be a useful source of information regarding the policy and its likely consequences in-country (Gray, 1973; Massey et al., 2014; Shipan and

Volden, 2008; Smith and Urpelainen, 2014). Second, learning from neighbours about policies or technologies lowers the fixed costs associated with learning about the technology (Feder and O'Mara, 1982; Griliches, 1957; Rogers, 2003).

The second diffusion mechanism, imitation or emulation, refers to copying the actions of peer states and is used to describe the adoption of innovations with a high degree of uncertainty regarding its costs and benefits (Biesenbender and Tosun, 2014). Generally, peer states will either be recognised as being pioneers, would share ideological predispositions, or would be geographically close (Berry and Baybeck, 2005; Lyon and Yin, 2010; Matisoff, 2008; Nicholson-Crotty, 2009). Boschma (2005) argues that geographical proximity is neither necessary nor sufficient for the transfer of innovations, but it facilitates learning and transfer of knowledge. In addition, geographical proximity is often correlated with institutional proximity, as well as certain geographic characteristics important for renewable energies (e.g. annual average of solar radiation).

The third mechanism is through competition, where theorists argue that competition for trade and capital drive states to adopt innovative policies or technologies to gain competitive advantage over proximate states (Berry and Berry, 2007; Boehmke and Witmer, 2004; Massey et al., 2014). As such, countries are likely to adopt the policy if there are positive spillovers from that policy to nearby states (Shipan and Volden, 2008). One common aspect across these mechanisms is that in all mechanisms there is a geographical aspect to the adoption and diffusion of a certain policy or technology.

Empirical Evidence on the link between Diffusion and Geography

Empirically, studies on technology diffusion have highlighted the role of geographical proximity to adopters on the intensity of domestic diffusion of technology. According to Ciccone (1996), technological interdependence across countries exist, implying that the aggregate level of technology in a country does not only depend on domestic factors, but also on the level of technology of neighbours (see Caselli and Coleman, 2001; Ciccone, 1996; Comin et al., 2012; Keller, 2002, 2004) with an intensity which decreases with distance (Ertur and Koch, 2007). Comin and Hobijn (2004) and Comin et al. (2012) find that geographical proximity to early and/or intensive adopters leads to an increase in the intensity of adoption of a given technology. This result is consistent across a set of 20 major technologies using a sample of 161 countries. The authors postulate that this positive spill-over occurs as a result of knowledge transfer from adopters to non-adopters. The knowledge transfer itself is made possible by the interaction between users and non-users of a technology and probability of interaction is assumed to be increasing with geographical proximity. Keller (2002) finds that geographic distance between countries matters for industry productivity gains. The author finds that an additional 1,200 kilometers between two countries is associated with a 50-percent drop in technology adoption, presenting evidence that technology diffusion is geographically localized. The findings also support the hypothesis that localization of diffusion tends to decrease over time.

Authors have also used patent citations as a proxy of knowledge spillover to test for technology diffusion determinants. Jaffe et al. (1993) test if knowledge spillovers are localized. They find that localization of knowledge fades over time as technology diffuses faster across regions and that distance matters for knowledge flows within the USA. Similarly, Eaton and Kortum (1996) looked at determinants of productivity gains in OECD countries, they found that larger geographical distance between innovators inhibits the flow of ideas between countries, while trade relationships enhances it. Using a sample across 147 sub-national regions in Western Europe and North America for the (1975-1996) period, Peri (2005) estimates that geographic distance reduces knowledge flows by 3% for each thousand kilometers travelled, in addition to 19 % loss of knowledge flow if the language between regions is different. MacGarvie (2005) uses a similar dataset on few EU countries and USA for the (1980-1995) period and find that countries which are 10% geographically closer than the average country pair have 1% more citations, however, the effect of geographical proximity diminishes over time.

Regarding energy-related innovations, there are few studies that examine the spatial aspect of technology diffusion. Vega et al. (2018) use the observed pattern of wind technology installations in 195 countries to estimate the determinants of network formation. They find that geographical proximity has a positive impact on diffusion of wind energy technology, but that this effect was statistically insignificant. Similarly, Stadelmann and Castro (2014) only find a significant effect of neighbouring countries' RE adoption on domestic adoption if the peers had the same colonial history. Verdolini and Galeotti (2009) explicitly consider geographical proximity as moderating factor for knowledge flows of energy-related innovations for 38 countries using patent citations. They find that the flow of knowledge is geographically localised and that higher technological and geographical distances decrease the probability of innovation diffusion. Bento et al. (2018) differentiate between initial markets and late adopters in their analysis of spatial diffusion of 15 energy technologies using hazard models. They find that the speed of diffusion is related to the extent of the knowledge spillover in follower markets as well as a number of technology-specific factors. The adoption of RE policy was found to be correlated with EU membership and authors argue that regional memberships facilitate horizontal policy diffusion through peer-group effects (Schaffer and Bernauer, 2014; Stadelmann and Castro, 2014). Smith and Urpelainen (2014) use the average Feed-in Tarriff (FIT) in neighbouring countries as a predictor of a country's FIT in 26 industrialised countries. According to these previous studies, geographical proximity is an important determinant of adopting a new policy or technology.

Other studies look for alternative channels through which knowledge may be transferred. Two important mechanisms cited in the literature are trade and investments of foreign enterprises. Boschma (2005) argues that access to international trade is a way to avoid spatial lock-in. Eaton and Kortum (2002), for instance, argue that traded capital goods embody new technological knowledge and, as such, are a vehicle through which knowledge is transferred. Similar findings were found by Ferrier et al. (2016) where direct and indirect network effects of trade increased the diffusion of 24 technologies in a panel of 145 countries over the (1962-2000) period. Grossman and Helpman (1991) found that productivity increase depends on the stock of local knowledge capital which is an increasing function in the frequency of contacts with the international research and business communities. Additionally, the authors argue that an increase in the number of trade partners is likely to lead to increases in productivity since this is linked to an increase in the frequency of contacts. Caselli and Coleman (2001) find a strong association between trade openness and computer technology adoption for a panel of 155 countries spanning the 1970-1990 period.

Literature has also focused on the impact of trade openness on the adoption and diffusion of environmental-friendly technologies. For example, Vega et al. (2018) found that economic integration is an important determinant of the diffusion of wind energy technology. Reppelin-Hill (1999), using a sample of 30 countries over the 1970-1994 period, found that the diffusion of a cleaner steel production technology was faster in countries with more open trade regimes. Similarly, Wheeler and Martin (1992) found that openness enhances the speed of diffusion of thermomechanical pulp technology, a clean pulping process, in a sample of 60 countries. Overall, there is empirical evidence supporting that trade plays a role in diffusing innovations and technologies, especially when trade partners have a high knowledge stock (Coe et al., 1997; Navaretti and Tar, 2000).

At the micro level, studies have looked at factors affecting diffusion of energy technologies. Socio-economic factors such as education, wealth and prices of substitutes are positively correlated with the use of clean energy sources (Rahut et al., 2017; Mottaleb et al., 2017; Guta, 2018; Lay et al., 2013; Rahut et al., 2014; Sardianou and Genoudi, 2013; Shi et al., 2013). In terms of demographics, female-headed, urban and households as well as younger household heads were found to be more likely to spend more on cleaner energy sources (Mills and Schleich, 2012; Willis et al., 2011; Rahut et al., 2017). Finally, more relevant for this paper is the literature on social, peer and geographic effects at the micro-level. Overall, peer and social effects were found to be significant in the demand for solar photovoltaic panels in the state of Connecticut and in Sweden (Graziano and Gillingham, 2015; Palm, 2017). In another study, Kwan (2012) found that the probability of installing residential solar photovoltaic is influenced by adoption in adjacent ZIP codes, which generally share similar demographics and resource potential.

However, although there are some examples of studies focusing on renewable energies, the majority of literature to date has focused on the adoption of telecommunication (telephone, computers, television, internet), transportation (e.g. Shipping, rails, aviation) and industry (tractors, ATM, electricity). Few studies have empirically examined the effect of geographical proximity to adopters on the intensity of production of renewable energies.

Importantly, renewable energy technologies may be different from other technologies in terms of the pattern of adoption. In the case of other technologies, often they represented a marked improvement on the existing technology and no substitute could deliver the same outcome at a lower cost. For example, trains and cars cannot be easily substituted by horses. In the case of renewable energies, however, there are a number of different options to generate electricity. Additionally, economic incentives to adopt renewables will depend on predefined geographical characteristics and natural resource endowment (e.g. wind, sun radiation) which may be correlated across space. As such, it is not clear that the same geographical pattern of technological adoption should prevail in the case of renewable energies.

As such, we test three hypotheses. First, we test whether geographical proximity to intensive adopters has an effect in the domestic intensity of renewable energies. While the expected sign is more ambiguous for renewable energies, we expect there to be a positive correlation, given that the experience neighbouring countries sharing similar characteristics often offers a good indication of the potential success of the technology domestically. Second, we test whether increased contact (through trade) with intensive adopters has a significant effect on the diffusion of renewable energies. Given the previous literature, we would expect trade with intensive adopters to be positively correlated with intensity of renewable energy domestically. Finally, we also test whether the effect of geographical proximity, if any, increases or decreases over time. For most other technologies, the literature finds a decrease in the effect over time. However, for renewable energies since the technologies have not yet fully diffused and because each individual technology may be at a different stage of maturity and associated with a different speed of diffusion, we argue that this relationship is not so clear (Bento et al., 2018).

3.3 Data and Methodology

3.3.1 Data

Given that our main focus is on the pattern of diffusion intensity of renewable energies, our main dependent variable will be the *per capita* net production of renewable electricity (excluding hydro) in the country[3]. This variable is constructed by dividing the total renewable electricity net generation (Bil kWh) by the total population of a country in a given year. Empirical literature available has proposed two possible measurements for technology adoption. First, the extensive margin of adoption which measures the share of producers who adopt a given technology at a certain point of time (Audtretsch and Feldman, 1996;

[3] We have excluded countries that have never adopted renewable energy technologies during the (1990-2012) period as the dependent variable would be zero.

Gort and Klepper, 1982; Griliches, 1957; Mansfield, 1961). Such measure is usually applied at the micro level. Second, the intensive margin of adoption measures the production of unit of outputs embodying the technology or the share of output produced with the technology (e.g. the share of electricity produced from renewable sources) (Comin and Hobijn, 2004; Comin et al., 2006; Comin and Mestieri, 2013)

We favour the use of the intensive margin measure of renewable energy diffusion to the extensive measure primarily for two main reasons. First, the intensive measure is probably more directly related to climate change mitigation efforts than the share of adopters, since it reflects the extent to which energy systems are shifting towards clean sources and not just counting the number of adopters. And second, using a standard output of the technology (Bil kWh) provides more insights to understanding cross-country differences in production intensity more than just using the share of producers.

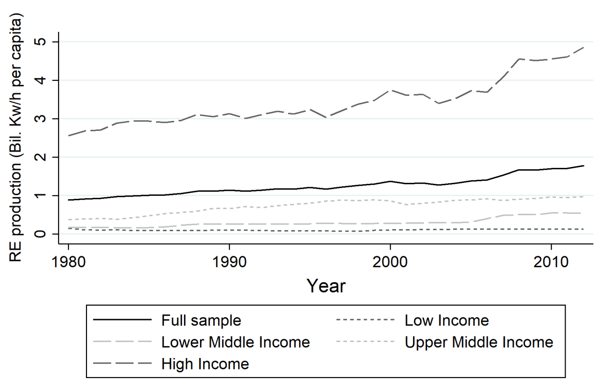
Table 4.1 provides the definitions and sources of the main variables we used. A number of standard control variables in the literature are used such as population size, GDP per capita and carbon dioxide emission. Literature has also pointed out to the role of income level and market size proxied by GDP per capita and population size respectively in adopting alternative energy sources (Aguirre and Ibikunle, 2014; Pfeiffer and Mulder, 2013). In addition, we control for the levels of CO_2 emissions, which can either have a positive or a negative effect on adoption of renewables depending on whether policy makers are concious about environmental concerns or not (Aguirre and Ibikunle, 2014; Marques et al., 2011).

Table 3.1: Variable Definitions and Sources

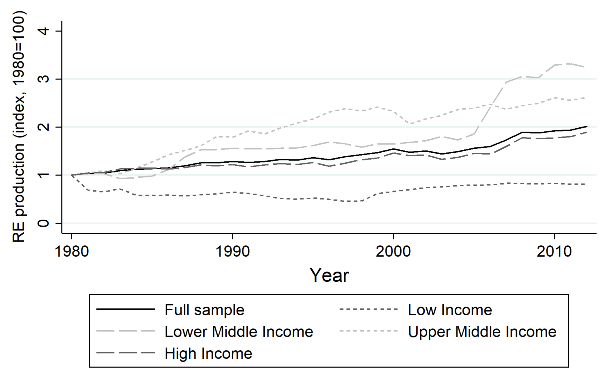
Variable	Definition	Source
Intensity	Total renewable electricity net generation, excluding hydro (Billion kWh)	EIA
Population	Total population (Millions)	WDI: World Bank
GDP per capita	Gross domestic product divided by midyear population (constant 2010 USD)	WDI: World Bank
CO_2 emission	CO_2 emission per capita(metric tons)	WDI: World Bank
Electricity consumption	Electric power consumption growth rate (%)	WDI: World Bank
Electricity from Fossil	Fossil Fuel energy consumption (% total)	WDI: World Bank
Kyoto	Ratification for the kyoto protocol (Dummy)	UNFCCC
RE policy	Adoption of RE policies and measures (Dummy)	IEA
Distance	Bilateral distances between the biggest cities of two countries (1000 Km)	CEPII's geodist database
Trshare	Bilateral flow of trade (1000 USD) as a proportion of total trade	CEPII's TradeProd database, Authors' calculations
DIRE 1 (index 1)	The sum of intensity of renewable electricity production in country j (per capita) divided by distance between country i and country j, for all j countries	Authors' calculation
DIRE 2 (index 2)	The sum of the product of intensity of renewable electricity production in country j (per capita) and bilateral distance between country i and country j, for all j countries	Authors' calculation
Trade Index 1	Distance index 1 weighted by trade shares between country I and J	Authors' calculation
Trade Index 2	Distance index 2 weighted by trade shares between country I and J	Authors' calculation

Figure 3.1 graphically illustrates the trends in renewable energy observed in our dataset. Specifically, it shows that while the intensity of *per capita* net production of renewable electricity is increasing, the growth was uneven across different income groups during the analysed period (1980-2012). While the total renewable energy intensity is higher in developed countries, it has grown at a faster rate in lower- and upper-middle income countries. However, panel (c) also shows the (unweighted) average share of renewable energy as a proportion of the total energy production and consumption, which decreased over time. In general, this pattern can be explained by regulatory, social-cultural and market barriers which slow down diffusion (Sen and Ganguly, 2017; Richie and Roser, 2019). In our sample, the choice of an unweighted average may also drive this trend as in many of the analysed countries, demand for electricity has outpaced renewable energy production.

Figure 3.1: Renewable energy intensity, production and consumption over time

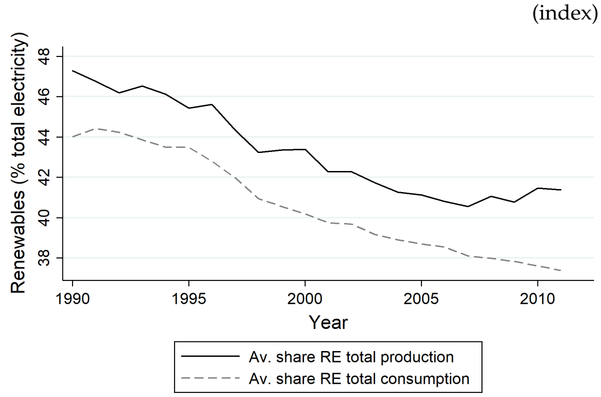


(a) RE production intensity *per capita* by income group



(b) RE production intensity *per capita* by income group

(index)



(c) RE production and consumption (% total)

Notes: For panels (a) and (b) RE production intensity is expressed as Billion Kwh *per capita*. Data on energy intensity is sourced from the IEA dataset and population data from the World Bank development indicators database. Panel (a) displays the unweighted average for the countries included in the balanced sample. In panel (b), the same dependent variable is plotted, but it is index and assigned a value of 1 at the beginning of our data series (1980). Panel (c) shows the percentage of renewable energy production and consumption as a proportion of the total. Once again, a simple unweighted average is used and only countries in the balanced sample are included.

There are several approaches applied in the literature to define “neighbourness" of a state (Mooney, 2001). The most standard one is using the proportion or number of countries sharing a border which adopted a certain policy (Biesenbender and Tosun, 2014; Lutz, 1987; Matisoff, 2008; Mooney, 2001; Stadelmann and Castro, 2014). Other authors have allowed for a more flexible definition of a neighbour by allowing countries to be as far as a certain defined threshold (ex. 100 Km) (Schaffer and Bernauer, 2014) or using the distance between capital cities or length of borders (MacGarvie, 2005).

A crucial part of our analysis rests on the construction of an index which reflects geographic proximity. As such we need an index that is capable of accounting both for the intensity of adoption in a given neighbouring country as well as the distance between the two countries. We primarily use one of the indices suggested by Comin et al. (2012), constructed as follows:

$$DIRE1_{it} = \sum_{j \neq i} \frac{int_{jt}}{dist_{ij}} \tag{3.1}$$

Where $DIRE1_{it}$ is the distance-weighted index of renewable energy intensity we construct using bilateral distances and intensity of renewable energy in other countries. int_{jt} refers to the per capita intensity of production of electricity from renewable energy sources (in Bil. kWh) in country j at time t. $dist_{ij}$ refers to the geographical distance (in 1000 KM) between country i and j. In order to build this index for country i at time t we thus divide the intensity of electricity production per capita in country j at time t by the distance between country j and country i and then sum over all countries, with the exception of country i. Throughout this paper we use the *per capita* version of this index to increase the comparability of the measure between countries. This index is increasing in the intensity variable. However, it increases by a larger amount for countries closer to country i due to the shorter distance between countries i and j. As such our index links all the countries in our data set with each other, but the relative importance of other countries varies with distance. The exogeneity of such a variable can be plausibly advocated by the fact that it is a weighted average of the intensities in a large number of countries, each with a small share (Comin et al., 2012).

In addition to this, we also use an alternative index to test the robustness of our main conclusions. The alternative index we use is also proposed in Comin et al. (2012) and is defined as:

$$DIRE2_{it} = \sum_{j \neq i} int_{jt} * dist_{ij} \tag{3.2}$$

Where index $DIRE2_{it}$ is simply the scalar product of the per capita intensity of electricity production from renewable energies in country j at time t and bilateral distance between the countries.

This index is increasing in the intensity of use of renewables in other countries but increases more for intensive use of renewables in more distant countries[4].

Finally, we are also interested in examining the role of trade in accelerating the geographical pattern of technological diffusion since knowledge flows could be mapped through international trade patterns (Feldman, 1999). As such, we also build an index which weighs the distance-weighted index of renewables 1 ($DIRE1$) by the share of trade flow between the countries. The trade index 1 ($TRI1$) can be constructed as follows:

$$TRI1_{it} = \sum_{j \neq i} STF_{ijt} * \frac{int_{jt}}{dist_{ij}} \tag{3.3}$$

The trade index 1 is the sum of of the interaction term between the share of the trade flow (STF_{ijt})[5] between countries i and j at time t as a percentage of the total trade flow of country i and the distance-weighted index of renewable energy (DIRE 1) given by equation (2) for country i at time t.

For robustness checks, we also construct an alternative trade index 2 ($TRI2$) which is identical to ($TRI1$), but where the distance-weighted index of renewables for country i is given by equation (2). The trade index 2 is defined as:

$$TRI2_{it} = \sum_{j \neq i} STF_{ijt} * int_{jt} * dist_{ij} \tag{3.4}$$

Table 4.2 provides summary statistics of the main variables used in the paper. We use a panel of total renewable electricity net generation covering the (1980-2012) period with up to 116 countries when using the balanced sample and up to 163 countries when we used the unbalanced sample for robustness checks. The country coverage is entirely driven by the availability of data. As can be seen, the sample size for some variables varies due to missing data. For instance, for the trade index, data on trade pairs is only available until 2006.

[4]This point should be noted when comparing the results of table 3 and A2. Distance-weighted index of renewables 1 (DIRE 1) uses distance as inverse but distance-weighted index of renewables 2 (DIRE 2)uses distance as a multiplicative.

[5]In this paper, trade flow is defined as the sum of imports and exports (in 1000 USD.

As a result, for this variable, we have fewer observations. In addition, where we control for other covariates as population, GDP per capita and Co_2 emissions, the sample size is reduced due to incomplete data for all countries during the period of study.

Table 3.2: Summary Statistics

Variables	N	Mean	S.d.	Min	Max
Population (millions)	3828	45.21	146.31	0.04	1350.70
GDP *per capita* (constant 2011)	3520	11358.34	16977.28	130.44	110001.1
Co2 emission *per capita*(metric tons)	3651	3.76	4.82	0.02	38.34
Electricity production from renewables (Bil. kWh)	3828	21.50	64.12	0.00	1003.52
Electricity production from renewables per capita (Billion kWh)	3828	1.25	3.91	0.00	54.33
DIRE index 1 (log) [1]	3828	3.57	0.66	2.26	6.22
DIRE index 2 (log) [2]	3828	7.07	0.36	6.17	8.17
Trade index 1 (log) [3]	2984	2.41	1.95	-6.69	8.52
Trade index 2 (log) [4]	2984	12.58	0.88	7.26	15.37
Electric power consumption growth rate (%)	2909	3.33	9.21	-56.03	120.78
Fossil Fuel energy consumption (% total)	3041	61.58	29.71	0	99.94
School enrollment, secondary (% gross)	2787	65.45	33.12	2.60	161.02
Kyoto	3828	0.29	0.45	0.00	1.00
RE policy	3828	0.35	0.48	0.00	1.00

[1] For each country i, Index 1 sums the *per capita* net renewable energy production in country j divided by the distance (in 1000 KM) between countries i and j for all j countries.

[2] DIRE index 2 stands for distance weighted index of renewable energy intensity. It is calculated as the sum of all pairwise multiplications of distance (in 1000 KM) and per capita renewable production.

[3] The trade index 1 weighs the DIRE index 1 by the bilateral trade share between countries.

[4] The trade index 2 weighs the DIRE index 2 by the bilateral trade share between countries.

3.3.2 Method

In order to test for the role of geographic proximity on the intensity of renewable energy adoption, while controlling for unobserved heterogeneity, we use a fixed effect panel approach. Specifically we estimate the following model 4.2:

$$int_{it} = \boldsymbol{\alpha_i} + \beta_{it} * T + \beta_{it} * T^2 + \beta_1 DIRE1_{it} + \beta_2 TRI_{it} + \beta_3 DIRE1_{it} * T + \boldsymbol{\gamma} \mathbf{X_{it}} + e_{it} \tag{3.5}$$

Where int_{it} denotes the log *per capita* intensity of net renewable electricity generation in country i at time t, $\boldsymbol{\alpha_i}$ denotes a vector of country fixed effects to control for time-invariant country-specific heterogeneity, $\beta_{it} * T$ and $\beta_{it} * T^2$ denote a country-specific time trend and its quadratic form respectively to control for country-specific quadratic trends in the adoption of renewable energies (e.g. technical progress, policies) which may vary by country. $DIRE1_{it}$ is the distance weighted index of renewable energy intensity 1 derived in equation 1, $TRI1_{it}$ is the trade index derived in equation 3, $\mathbf{X_{it}}$ denotes a vector of controls which depend on the specification used in section 3.4. e_{it} is a stochastic error term. All our explanatory variables are in logarithmic form, and thus coefficients are interpreted as elasticities.

Regarding the expected signs of the coefficients in equation 4.2 for the main independent variables, we have three expectations. First, since we argue that geographical proximity is likely to play a role in the inter-country diffusion of technologies, we would expect that the β_1 coefficient on the distance weighted index of renewable energy intensity ($DIRE1_{it}$) to be positive[6]. The second hypothesis relates to the trade channel. We would expect a positive coefficient for our trade index ($TRI1_{it}$) since a stronger effect of diffusion is likely to be observed if a trade partner is an intensive adopter of the technology. The third hypothesis related to the importance of geographical proximity over time is captured by the coefficient on the interaction term ($DIRE1_{it} * T$). The sign of this coefficient could either be positive or negative depending on which part of the S-curve renewables adoption currently is. As such, β_3 will be positive if countries are in the accelerating phase of adoption of renewables (i.e the initial part of S-curve) and negative if the adoption rate is decelerating.

3.4 Main Results and Discussion

Table 3.3 presents the main results. The dependent variable is log per capita total renewable electricity net generation, excluding hydro(Bil kWh). The distance index refers to DIRE1 which is the log of the sum of per capita intensity of renewable electricity production in country j divided by the distance between countries i and j (in 1000 KM) for all j countries.

[6]In the case of using the alternative index $DIRE2_{it}$, the expected sign of the coefficient is negative since the index is a product of distance and intensity of adoption

Regarding the importance of geographical proximity to adopters, the main variable of interest (DIRE1 index) is consistently positive (as expected) and statistically significant at the 1% level in all model specifications of table 3.3. The magnitude of the effect of geographical proximity is even stronger in column (9), when other covariates (GDP per capita and population), country-specific trends, country and time fixed effects are included. This provides strong support for the effect of the geographical proximity as a key driver of adoption of renewable energy in our sample.

We also test whether the effect of geographical proximity becomes more important given trade links with intensive adopters of renewable energy technology. In terms of the trade index in table 3.3, it also displays the hypothesized sign in every specification, and is statistically significant at the 5% level at two of the three specifications. The latter suggest that, in addition to a positive spatial diffusion of intensity of renewables, this effect is stronger when main trade partners are also intensive adopters of renewable energies. This finding is in line with literature where international trade plays a crucial role in technology diffusion, as it increases a country's exposure to innovations and the capability to absorb new technologies (Eaton and Kortum, 2002).

With regards to the interaction of the trend with the distance weighted index of renewable energy, it serves to capture if the importance of spatial interdependence changes over time or not. We note that the significance and the sign of the coefficient of the interaction term ($DIRE1$ *Trend) of table 3.3 is not robust to different model specifications. In columns 2 and 3, we note that it is positive and significant at the 5% or 10% level, which suggests that the effect of spatial interdependence slightly increases over time. However, once country-specific trends are controlled for, the coefficient of the interaction term loses significance and is negative, supporting our initial hypothesis. There are two possible explanations regarding why this result is weaker for renewable energies compared to other technologies. First, in many countries the technology is still in its formative phase (Bento et al., 2018), which is often characterised by uncertainties, testing and creating suitable market conditions before mass commercialisation of the technology. Secondly, since the dependent variable captures electricity generation from a number of different renewable energy technologies, some technologies may be at an advanced stage whereas others may still be in their formative phase in the analysed countries.

With regards to the controls used, consistent with literature on adoption of renewable energy technologies, countries with higher income per capita are more likely to adopt renewable sources for electricity generation (Aguirre and Ibikunle, 2014; Eyraud et al., 2011). A larger domestic market size proxied by population size does not seem to play a role in the intensity of diffusion on renewable energy as the coefficient on population is insignificant, consistent with some findings in the literature (Eyraud et al., 2011). Despite the positive coefficient on the carbon emissions variable which indicates the effect of environmental concerns on adopting alternative clean energy sources, it is nonetheless insignificant.

Regarding the validity of our results, given the correlation between geography and certain renewable energies (e.g. solar), one could argue that the effect captured by the geographical proximity variable could also be capturing the effects of a number of unobserved variables. The approach we use in this paper is able to partially account for this through the inclusion of fixed effects. In addition to this, as argued in Comin et al. (2012), our index choice is also likely to address the potential issue of the endogeneity of the geographical proximity index as each country carries a small weight in the index and because, under the Null hypothesis (of no effect of proximity), the tests are still valid.

However, there is still the possible existence of omitted variable bias. We try to minimize this by including country-specific fixed effects (that deal with time-invariant country-specific unobservable factors), year fixed effects (that deal with time-specific unobservable factors that affect the whole sample) and country-specific quadratic time trends that account for the different pattern of diffusion in different countries. We also show in the appendix that our main results are robust to the inclusion of additional control variables. However, we are not able to control for all variables that could potentially affect the diffusion and, as such, while we argue that our approach reduces the risk of our results being driven by omitted variable bias, its existence can never be completely ruled out.

Table 3.3: Main results - Intensity renewable energy production per capita

	Dependent variable: Log renewable production per capita								
Variables	1	2	3	4	5	6	7	8	9
Distance index 1 (pc, log)	2.475***	2.309***	2.457***	2.418***	2.733***	2.717***	2.532***	2.954***	3.170***
	(0.360)	(0.352)	(0.456)	(0.341)	(0.649)	(0.707)	(0.302)	(0.603)	(0.680)
Distance index 1 (pc, log) * Trend		0.016**	0.016*		-0.023	-0.031		-0.032	-0.05
		(0.007)	(0.008)		(0.027)	(0.038)		(0.027)	(0.038)
Trade index (pc, log)			0.069**			0.022**			0.017
			(0.033)			(0.011)			(0.012)
Population (log)							2.205	2.19	0.996
							(2.026)	(2.001)	(1.346)
GDP pc (log)							0.316**	0.309**	0.2
							(0.146)	(0.144)	(0.147)
Co_2 emissions pc (log)							0.079	0.081	0.085
							(0.060)	(0.061)	(0.062)
Constant	-9.740***	-9.263***	-9.781***	-9.629***	-10.559***	-10.467***	-17.089***	-18.240***	-15.521***
	(1.156)	(1.122)	(1.430)	(1.060)	(1.964)	(2.091)	(5.507)	(5.896)	(4.682)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-specific trend	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observation	3828	3828	2970	3828	3828	2970	2976	2976	2430
Number of periods per country	33	33	27	33	33	27	32	32	27
Number of countries	116	116	110	116	116	110	93	93	90
R-squared (within)	0.369	0.397	0.358	0.798	0.799	0.796	0.799	0.8	0.802

*, **, *** deonte statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the country level. All numbers in the table were rounded to 3 decimal places. All specifications use a balanced sample for the variables included in the specification.

For the specifications where we use the trade index as a control we lose 6 years of data as the data for pairwise trade flows were only available until 2006.

For all specifications that include country-specific trends, we include a quadratic trend.

3.4.1 Robustness Checks

We conducted six robustness checks. First, we estimated the model using the unbalanced sample in table A1 in appendix. The sample size includes a larger set of countries that ranges between 144 and 163 countries. Overall, we find that the sign and magnitude of the distance index remain similar. However, while the significance of the index interaction with trend is positive and significant throughout most specifications, the trade index is only statistically significant in column 3.

Following Comin et al. (2012), table A2 presents the results using the alternative Distance index 2 [7]. Since it is a multiplicative function of distance, as hypothesized, the sign of the coefficient is the opposite of those obtained using our main index. We find a statistically significant relationship in all specifications where we exclude interactions. When interactions are included the effects are still similar in terms of magnitude, but no longer statistically significant.

Third, there are often time lags in the adoption of technology as countries are unlikely to instantaneously react to adoption patterns of neighbouring countries. As a result, we test the sensitivity of our results by running regressions using a one or two years lag of our distance weighted index of renewable energy intensity. Regression results are presented in table A3. We note that the index has a positive and significant effect in all our specifications. In addition, we also note that the interaction with the trend becomes negative and significant when trends and controls are included. However, the trade index becomes insignificant.

The pattern of adoption of renewable energy may be spatially correlated between observation. As a result, we estimate the model adjusting the standard errors to account for spatial autocorrelation and heteroskedasticity. Moreover, the estimates of the country-specific serial correlation are estimated to decay to zero after a lag of 3 years. This method adjusts the standard errors to control for heteroskedasticity, county-specific serial correlation as well as cross-sectional spatial correlation, Hsiang (2010). Table A4 reports the results and the main findings remain unchanged. The coefficient on the DIRE1 index remains positive and significant after controlling for spatial correlation. In addition the trade index as well as the trend

[7] Given by the logarithm of the sum of the product of per capita total renewable electricity net generation in country i and bilateral distance between country i and country j, for all j countries

interaction with the distance index are positive and significant across all specifications.

We disaggregate the sample using the World Bank income classification. Table A5 shows the results of the regression where each income group is expressed in two columns. The distance index is positive and significant across all income groups except for low-income and the results suggest heterogeneity in terms of the coefficients, which are highest in upper and lower-middle income countries. There are at least two possible explanations for the insignificant effect of geographical proximity in low income countries. First, since countries in the same income level tend to be geographically clustered and that adoption rates observed in low income countries are low, (see figure 3.1), there may be no considerable stock of knowledge in neighbouring countries. Second, renewable electricity in a number of low income countries comes from hydro power plants (World Bank, 2018), which is not captured by our dependent variable since it excludes hydro sources. The trade interaction is positive and statistically insignificant for all the sub-samples, but higher in low-middle income countries. High income countries display a positive interaction with time, whereas other income groups display an insignificant negative interaction.

Finally, in table A6 we add a set of controls that have been included in other studies and which could be associated with the diffusion of renewable energy technologies (Pfeiffer and Mulder, 2013) where columns (1-3) include the independent variables in levels and columns (4-6) the variables are lagged by one year. These variables include schooling levels, renewable energy policy instruments (economic and regulatory), kyoto protocol ratification, growth in electricity consumption and fossil fuel dependence. We find that our main results remain when controlling for other factors. We also find no evidence that the either the implementation of policy instruments or the ratification of Kyoto protocol accelerate the diffusion of green technologies. In contrast, high share of electricity production from fossil fuel sources is statistically significant and negative across all models specifications.

3.5 Conclusion and Policy Implications

In this paper, we argue that in the context of renewable energy technology, the diffusion of the technology is affected by the adoption pattern of neighbouring countries and is accentuated by trade relations with intensive adopters of the technology. In examining the effect of geographical proximity to adopters on the diffusion of renewable energies, we constructed two indexes such that the intensity of technology adoption in one country is a function of (1) geographical proximity to an intensive adopter (distance-weighted index of renewable energy intensity), and (2) higher bilateral trade flows (trade index).

From a methodological perspective, we believe the empirical method employed in this paper represents an improvement on previous attempts to quantify the effect of geographic proximity in the policy diffusion literature. By failing to control for time-invariant country characteristics, the geographic diffusion variables could actually be capturing an average effect of a number of different factors. Also, as discussed in Mooney (2001), many of the early studies on policy diffusion provided biased estimates of neighbouring effects. According to the author, these biases were a consequence of the choice of the regional effect variable (share of neighbours adopting a policy) and the statistical method applied (often event history analysis), which did not account for country-specific effects and trends. The methodology we use represents an improvement as the geographic proximity variable and the estimation method we use allow us to account for country fixed-effects and country-specific trends.

The results bear a number of implications. First, they show that, in terms of the role of geographical proximity to adopters, renewable energies seem to exhibit the same pattern as other technologies (Comin et al., 2012). Second, it thus follows that, to a certain extent, we can expect geographical spillovers in the diffusion of renewable energies to occur. Nevertheless, the potential effect of this geographical spillover is inconclusive over time. As such, domestic policies actively promoting the diffusion of renewable energies are likely to remain important. Third, the findings of this paper highlight the importance of trade links with adopters of renewables as catalyst of the diffusion of renewable energies. Economic policies towards innovation and environmental sustainability, can become more effective if they focus on strengthening ties with trade partners or neighbouring countries who had a successful experience implementing policies to encourage the diffusion of the new technology. As such, lowering trade barriers especially in developing countries is likely to trigger faster diffusion of renewable energy technologies, where we find a lower spatial diffusion of technology. This could be reflecting either a low amount of technology-specific knowledge in neighbouring countries, capital constraint, inadequate policy support or other hurdles. In other words, countries may be able to observe the technology being adopted successfully, but not being able to replicate this domestically.

However, our results with regards to the spatial diffusion of renewable energies also highlight a number of areas for future research. First, while our paper finds an effect of geographic proximity to intensive adopters on overall renewable energy intensity, it is not able to assess how these patterns differ across different sources of renewable energies. Given the different nature of each source of renewable energies in in terms of its prospects, marketability and challenges, each source might have a different adoption pattern. Second, while we find differentiated results of spatial diffusion by income level, further analysis could be undertaken to further investigate the determinants of this heterogeneous diffusion pattern. Finally, we tried to capture how interactions between countries, proxied by trade relations, can affect the diffusion of technology adoption in the case of renewable energies. However, future work could further explore whether certain types of interaction have a more pronounced effect on technology diffusion.

3.6 Appendix

Table A1: Robustness Check 1 - Renewable energy production *pc*, Unbalanced Panel

	Dependent variable: Log renewable production per capita, unbalanced								
Variables	1	2	3	4	5	6	7	8	9
DIRE index 1 (pc, log)	2.481***	2.298***	2.443***	2.497***	2.177***	2.151***	2.749***	2.307***	2.569***
	(0.328)	(0.323)	(0.423)	(0.279)	(0.534)	(0.500)	(0.257)	(0.372)	(0.333)
DIRE index 1 (pc, log) * Trend		0.017**	0.016**		0.023	0.018		0.034**	0.016
		(0.007)	(0.008)		(0.027)	(0.028)		(0.017)	(0.014)
Trade index (pc, log)			0.068**			0.031			-0.004
			(0.031)			(0.020)			(0.012)
Population (log)							-0.335	0.433	0.351
							(0.403)	(0.391)	(0.338)
GDP pc (log)							0.189	0.176	0.237*
							(0.131)	(0.130)	(0.124)
Co2 emissions pc (log)							0.008	0.063	0.043
							(0.050)	(0.054)	(0.044)
Constant	-10.048***	-9.530***	-10.028***	-10.137***	-9.201***	-9.055***	-11.830***	-11.973***	-12.945***
	(1.070)	(1.044)	(1.347)	(0.885)	(1.605)	(1.467)	(1.681)	(1.660)	(1.523)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-specific trend	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observation	4628	4628	3518	4628	4628	3518	4068	4068	3214
Number of periods per country	28.393	28.393	23.453	28.393	28.393	23.453	26.416	26.416	22.319
Number of countries	163	163	150	163	163	150	154	154	144
R-squared (within)	0.341	0.37	0.352	0.687	0.69	0.741	0.687	0.694	0.742

*, **, *** deonte statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the country level. All numbers in the table were rounded to 3 decimal places.

For the specifications where we use the trade index as a control we lose 6 years of data as the data for pairwise trade flows were only available until 2006.

For all specifications that include country-specific trends, we include a quadratic trend.

Table A2: Robustness Check 2 - Alternative Index, logs

	Dependent variable: Log renewable production per capita								
Variables	1	2	3	4	5	6	7	8	9
DIRE index 2 (pc, log)	-3.155***	-2.788**	-1.442	-1.042**	-0.792	-0.884	-1.290**	-1.018	-1.574
	(0.847)	(1.089)	(1.031)	(0.480)	(1.074)	(1.062)	(0.562)	(1.048)	(1.156)
DIRE index 2 (pc, log) * Trend		-0.006	-0.001		-0.023	0.03		-0.024	0.077
		(0.015)	(0.019)		(0.076)	(0.076)		(0.075)	(0.084)
Trade index 2 (pc, log)			-0.015			0.009			0.01
			(0.028)			(0.018)			(0.022)
Population (log)							2.665	2.659	1.529
							(2.622)	(2.612)	(2.182)
GDP pc (log)							0.444**	0.443**	0.327*
							(0.179)	(0.177)	(0.182)
Co2 emissions pc (log)							0.048	0.047	0.022
							(0.064)	(0.064)	(0.072)
Constant	19.131***	16.725**	7.937	4.909	3.399	3.497	-2.539	-4.157	1.925
	(5.609)	(7.168)	(6.840)	(3.196)	(6.682)	(6.624)	(6.300)	(9.575)	(7.881)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-specific trend	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observation	3828	3828	2970	3828	3828	2970	2976	2976	2430
Number of periods per country	33	33	27	33	33	27	32	32	27
Number of countries	116	116	110	116	116	110	93	93	90
R-squared (within)	0.181	0.182	0.108	0.752	0.752	0.751	0.748	0.748	0.752

*, **, *** deonte statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the country level. All numbers in the table were rounded to 3 decimal places.

For the specifications where we use the trade index as a control we lose 6 years of data as the data for pairwise trade flows were only available until 2006.

For all specifications that include country-specific trends, we include a quadratic trend.

Table A3: Robustness Check 3 - Lagged index values

	Dependent variable: Log renewable production per capita														
Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Lag 1 DIRE index 1 (pc, log)	2.107***	1.936***	2.022***	1.346***	1.960***	2.074**	1.446***	2.103***	2.412***						
	(0.336)	(0.329)	(0.438)	(0.334)	(0.642)	(0.812)	(0.287)	(0.581)	(0.744)						
Lag 2 DIRE index 1 (pc, log)										1.798***	1.618***	0.601**	1.648**	1.347**	1.757**
										(0.287)	(0.376)	(0.260)	(0.711)	(0.597)	(0.719)
Lag 1 DIRE index 1 (pc) * Trend		0.016**	0.015*		-0.043	-0.092		-0.047*	-0.105*						
		(0.007)	(0.009)		(0.027)	(0.056)		(0.028)	(0.055)						
Lag 1 trade index (pc, log)			0.062*			0.014			0.005						
			(0.034)			(0.013)			(0.014)						
Lag 2 trade index (pc, log)											0.056		0.013		0.005
											(0.035)		(0.015)		(0.016)
Lag 2 DIRE index 1 (pc) * Trend											0.015*		-0.127**	-0.045	-0.126**
											(0.009)		(0.056)	(0.032)	(0.056)
Population (log)							2.628	2.599	1.651					2.625	1.888
							(2.518)	(2.446)	(1.969)					(2.839)	(2.431)
GDP pc (log)							0.350**	0.326**	0.218					0.330***	0.222
							(0.135)	(0.127)	(0.146)					(0.119)	(0.146)
Co2 emissions pc (log)							0.043	0.05	0.053					0.038	0.037
							(0.062)	(0.064)	(0.071)					(0.067)	(0.081)
Constant	-8.558***	-8.117***	-8.431***	-6.334***	-8.027***	-8.184***	-15.025**	-16.576**	-14.473**	-7.573***	-7.183***	-4.100***	-6.530***	-14.392*	-12.839*
	(1.086)	(1.047)	(1.376)	(1.034)	(1.869)	(2.216)	(6.671)	(6.842)	(6.175)	(0.936)	(1.178)	(0.792)	(1.747)	(7.630)	(7.031)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-specific trend	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observation	3712	3712	2860	3712	3712	2860	2883	2883	2340	3596	2750	3596	2750	2790	2250
Number of periods per country	32	32	26	32	32	26	31	31	26	31	25	31	25	30	25
Number of countries	116	116	110	116	116	110	93	93	90	116	110	116	110	93	90
R-squared (within)	0.319	0.349	0.293	0.763	0.764	0.752	0.758	0.76	0.755	0.283	0.243	0.746	0.736	0.737	0.734

*, **, *** deonte statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the country level. All numbers in the table were rounded to 3 decimal places.

For the specifications where we use the trade index as a control we lose 6 years of data as the data for pairwise trade flows were only available until 2006.

For all specifications that include country-specific trends, we include a quadratic trend.

Table A4: Robustness Check 4 - Adjusting for spatial autcorrelation using balanced sample

	Dependent variable: Log renewable production per capita								
Variables	1	2	3	4	5	6	7	8	9
DIRE index 1 (pc, log)	2.475***	2.477***	2.713***	2.418***	2.748***	2.775***	2.562***	2.888***	3.050***
	(0.042)	(0.044)	(0.049)	(0.078)	(0.081)	(0.099)	(0.091)	(0.098)	(0.114)
DIRE index 1 (pc, log) * Trend		0	0.001***		0.002***	0.002***		0.002***	0.002***
		(0.000)	(0.000)		(0.000)	(0.000)		(0.000)	(0.000)
Trade index (pc, log)			0.073***			0.022***			0.015*
			(0.006)			(0.007)			(0.008)
Population (log)							2.036***	1.714***	0.739*
							(0.440)	(0.433)	(0.443)
GDP pc (log)							0.342***	0.330***	0.161*
							(0.069)	(0.069)	(0.093)
Co2 emissions pc (log)							0.078***	0.060**	0.064**
							(0.026)	(0.026)	(0.030)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-specific trend	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observation	3828	3828	2970	3828	3828	2970	3366	3366	2708
R-squared (within)	0.246	0.246	0.269	0.744	0.75	0.762	0.75	0.756	0.765

*, **, *** deonte statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent standard errors that account for spatial correlation (uniformly weighted up to 1000 km) and country-specific serial correlations using a Bartlett window of 3 years. All numbers in the table were rounded to 3 decimal places.

For the specifications where we use the trade index as a control we lose 6 years of data as the data for pairwise trade flows were only available until 2006.

For all specifications that include country-specific trends, we include a quadratic trend.

Table A5: Robustness Check 5 - Disaggregating by income groups using balanced sample

	Dependent variable: Log renewable production per capita							
Variables	High	High	Upper middle	Upper middle	Lower middle	Lower middle	Low income	Low income
DIRE index 1 (pc, log)	1.473***	1.428***	2.992***	2.763***	3.491***	4.169***	3.592	3.335
	(0.506)	(0.449)	(0.618)	(0.709)	(1.095)	(1.023)	(3.204)	(2.953)
DIRE index 1 (pc, log) * Trend	0.024	0.028	-0.021	-0.008	-0.048	-0.107*	-0.133	-0.224
	(0.021)	(0.025)	(0.031)	(0.041)	(0.055)	(0.061)	(0.110)	(0.210)
Trade index (pc, log)		0.036		0.004		0.023		0.074
		(0.022)		(0.015)		(0.025)		(0.062)
Constant	-6.320***	-6.062***	-10.853***	-10.210***	-12.350***	-14.094***	-12.991	-12.137
	(1.856)	(1.564)	(1.811)	(2.064)	(2.922)	(2.672)	(8.476)	(7.642)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-specific trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observation	1089	783	1056	864	1056	837	627	486
Number of periods per country	33	27	33	27	33	27	33	27
Number of countries	33	29	32	32	32	31	19	18
R-squared (within)	0.911	0.875	0.796	0.766	0.852	0.864	0.601	0.714

*, **, *** deonte statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent standard errors. All numbers in the table were rounded to 3 decimal places.

For the specifications where we use the trade index as a control we lose 6 years of data as the data for pairwise trade flows were only available until 2006.

For all specifications that include country-specific trends, we include a quadratic trend.

Countries are classified to four groups according to World Bank income classification using the Atlas method, where low-income economies are those with a GNI per capita of 1,005 or less; lower middle-income economies are those with a GNI per capita between 1,006 and 3,955; upper middle-income economies are those with a GNI per capita between 3,956 and 12,235; high-income economies are those with a GNI per capita of 12,236 or more (World Bank, 2017).

Table A6: Robustness Check 6 - Using more control variables using unbalanced sample

	Dependent variable: Log renewable production per capita					
Variables	*Using level (t)*			*Using lags (t-1)*		
DIRE index 1 (pc, log)	2.141***	2.060***	2.276***	1.431***	1.187***	1.198***
	(0.353)	(0.382)	(0.409)	(0.364)	(0.401)	(0.448)
Population (log)	0.000	0.000	0.000	-0.093	0.544	0.993*
	(0.001)	(0.001)	(0.001)	(0.518)	(0.460)	(0.519)
GDP pc (log)	0.000**	0.000*	0.000*	0.532**	0.582***	0.607**
	(0.000)	(0.000)	(0.000)	(0.217)	(0.221)	(0.238)
Co_2 emissions pc (log)	0.026	0.034	0.012	0.001	0.071	0.079
	(0.024)	(0.024)	(0.022)	(0.072)	(0.080)	(0.058)
Electricity consumption growth (%)	0.13	0.129	0.228	0.188	0.218	0.374*
	(0.117)	(0.120)	(0.170)	(0.163)	(0.160)	(0.218)
Electricity from fossil (% of total)	-0.020***	-0.019***	-0.018***	-0.016***	-0.015***	-0.014***
	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)
Enrollment, secondary (% gross)	0.005**	0.005**	0.005*	0.003	0.003	0.002
	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)
kyoto (dummy)	0.021	0.019	0.039	-0.016	-0.019	0.016
	(0.049)	(0.047)	(0.059)	(0.046)	(0.046)	(0.046)
Renewable Energy Policy (dummy)	-0.013	-0.019	0.033	-0.045	-0.068	0.006
	(0.090)	(0.094)	(0.094)	(0.090)	(0.088)	(0.093)
DIRE index 1 (pc, log) * Trend		0.006	-0.001		0.017**	0.019*
		(0.009)	(0.008)		(0.008)	(0.010)
Trade index (pc, log)			0.076			0.06
			(0.053)			(0.050)
Constant	-8.470***	-8.259***	-9.118***	-10.135***	-11.504***	-12.954***
	(1.222)	(1.282)	(1.385)	(2.706)	(2.645)	(2.896)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Country-specific trend	No	No	No	No	No	No
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Number of observation	2511	2511	1972	2521	2521	1979
Number of periods per country	21.28	21.28	17.451	21.185	21.185	17.513
Number of countries	117	117	112	118	118	112
R-squared (within)	0.437	0.438	0.425	0.367	0.384	0.345

*, **, *** deonte statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent standard errors. All numbers in the table were rounded to 3 decimal places.

For the specifications where we use the trade index as a control we lose 6 years of data as the data for pairwise trade flows were only available until 2006.

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Chapter 4

Greening Industry in Vietnam: Environmental Management Standards and Resource Efficiency in SMEs

Abstract

Over the past decade, enterprises have sought to minimize their ecological footprints and incur the associated added costs through cleaner products and production strategies. Evidence can be gathered to support either the view that adopting environmental management standards (EMS) is a cost burden on firms and is detrimental to competitiveness or that adopting standards increases savings giving firms competitive advantage on the long run. In an effort to resolve this seeming paradox in an emerging country context, the relationship between adopting environmental standard certificates and resource efficiency is examined empirically using a panel sample of 1333 manufacturing SMEs in Vietnam for the (2011-2013) period and applying an instrumental variable approach. The results indicate that certification leads to resource savings by about 2.3% holding other factors constant. Moreover, the paper highlights a number of determinants that should be considered in the design and promotion of environmental certificates, especially in developing countries.

Key Words: SMEs, Environmental Management Standards, Certificate, Manufacture, Resource Efficiency

JEL classification: C26, D22, L15, O31, Q32, Q53, Q53

4.1 Introduction

In recent years, the importance of shifting to more sustainable patterns of consumption and production has been globally recognized. However, such a transition requires a policy that is capable of promoting the adoption of production systems that would enhance the efficient use of resources and reduce the negative externalities associated with the life cycle of product manufacture, whether they be environmental, human health or welfare related. Moreover, fulfilling increasing economic demand and projected increase in global population will continue to be fundamental challenges, especially in view of future resource scarcity concerns (Salim et al., 2018). As such, policy makers have used a wide range of industrial policy instruments, some of which are voluntary and others are mandatory, to hold business operations accountable for pollution and waste management (Borck and Coglianese, 2009; Harrison et al., 2017; Rodrik, 2014). While most success stories of green industrial policies relate to large-scale enterprises in industrialised countries, little is known about the effectiveness of these policies on resource conservation in small and medium-sized enterprises (SMEs) in an emerging country context.

Achieving resource efficiency through the conservation of energy, water, and raw materials is more than just a question of environmental sustainability. Theoretical Approaches to sustainability emphasize the role of adopting environmentally sound technologies in reconciling reductions in resource utilisation and pollution, whilst maintaining economic prosperity and social well-being (Bentley, 2008; Vergragt et al., 2014; Schaltegger and Synnestvedt, 2002). From a technical point of view, these technologies can contribute to the reduction in environmental impacts by maximising the input-output efficiency, i.e higher output per unit of input (Del Río González, 2005; Flachenecker and Rentschler, 2018). Consequently, the environmental impact per unit of output would be less. This means that, resource efficiency can increase the firm's competitiveness through cost reductions or increases in revenues (for example by increased sales resulting from green reputation) (Del Río González, 2005; Porter and Van Der Linde, 1995). Beyond this, promoting environmentally sound production techniques unlocks additional competitive opportunities, as a driver of innovation (Shrivastava,1995) as well as opening new markets for firms in developing countries and higher profits (Darnall et al., 2000; Jaffee and Masakure, 2005; Jacobs et al., 2010; Khanna and

Damon, 1999; Fontagné et al., 2015; Nishitani, 2010, 2011).

Since global emissions from the industrial sector account for 21% of total emissions in 2010 (EPA, 2018), green industrial policies have been at the top of national and international policy agendas, especially in Asia where 52% of industrial emissions in 2010 originated from that region alone (IPCC, 2015). The biggest challenges for these policies are posed by decoupling energy, water, and fuel consumption from manufacturing growth. In practical terms, the most prominent of these policies, are environmental management standards/systems (EMS) certificates[1] that aim to encourage industries to control, minimise and monitor environmental impact of producing goods and preventing ecological damage (Massoud et al., 2010).

Vietnam is an example where such a policy instrument became mandatory on polluting industries of the manufacturing sector, to address environmental degradation. The government of Vietnam has undergone major structural change since the process of economic reform began in 1986, led by industrial transformation and export-led growth strategies (World Bank, 2018). Given the rapid development of industrial sector in Vietnam and projected higher demand on raw material and energy, the government of Vietnam has highlighted the importance of environmental management standards certification as a core element in its National Strategy for Environmental Protection for 2010-2020 (GOV, 2003). Specifically, it aims to increase certification rate of environmental management standards of manufacturing and services enterprise from 50% in 2010 to 80% by 2020. Since 97.6% of enterprises in Vietnam are small and medium-sized enterprises (SMEs) and which account for an estimated 40% of GDP in 2014 and 77% of total employment (Yoshino and Wignaraja, 2015), the rate of compliance of SMEs is likely to determine success or failure of the national plan in environmental protection. In addition, the extent to which EMS certificates contribute to resource efficiency in the manufacturing sector plays a fundamental role in the country's achievement of its cleaner production strategy, which aspires that by 2015, firms adopting cleaner production shall save 5% to 8% of energy, materials and fuels per unit produced (GOV, 2009).

[1]Environmental management standards refer to the set of organizational or technical procedures that the firm undertakes to reduce the environmental impact resulting from its operations (Cramer, 1998) through a systemic process which implements corporate-wide environmental policies, goals and audits (Steger, 2000). The most widely recognised environmental management standard is the ISO 14001 standard developed by the International Organisation for Standardization (ISO) in 1996 (Nishitani, 2010).

In practice, the diversity of local context and heterogeneity of sectors where EMS are being adopted make inference on EMS effectiveness more complex than suggested by literature. Available empirical studies addressing the relationship between environmental policy instruments (such as environmental management standards) and competitiveness, suggest mixed evidence on whether EMS is a burden or a boon to firms (Babakri et al.,2003; Bansal and Bogner, 2002; Endrikat et al., 2014; Jaffe et al., 1995). Moreover, only in recent years, the focus on SMEs environmental management practices in developing and emerging markets has grown due to their non-negligible environmental footprint (Hillary, 2004). The few empirical studies on developing countries typically focus on a set of economic (e.g. export, productivity, working conditions) or financial indicators (e.g. return on assets, returns on equity, profit margins) or study the determinants of EMS adoption (Agan et al., 2013; Campos, 2011; Ferenhof et al., 2014; Gavronski et al., 2008; Nguyen and Hens, 2015; Masakure et al., 2009; Massoud et al., 2010; De Oliveira et al., 2010; Rao et al. 2006; Seiffert 2008; Trifković, 2017). While achieving resource efficiency is claimed to be a by-product of certification, such evidence is empirically lacking on two levels jointly: (1) on small and medium enterprises, which usually face financing or knowledge constraints, and (2) on emerging markets, who rely more on on environmental resources for economic development (Rietbergen-McCracekn and Abaza, 2014)

Given this context, this paper tests if the adoption of environmental management standards certificates by small and medium-sized enterprises (SMEs)[2] in Vietnam contributes to resource efficiency in the manufacturing sector over the 2011-2013 period. In doing so, I construct variable of resource intensity per unit of output, using the aggregated material cost of water, fuel and electricity and total output. With the availability of a rich panel dataset on 1,333 SMEs manufacturing enterprises, I am able to account for heterogeneity across firms, sectors, legal status and locations along with a set of controls. In addition, I apply an instrumental variable approach to control for the possible sources of endogeneity arising for the reverse causality between certificate adoption and resource efficiency.

Three main findings emerge. First, the findings show that adopting EMS certificates among manufacturing SMEs in Vietnam contributes to higher aggregate resource efficiency (i.e less

[2]Enterprises are classified according to the current World Bank and Vietnamese government definition, with small-scale enterprises up to 50 employees, medium-sized enterprises up to 300 (UNU-WIDER).

resource use for each unit of output). The high investment cost needed in installing equipments necessary for EMS certificate as well as the poor level of knowledge on environmental regulations partly explain the low adoption rate of certificates among SMEs in Vietnam. Second, the extent of resource use efficiency differs across the different sources, that is to say that larger resource saving occurred in the consumption of electricity (3.25%) followed by fuel (2.68%) and water (2.2%). Third,receiving government assistance and using larger share of raw material from households contribute to higher resource efficiency.

The rest of the paper is structured as follows. Section 2 provides contextual background on industrial development and on environmental management standard certification scheme in Vietnam. Section 3 presents the main theoretical frameworks on the relationship between environmental policies and firm competitiveness and links those to empirical evidence. Section 4 describes data and estimation strategy. Section 5 presents results and discusses main findings. Finally, section 6 concludes, highlighting the policy implications.

4.2 Background and Context

4.2.1 Industrial Development in Vietnam

In recent years, the rapid industrial development in Vietnam spurred by the Doi Moi (literally meaning *renovation*) economic liberalization and reform in 1986, followed by the country's recent accession to World Trade organization in 2007 (World Bank, 2018) have proved to be a key driver for economic growth and poverty eradication. Although Vietnam's economic development started later than newly industrialised economies of Asia (Hong Kong, China, the Republic of Korea, Singapore)(Asian Development Bank, 2018), its annual per capita GDP growth rate has grown from 2.9% in 1990 to 5.7% in 2017; a rate that exceeds newly industrialised economies (5.1% and 3.85% for the same period). Industry output made up on average 37.6% of GDP at current market prices for the 2000-2017 period compared to 20.5% of GDP from agriculture and forestry (Asian Development Bank, 2018). Similarly, the share of employment in the industrial sector has increased from 22.7% to 33.4% (World Bank, 2018).

Since Doi Moi economic reforms, the emphasis in industrial development had shifted from heavy industry to light industry such as wearing apparel, food and beverages, leather, wood products, electric machinery and fabricated metal products. This reallocation of resources mirrors the country's gradual transformation from a purely command economy to a market oriented one (Frijns et al., 2000; Vu-Thanh, 2017). Currently, light and heavy industrial products and handicraft goods constitute 85% of total export value (GSO, 2019). The majority of industrial production is concentrated in five provinces: Ha Noi and Hai Phong in the North and Ho Chi Minh City (HCMC), Binh Duong, and Dong Nai in the South (GSO, 2019). The Government of Vietnam has set out targets in its Socio-Economic Development Plan, where it aims to reach industrialized nation status by 2020 with a focus on a group of industries, such as machinery and equipment serving agriculture, automobiles and mechanical spare parts, and steel for production (GOV, 2019a). The industrial sector is expected to contribute to 45% of GDP by 2020 and the value of hi-tech industrial products will account for approximately 45% of GDP by 2015 (GOV, 2019b).

4.2.2 Environmental Problems Related to Industrialization

The economic transformation towards industrialisation has placed heavy burden on the environment and provoked growing concerns about the rapid depletion of natural resources, especially air pollution and waste water discharge in resource intensive industries (Frijns et al., 2000), soil degradation and loss of biodiversity (Rodi et al., 2012; Ortmann,2017). Of primary concern is the manufacture of chemicals, fertilizers and leather products due to their impact on air and water pollution (Dore et al., 2008). Major pollution at three river basins (Cau, Nhue-Day and Sai Gon-Dong Nai) located in key industrial zones has already reached alarming levels. Metals, suspended solids and oil discharged into the rivers account for the pollution generated in these rivers. For example, it is estimated that in 2004 about 2,000 industrial enterprises in the Cau river sub-basin involved in the metallurgy, food processing and construction material made up approximately 88% of waste water discharged to the river (MoNRE, 2006). As a result, high concentrations of pollutants as Ammonia, nitrates are found at exceedingly high levels. In addition, the industrial activity is the source of approximately 70% for contribution in sulfur dioxide emission (Hoang et al., 2017)

4.2.3 Environmental Regulations and EMS Certificates

Realizing the urgent need to promote a shift towards more sustainable industrial development pathways and responding to foreign customers' requirement about product quality and environmental footprint, the Government of Vietnam has enacted the Law on Environmental Protection (No. 52/2005/QH11) in 2005 (GOV 2005)[3]. The law aims to provide a foundational framework for managing the country's resources in an environmentally sustainable way (Nguyen, 2012).

Of special interest are the circular No. 2781/TT-KCM (GOV, 1996) and decree No. 80/2006/ND-CP (GOV, 2006) and its amendment No. 21/2008/ND-CP (GOV, 2008), which guide the implementation of several articles of the law. According to these regulations, it is mandatory for firms engaged in specific polluting sectors[4] regardless of legal status to submit an environmental impact assessment (EIA)[5] report of their activities to the State Environmental Protection Agency. Firms are granted the certificate acknowledging satisfaction of environmental standards if they comply with the requirements set forth in the EIA, specifying the environmental factor that firm owners are aiming to treat. These include addressing water pollution, air quality, waste disposal, soil degradation, noise and heat. The certificate is renewable and valid for a period of three years for enterprises using toxic or radioactive waster and for five years for other enterprises. The maximum fines charged on non-compliant firms has increased from 70 million VND in 2004 (Article 8 of Decree No. 121/2004/ND-CP) to 500 million VND in 2009 (Decree No. 117/2009/ND-CP).

Initially, the Ministry of Natural Resources and the Environment (MoNRE) had issued 97 national environmental quality standards (referred to as TCVN) set forth in the Decision No. 2920-QD/MTg in 1996 and which were developed on the basis of regional and international experiences (IISD, 2003). By 2005, the volume of standards has increased to more than 400 national standards that address ambient air, surface and ground water quality, industrial emissions, land and noise (USAID, 2005). Under Vietnamese law, the environment

[3]The first version of the law was adopted in 1993.

[4]The list of eligible sectors are detailed in Decree 29/2011, which include 144 types of activities and excludes those of the recycling and services sectors.

[5]According to Decree no. 175/CP, EIA reports must include the following information: (i) assessment of the present state of the environment in the area of operation of the project or the enterprise; (ii) assessment of the effect exerted on the environment by the operation of the project or the enterprise; and (iii) proposed plan and measures for environmental protection (GOV, 1994).

department and the provincial/municipal People's committees are the institutional entities responsible for granting or revoking certificate of satisfaction of environmental standards.

A central element of evaluating environmental management standards effectiveness lies in their success in creating compatibility between environmental protection goals and firms' profitability. Therefore, adequately understanding the extent of resource saving as a result of EMS certification and its determinants, is worth investigating empirically.

4.3 Theoretical Foundation and Literature Review

4.3.1 Theoretical Framework

One aspect of firm's competitiveness can be realised through efficiency gains related to cost reductions or material productivity, arising from procedural or technological changes (Flachenecker and Rentschler, 2018). In that regards, Koirala (2018) points out to a number of channels through which greening production in SMEs can reduce costs. These channels are; infrastructure efficiency (i.e saving associated with insulation and heating, energy-efficiency lighting), materials savings (i.e materials substitution, materials re-use or recycling), product design (i.e redesign product to reduce packaging costs), and manufacturing efficiency (i.e reduce waste through improved utilisation of by-products and less input per unit) (Koirala, 2018; Jump, 19995).

The debate on the relationship between environmental policy and firm's competitiveness is centred around three main areas; whether, under which conditions and how environmental issues are related to innovation and competitiveness at the firm-level (Iraldo et al., 2009; Ambec and Lanoie, 2008). Accordingly, three theoretical views have emerged regarding the effect between environmental and economic performance of the firm. The first one is referred to as the 'traditionalist' view, and which reflects neo-classical theory (Wagner et al., 2002). This view argues that environmental regulation measures tend to burden firms with higher production costs, while decreasing the marginal benefit of economic performance (Jaffe et al., 1995; Wagner et al., 2001; Ederington and Minier, 2003). The competing view refer to the "porter hypothesis" (Porter, 1991), which suggests that properly implemented environmental management standards can increase firm's comparative advantage and product quality and hence improve competitiveness and corporate image (Babool and Reed, 2010; Lanoie et al., 2009; Porter and Van der Linde, 1995; Klasen and McLaughlin, 1996). Thus, pollution abatement costs are offset by reduction of expenditures on raw material and energy (Ambec and Lanoie, 2008; Wagner et al., 2002). This view is commonly known as the 'revisionist view" (Horváthová,2010).

The third approach known as 'resource-based" view supports the idea that there is no direct obvious link between environmental and economic performance of the firm (Hart, 1995). Competitiveness gains are therefore dependent on capabilities and resources of the enterprise as well as market conditions, such as consumers willingness to pay, business regulations and the available technology (Schaltegger and Synnestvedt, 2002; Hart and Ahuja, 1996).

4.3.2 Empirical Evidence

An extensive amount of research has been carried out that examines environmental management standards, especially ISO 14001 and their relationship to the firm's environmental and financial performance. However, there is limited literature examining the effects of mandatory environmental policy instruments and EMS, in particular, in developing countries in general and in SMEs in particular. Ferenhof et al. (2014) provide a a systemic review on available studies on SMEs environmental and financial performance. Evidence on a causal link between EMS or environmental regulations and resource efficiency is scarce. In addition, available evidence is often based on case studies of enterprises in industrialised countries with inconclusive results.

For example, Arimura et al. (2016) using self reported data of managers in manufacturing firms, find that in the U.S.A, there is no robust evidence that adopting ISO 14001 reduced natural resource usage in manufacturing facilities, while in Japan the probability of reduction is significant and ranges between 0.24-0.56 for natural resource use, 0.35 for waste generation and 0.18 for waste water discharge (Arimura et al., 2008). Zobel (2013) used a t-test to compare the change in resource use for the 1997-2002 period in 2331 manufacturing firms in Sweden. They find that resource use of water and fuels in certified firms has increased by

1% but decreased by 7% in non-certified firms, while energy use has been reduced by 2% and 13% in both groups respectively.

In India, Shetty and Kumar (2017) report insignificant effect of the adoption of voluntary environmental program and environmental efficiency for 49 firms in the cement, steel and power sectors. On the other hand, Singh et al. (2015) find that among 63 SMEs in Delhi and Noida, ISO 14001 certified SMEs achieved a reduction in waste by 25% in the manufacture and services sectors. De Oliveira et al. (2010) mention that only 4.77% of 69 company managers in Brazil reported a reduction in energy, water, gas and fuel consumption after adoption of EMS. A technical assistance program in Palestine deploying cleaner production methods by re-suing chemicals in the leather tanning industry resulted in the reduction of water use by 58% (Nazer and Siebel, 2006). Another cleaner production initiative was implemented in Mexico in 2005-2010 period under the sustainable supplier program for SMES. The results showed major environmental benefits achieved in terms of raw material conservation (426,292 ton), water savings (15,438427 m3) and energy savings (1,102,145 ton CO_2)(Van Hoof and Lyon, 2013). In Malaysia, the cost reduction from material saving or through substitution was on average 16% among 18 firms which adopted EMS since 1998 (Tan, 2005). Kamande and Lokina (2013) measure eco-efficiency of resources (water, fuel oil and electricity) resulting from EMS adoption in a sample of 235 manufacturing firms in Kenya during the 2001-2002 period. They find that EMS adopters are more eco-efficient in the use of water and waste. However, eco-efficiency is insignificant for profitability (Kamande and Lokina, 2013).

Another strand of research has examined if EMS is a burden or a boon to firms' financial performance, mainly in industrialised countries (for full review, see Horváthová 2010; Blanco et al., 2009; Molina-Azorín et al., 2009) with mixed evidence on a win-win situation (Endrikat et al., 2014). Typically, adopting certificates would imply an added costs on firms, in the form of installing new technology, training costs and maintenance fees, which could reduce profitability (Babakri et al.,2003; Bansal and Bogner, 2002; Jaffe et al., 1995; King and Lenox, 2011). Proponents of the 'revisionist" view have found that EMS contribute to better performance when measured on indicators such as Tobin's Q , return on assets (ROA), return on sales (ROS) and stock performance (Dowell et al. 2000; Nishitani, 2011; Ziegler et al., 2007). According to several authors, these positive effects could occur either through

(1) increased market demand; domestically or internationally for environmentally-friendly products (Masakure et al., 2009, 2011; Fontagné et al., 2015; Konar and Cohen, 2001; Bellesi et al., 2005), or (2) improved productivity and innovation (Hart and Ahuja, 1996; Ullah et al., 2014; Trifković , 2017; Delmas and Pekovic, 2013).

The variability in the results of the relationship between environmental management of the firm and its economic performance could be attributed to three main factors. First, data constraints have limited the applicability of estimation techniques to establish empirical/causal relationship between environmental and firm performance, and just relied on correlation tests or ANOVA tests (Wagner, 2001). In addition, self-reported data or subjective judgement on environmental management can distort results. The second factor is related to the research methodology. Often, authors do not control for endogeneity, i.e it could be the case that already successful firms are adopting EMS (Potoski and Prakash, 2005; Schaltegger and Synnestvedt, 2002). In other words, it is hard to distinguish between a ‘treatment effect" and a ‘selection effect" of EMS (Heras-Saizarbitoria et al., 2011). Third, the specific national context in which the different types of environmental management standards are being adopted could influence the results (King and Lenox, 2001; Hudson and Orviska, 2013). For example, the adoption of standards may have different net effect across industries, sectors and even across countries, as Yang et al. (2011) find a positive effect of environment management standards on firm performance in a set developed countries but such effect did not occur in developing countries. As such, other factors like the stringency of environmental regulation, type of industry, size of the firm, market structure, and customer behavior, can affect the relationship between EMS and firm performance.

4.4 Data and Methodology

4.4.1 Data

To examine the impact of adopting national environmental management standards certificate on resource efficiency in SMEs in Vietnam, I use a panel dataset for the years 2011 and 2013 of the Small and Medium Scale Manufacturing Enterprise (SME) survey[6]. The survey is representative at the province level and includes 10 out of the 64 provinces of Vietnam: Hanoi, Ha Tay, Hai Phong, Ho Chi Minh City (HCMC), Phu Tho, Nghe An, Quang Nam, Khanh Hoa, Lam Dong, and Long An. The enterprises surveyed are stratified by ownership type to cover the different legal ownership types, such as household-owned, limited liability, private, cooperative and joint stock ownership. Firms are distributed across approximately 17 manufacturing industry such as: food processing, fabricated metal products, chemicals and manufacturing of wood products.

The analysis is based on the balanced sample of enterprises which have participated in the two rounds of the survey between 2011 and 2013. This limits the sample size to 1,333 only (balanced). Although the wave for 2015 is available, the question on resource cost was not included in this wave,which limits the period of study for 2011 and 2013. In addition, firms in the recycling and service sectors are excluded from the sample as they are exempted from the regulation.

There are several approaches to define and measure resource efficiency at the firm-level. Empirical studies have pointed out that efficiency is achieved by either increasing resource productivity or by reducing resource intensity (Cleveland and Ruth, 1998; Bahn-Walkowiak and Steger, 2015; Flachenecker and Rentschler, 2018; OECD, 2011, 2015). In this paper, I use reported data on real total cost of resources (water, fuel and electricity) for each firm and the total output produced to construct a variable for resource intensity (RI). It is expressed as:

[6]The survey is conducted in collaboration with the Central Institute for Economic Management (CIEM) of the Ministry of Planning and Investment of Vietnam, the Institute of Labour Science and Social Affairs (ILSSA) of the Ministry of Labour,Invalids and Social Affairs of Vietnam, the Development Economics Research Group (DERG) at the University of Copenhagen and the United Nations University World Institute for Development Economics Research (UNU-WIDER).

$$RI_{it} = \frac{C_{it}}{Y_{it}} \tag{4.1}$$

Where C_{it} represents the real total cost of resources in (million 2010 VND) of firm i at time t. Y_{it} is the total output units, such that $Y_{it} > 0$. Table 4.1 provides definitions for the main variables.

Table 4.1: Variables Definitions

Variable	Definition
EMS Adoption (dummy)	Firm adopting environmental management standards certificates
Resource Intensity (million VND/unit)	Resource cost per unit of output
Firm Size	Total Number of regular full time employees
Firm Age (years)	Firm age at the time of survey
Innovation (dummy)	Firm introduced new technology or new product group or modified existing ones
Intermediate Input (% of total sales)	Production output used as intermediate input in manufacturing
Raw Material (%)	The share of raw material from Households
Capital-Labor ratio	The ratio between total real assets and wages
Loan (dummy)	=1 if firm applied for formal loan in previous year
Competition (dummy)	=1 if firm faces competition from same field of activity
Training (dummy)	=1 if firm provides training to new or existing workers
Association (dummy)	=1 if firm is a member of a business association
Capacity (dummy)	=1 if firm can increase production capacity by 25 percent or more
E-trade (dummy)	=1 if firm sells its output via e-trade
Assistance (dummy)	=1 if firm received some sort of government assistance in the previous year
Vintage (%)	The share of machines which are less than 3 years old

Note: VND stands for Vietnamese Dong. 1 USD is approximately equal to 20,000 VND.
Resource cost is the real aggregated cost of water, fuel and electricity.

Summary Statistics

Table 4.2 shows the summary statistics by adoption status of the EMS certificate using the balanced sample. Although the certificate is mandatory by law, compliance rate is only 20% in the sample of SMEs. This is not surprising, given the fact that only 7% of firm owners reported being inspected by technical compliance officers in the previous year. In addition, certified firms tend to be approximately three times larger than non- certified ones, with average labour force size of 29 workers. Consequently, providing training of existing and new workers is likely to be observed in certified firms (27%). A higher share of certified firms have applied for formal loans and are engaged in e-trade for selling their outputs.

Certified firms tend to have a relatively same share of raw material from household as non-certified firms. Increasing shares of raw material from households are important in the context of measuring resource intensity because the use of resources would be different depending on whether the raw material is semi manufactured, recycled or raw. Some aspects related to the distribution of certificates across provinces, legal status and across sectors are shown in figure 4.1. Approximately 40% certified firms in the sample are in the food and beverages sector, followed by the rubber industry (11%) and the fabricated metal products (8.5%). It is noticeable that in general, the share of adoption across sectors has either increased or remained constant over the (2011-2013) period in most sectors. The decrease in certification rate between 2011 and 2013 in some sectors, for example, food and beverages, could be explained by either EMS certificate being revoked or non renewed by firm owner. With regards to the legal status of certified firms, on average two thirds of the certified firms are in the form of household ownership. Over the survey years (2011-2013), several firms have changed their ownership type from household to limited liability, which explains the rise in the certification share for this type of ownership over the survey years. The geographical distribution of certified firms shows concentration in two provinces: Ho Chi Minh city (HCMC)and Hanoi. There is a small share of certified firms which export, although the share has slightly increased between 2011(13%) and 2013 (15%).

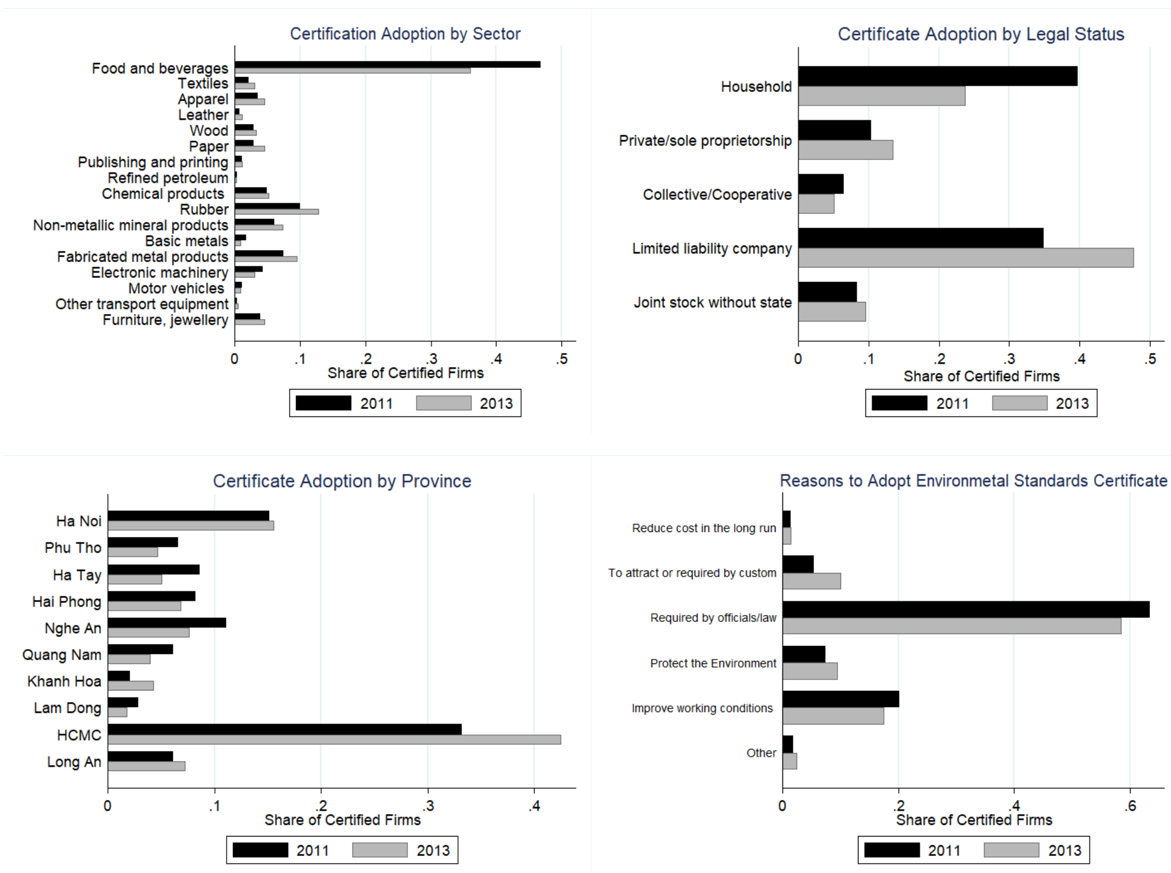
Table 4.2: Summary Statistics by Adoption Status

	All		Non Adopters		Adopters		
VARIABLES	Mean	S.D	Mean	S.D	Mean	S.D	t-test
Resource Intensity (million VND/unit)	18.547	77.096	19.242	76.596	15.672	79.141	0.946
Firm Age (years)	14.106	9.304	14.253	9.307	13.495	9.275	1.666**
Firm size	15.025	25.48	11.721	21.024	28.694	35.727	-14.115
Innovation (dummy)	37.7	48.5	37.7	48.5	37.8	48.5	-0.035
Training (dummy)	19.7	39.7	17.9	38.3	27.0	44.4	-4.693***
Intermediate output (%)	15.777	31.429	15.209	30.946	18.129	33.281	-1.9*
Business Association Member	10.1	30.1	8.20	27.5	17.5	38.1	-6.361***
Loan (dummy)	32.9	47.0	31.5	46.5	38.5	48.7	-3.072***
Raw material from Household (%)	6.336	11.218	6.558	11.528	5.421	9.791	2.072**
Capital-Labour Ratio	20.53	42.43	20.819	44.94	19.334	29.894	0.715
Capacity Utilization (dummy)	30.0	45.8	29.9	45.8	30.3	46.0	-0.134
Selling products via e-trading	6.9	25.4	5.2	22.1	14.3	35.0	-7.383***
Government Assistance (dummy)	13.8	34.5	13.4	34.1	15.2	36.0	-1.072
Equipment Vintage (%)	15.3	26.28	16.0	26.659	14.478	24.662	0.819
Competition (dummy)	0.904	0.295	0.900	0.299	0.919	0.273	0.193
Real net profits (million 2010 VND)	561.615	6046.427	459.278	6563.745	984.302	3069.88	-1.767*
Observations	2666		2147		519		

Summary statistics for dummy variables (1/0) show percentages.
Real values are calculated using annual GDP deflator with 2010 as base year.Calculations are based on the balanced sample for the 2011 and 2013 waves.

It is worth noting that firm owners had different motivations for adopting EMS. About 60% of certificate holders in 2011 and 2013 have reported that the main motivation for certification is the environmental law followed by the objective of improving working condition for labour. There is a smaller share of certified firms who have adopted the certificate based on the belief that certificates are cost saving in the long run, which highlights that firm owners might have the perception that certificates are expensive and will not have direct effect on the firm's profitability in the short run. Firm owners seem to lack good understanding of the requirements of the law as indicated by figure A2 in the appendix. About 40% of firm owners either have no knowledge at all about the law or it is not of their interest.

Figure 4.1: Distribution of EMS Certificate in Manufacturing Sector (2011-2013)



Source: Author's Calculation based on Vietnamese manufacturing SMEs surveys for balanced sample.
Notes: The sample excludes SMEs in the recycling and services sector since the law is non-applicable on those sectors.

4.4.2 Empirical Model

Panel Regression Method

The main objective is to estimate the impact of adopting environmental management standards certificate on firms' resource intensity over the 2011-2013 period. The basic panel model specification is expressed as follows:

$$RI_{it} = \alpha + \boldsymbol{\beta_{it}} * \textbf{EMScertificate} + \gamma \mathbf{X_{it}} + \nu_i + \kappa_s + \rho_p + \varphi_t + \partial_l + e_{it} \tag{4.2}$$

where i, s, p, t are subscripts representing the firm, sector, province and year, respectively; RI_{it} is the dependent variable reflecting firms' resource intensity (i.e resources per unit output). EMS certificate is the key explanatory variable that indicates whether firm has adopted an environmental standard certificate (a dummy variable equals one) or not; and X_{it} is a vector of control variables at the firm-level such as firm size, firm's age, investments in new technology, level of competition, among other variables. Finally, I include the sector dummies (κ_s), province dummies (ρ_p), legal status dummies (ρ_l) and year dummies (φ_t) to capture the industry and location differences that might affect a firm's performance as well as the different forms of legal ownership of the firm. e_{it} is the error term. Robust clustered errors are clustered at the firm level to account for heteroskedasticity.

Problem of Endogeneity: Instrumental Variable Approach

The specified panel regression may suffer from endogeneity for the following reasons. First, some unobserved omitted variables which might influence both the firms' decisions to adopt the environmental standard certificate and the efficiency of resource use, may bias the results. For example, the managerial style and workers' level of education might be related to both certificate adoption and resource efficiency. Second, reverse causality may arise, in the sense that already resource efficient firms may have a higher probability to adopt the certificate. Those firms might possess technical capabilities and willingness to innovate that make them more likely to engage in resource productivity investments (Calantone et al., 2002). This raises the concern that OLS estimates may be biased. To address the endogeneity issue, I apply a two-stage least square (2SLS) procedure using an instrumental variable (IV)(Wooldridge, 2002). The adoption of the environmental certificate is first estimated using all the variables of the resource intensity equation, plus the instrumental variable.

As an instrument, I use an interaction variable between the share of EMS certificate adoption by sector-province-year and business owners' social network. To elaborate, the social network for firm *i* would be business people within the same sector and province with which owner of firm *i* have regular contact with. Information about local competitors' adoption status is likely to be positively correlated with the individual business owner decision to adopt EMS certificate, hence satisfying the relevance condition of an IV. On the other hand, knowledge about other firms certificate adoption is not directly related to the firm's resource intensity, thus satisfying the exogeneity or exclusion restriction condition of an IV. A similar rational for choosing instruments for certificate adoption has been used in the literature, arguing that social networks as a source of information about standards among SMEs, can influence certificates adoption (see Calza et al., 2017; Trifković, 2017; Halila, 2007; Barla, 2007). As such, firm owners located in provinces where there is a higher share of EMS certificate in their sector and with a larger size of social networks are more likely to have access to information about EMS certificate and, thus more likely to adopt the certificate.

4.5 Results and Discussion

4.5.1 The Adoption of Environmental Management Standards Certificate

Table 4.3 presents results on the likelihood of adopting an environmental management standard certificate using different estimation models, including the first stage regression result for the two stage least square equation 4.2 in columns(3-8). All variables used in that equation are included in addition to the chosen instrument. In essence, firm owners will choose to adopt environmental standards if the expected discounted benefits (e.g. profits, savings, exports)exceed the discounted cost of certification. In other words, firm owners will adopt certification if the expected net present value of investment in certificates is positive (Gebreeyesus, 2015). The average cost of investment in equipment as a prerequisite for EMS certification as reported by firm owners varies according to which environmental factor is being treated. For example, figure A1 shows that treatment of lighting, fire heat and air quality require on average investments below 50 million VND[7], while on average, it is around 130 million VND for treating water pollution.

In line with most findings in literature, larger firms are more likely to adopt international standards certificates since they can afford the upfront fixed costs involved in the certification process compared to smaller firms (Nakamura et al. 2001; King and Lenox, 2001; Masakure et al., 2011). Firms which are closer to the technology frontier, who are engaged in selling their products via e-trade are more likely to be certified. The availability of capital as compared to labor is a significantly important variable in the decision to adopt certification as the coefficient on the capital-labor ratio is significant at 1% in all models. This variable could also enable the firm to increase its production capacity by 25% or higher in the next year, which is also significantly positive in explaining adoption.

As expected, the chosen instrument is positive and significant at 1% and 5% significance level in all model specifications, even when controlling for province, year, legal status and sector of the firm. The first stage results show that for firms that are facing competition in their sector and which are members of a business association tend to adopt the certificate. These two variables are considered channels of information through which business owners have better knowledge on certificates and hence they significantly influence firm owners to adopt the certificate.

[7]The exchange rate is approximately 1 USD for 20,000 VND (Vietnamese Dong) for the 2011-2013 (WDI, 2019).

Table 4.3: Determinants of EMS Certificate Adoption

	Dependent variable: Adoption of EMS Certificate							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Probit full Pooled	Probit balance RE	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
EMS certificate: IV			0.364***	0.306***	0.290***	0.199***	0.191***	0.088**
			(0.023)	(0.023)	(0.024)	(0.026)	(0.027)	(0.043)
Firm Age (logs)	0.0889*	0.111		0.005	0.006	0.002	0.001	0.266***
	(0.0497)	(0.120)		(0,012)	(0.013)	(0.013)	(0.014)	(0.091)
Firm size (logs)	0.424***	0.727***		0.102***	0.093***	0.090***	0.096***	-0.011
	(0.0403)	(0.0997)		(0.011)	(0.013)	(0.012)	(0.012)	(0.025)
Innovation (dummy)	-0.143**	0.0873		-0.019	-0.019	0.002	-0.001	0.022
	(0.0603)	(0.124)		(0.015)	(0.016)	(0.015)	(0.016)	(0.022)
Training (dummy)	0.0235	-0.168		0.012	0.002	-0.002	0.001	-0.014
	(0.0630)	(0.120)		(0.018)	(0.018)	(0.017)	(0.018)	(0.023)
Intermediate output (%)	-0.00202**	-0.00130		0.000	0.000	0.000	0.000	-0.000
	(0.000902)	(0.00196)		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Association (dummy)	0.104	0.435**		0.044	0.04	0.057*	0.060**	0.040
	(0.0951)	(0.213)		(0.029)	(0.030)	(0.030)	(0.030)	(0.048)
Loans (dummy)	0.0638	-0.0616		0.008	0.001	0.005	-0.001	-0.016
	(0.0651)	(0.135)		(0.017)	(0.017)	(0.017)	(0.017)	(0.024)
Raw Material from Household (%)	-0.00352	-0.0113**		-0.001**	-0.001*	-0.002***	-0.002***	-0.001
	(0.00256)	(0.00519)		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Capital Labour Ratio	0.168***	0.231***		0.025***	0.031***	0.019***	0.023***	0.014
	(0.0274)	(0.0615)		(0.007)	(0.007)	(0.007)	(0.007)	(0.012)
Capacity (dummy)	0.00907	0.255**		0.030**	0.028*	0.036**	0.034**	0.040*
	(0.0601)	(0.126)		(0.015)	(0.015)	(0.015)	(0.015)	(0.023)
E-trading (dummy)	0.126	0.316		0.067*	0.065*	0.059*	0.066*	-0.022
	(0.101)	(0.194)		(0.036)	(0.037)	(0.036)	(0.036)	(0.045)
Competition (dummy)	0.0102	0.321*		0.034	0.031	0.037*	0.040*	0.030
	(0.0918)	(0.188)		(0.023)	(0.023)	(0.023)	(0.023)	(0.035)
Government Assistance (dummy)	-0.0862	-0.150		-0,029	-0,029	-0,028	-0,026	-0.008
	(0.0759)	(0.159)		(0.020)	(0.020)	(0.021)	(0.020)	(0.026)
Machine Vintage (%)	-4.15e-05	-0.00137		0.000	0.000	0.000	0.000	0.000
	(0.00108)	(0.00224)		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-2.703***	-3.900***	0.068***	-0.221***	-0.297***	-0,061	-0.128*	0.278
	(0.218)	(0.551)	(0.009)	(0.047)	(0.058)	(0.056)	(0.066)	(0.236)
Observations	3,680	2,662	2,666	2,666	2,666	2,666	2,666	2,666
Number of id	2,350	1,332	1,333	1,333	1,333	1,333	1,333	1,333
R-squared Adj.	0,1562		0,143	0,215	0,226	0,25	0,253	
t-stats			15,58	13,23	12,02	7,67	7,14	
Legal FE	YES	YES	NO	NO	YES	YES	YES	NO
Province FE	YES	YES	NO	NO	YES	NO	YES	NO
Sector	NO	YES	NO	NO	NO	YES	YES	NO
Year FE	YES	YES	NO	NO	YES	YES	YES	YES
Firm FE	NO	NO	NO	NO	NO	NO	NO	YES
Kleibergen-Paap F-statistic (weak)			242,606	175,04	144,694	58,978	51,043	4.178
Kleibergen-Paap LM-statistic (under)			134,677	125,488	110,373	45,012	40,296	8.282
Cragg-Donald Wald F-statistic (weak)			445,593	315,33	255,064	99,847	85,719	12,911

*, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the firm level. All numbers in the table were rounded to 3 decimal places. Real values are calculated using annual GDP deflator with 2010 as base year.Calculations are based on the balanced sample for the 2011 and 2013 waves.

4.5.2 The Effect of Certificates on Resource Intensity

Table 4.4 shows the results of the different estimation models, where the log of resource intensity is the dependent variable. Column (1) indicates that the effect of certificates on resource intensity using pooled OLS and without any controls or fixed effects is a decrease of about 0.50%. As resource efficiency could arise from unobserved heterogeneity, such as location of firms and legal status, as well as self selection of firms, i.e resource efficient firms will choose to be certified, fixed effects and instrumental variable approach are applied in columns (2-8). The effect of certificates is consistently negative and significant across most models, with larger effect in model (5) using year, status and province fixed effects.

The magnitude and significance of coefficients of certificates using the 2SLS are different, highlighting the endogeneity bias discussed earlier. The higher resource savings in IV models compared to OLS have also been reported in other studies (Delmas and Pekovic, 2013; Trifković, 2017) indicate that unobserved heterogeneity are correlated negatively with certification of standards. In other words, fixed effects estimates are biased downwards. The results of 2SLS regressions are consistent across the models showing that the adoption of environmental certificates in SMEs in the manufacturing sector contributes to reducing resource intensity by 2.3% on average. The Kleibergen-Paap Wald F-statistics for weak instrument diagnostic as well as the Kleibergen-Paap LM statistic for under-identification test of the instrument show that the instrument is valid.

With regards to the control variables, since larger firms would be expected to have higher output level, the resource costs would also be higher and thus having higher resource intensity. Receiving government assistance is likely to be an important factor in achieving resource efficiency, as it could be allocated for investments in new machinery or providing training, which can potentially decreases resource intensity as shown in columns (4) and (5). Although providing training and being engaged in innovative activities (i.e improving an existing product, introducing new technology or product group) are expected to contribute to overall efficiency of production, this hypothesis is not supported by our results. Contrarily, they lead to higher resource intensity. There are two possible explanations for this finding. First, it could be that the type of training provided is not directly related to the efficient use of resources, for example training related to sales or marketing rather than to production or to minimise waste. Second, it takes time for the adjustment in production lines to accommodate the new product or technology. Thus, longer time series would be needed to capture the dynamic effects of training and innovation on resource intensity.

Since resource costs account for more than 57% of total indirect cost of manufacturing SMEs in Vietnam, competition is argued to motivate firms to cut their resource consumption to enable firms to charge lower prices for their output (Fischer and O'Brien, 2012) which increases their competitiveness. However, this proposition is rejected by our results, where firms facing competition in the sample on average have higher significant resource intensity at 10% significance level, however, this result is not robust. In line with literature on resource efficiency, recycling and using raw materials from households are sources of reducing input cost (Koirala, 2018; Flachenecker and Rentschler, 2018). The results show that higher the share of raw material from households (i.e recycling) is like to minimise resource use per unit of output as indicated by the negative and significant coefficients in most model specifications.

I extend the results abit further and test the impact of EMS certificate on resource intensity disaggregated by type of resource; electricity, fuel and water as it can be argued that implementing environmental standards might lead to a reallocation of resources, i.e less use of water but more of electricity. The results as shown in table 4.5 are consistent across resources, indicating larger efficiency gains in electricity use (3.25%) and fuel consumption (2.68%) per unit of output compared to water consumption (2.2%). Additionally, I test if the magnitude of resource saving is uniform across the different types of industrial activities, since it has been shown that different industries react differently to environmental regulations (Wagner et al., 2002). In this respect, i divided the sectors of the sample into two groups; light industrial activities(includes food and beverages, textile, apparel, wood, paper, leather and paper) and heavy industrial activities. Tables 4.6 shows that EMS certificates have a heterogeneous effect on the extent of resource saving depending on the sector of operation. For example, light industrial activities achieved resource saving ranging between 3.6% - 4.5% depending on model specification at 1% significance level, while in heavy industrial activities, resource savings is between 1.5% and 2.4%.

Table 4.4: Impact of Environmental Management Standards Certificates on Resource Intensity

Dependent Variable: Resource Intensity (logs)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	OLS	Fixed Effects	2 SLS	2 SLS	2 SLS	2 SLS	2 SLS	2 SLS
ESC certificate:IV	-0.505***	-0.247	-2.282***	-2.391***	-3.361***	-1.353*	-0.841	-2.305
	(0.161)	(0.166)	(0.453)	(0.542)	(0.565)	(0.752)	(0.778)	(2.027)
Firm Age (logs)		0.171		0.511***	-0.039	-0.034	-0.098	0.733
		(0.346)		(0,095)	(0,102)	(0,082)	(0,082)	(0.674)
Firm size (logs)		-0.0479		-0.044	0.283**	0.085	0.131	-0.066
		(0.113)		(0.111)	(0.114)	(0.106)	(0.115)	(0.118)
Innovation (dummy)		0.0127		-0.922***	0.379***	0.160*	0.191**	0.056
		(0.0915)		(0.135)	(0.112)	(0.094)	(0.091)	(0.106)
Training (dummy)		0.0631		1.155***	0.281**	0.360***	0.271**	0.019
		(0.111)		(0.164)	(0.139)	(0.117)	(0.117)	(0.128)
Intermediate inputs (%)		-0.000745		-0.002	0.001	-0.001	0.000	-0.002
		(0.00171)		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Association (dummy)		-0.203		0.937***	0.151	0.046	-0.179	-0.107
		(0.187)		(0.228)	(0.204)	(0.173)	(0.174)	(0.225)
Loans (dummy)		0.127		0.713***	0.420***	0.424***	0.305***	0.091
		(0.118)		(0.143)	(0.127)	(0.107)	(0.106)	(0.128)
Raw Material from Household (%)		-0.0130***		0.028***	-0.012***	-0.008*	-0,005	-0.014***
		(0.00422)		(0.006)	(0.005)	(0.004)	(0.004)	(0.005)
Capital Labour Ratio		0.0941		-0.261***	0.113*	0.103**	0.137***	0.126*
		(0.0591)		(0.060)	(0.058)	(0.047)	(0.049)	(0.067)
Capacity (dummy)		-0.0360		0.419***	0.126	0.148	0.043	0.039
		(0.0991)		(0.138)	(0.118)	(0.102)	(0.102)	(0.129)
E-trading (dummy)		0.704***		0.414	0.488*	0.321	0.262	0.662***
		(0.202)		(0.277)	(0.258)	(0.226)	(0.219)	(0.212)
Competition (dummy)		-0.165		0.445**	0.203	0.018	0.006	-0.116
		(0.182)		(0.215)	(0.186)	(0.161)	(0.158)	(0.190)
Government Assistance (dummy)		-0.259**		-0.494**	-0.288*	-0,182	-0,2	-0.269**
		(0.126)		(0.195)	(0.155)	(0.132)	(0.128)	(0.129)
Machine Vintage (%)		-0.000175		-0.005**	-0,003	-0,002	-0.003*	0.000
		(0.00169)		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Constant	-1.005***	-3.575***	-0.659***	-1.959***	-4.530***	-4.745***	-4.923***	-0.827
	(0.0709)	(0.860)	(0.103)	(0.407)	(0.464)	(0.318)	(0.359)	(1.203)
Observations	2,666	2,666	2,666	2,666	2,666	2,666	2,666	2,666
Number of id	1,333	1,333	1,333	1,333	1,333	1,333	1,333	1,333
R-squared	0.004	0.811	0,042	0,044	0,404	0,574	0,597	0,773
Legal FE	NO	YES	NO	NO	YES	YES	YES	NO
Province FE	NO	YES	NO	NO	YES	NO	YES	NO
Sector	NO	YES	NO	NO	NO	YES	YES	NO
Year FE	NO	YES	NO	NO	YES	YES	YES	YES
Firm FE	NO	NO	NO	NO	NO	NO	NO	YES

*, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the firm level. All numbers in the table were rounded to 3 decimal places. Real values are calculated using annual GDP deflator with 2010 as base year.Calculations of the balanced sample are based on 2011 and 2013 waves.

Table 4.5: Disaggregated Resource Intensity by Source: Electricity-Fuel and Water

	Electricity Intensity			Fuel Intensity			water Intensity		
Variables	Model 1a	Model 2a	Model 3a	Model 1b	Model 2b	Model 3b	Model 1c	Model 2c	Model 3c
EMS certificate:IV	-2.723***	-3.780***	-1.203	-2.686***	-3.583***	-1.797**	-1.512**	-2.804***	-1.323
	(0.582)	(0.625)	(0.801)	(0.596)	(0.613)	(0.844)	(0.587)	(0.566)	(0.843)
Firm Age (logs)	0.489***	-0.044	-0.041	0.469***	-0.090	-0.069	0.491***	-0.004	-0.019
	(0.101)	(0.110)	(0.086)	(0.101)	(0.109)	(0.091)	(0.109)	(0.116)	(0.096)
Firm size (logs)	0.015	0.320***	0.095	-0.055	0.272**	0.040	-0.297**	0.058	-0.055
	(0.117)	(0.123)	(0.112)	(0.121)	(0.124)	(0.120)	(0.118)	(0.123)	(0.119)
Innovation (dummy)	-0.846***	0.476***	0.221**	-0.999***	0.324***	0.130	-1.111***	0.275**	0.191
	(0.139)	(0.118)	(0.096)	(0.143)	(0.121)	(0.106)	(0.158)	(0.137)	(0.120)
Training (dummy)	1.194***	0.330**	0.399***	1.213***	0.332**	0.391***	1.140***	0.518***	0.566***
	(0.169)	(0.145)	(0.120)	(0.178)	(0.151)	(0.130)	(0.183)	(0.158)	(0.137)
Intermediate inputs (%)	-0.003	0.001	-0.002	-0.002	0.001	-0.001	-0.005**	-0.002	-0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Association (dummy)	0.923***	0.143	-0.024	0.844***	0.158	0.116	0.863***	0.203	0.041
	(0.236)	(0.219)	(0.176)	(0.250)	(0.221)	(0.192)	(0.288)	(0.263)	(0.248)
Loans (dummy)	0.662***	0.419***	0.369***	0.789***	0.404***	0.483***	0.615***	0.239	0.116
	(0.149)	(0.135)	(0.110)	(0.153)	(0.137)	(0.118)	(0.171)	(0.154)	(0.136)
Raw Material (%)	0.030***	-0.012**	-0.005	0.027***	-0.011**	-0.009*	0.025***	-0.004	-0.004
	(0.006)	(0.005)	(0.005)	(0.006)	(0.005)	(0.005)	(0.007)	(0.005)	(0.005)
Capital Labour Ratio	-0.254***	0.102	0.099**	-0.216***	0.181***	0.128**	-0.322***	0.078	0.083
	(0.063)	(0.063)	(0.050)	(0.065)	(0.062)	(0.051)	(0.071)	(0.067)	(0.056)
Capacity (dummy)	0.456***	0.161	0.150	0.501***	0.199	0.222**	0.431***	0.145	0.135
	(0.143)	(0.127)	(0.105)	(0.148)	(0.126)	(0.112)	(0.161)	(0.143)	(0.127)
E-trading (dummy)	0.379	0.436	0.264	0.406	0.567*	0.397	0.421	0.607**	0.418
	(0.286)	(0.273)	(0.230)	(0.307)	(0.291)	(0.261)	(0.318)	(0.298)	(0.288)
Competition (dummy)	0.613***	0.391**	0.180	0.299	0.077	-0.082	0.288	0.205	0.009
	(0.223)	(0.194)	(0.160)	(0.230)	(0.208)	(0.187)	(0.262)	(0.234)	(0.197)
Government Assistance (dummy)	-0.555***	-0.345**	-0.213	-0.432**	-0.223	-0.118	-0.625***	-0.232	-0.099
	(0.202)	(0.167)	(0.137)	(0.199)	(0.162)	(0.145)	(0.215)	(0.186)	(0.168)
Machine Vintage (%)	-0.005*	-0.002	-0.001	-0.007**	-0.005**	-0.004**	-0.009***	-0.008***	-0.007***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
Constant	-2.773***	-5.230***	-5.782***	-3.064***	-5.802***	-5.617***	-6.867***	-7.134***	-7.078***
	(0.428)	(0.491)	(0.330)	(0.444)	(0.505)	(0.358)	(0.502)	(0.382)	(0.422)
Observations	2664	2664	2664	2466	2466	2466	1966	1966	1966
Number of id	1333	1333	1333	1305	1305	1305	1145	1145	1145
R-squared	0.019	0.360	0.571	0.030	0.373	0.523	0.085	0.395	0.540
Legal FE	NO	YES	YES	NO	YES	YES	NO	YES	YES
Province FE	NO	YES	NO	NO	YES	NO	NO	YES	NO
Sector	NO	NO	YES	NO	NO	YES	NO	NO	YES
Year FE	NO	YES	YES	NO	YES	YES	NO	YES	YES

*, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the firm level. All numbers in the table were rounded to 3 decimal places. Real values are calculated using annual GDP deflator with 2010 as base year.Calculations of the balanced sample are based on 2011 and 2013 waves.

Table 4.6: Disaggregated Resource Intensity by Type of Industrial Activity

Dependent Variable: Resource Intensity (logs)						
	Heavy Industrial Activities			Light Industrial Activities		
Variables	(1)	(2)	(3)	(4)	(5)	(6)
EMS Certificate	-1.505***	-1.588**	-2.407***	-3.611***	-3.465***	-4.475***
	(0.542)	(0.792)	(0.796)	(0.780)	(0.822)	(0.898)
Firm Age (logs)		0.380***	-0.033		0.581***	-0.032
		(0.141)	(0.141)		(0.129)	(0.149)
Firm size (logs)		-0.195	0.019		0.153	0.517***
		(0.181)	(0.192)		(0.145)	(0.139)
Innovation (dummy)		-1.179***	0.064		-0.733***	0.588***
		(0.199)	(0.170)		(0.186)	(0.156)
Training (dummy)		1.622***	0.634***		0.737***	-0.042
		(0.228)	(0.202)		(0.230)	(0.191)
Intermediate inputs (%)		-0.005*	0.001		-0.006	-0.007*
		(0.003)	(0.002)		(0.004)	(0.003)
Association		0.858**	0.196		0.886***	0.104
		(0.356)	(0.324)		(0.316)	(0.262)
Loans (dummy)		0.489**	0.314*		0.845***	0.445**
		(0.215)	(0.179)		(0.194)	(0.179)
Raw material from households(%)		0.024**	-0.011		0.034***	-0.011*
		(0.012)	(0.008)		(0.007)	(0.006)
Capital labor ratio		-0.303***	-0.05		-0.200**	0.257***
		(0.089)	(0.085)		(0.081)	(0.078)
Capacity		0.416**	0.173		0.458**	0.137
		(0.198)	(0.174)		(0.186)	(0.162)
E-trading (dummy)		0.442	0.630*		0.388	0.285
		(0.404)	(0.372)		(0.405)	(0.359)
Competition		0.37	0.116		0.494*	0.308
		(0.322)	(0.261)		(0.291)	(0.260)
Government Assistance (dummy)		-0.689**	-0.353		-0.376	-0.269
		(0.307)	(0.246)		(0.249)	(0.203)
Vintage		-0.009***	-0.003		-0.005	-0.004
		(0.003)	(0.003)		(0.003)	(0.003)
Constant	-0.536***	-0.779	-3.099***	-0.593***	-2.824***	-5.859***
	(0.129)	(0.605)	(0.641)	(0.167)	(0.558)	(0.639)
Observations	1070	1070	1070	1596	1596	1596
Year FE	No	No	Yes	No	No	Yes
Province FE	No	No	Yes	No	No	Yes
Legal FE	No	No	Yes	No	No	Yes

*, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the firm level. All numbers in the table were rounded to 3 decimal places.Calculations of the balanced sample are based on 2011 and 2013 waves.

4.5.3 Robustness Checks

In order to check the validity of the results, i conduct two robustness test. First, I test if firms surveyed in both rounds of the survey in 2011 and 2013 (i.e balanced sample) are not systematically different from firms existing in 2013 round with respect to their resource use. For that purpose, I replicated the main results of table 4.4 using the unbalanced sample, following Verbeek and Nijman (1992) to test for selectivity bias. Intuitively, if there is selection bias, then estimates from the balanced and unbalanced sample will be different. Results in table 4.7 indicate that the average resource saving in the full sample is comparably similar to the estimates obtained using the balanced sample of firms. However, the coefficients on ESM certificate in models 5 and 6 are insignificant when year, province, sector and firm fixed effects are controlled for.

The second robustness check is related to testing the validity of the instrument, which follows the same application as in Trifkovic (2017). The falsification test rests on the idea that if the instrument is significant is explaining the adoption of EMS certificate using a probit model but is statistically insignificant on the dependent variable (resource intensity) for non-adopters of the certificate, then this suggests no direct effect of the IV on the dependent variable other than through EMS certificate adoption. The results of the significance of the IV on EMS has been shown and discussed earlier. Table 4.8 shows that the instrument is insignificant in explaining resource intensity in non adopting firms using both the balanced and unbalanced samples. This results is an indication that the instrument is valid.

Table 4.7: Impact of EMS on Resource Intensity Using Unbalanced Sample

Dependent Variable: Resource Intensity (logs)						
Variables	(1)	(2)	(3)	(4)	(5)	(6)
ESM Certificate	-1.769***	-2.497***	-2.993***	-1.283*	-0.182	-3.592
	(0.395)	(0.572)	(0.586)	(0.760)	(0.835)	(3.208)
Firm Age (logs)		0.341***	-0.028	-0.014	-0.118*	1.084
		(0.079)	(0.081)	(0.067)	(0.067)	(0.981)
Firm size (logs)		0.088	0.271***	0.091	0.1	-0.077
		(0.102)	(0.100)	(0.097)	(0.107)	(0.129)
Innovation (dummy)		-0.995***	0.217**	0.066	0.097	0.082
		(0.115)	(0.099)	(0.085)	(0.082)	(0.123)
Training (dummy)		1.075***	0.197	0.223**	0.158	-0.008
		(0.140)	(0.122)	(0.105)	(0.105)	(0.147)
Intermediate inputs (%)		-0.001	0.002	-0.001	0	-0.002
		(0.002)	(0.002)	(0.001)	(0.001)	(0.002)
Association		0.754***	0.165	0.146	-0.116	-0.047
		(0.191)	(0.174)	(0.155)	(0.154)	(0.274)
Loans (dummy)		0.742***	0.496***	0.517***	0.353***	0.068
		(0.122)	(0.109)	(0.094)	(0.093)	(0.141)
Raw material frrom households (%)		0.039***	-0.001	0.001	0.006	-0.015***
		(0.005)	(0.004)	(0.004)	(0.004)	(0.005)
Capital labor ratio		-0.228***	0.107**	0.086**	0.121***	0.146*
		(0.050)	(0.048)	(0.040)	(0.042)	(0.078)
Capacity		0.286**	-0.025	0.092	-0.055	0.085
		(0.117)	(0.102)	(0.088)	(0.089)	(0.165)
E-trading (dummy)		0.633***	0.569***	0.349*	0.286	0.636***
		(0.232)	(0.213)	(0.190)	(0.184)	(0.229)
Competition		0.328*	0.07	-0.096	-0.093	-0.086
		(0.182)	(0.156)	(0.140)	(0.136)	(0.207)
Government Assistance (dummy)		-0.530***	-0.275**	-0.204*	-0.190*	-0.276**
		(0.159)	(0.132)	(0.116)	(0.112)	(0.138)
Vintage		0	0	0	-0.001	0
		(0.002)	(0.002)	(0.001)	(0.001)	(0.002)
Constant	-0.965***	-1.823***	-4.231***	-4.648***	-4.751***	-0.313
	(0.078)	(0.337)	(0.374)	(0.262)	(0.295)	(1.609)
Observations	4733	3685	3685	3685	3685	3685
Year FE	No	No	Yes	Yes	Yes	yes
Province FE	No	No	Yes	No	yes	No
Legal FE	No	No	Yes	Yes	yes	No
Sector FE	No	No	No	Yes	yes	No
Firm FE	No	No	No	No	No	yes

*, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively. Numbers in parentheses represent clustered standard errors at the firm level. All numbers in the table were rounded to 3 decimal places.Calculations of the balanced sample are based on 2011 and 2013 waves.

Table 4.8: Falsification Test of the Instrument

Dependent Variable: Resource Intensity (logs)		
	Balanced	Unbalanced
VARIABLES	Model 1	Model 2
IV	-0.122	0.0218
	(0.173)	(0.167)
Constant	-4.637***	-4.455***
	(0.389)	(0.323)
Observations	2,147	2,980
Number of id	1,157	1,990
Legal FE	Yes	Yes
Province FE	Yes	Yes
Sector	Yes	Yes
Year FE	Yes	Yes

Models 1 and 2 are fixed effects models on the sample of non-adopters of EMS certificates. Numbers in parentheses represent clustered standard errors at the firm level. All numbers in the table were rounded to 3 decimal places. Controls are the same as in table 4.4.

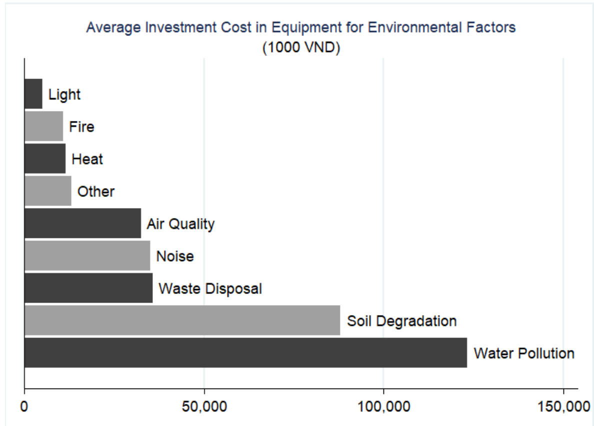
4.6 Conclusion and Policy Implications

The debate of whether environmental management systems/standards contribute to a win-win situation environmentally and economically has been an issue of interest recently. This paper contributes to the literature by examining resource savings outcomes of adopting environmental management standards in the manufacturing sector in Vietnam. Using a two-stage least square (2sls) estimation on a sample of 1,333 SMEs, the results show that adopting EMS certificate in SMEs contributed to resource savings of 2.3% on average during the 2011-2013 period. Additionally, certification was found to have a heterogeneous effect on the extent of resource saving depending on the sector of operation; whether light industry (3.6% - 4.5%) or heavy industry (1.5% to 2.4%). This rate is still below what the government aims to achieve by 2015 as part of its Clean Production Strategy (GOV, 2009).

The findings of the paper are not only relevant in the context of Vietnam, but also to a large number of developing and emerging countries where SMEs tend to have the largest environmental footprint in the country. Further improvements in resource efficiency could be achieved conditional on scaling-up the adoption rate among business owners and improving environmental governance. More importantly, efforts should be made to understand the obstacles facing SMEs to comply to environmental regulations, and design targeted assistance; whether financial or technical that would enhance implementation of EMS certificates. The development of effective information channels and practical guidance on EMS benefits, especially its impact on different aspects of competitiveness should help to support those efforts.

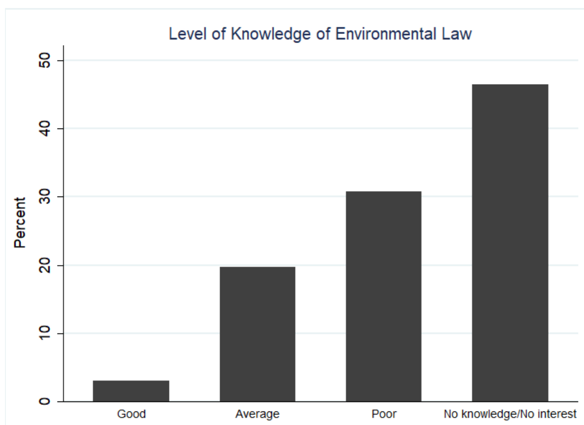
4.7 Appendix

Figure A1: Average Cost of Invetsment (2011-2013)



Source: Author's Calculation based on Vietnamese manufacturing SMEs surveys for balanced sample.
Notes: The sample excludes SMEs in the recycling and services sector since the law is non-applicable on those sectors.

Figure A2: Level of Knowledge on Environmental Law Regulation



Source: Author's Calculation based on Vietnamese manufacturing SMEs surveys for balanced sample.
Notes: The responses are based on subjective evaluation of firm owners on their knowledge of the law.

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