Inequality and Green Innovations

Master Thesis
Department of Economics
University of Zurich

Prof. Dr. Josef Zweimüller
Supervisor: Dr. Christian Kiedaisch

Author:	Stefanie Marty
Course of Studies:	Economics
Student ID:	08-714-065
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Abstract

This paper addresses the impact of income inequality on the incentives to eco-innovate by means of a literature review on the topic and two case studies on the transport sector. Technology, regulation, and market factors are identified as the main determinants of eco-innovations. Thereby, depending on the nature of the change and the technology under consideration these determinants are found to play different roles in incentivizing different kinds of eco-innovations. Thus, income inequality which influences eco-innovations through two effects does not impact all eco-innovations to the same extent. The first effect is the negative indirect political economy effect which is present in any case and likely to be higher in developed than in developing countries. The second effect is the direct positive market size effect. It plays a key role in inducing more radical innovations but also more mature technologies. In contrast, the market size effect is shown to be of lesser importance for incremental changes and for technologies in the early stages of the development process.

The first case study deals with the introduction of electric vehicles in developed countries and thus addresses the case of a relatively immature technology for which the pioneer consumer effect is likely not to work. The second case study introduces the recent concept of frugal innovations emerging from developing countries for which the market size effect plays a crucial role.

Table of Contents

1 Introduction

This paper addresses the impact of income inequality on the incentives to eco-innovate by means of a literature review on the topic and two case studies on the transport sector. Increasing environmental concern and growing income inequality are both very timely issues. Spurred by population growth and rising economic activity, world primary energy use is expected to rise by over 54% by 2030 compared to the 2005 level (OECD, 2011b). In order to address this issue governments and different international organizations stress the need for green growth and provide energy outlooks in which they heavily rely on technological progress to mitigate environmental pressure in the future. They call for more efficient ways of natural resource use, encourage to undertake innovative activities and to foster green markets that allow a balanced economic growth. But the way to a green economy cannot be achieved solely through technological improvement, environmental policies and the development of green markets are equally important in the transition towards a green economy. Thereby, increasing consumers' environmental awareness and associated behavioral changes are crucial changes which need to happen to achieve the ambitious environmental goals. Over the last two decades, especially developed countries have showed progress in this respect, but there is still a long way to go. At the same time, the concern about the rising income inequality in countries across the world has grown in past decades.

These two issues are simultaneously discussed in this paper by analyzing how income inequality affects the incentives to undertake environmentally-friendly innovations in developing as well as developed countries. By means of the available literature on eco-innovations different drivers are found to be the main determinants for the development of green innovations depending on the nature of the change and the technology under consideration. Thereby, regulation, market incentives, and technology play different roles such that income inequality does not influence all eco-innovative activities to the same extent.

The paper is roughly structured into two parts. The first part of the paper consists of a literature review on the topic on inequality and green innovations while the second part analyzes the issue by means of two case studies. In Section 2 the concept of eco-innovation is introduced followed by a quick overview of eco-industries and sectors possessing a high potential for green innovations in Section 3. Section 4 discusses the current literature on the determinants of eco-innovations including technology and environmental regulation, but also the roles of the demand and green consumerism. In Section 5 inequality is introduced and its impact on the incentives to eco-innovate is analyzed. The case studies in Section 6 discuss two different kinds of eco-innovations in the transport sector together with the concept of frugal innovation and the rebound effect. Section 7 concludes.

2 The Concept of Eco-Innovation

The concept of eco-innovation is a very recent as well as a very complex one. There exists no universal definition of eco-innovation, but generally it can be defined as an innovation resulting in a reduction of environmental impact, regardless of whether this impact is intended or not (OECD, 2009). Different concepts which are mostly used interchangeably with “eco-innovation” are used in the literature. To these belong the concepts of “green innovation”, “environmental innovation”, “innovation for sustainable development”, “sustainable innovation”, “sustainable manufacturing”, or “clean technology” (OECD, 2008c, 2009).

Some of the first ones who stressed the indispensability of eco-innovations were Fussler and James in 1996 in their book *Driving eco-innovation* (Fussler and James, 1996). In 1997, in a subsequent article to the book, James defined eco-innovation as “new products and processes which provide customer and business value but significantly decrease environmental impacts” (James, 1997, p.53). From then on, the concept of eco-innovation has gained increased attention among business and policy makers and different definitions for eco-innovation have emerged. All of them differ in some details, but at the same time all of them draw on two important strands of the eco-innovation concept: firstly, the innovative nature and secondly, the environmental compatibility aspect of such innovations, which both will be investigated more closely in the following.

2.1 Innovativeness

The concept of eco-innovation has been developed over time. The Oslo Manual definition of conventional innovation - “the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations” (OECD, 2005, p.46) helps to describe the typology of eco-innovations. According to the OECD definition, an eco-innovation can be analyzed with regards to three different dimensions: The innovation’s target, its mechanism, and its impact (OECD, 2008c). The target and mechanism in turn can be summarized as the innovation’s design which includes on the one side the area the innovation aims at and on the other side the progress that is achieved with an innovation.

It is especially the target in which the various existing definitions for eco-innovation differ. Table 1 shows which dimensions are included in selected definitions for eco-innovation. The table aims to show that there is no universally accepted definition of eco-innovation and that the concept has been evolving constantly over time. One of the first definitions of Hemmelskamp (1996) only included product, process, and organizational innovations. While this definition is in line with the definition of conventional innovations, the more recent definitions such as the one of the OECD (2008c) or the eco-innovation observatory (EIO) (EIO, 2013) include a broad range of targets including social and institutional dimensions but also innovations in whole systems.

The recently added targets are defined widely. In order to describe these changes Rennings (2000) uses the terms “social” and “institutional” innovations, the EIO (2013) calls them “social” and “systematic” while the OECD (2008c) restricts the definition simply to “institutional” innovations with a distinction between formal and informal innovations (see Table 1). Institutional innovations can be divided into the so-called formal and informal institutional ones. According to the OECD (2008c) changes in formal institutions include changes in institutional structures (e.g. laws, regulations, and institutional frameworks) and result out of strategic considerations, while informal institutional changes include amongst others changes in social norms, cultural values, and beliefs that alter social behavior and result in improved environmental conditions. These institutional innovations possess some special characteristics. As Rennings (2000) argues they can be seen as eco-innovative solutions themselves or at least as important determinants of eco-innovations.

Hemmelskamp, 1996	**Rennings, 2000**	**OECD, 2008c**	**EIO, 2013**
Technological: - Products - Processes	Technological	Technological: - Products (Goods and Services) - Processes	Technological: - Products (Goods and Services) - Processes
Non-technological: - Organizational	Non-technological: - Organizational - Social - Institutional	Non-technological: - Marketing - Organizational - Institutional (Formal and Informal)	Non-technological: - Marketing - Organizational - Social - System

Table 1: Target of different eco-innovation definitions

Regarding the mechanism, which measures the kind of progress that is achieved by the introduced innovation, the definitions referred to above agree on the most parts. The consensus implies that not only a creation, but also an implementation of an environmentally-friendly product, process, method, or system is regarded as an eco-innovation. The OECD definition (2008c) reflects this consensus with including the four following categories in its definition of eco-innovation: modification, redesign, alternatives, and creation. The Oslo Manual but also other definitions stress that innovations include more than the sole creation of new ideas. In their work about sustainable innovation Charter and Clark (2007, p.9) define innovation as “the successful exploitation and commercialization of new ideas. It is far more than the common perception that innovation is only about new ideas or research and development (R&D)”.

2.2 Environmental Compatibility

The effect an eco-innovation has on environmental conditions is addressed by the impact and is a result of the innovation’s design. As shown in Table 2 different definitions of eco-innovation address the environmental aspect differently but do not necessarily contradict. Observable is also the development over time as the definitions have broadened. While at first the focus was put on the reduction of the environmental impact, more recent definitions also point to the necessity of adopting a more sustainable lifestyle (e.g. EIO, 2013).

The most elaborated definitions in this respect are the ones of the OECD (2008c) and of Kemp and Pearson (2007). Both regard any innovation that has environmental benefits compared to available alternatives as eco-innovations. As stated by the OECD (2008c) when adopting this interpretation, an eco-innovation can only be distinguished from a conventional innovation by its impact on the environment compared to an available alternative. This view of classifying any innovation that harms the environment less than currently available alternatives as an eco-innovation is mostly acknowledged in the literature today. Interesting in this manner is that the eco-innovation does not need to be motivational-based. By adopting this definition, the performance □whether an innovation leads to environmentally-friendlier outcomes than any available alternative □and not the motivation behind the innovation should decide over whether the innovation is regarded as eco-innovation or not. This distinction between motivation and performance is also crucial when assessing the eco-industries and sectors with high potential for green innovations in Section 3.

Hemmelskamp, 1996	**Rennings, 2000**	**OECD, 2008c**	**EIO, 2013**
□□ aim at reducing the negative environmental impacts.□	□□ contribute to a reduction of environmental burdens or to ecologically specified sustainability targets.□	□□ lead to environmental improvements compared to relevant alternatives.□	□□ reduce the use of natural resources and decrease the release of harmful substances.□

Table 2: Impact of different eco-innovation definitions

2.3 Definitions

There does not exist a universal definition for the concept of eco-innovation in the literature. The two following are two elaborated recent definitions. Thereby, when adopting these definitions the broad target, mechanism, and design are responsible that the majority of firms innovating will be regarded as eco-innovators. The following analysis will not be based on a specific definition, but much more build on the broad concept of eco-innovation.

□*Eco-innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives*□.

(Kemp and Pearson, 2007, p.7)

"... *the creation of new, or significantly improved, products (goods and services), processes, marketing methods, organisational structures and institutional arrangements which - with or without intent - lead to environmental improvements compared to relevant alternatives*". (OECD, 2008c, p.19)

Figure 1 shows the typology of eco-innovations analyzed by means of the three dimensions – target, mechanism, and impact – which the OECD definition (2008c) identified to be crucial for the classification of eco-innovations. It can be seen that the bigger the change the eco-innovation consists of, the higher the potential for environmental benefits. Further, those innovations that have only recently been acknowledged as eco-innovations - organizational and institutional ones – possess a higher potential for environmental benefits than such innovations targeted at conventional levels.

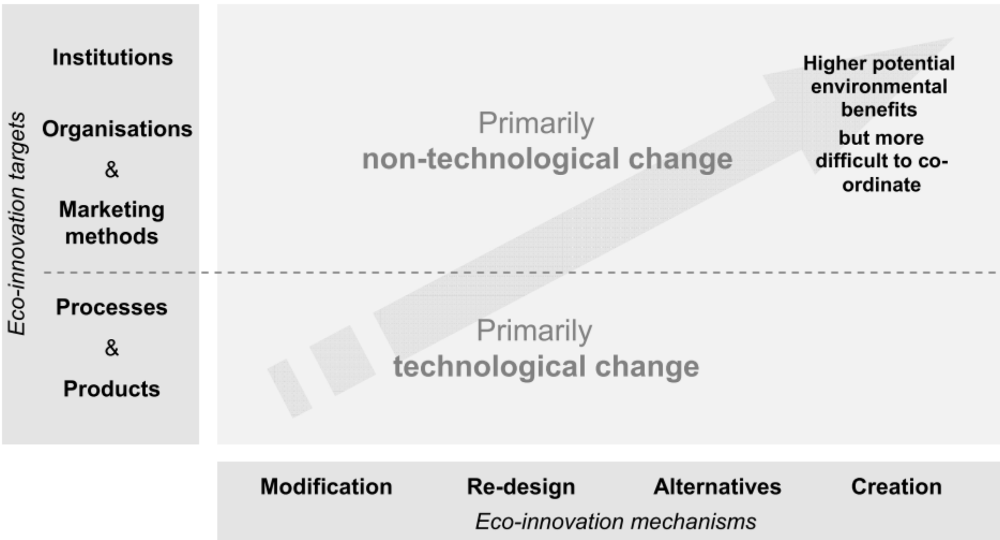

Figure 1: The typology of eco-innovations Source: OECD, 2009, p.46

3 Industries and Sectors

Having an understanding of the concept of eco-innovation I turn to industries and sectors heavily involved in innovating towards a greener economy, but also to those possessing a big potential to do so. The introduction of eco-innovations in markets can be broadly divided into two segments labeled as "core eco-industries" and as "connected eco-industries" (Ecorys and IDEA, 2009). While the "core eco-industries" relate to markets for environmental goods and services, the latter ones refer to more general eco-innovations including process, product, and systemic innovations across different economic aspects aiming at reducing resource use (EIO, 2012). The majority of the several existing studies trying to quantify eco-innovations focus on innovations in goods and services in the "core eco-industries" mostly labeled simply as "eco-industries". Adopting this notation of the EIO, I will use the term "eco-industry" interchangeably with "core eco-industries" and call the "connected eco-industries" also "emerging markets for eco-innovations". In the following the up-to-date performance and the future potential of both market segments will be briefly analyzed.

3.1 The Eco-Industry

The eco-industry can be simply described as markets for environmental goods and services and is defined by the OECD – Eurostat definition as "those [identifiable] sectors within which the main – or a substantial part of – activities are undertaken with the primary purpose of the production of goods and services to measure, prevent, limit, minimize or correct environmental damage to water, air and soil, as well as problems related to waste, noise and eco-systems. This includes cleaner technologies, products and services that reduce environmental risk and minimise pollution and resource use." (OECD/Eurostat, 1999, p.9). Companies in these markets sell products that aim at cleaning up the environment (EIO, 2012).

According to a study by Ernst & Young (2006) it can be distinguished between two general categories within the eco-industry: activities related to pollution management and activities related to resource management. Sectors classified as pollution management activities are amongst others "Solid Waste Management & Recycling", "Waste Water Treatment", or "Air Pollution Control". To the resource management activities sectors belong for example "Water Supply", "Recycled Materials", or "Renewable Energy Production". Besides being able to distinguish active firms in the industry between aiming at reducing environmental damage and increasing resource productivity, a further distinction can be made based on the complexity of the involved activities. Activities range from novel and very complex (e.g. renewable energy, air pollution control) to well established ones (e.g. waste management). This diversity among eco-activities makes it difficult to distinguish the core eco-industries from the connected ones and to quantify them.

Despite being relatively new, the EIO already labels the eco-industries as "established markets". This with good reason as the data show: Ecorys and IDEA (2009) estimates the eco-industry in the EU to have a turnover of €319 billion in 2008, which represents a GDP share of about 2.5%. Further, the estimates also suggest the EU eco-industry to have grown on average at about 7.5% annually from 1999 to 2008. Other studies trying to quantify the EU eco-industry in terms of turnover and employment by sector and by country (Ecotec, 2002; Ernst & Young, 2006; GHK et al., 2007) come up with different numbers, but the results all lead in the same direction. They indicate that the eco-industry is a rapid developing industry which is expected to grow steadily in the future (Ernst & Young, 2006). If real growth of the eco-industries continues at the same rate as it has in the past, GDP share in the EU is expected to increase to 3-5% by 2020 and 5-9% by 2030 (Ecorys and IDEA, 2009).

3.2 Emerging Markets for Eco-Innovations

From an ecological point of view the eco-industry has already contributed a lot over the last 15 years and is an area with huge potential. But the environmental contribution of the eco-industry which has mainly focused on technological progress in the past is not enough to reach sustainability goals. Companies from all different economic areas need to increase their resource efficiency. Eco-innovations in connected eco-industries are expected to provide part of the solution. Such innovations do include technological progress but also other targets such as marketing, organizational and institutional eco-innovations.

According to the EIO (2012) sectors focusing on energy, transport, chemicals, bio-based products, waste management, and information and communication technologies (ICT) can be put in this category. Their common characteristic is that they possess a high growth potential as active firms in these sectors turn to radical, more comprehensive solutions such as innovation in products, processes, and systems that aim to increase resource productivity and can even include collaboration across sectors.

A market survey conducted by the EIO (2012) identified the sectors which are expected to have a leading role in implementing radical eco-innovations across world regions over the next 20 years. The results are shown in Table 3 and show that in Europe, the energy sector including renewable energy, the sector for cars and other motor vehicles, and the waste management sector are the sectors that are expected to have the highest potential for eco-innovations. One can see that depending on the region different industries are expected to grow the most. Industrial, emerging, and least developed countries face different challenges and opportunities which all have to be addressed individually.

Europe	North America	South America	Australia & Oceania	Africa	Asia
Energy, incl. renewable energy	Energy, incl. renewable energy	Agriculture	Energy, incl. renewable energy	Agriculture	Computer and electr. products
Cars and other motor vehicles	Computer and electr. products	Energy, incl. renewable energy	Mining	Water	Energy, incl. renewable energy
Waste management	Cars and other motor vehicles	Paper, wood and bio-based products	Water	Energy, incl. renewable energy	Cars and other motor vehicles

Table 3: Top three sectors expected to be implementing eco-innovations across world regions by 2030
Source: EIO, 2012

As seen above, it is very difficult to quantify industries introducing eco-innovations which is due to the relative new and diverse nature of eco-innovations. So far, research has mainly focused on innovations in the core eco-industries. Eco-innovations which lead to environmental improvement in other areas have been neglected to measure in the past (Arundel and Kemp, 2009). Therefore, few studies have started to investigate the best ways to measure eco-innovations at the European or OECD level (see Kemp and Pearson, 2007 and Arundel and Kemp, 2009). The authors of these studies argue that better measurement of eco-innovations are expected to trigger innovations by allowing for better monitoring and in turn for more informed policy support. An example of this measurement problem poses the waste management sector which cannot be clearly placed into either the core or the connected eco-industry. Confusingly, the "solid waste management" sector is put in the established eco-industry by some authors, e.g. by Ernst & Young (2006), while "waste management" is seen as an emerging market for others, e.g. by EIO (2012). This shows that the waste management is already a well-established sector focusing on minimizing environmental pollution. At the same time waste management holds a huge potential to increase resource productivity which can be achieved through more complex processes (e.g. the use of waste as energy or as raw materials for other products).

3.3 Empirical Evidence

Two similar studies provide useful insight into the development of climate change-mitigation technologies (Dechezleprêtre et al., 2009, 2011). The studies are based on comprehensive PATSTAT data and conduct extensive analyses on the geographical distribution and the international diffusion of eco-innovations between 1978 and 2003 and between 1978 and 2005 respectively. Thereby, the studies are restricted to developed and developing countries and do not include the least developed countries as eco-innovations have primarily been developed in industrialized countries and have gained an increased role in developing countries. Dechezleprêtre et al. (2011) find that 90% of all innovations from 2000 to 2005 in climate change-mitigation technologies stem from 12 countries. Thereby, Japan, the U.S., and Germany account for two-thirds of all innovations and are surprisingly followed by emerging economies (China, South Korea, and Russia). Taking into account the quality of the innovations, the performances of emerging countries is worsened as their contributions typically are of relatively low value.

Dechezleprêtre et al. (2009) specifically take a look at the amount of innovation in climate change-mitigating technologies conducted by different technology types which is reflected in Figure 2.

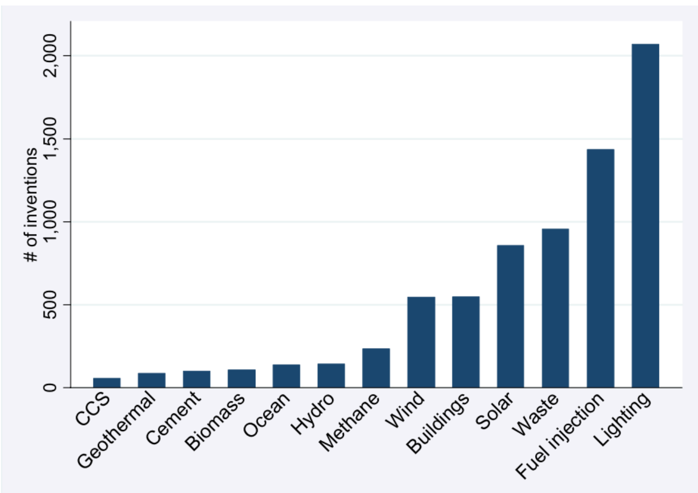

Figure 2: Average of annually patented inventions from 1998 to 2003 by technology
Source: Dechezleprêtre et al., 2009, p.14

The figure indicates the high innovative activity in renewable energy technologies (including amongst others wind and solar) and in lightning. The study further provides interesting insight regarding the maturity of certain technology markets. The authors argue that while certain technologies including biomass, hydropower and geothermal energy are already mature, other technologies such as ocean energy and CCS (Carbon Capture & Storage) are in the development stages.

Additionally to the absolute innovation activities by technology type Dechezleprêtre et al. (2011) investigate the technologies development. Table 4 shows the average annual growth rates of innovations by technology types. It shows the high potential of certain technologies (lightning, renewable energy, heating, cement) and indicates the role environmental policies might play in inducing innovation. While the top four categories in the table have mainly been influenced by an increased number of environmental policies after 2000, the technologies in the bottom part of the table are characterized by regulations introduced in the early 1990s.

Technology	1990-1999 (%)	2000-2005 (%)
Lightning	7.6	15.9
Renewable energy	1.8	8.0
Heating	1.0	7.7
Cement	-1.3	5.2
Electric and hybrid	13.9	7.8
Methane	4.0	1.7
Waste	13.8	-7.3
Insulation	6.4	-1.0

Table 4: Average annual growth rates of innovations based on technology type
Source: Dechezleprêtre et al., 2011, p.118

In light of this rapid development and the huge potential of not only the eco-industry but also related industries aiming at preserving the environment, industrialized countries have started to incorporate environmental policy with innovation policy. More attention has recently been paid to systemic innovations and to the collaboration between sectors that enable radical innovations. These developments show the wide range core and connected eco-industries encompass and the importance of eco-innovations. In the following, I will address the factors determining eco-innovations.

4 Determinants of Eco-Innovations

Much is expected from core and connected eco-industries to lead the way to a green economy. But in order for these industries to succeed much technological as well as non-technological progress is necessary to increase the incentives for consumers and firms to eco-innovate. The incentives to eco-innovate are determined by a wide range of factors. Thus, in order to identify the main determinants of eco-innovations one has to start at the very basics. Cleff and Rennings (1999) do this in a tractable way as they pay particular attention to the peculiarities of environmental innovations and investigate the contributions of both environmental and innovation economics. The contribution of innovation economics includes the role of technological development and of demand factors. What is missing is the third dimension, a regulatory framework which is crucial for firms incentives to eco-innovate. This is the contribution of environmental economics which mainly focuses on identifying optimal policy instruments to incentivize eco-innovations and ignores any market pull or technology push factors. The influence of these three categories technology, regulations, and markets on eco-innovations is graphically represented in Figure 3.

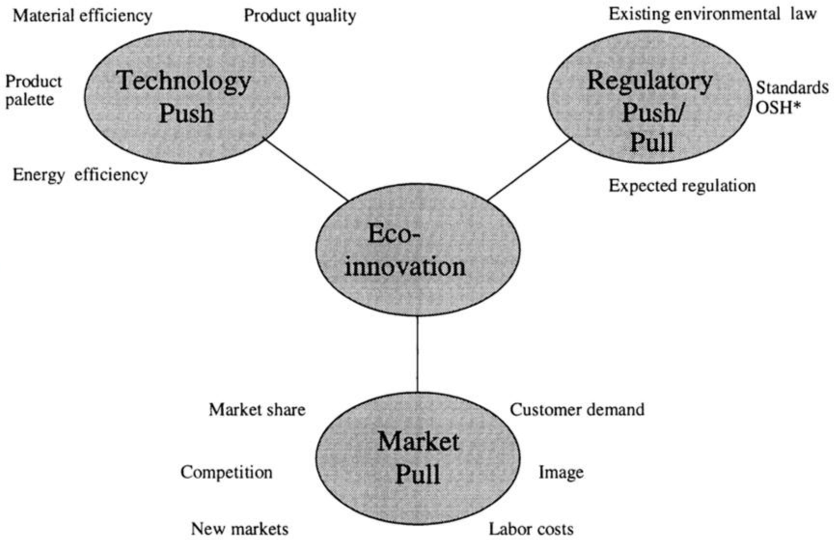

Figure 3: Determinants of eco-innovations Source: Rennings, 2000, p.326

In the following, I am going to address the issue on how technology, regulation, and markets impact the incentives to eco-innovate. Due to the interrelation of these three factors it is almost impossible to assess them independently. Instead, to account for this problem of interrelation environmental and innovation economics are connected. I will first turn to the regulations and technological change, before I will discuss the role of the market pull while focusing on consumer demand and green consumerism.

4.1 Environmental Policies and Technological Change

Technological eco-innovations typically including product- and process-innovations are the most studied types of eco-innovations due to different reasons. Such innovations are the best quantifiable among different eco-innovations, possess a high potential in inducing technical change, and the incentives to innovate in such green technologies are highly dependent on environmental policies. Thereby, according to Schumpeter (1942) technical change can be classified into the three stages of invention, innovation and diffusion, whereas invention and innovation can be summarized as research and development (R&D) and together are often termed simply as innovation in the literature. Invention and innovation include the creation of the idea and its development into commercial viable products and processes while the diffusion stage considers the adaption and the diffusion of the innovation. In the following, I am first going to discuss the peculiarities of eco-innovations that stress the need for environmental policy before I turn to theoretical and empirical evidence including the Porter Hypothesis on how regulations affect the incentives to eco-innovate.

4.1.1 Peculiarities of Eco-Innovations

Economists typically point to two different kinds of market failures associated with eco-innovations that reduce the incentives for firms to innovate and thus lead to a sub-optimal level of environmental R&D investment unless policy actions are taken to correct these market failures (e.g. see Jaffe et al., 2005; Popp, 2011). On the one hand it is the market failure associated with environmental pollution and on the other hand the one associated with the innovation and diffusion of new technologies.

The first market failure is represented by the negative environmental externality economic activity brings about. Because environmental pollution is not priced by the market the consequences of the pollution are not borne by the polluters themselves but by other parties, often times the whole society. There lacks the incentives for firms and consumers to reduce emissions unless appropriate policies are introduced. Such policies can either internalize the occurred environmental costs or put a limit on the allowed pollution. The second market failure is the positive externality associated with environmental R&D and due to the public goods nature of new knowledge. A firm that invests in environmental R&D reaps only part of the benefits of the investment but incurs all the costs. The new knowledge becomes available to the public which might lead to additional innovations. This knowledge spillover effect implies that the incentive for firms to innovate at the socially optimal level is too low unless properly designed policies that spur the development and adoption of environmentally-friendly technologies are implemented. In case of technological progress worth mentioning is the dynamic character the development possesses which makes the analysis much more complex than in a static setting. The development of environmentally-friendly technologies does not only decrease pollution today, but it also provides additional social benefits by reducing the cost of polluting less in the future, which changes the firms□incentives to develop new technologies.

Jaffe et al. (2005) extend their analysis on the complex issue about the incentives to conduct environmental R&D and argue that besides the two externalities additional forces can be identified that might further weaken the incentives to eco-innovate. These forces include positive adoption externalities in the adoption and diffusion stage of new technologies and incomplete information in the innovation and diffusion stage. Adoption externalities are often referred to as dynamic increasing returns and may be generated when the value of new technologies increases with increased usage. This includes learning-by-using by consumers, learning-by-doing by suppliers and network externalities. The second externality is associated with incomplete information and thus uncertainty and is expected to intensify the spillover effect.

Rennings (2000) terms the two market failures together as the double-externality problem and calls for governmental intervention and for the coordination of innovation and environmental policy in order to correct the market failures. The potential of policy approaches that combine these two areas was already recognized over 30 years ago (Jänicke and Lindemann, 2010), but did not get much attention until Porter formulated his win-win hypothesis for the first time in 1991. From then on the impact of different environmental policy instruments on eco-innovations has been widely discussed in the literature.

4.1.2 The Porter Hypothesis

In 1991 in his article *American's Green Strategy* the Harvard economist Michael E. Porter stated that "strict environmental regulations do not inevitably hinder competitive advantage against rivals; indeed, they often enhance it" (Porter, 1991). This revolutionary view on the relationship between environmental regulation and competitiveness has become known as the Porter Hypothesis (PH) and has provoked a long and still lasting debate on how to best trigger innovations while taking environmental problems into account. The hypothesis was so revolutionary because it contradicted the at this time prevailing belief that any existing profitable opportunity would be undertaken by firms and thus any regulation would restrict firms, increase their costs and decrease their competitiveness. The belief that environmental improvement can only be achieved through less competitiveness was widely accepted. Porter and van der Linde (1995, p.98) challenged this prevailing trade-off between the environment and competitiveness and state that "properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs complying with them". These innovation offsets are due to different reasons, the authors state at least six purposes (Porter and van der Linde 1995, p.100). They argue that regulation:

1. signals companies about likely resource inefficiencies and potential technological improvements.
2. can achieve major benefits by raising corporate awareness.
3. reduces the uncertainty that investments to address the environment will be valuable.
4. creates pressure that motivates innovation and progress.
5. levels the transitional playing field.
6. is needed in the case of incomplete offsets. In such cases regulations are necessary to improve environmental quality.

Figure 4 represents the PH in a graphical way and helps to understand the different versions of the hypothesis that have emerged in the literature over the last 20 years. Because there is confusion about what exactly the PH says different authors distinguished different versions of the hypothesis in order to conduct empirical as well as theoretical studies. The following classification goes back to Jaffe and Palmer (1997) who classified the PH into the weak (PHW), strong (PHS), and narrow (PHN) versions.

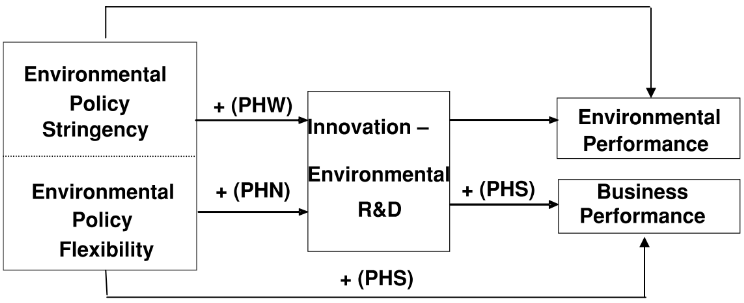

Figure 4: The Porter Hypothesis causality chain Source: Lanoie et al., 2011, p.809

First, the weak version says that properly designed regulation will foster certain types of innovation. This can be seen in the positive relationship between environmental policy stringency and innovation in Figure 4. Newly introduced regulations place some constraints to the firms and thus make the firms act differently than they would without regulations. This version is called the weak one since it does not indicate whether the innovation is beneficial for the firm or not.

Second, the strong version deals with the impact of environmental regulation on the firm's business performance and can be seen in Figure 4 as the link between the first and the last step in the chain or also as the positive impact of increased environmental R&D activity of the firm on its business performance. It shows that new regulations lead firms to the discovery of new profitable opportunities which are not found or undertaken without regulations. In this form the benefits of innovations induced by regulations are bigger than the cost of complying with them and thus regulations lead to increased competitiveness. However, the strong version does not state that environmental regulations always lead to increased competitiveness. Instead, it only states that these innovation offsets are probable.

And third, the term narrow version goes back to Porter's statement that environmental regulations should focus on outcomes and not on technologies and says that certain types of environmental regulations foster innovations. Thus, as seen in Figure 4, flexible instruments such as market-based instruments and performance standards are regarded as superior to prescriptive ones such as technology-based standards.

The first reactions to the PH were diverse. In political debates Porter's findings were taken positively as they implied that economic growth does not necessarily lead to more environmental harm. This win-win situation that includes higher profits for businesses and social benefits through more environmental protection was a call for more environmental regulations. At the same time the PH was also heavily criticized. Amongst the critics were Palmer et al. (1995) and Jaffe and Palmer (1997). Over the last two decades many studies have tried to test the PH either theoretically or empirically. Ambec et al. (2011) review the findings of a sample of these studies in their elaborated work on the PH over the last 20 years. They find that from a theoretical point of view, the PH possesses a solid background and is widely accepted in the literature today. From an empirical perspective the findings are diverse. While the weak hypothesis is mainly accepted in the literature, the empirical evidence on the strong hypothesis is mixed. In the following I will closer investigate some of these studies focusing on the weak version, i.e. the relationship between environmental regulations and innovations, and what their findings indicate for the determinants of eco-innovations.

4.1.3 Theoretical and Empirical Evidence on the Weak Porter Hypothesis

Theoretical models and empirical studies which test the PH all rely on technological progress. Porter himself argues that environmental policies lead to technological change by stating that "regulation signals companies about likely resource inefficiencies and potential technological improvements" and that "regulation creates pressure that motivates innovation and progress" (Porter and van der Linde, 1995). The technological progress associated with environmental policies is often not taken into account by environmental policy models which instead assume technology to be an exogenous factor. In reality environmental regulations and policies do potentially play an important role in inducing technological progress (Popp, 2002, 2004; Acemoglu et al., 2012). Popp (2004) estimates that by ignoring technological progress the welfare costs of an optimal carbon tax policy are overstated by almost 10%. This important role of technological change within the field of environmental economics has widely been acknowledged in the literature. See Popp et al. (2010) for a review of the literature on the topic and the future role of technological change in the field of environmental economics.

Acemoglu et al. (2012) specifically study the effect of different environmental policies on technological change by means of an endogenous growth model of directed technical change with environmental constraints. The model is a two sector model producing one final good with one sector using "dirty" and the other sector using "clean" technology. At the center of the analysis is the induced-innovation hypothesis introduced by Hicks (1932) stating that the direction of invention is affected by the relative prices of the production factors such that the need for the relative expensive factor is reduced. In the specific case of eco-innovations one can think of changes that raise the cost of emissions relative to other production factors (e.g. increase in energy prices, taxes on dirty production, subsidy of clean production). These changes in the relative cost of producing provide incentives to innovate in green technologies.

Different empirical studies provide evidence of this induced-innovation hypothesis. For example Newell et al. (1998) investigate consumer durables for the influence of regulation on energy-efficient innovations. They find that in the market for air conditioning and water heaters both energy prices and government regulations had a positive influence on the products' energy efficiency. Crabb and Johnson (2007) examine the automotive industry and also find a positive relationship between oil prices and energy-efficient technology innovation in this industry. By using U.S. patent data from 1970 to 1994 Popp

(2002) finds that energy prices positively and strongly impact energy-efficient innovations. Investigating the development of the oil price and patent filings in climate change-mitigating technologies Dechezleprêtre et al. (2011) identify two distinct time periods. Before 1990 oil prices and innovative activities show a similar development. Thereafter, the development of innovations and oil prices depart from each other which might indicate the important role environmental policies and regulations have recently earned in determining eco-innovations. Interesting in this respect is also the speed of innovations that has accelerated since 2000 when more policies were introduced. Hascic et al. (2009) also find a strong influence of environmental regulations and fuel prices on emission-control technologies in the case of the automotive industry by investigating patent data from OECD countries. Particularly interesting are their findings indicating that depending on the type of eco-technology fuel prices and regulations have a different importance. While fuel prices are important drivers of innovation in integrated eco-technologies, regulations are more important in determining innovation in post-combustion technologies in the automotive industry.

Acemoglu et al. (2012) develop a more comprehensive framework to characterize the structure of optimal regulation with regards to social welfare. They conclude that “under reasonable parameter values and with sufficient substitutability between inputs, it is optimal to redirect technical change towards clean technologies immediately and optimal environmental regulation need not reduce long-run growth”. The authors further show that optimal policy includes a mix between carbon taxes and research subsidies. The tax is implemented to control emissions and thus to mitigate the negative environmental externality and the subsidy is designed to steer the research towards clean technologies and thus to mitigate the R&D externality. In this analysis the market size effect and the price effect are central and determine the direction of technical change as more closely analyzed in Acemoglu (2002). The market size effect induces innovation towards the larger sector, while the price effect encourages innovation towards the smaller sector characterized by higher prices. Acemoglu et al. (2012) argue that the relative size of the two effects depend on the elasticity of substitution between the dirty and the clean sector, the relative levels of technology development of the two sectors, and whether the inputs used in the production in the “dirty” sector are exhaustible or not. In the case of energy sources the authors argue that the elasticity of substitution between dirty and clean inputs is likely to be high. Without any governmental action taken, this high substitutability between inputs would direct production to the bigger, dirty sector (market-size effect) and rapidly lead to environmental degradation. The level of technology development obviously alters over time and changes the optimal regulations because as long as the inputs are sufficiently substitutable, policy interventions need only to be of temporary nature in the used framework. Another important implication of the paper is that when exhaustible resources are used in the production in the dirty sector more research is going to be put towards the development of clean technologies. Scarcity in a production factor increases the cost of production and directs technological development towards the other sector as already discussed above with the induced-innovation hypothesis.

Acemoglu et al. (2012) find that besides the externalities that reduce the incentive to innovate in clean technologies, there is path dependency such that a firm’s decision whether to innovate in clean technologies depends on the level of clean technology used by the firm in the past. This path dependency is also found by multiple other authors (e.g. Horbach, 2008; Aghion et al., 2012). Aghion et al. (2012) empirically analyze the role of directed technological change in reducing greenhouse gas emissions in the auto industry across 80 countries. Similar to the model above, where it can be distinguished between dirty and clean production methods, the authors classify the patents into being either dirty or clean. With respect to higher fuel-prices due to tax increases the empirical results are in line with the theoretical ones such that firms facing higher fuel prices invest more in green and less in dirty technologies. The results of Aghion et al. (2012) interestingly suggest that a 40% increase of fuel prices compared to 2005 is necessary in order for clean innovation stocks to overtake the dirty innovation stocks after 15 years.

Calel and Dechezleprêtre (2013) approach the topic of the environment and directed technical change from an empirical point of view by investigating the effect of the European Emissions Trading Scheme (EU ETS) on the speed of directed technological change towards a low-carbon economy. The analysis shows that while mainly operational changes have contributed to emissions reduction, the EU ETS has only had a limited effect on the development of low-carbon technologies. Thus, while the Schemes is important for reducing emissions, it is mainly responsible for incremental changes but it clearly does not provide enough incentives for the development of new technologies which is indeed needed in order to reach the ambitious environmental goals.

Several other empirical studies relying on technological progress have been conducted to test the weak version of the PH. Lanjouw and Mody (1996), Brunnermeier and Cohen (2003), Popp (2003, 2006), Johnstone et al. (2010, 2012) and Lanoie et al. (2011) all measure the impact of environmental policy stringency on the number of patents filled and find a positive relationship. Johnstone et al. (2012) for example conduct a panel data study that covers 77 countries in the time frame from 2001 to 2007 and use a reduced-from model to measure the effect of environmental policy on technological eco-innovations. The study only focuses on the weak PH and confirms Porter’s claim that policy stringency induces eco-innovations. At the same time Jaffe and Palmer (1997) only find a significant positive effect of environmental expenditure on R&D expenditures, but not on the number of patents filled in U.S. manufacturing. Overall, it can be concluded that there is a positive relationship between environmental regulation and innovations that varies in strength (Ambec et al. 2011).

Studies testing the weak PH typically use either surveys, R&D expenses or successful environmental patent applications as a proxy for innovation. For assessing the stringency of environmental regulation, environmental compliance costs (e.g. pollution abatement costs) are typically used. Using patent data as a proxy of innovation activities implies that mainly more radical innovations - typically technological product and process innovations - are considered while other kinds of innovations such as organizational or institutional ones characterized by incremental changes are not accounted for. Survey data used in different studies suffers from its different methodological approaches but allows for also measuring incremental changes.

Referring to the difference between product and process innovations Rave et al. (2011) argue that most survey data show that stricter regulation induces more process eco-innovations, while this might not be the case for eco-innovations in products. The findings of the study of Rave et al. (2011) show that incremental eco-innovations which are typically process innovations are mainly driven by the goal of reducing cost or by strict regulations. While this kind of innovations primarily simplifies the diffusion of already existing technologies, the more radical eco-innovations characterized by being patented typically introduce new products to the market. Such product innovations are often motivated by market objectives and government subsidies and environmental policy only plays an indirect role by providing the framework that incentivizes eco-innovations. Cleff and Rennings (1999) analyze the determinants of environmental product- and process-innovations in integrated green technologies by means of survey data and find different drivers for the different targets. While product innovations in integrated environmental protection are found to be mainly motivated by maintaining or increasing the firm's market share, process innovations are primarily driven by complying with regulations. This might indicate that integrated environmental protection at the product level is driven by market demand as it enhances customer value while customers only gain no or only little benefit from integrated green innovations at the process level. By using patent data Popp (2003) finds that technological change strongly depends on the incentives provided to innovate and that any policy (traditional and market-based) provides incentives to eco-innovate. The analysis shows that the stricter policy (technology standard) did not only induce a higher level of innovative activity but also induced different eco-innovations than the market-based policy with tradable permits. Innovations under the technology standard policy were characterized by being less radical and by reducing the cost of complying with regulations. Innovations under the market-based policy were more environmentally-friendly in a sense that they included the development of more efficient technologies. To summarize, Cleff and Rennings (1999) and Rave et al. (2011) identify the technology push and the market pull as the dominant effects for more radical product innovations while regulations only play a subordinate indirect effect. The regulatory push/pull effect is identified as the main driver for process innovations in integrated eco-technologies as also identified by Popp (2003) and Calel and Dechezleprêtre (2013).

The analysis of Johnstone et al. (2010) leads in the same direction as the one of Popp (2003). They estimate the impact of environmental policies on technological innovation in the renewable energy sector across 25 OECD countries. As a proxy for innovation, patent counts are used and environmental stringency was measured by different types of policies. In addition to finding a positive relationship between environmental stringency and numbers of successful patent applications, they find that different kinds of instruments are effective for innovation in different renewable energy technologies. For less expensive energy technologies which are typically more mature technologies and close substitutes to fossil fuels broad based-policies such as tradable certificates are more effective in fostering innovations while for more complex technologies still at the early development phase such as solar power, more specific subsidies such as feed-in tariffs are more efficient. Rennings and Beise (2005) also find that different eco-technologies are driven to a different extent by different factors. More specifically the authors investigate the industry for fuel-efficient cars in Germany and the Danish wind-generation industry which are both characterized by early adoption and strict regulation. In the case of fuel-efficient German cars strict regulations were identified to be a crucial factor for eco-innovative activities, but are offset by strong demand factors. Market factors are assessed as especially crucial as environmental care is not a top priority instead other criteria such as quality or price of a product are still more important. In the case of the Danish wind industry strict regulation is the deciding success factor for eco-innovations. The authors conclude that especially renewable energies would not be competitive without strict regulations. These findings might indicate that regulation does play a crucial role for less mature eco-technologies which are close substitutes to current dirty technologies □ a result that is in line with Acemoglu et al. (2012). With time, once the technology advances, the importance of regulations declines.

Most of the studies addressed so far have focused on the impact policy has in determining innovation in environmental-friendly technologies. Thereby, the patents considered were usually granted in the U.S., the EU or more generally in industrialized countries. Dechezleprêtre et al. (2011) pay closer attention to the questions of which countries are leading in the development of green innovations and what role emerging economies play in this development process. Part of the results of the study is already provided in Section 3.3. It indicates the development by technology types and the high concentration of the development of climate change-mitigation technologies in developed countries. What has not been addressed so far is the positive impact the adaption of the Kyoto Protocol has had on eco-innovative activities in countries under consideration (except the U.S., which did not commit to the Kyoto Protocol) and the transfer from eco-innovations which is especially important among OECD countries but also from OECD to Non-OECD countries. 73% of total transfers of climate change-mitigation technologies occur between OECD countries and 22% of total transfers flow from OECD to Non-OECD countries. Technologies that stem from Non-OECD countries and are transferred to either OECD countries (4%) or Non-OECD countries (1%) are of negligible size. Popp (2011) points out the importance of the transfer of eco-friendly innovations from developed to developing countries. He performs a literature review on the transfer of green technologies and primarily finds that the process involved in the diffusion of such technologies is slow and gradual. While energy-efficiency enhancing technologies are shown to be diffused to developing countries without any environmental regulation, policies are necessary to induce the transfer of other green technologies.

Similar to Dechezleprêtre et al. (2011), Lanjouw and Mody (1996) and Popp (2006) extend the analysis on how regulations affect the incentives to innovate by also considering the diffusion of such green innovations. Thereby, technological transfer is measured by considering in how many foreign countries an environmental patent is filled. Besides the positive relationship found between pollution abatement expenditures and innovation within a country, Lanjouw and Mody (1996) measure the importance of the diffusion of eco-technologies especially to developing countries. Similar to Dechezleprêtre et al. (2011) they find that even though developing countries also perform a non-negligible amount of environmental innovations, their contributions possess lower values as they are frequently imported technologies that are adapted to local conditions. Thus, almost all technologies that diffuse globally stem from developed countries. Lanjouw and Mody (1996) further find that developing countries import a high amount of foreign patents which are not adapted to the local factors and which mainly are complex technologies targeting pollution abatement.

Another interesting research finding concerns the impact of domestic policies on foreign innovation incentives. By means of the strict regulation on vehicle emissions first adopted in the U.S. Lanjouw and Mody (1996) find evidence that environmental regulations do not only spur domestic, but also foreign innovation. The more stringent regulations in the U.S. put pressure on Japanese and German innovators to develop environmentally-friendlier cars. The increase in patents granted for eco-innovative cars to German and Japanese innovators in the U.S. shows this effect. Dechezleprêtre and Glachant (2012) also find that foreign policy induces domestic eco-innovations although to a much lesser extent by investigating the wind industry in OECD countries. While increased foreign demand leads to increased technology diffusion which is measured by patent transfers across countries and thus spurs innovation, the effect of domestic policies on domestic innovation is shown to be 25 times larger than the one of foreign policies. By examining U.S., German, and Japanese patent data on eco-technologies for coal-fired power plants Popp (2006) finds opposing results. He assesses the role domestic as well as foreign environmental regulations play in inducing eco-innovations. The results indicate that while domestic regulation pressures innovations within the country, foreign regulation does not affect the rate of domestic innovation. There is shown to be only an indirect technology transfer. Countries which adopt regulations relatively late make use of technologies that are already further developed abroad. The late-adopting countries undertake R&D in order to adapt the technology to the local market. Popp (2011) assesses the opposing results and argues that unlike innovation in the automotive sector, innovation in the electricity sector is not a tradable commodity. This non-tradability might also apply to the wind sector and can be seen by the fact that the majority of emission control equipment in countries such as the U.S., Japan, and Germany is supplied by domestic innovators and does not stem from abroad.

The theoretical and empirical evidence considered so far mainly addressed the issue of how policy affects the incentive to eco-innovate and thus mainly focused on the R&D stage of the innovation process. The diffusion process is only briefly discussed by considering the effect of foreign environmental policy on domestic innovation and the importance of the adoption of eco-technologies by developing countries. For further evidence on the international transfer of environmentally-friendly technology see Popp (2011) and Dechezleprêtre et al. (2013). Popp (2011) provides interesting insight on technology transfer, its sources, the incentives for adopting eco-technologies in developing countries, and the role policy plays which is more specifically discussed by means of the Clean Development Mechanism (CDM). More empirical evidence on the CDM does further provide Dechezleprêtre et al. (2008). Dechezleprêtre et al. (2013) conduct an empirical study on the determinants of the international transfer of climate change-mitigation technologies across 96 countries in between 1995 and 2007.

4.1.4 The Narrow Porter Hypothesis and Environmental Policy Instruments

With respect to the narrow version of the PH the literature widely diverges. The PH itself is based on flexible market-based instruments and not on the more rigid command-and-control regulations. Ambec et al. (2011) review the literature on environmental policy design and mainly find arguments for market-based regulations over command-and-control policies. At least until recently, it had been widely accepted that market-based instruments (e.g. taxes, tradable permits) possess the highest innovation-efficiency among the available policy instruments as the incentives to reduce emission are permanent, while the introduction of technological standards was seen as not cost-efficient as the incentives to eco-innovate disappear once the standards are met (Cleff and Rennings, 1999). Exceptions to this view that market-based instruments are superior have emerged manifold (e.g see Rennings, 2000), such that Fischer et al. (2003) conclude that no instrument can generally be preferred. Instead the welfare gain of a certain environmental policy instrument depends on a wide range of circumstances. The more recent study of Jänicke and Lindemann (2010) also concludes that the focus of innovation-oriented environment policy should be put on ecologically-effective innovations and on developing smart regulations characterized by instrument mixes instead of relying on a single policy instrument. Frondel et al. (2007) show that the instrument policy choice only plays a subordinate role while policy stringency is more important. Figure 5 shows the available policy instruments divided into the contributions from innovation and environmental policy and into the three different phases of the innovation cycle.

The instruments provided in Figure 5 play a crucial role in the development of eco-innovations as they are identified as one of the three determinants thereof by Rennings (2000) and as they strengthen the incentives for firms and consumers to eco-innovate. As clearly shown in Figure 5 the different regulatory push/pull instruments are effective at different phases in the product development and have to be used accordingly. The analysis in Section 4.1.3 focused on environmental policies including market-based and regulatory instruments in the invention and innovation phases. In Section 4.3.4 I will turn to supporting instruments of environmental policy that are designed to increase the incentives for final consumers to eco-innovate. Also the impacts of technology push (analyzed above in Section 4.1.3) and demand pull (Section 4.2) on the incentives to eco-innovate can more clearly be assigned to the different stages of the product cycle. Horbach (2008) shows that there is consensus in the literature that the technology push is primarily important in the first phase of product development, while the market pull becomes more important in the diffusion phase.

Instrument/phase	**Invention**	**Innovation (market launch)**	**Diffusion**
Instruments of innovation policy			
Direct project support	Direct promotion of research and development (R&D)	Direct promotion of market launch	
Instruments of environmental policy			
Market-based instruments			
Taxes	Marked-based trend steering to influence the direction of technical progress		
Tradable permits			
Subsidy-like support	Marked-based fine-tuning for the promotion of specific technologies		
Regulatory instruments			
Command and control measures	Regulatory fine-tuning beyond the best available technology ('technology forcing')		Standards in accordance with the best available technology
Supporting instruments			
Green public procurement			Using state buying power
Eco-labels			Improving the information provided to the consumer

Figure 5: Instruments of innovation-oriented environmental policy
Source: Jänicke and Lindemann, 2010, p. 131

4.2 Market Pull and Consumer Demand

In the previous section the issue on how regulation and technological progress affect the incentives to eco-innovate has been addressed. In this section we turn to the third main determinant as identified by Rennings (2000), the market pull. To the market pull belong different factors that can have a strong influence on the incentives to eco-innovate (see Figure 3). In the following, I will focus on the role consumer demand plays in inducing environmentally-friendly innovations. Schmookler's (1966) concept of demand-induced innovation is at the center of any analysis focusing on the important role the demand plays in inducing innovations. Thereby, the demand and the associated market size effect — the higher the potential market, the higher the potential profits — are key drivers for innovation as identified by Schmookler.

Wangler (2013) empirically tests the demand-induced innovation hypothesis with patent data on green technologies in Germany. He assesses different sectors including wind, solar, water and ocean, geothermal and biomass. Thereby, the author treats the demand as exogenous as he argues it to be highly dependent on policy, uses patent data as proxy for innovation and the market size as proxy for the demand. The findings imply that on average policy-induced demand stimulates firms’ green innovative activities. Important to note is that the results widely differ across technologies. While in the wind sector demand has a strong and significant effect on innovation, for the water and ocean and the solar sectors demand has no significant impact on innovative activities. A possible explanation for this heterogeneity among technologies might be the different stages in the innovation life-cycle the respective technologies are in. The results further indicate that the market size and thus the firms’ incentives to innovate are endogenously influenced by innovations. The same findings are made by Popp et al. (2011) indicating that innovation in green technology by a firm can increase the market size of the market the firm is selling in. These findings imply that the demand cannot simply be regarded as being exogenously determined by policy but that different endogenous factors (e.g. innovation, policy, societal characteristics and inequality) determine the market size and directly the firms’ incentives to innovate.

Other authors assess the effect not only of environmental policy but also of the demand on the incentives to eco-innovate, e.g. Wagner (2007), Horbach (2008) and Kesidou and Demirel (2012). Horbach (2008) studies the determinants of environmental innovations by means of German panel databases. The study confirms the weak PH, finds that technological improvements spur eco-innovations and with respect to the demand channel it is found that an increase in the expected future demand has a positive effect on eco-innovations. Wagner (2007) uses survey data together with patent data of German manufacturing firms to measure the relationship between environmental management and eco-innovations. The findings indicate that the implementation of environmental management system is correlated with eco-innovations in processes, but not in products. Further, the level of environmental product innovations and also patented eco-innovations is higher the higher the stakeholders’ concern for the environment and thus also the demand for green products. Kesidou and Demirel (2012) study the drivers of eco-innovations in the UK manufacturing industry and find that demand factors measured by corporate social responsibility and consumer preferences do have an impact on the decision whether to eco-innovate or not, but do not impact the level of eco-innovation.

The three studies all make important contributions to the empirical literature on how the demand affects the incentive to eco-innovate. The demand channel in general (Horbach 2008), corporate social responsibility (Kesidou and Demirel 2012) and consideration of stakeholders’ environmental preferences (Wagner 2007) are all important determinants in incentivizing eco-innovations. But Kesidou and Demirel (2012) are the only ones who in addition to the decision on whether to eco-innovate measure the level of eco-innovation which implies that further research is needed in this respect. Nevertheless, the studys’ results have important implications for the incentives to eco-innovate. Firstly, demand factors do play a crucial role in the decision to eco-innovate, but secondly these factors do not alone lead to a greener economy as the level of eco-innovation seems not to be affected by them. Instead, only the minimum level of eco-innovation required by the market seems to be implemented by firms. While the demand pull seems to be an important contributor to boosting a green economy, other factors such as technological progress, regulatory push/pull and other market pull factors are crucial as well.

4.3 Green Consumerism

The demand for green goods and services has been shown to be a significant driver of eco-innovations. But who are the consumers that demand such products and which are their characteristics? Which are the special features of green products that provide value to consumers? Why do consumers demand such products? Is it consumption solely for egoistic reasons or does altruism play a role in the decision to buy a green good? In the following these issues are going to be analyzed by turning to the characteristics of green consumers, to the special features of environmental quality as a demanded good, to the consumers’ motives for demanding green goods, and finally to informal regulations implemented to spur the adoption of green consumerism.

4.3.1 Characteristics of Consumers Demanding Green Products and Services

Over time private and public consumption has put immense pressure on the environment and is further expected to do so mainly driven by population growth and higher living standards. Together with this development of increased environmental damage due to private and public actions, the environmental concern has been increasing as well. Consumers’ concern for environmental damage and actions taken towards a greener economy are influenced by a wide range of socio-demographic characteristics but also by attitudes and norms pertaining in a society. Most studies that try to specify the determinants of individuals’ green consumerism focus on developed countries and use surveys to measure the attitude towards environmental concerns. While most consumers have a positive attitude towards a green economy, this attitude is often passive such that the willingness to pay more for a green product is still relatively small (OECD, 2008b).

As early as in 1995, Inglehart (1995) took another approach by investigating a wide range of countries including rich and poor ones and by distinguishing between simple environmental care and the more profound commitment to green behavior. The findings of the study are in line with expectations but nevertheless provide interesting empirical insight. First, individuals’ environmental care is present in all regions around the world, but individuals’ environmental care and willingness to pay for environmental quality is bigger in countries with relative high environmental problems (e.g. high pollution levels). Such countries are typically poor countries which are still in the (early) stages of the industrialization process. Second, individuals’ values and norms also influence the degree of environmental care. By using the notion of "postmaterialist" values - focus on self-expression and quality of life - and "materialist" values - standing for economic and physical security being the top priority - Inglehart (1995) finds that on aggregate countries with a high degree of postmaterialist individuals typically characterized as high-income countries express a higher environmental care. Such high-income country individuals do not only express a high environmental care but are further willing to make financial sacrifices to contribute to a greener environment. The same results are found by Diekmann and Franzen (1999) who argue that on one hand environmental concern decreases with increasing GDP per capita and on the other hand the willingness and the ability to forgo something for environmental quality increases with increasing income. These findings are in line with economic theory such that the benefits of reduced environmental damage are weighted with the opportunity cost of mitigation. Poorer consumers with scarcer resources are typically less willing to give up the consumption of basic goods for a cleaner environment. The results further imply that over time as societies adopt more "modern" lifestyles, the willingness to contribute to a greener economy raises. Both factors - being exposed to pollution and having high postmaterialist beliefs - are important determinants of an individuals' willingness to pay for green products. Thereby, consumers in developing countries demand products that are likely less innovative but that decrease the amount of pollution on the environment to the extent that is affordable to them. Consumers in rich countries in contrast who overall are wealthier are able to afford more expensive products and demand more innovative products that decrease the environmental impact. These implications of Inglehart's (1995) results are in line with the statistics on the development of green technologies. Poorer countries are mainly responsible for lower value innovations that adopt the already existing products to local conditions, while it is mostly the industrialized countries that are responsible for more radical eco-innovations.

Recently, different OECD studies have tried to capture households characteristics that determine green behavior (OECD, 2008b, 2011a, 2013). From the 2008 survey it is shown that green consumerism is influenced by a wide range of factors such as gender, educational status, household size and composition, and location of residence. With respect to income the survey finds that respondents in higher income classes ranked environmental concerns relatively higher compared to respondents from lower income classes. Generally, it is found that the income-elasticity of demand for environmental quality is positive, but whether it is greater or smaller than unity is unclear and varies across goods (OECD, 2011a). That this income-elasticity might vary widely across individuals, goods and time is also found in the OECD study on sustainable consumption in which the findings indicate that consumers are willing to purchase green goods as long as the price premium is within the norm and that the performance and the quality are equally important (OECD, 2008b).

Windrum et al. (2009a, 2009b) exactly measure this persisting trade-off between environmental performance, price, and quality by using a dynamic simulation model. More specifically they investigate the role consumer heterogeneity plays in the development of environmentally-friendly products and technologies and assess the trade-offs that exist between preferences for quality versus environment on the one hand and between environmental-sensitivity and price-sensitivity on the other hand. Thereby, consumer heterogeneity is classified into different consumer classes but is not measured directly by income inequality. Nevertheless, the papers provide interesting insight into how consumers which care most about the environment might play a key role in the development of new radical technologies. Also, it is found that homogeneity in preferences within a consumer class which enables consumers to afford a new product that only distinguishes itself marginally from previous products might be more beneficial for the environment than a high degree of heterogeneity in preferences that lead to the development of a new radical technology. I.e. the market size effect induces less radical eco-innovations which are shown to be more effective than more radical innovations induced by the price effect.

Considering the two trade-offs, the findings show that the higher consumers value service characteristics relative to the environment, the smaller are the incentives to innovate in green technologies. This case of relatively low environmental care has been typically observed in history. An example provides the automotive sector in which mostly less-efficient cars have been developed highly driven by consumer demand. Many consumers are still interested in driving bigger and faster but less-efficient cars which can be seen as a status good (signaling) and pay relatively low attention to environmental concerns. Regarding the trade-off between environmental-sensitivity and price-sensitivity, it is found that in the case of high environmental-sensitivity and low price-sensitivity, clean products are developed. In the opposite case of low environmental-sensitivity and high price-sensitivity, cheap and environmentally-harmful products are mainly developed. It is the latter case that is the historically more relevant one. Windrum et al. (2009b) argue that there has been a high market for high-polluting passenger cars (of low and high price) because consumers either cannot afford another car or because they simply do not care enough about the environment. The other case in which consumers put high value on environmental performance has only recently found to be of relevance with the emergence of electric vehicles.

4.3.2 Preferences for Environmental Quality and Environmental Policy

Environmental quality is not only a normal public good, but as different empirical studies have shown it can be regarded as a superior good (e.g. OECD, 2008a; Diaz-Rainey and Ashton, 2011). As income raises, the willingness-to-pay (WTP) for environmental quality raises once needs lower in the hierarchical scale have been met. The structure of a hierarchical demand can be traced back to Engel's law stating that with increasing income the expenditure share spent on food decreases. Thus, it is safe to assume that environmental quality is a good higher in the hierarchical scale consumers are willing to consume once more basic needs have been satisfied.

Different theoretical models build on the fact that consumers in developed countries characterized by relatively high income levels have increased their demand for environmental quality, e.g. Arora and Gangopadhyay (1995), Cremer and Thisse (1999) and Bansal and Gangopadhyay (2003). The models incorporate environmental quality which is valued by all consumers and thus can be seen as a good that signals wealth such that consumers have a higher WTP for goods produced by eco-friendly technologies as long as the physical quality stays the same. Eco-friendliness for which the consumers differ on their WTP depending on their income levels can be regarded as a new quality attribute that is on top of the hierarchical scale.

The characteristics of environmental quality – being a normal and in some cases even a superior good higher in the hierarchical scale – have important implications for the demand of environmental policy (e.g see Nicolli and Vona, 2012). Different studies have shown that wealthier countries demand more stringent environmental policies, e.g. Dasgupta et al. (2001), Easty and Porter (2001) and Magnani (2000). Easty and Porter (2001) find a positive correlation between GDP per capita and the quality of the regulatory regime. Dasgupta et al. (2001) show that while environmental policy and income per capita are positively related the income-elasticity of environmental policy differs across environmental dimensions. In the development process, the protection of natural resources seems to have priority over water pollution regulation and air pollution control. These findings are crucial for the further discussion on how inequality affects the incentives to eco-innovate. While the income of households directly affects the incentives to eco-innovate through the demand channel, it also indirectly induces green innovations through the demand for environmental regulation.

4.3.3 Motivation of Adopting Green Consumerism

Inglehart's findings indicate that on the one hand individuals who are hit harder by environmental problems and on the other hand individuals from so-called "postmaterialist" societies care more for the environment and have a higher willingness to pay for environmental protection. While the first result is obvious since individuals simply act for individual reasons, the second result is more complex. Often times the decision process of whether to consume an environmentally-friendly good incorporates a mixture of private and public considerations. The purchase of an eco-friendly good has private and public benefits, e.g. the purchase of an electric vehicle helps to reduce overall greenhouse gas emission (public benefit) and at the same time reduces the private cost of operating the vehicle (private benefit). Why are people in such "modern" societies willing to pay more for a greener economy? Are such individuals driven by intrinsic or extrinsic reasons or is the purchase of a green product motivated by image?

Griskevicius et al. (2010) analyze the motivation behind green purchasing behavior by considering a good's environmental performance, its quality and the status signal it conveys to others. The authors argue that traditionally consumers have chosen the more luxurious goods in order to signal their status which is reasonable as luxury products are often associated with higher wealth. Griskevicius et al. (2010) measure the motives of consumer behavior by conducting three behavioral experiments in which they introduce an environmentally-friendly product such that the consumers have the option of either choosing a lower quality green product or a higher quality polluting product, both initially priced the same. The results of the study indicate that when consumption occurred in public consumers were more willing to forgo some luxury and consume the green good than if the good was consumed in private. This contradicts the traditional view of signaling ones status (consumption of luxury goods signals wealth) and leads to the costly signaling theory in which the observable public benefits of the purchase are crucial. Consumption of the green good displays altruism to others and conveys information that the consumer is willing and able to forgo private for public benefits. This behavior signals wealth to others because it reflects the individual's ability to incur costs and thus is an important status signal. Additionally, the authors found that pricing the green good above the higher-quality good might lead to make the good more attractive to such consumers who are looking for signaling their status. By being priced higher, the good does signal wealth and environmental care.

One of the most prominent examples of such a green status symbol in the literature is the Toyota Prius, a hybrid gas-electric vehicle which is more costly than conventional fuel-driven car, but nevertheless has in recent U.S. history been one of the most successful cars across different demographics. Purchasing costs of the Prius are relatively high, but the car possesses the private benefit of lower driving costs. At the same time, the Prius also has the public benefit of a reduced environmental impact. Interestingly, when asked for the key motives for the purchase of the Prius, owners cited the signaling of the status to be the number one reason as they reported "it makes a statement about me" (Maynard, 2007). Benefits that reduce the environmental impact were cited less often as the reasons for buying a Prius. By empirically testing the motives for the purchase of the Toyota Prius Sexton and Sexton (2011) reinforce this result by concluding that owners of the Toyota Prius were willing to pay up to several thousand dollars to signal their environmental awareness to the public. These results indicate the importance individuals see in signaling their altruistic behavior to others. An indication that the traditional view of signaling – luxury goods signal wealth – is being replaced by the costly signaling theory - consumers display altruism – is the fact that over 40% of early adopters of hybrid cars in the U.S. reported to have bought a green car as an alternative to a luxury car. Thus, in this light green consumerism and altruism can be seen as a new form of wealth. In order to signaling their status individuals are even willing to pay a premium.

The analysis of Griskevicius et al. (2010) is closely related to the studies of Benabou and Tirole (2006), Ariely et al. (2009) and Friedrichsen and Engelmann (2013) and suggests that there might be different incentives for green consumerism. Ariely et al. (2009) introduce the categories of intrinsic, extrinsic and image motivation. While intrinsic motivation is attributable to an individual's care for the environmental and the associated willingness to pay for greenness and thus reflects pure altruism, extrinsic motivation is any material reward in return to green consumption such as a subsidy or a tax break, and image motivation is the perception by others an individual is driven by which can also be referred to as signaling motivation. The interaction of these three different motivations is unchallenged and while the relationship between intrinsic and extrinsic motivation has received the most attention in the literature in the past (see Benabou and Tirole, 2006 and Ariely et al., 2009 for short summaries), I am mainly interested how signaling interacts with either extrinsic or intrinsic motivation.

While Benabou and Tirole (2006) theoretically and Ariely et al. (2009) empirically look at the former interaction, Friedrichsen and Engelmann (2013) address the latter one. Benabou and Tirole (2006) introduce the term “overjustification effect” for the possible negative impact of an extrinsic incentive on the image motivation. The Toyota Prius can be used as an example again. As addressed above, driving a Prius is likely to signal environmental awareness and wealth to others. As soon as an extrinsic incentive is introduced, outsiders are not able to distinguish between altruistic and egoistic behavior anymore. In their behavioral study Ariely et al. (2009) find evidence of the overjustification effect such that image motivation plays a crucial role for green consumerism and that extrinsic monetary incentives partially crowd out image motivation. Friedrichsen and Engelmann (2013) find no crowding out by conducting an experiment investigating how public perception influences intrinsic motivation. This opposing result is due to their findings that intrinsically motivated individuals do not change their behavior much in public compared to in private. Instead, only individuals who are not intrinsically motivated show a much higher willingness to pay for green products in public than in private. Benabou and Tirole (2006) support the results of Ariely et al. (2009) and further find that individuals’ behaviors depend on social norms such that the dominant reputational concern (whether it is stigma or altruistic behavior) decides over individuals’ actions.

The results in these studies show the importance of signaling as a motivation for green consumerism and also explain why people are willing to pay a premium to signal their wealth. Further, the findings are not only confined to the consumption of green goods but can be extended to volunteering or any donation in relation to charitable organizations and have important policy implications depending on the size of the crowding out due to extrinsic incentives. The findings of Benabou and Tirole (2006) and Ariely et al. (2009) imply that monetary incentives might be less effective in inducing visible green behavior (e.g. solar panels or green cars), but might be more effective for green behavior in private that is non-visible (e.g. water heaters). The results of Friedrichsen and Engelmann (2013) in contrast imply that crowding out does not occur because people who display altruism do this no matter whether they convey information on their status to the public or not.

Atruism helps to mitigate the negative externality problem, but to which extend this can happen is unclear. Eriksson (2004) analyses this issue and finds that such green consumerism can only partly replace more formal innovations. The study provides more insight regarding the relationship between how much altruism different consumers display and how this behavior affects firms to act in a green way. In the model, a high degree of heterogeneous preferences among consumers with respect to altruistic behavior leads to little environmental benefits. More equality among consumers leads more producers to act green as long as the consumers display a high enough altruistic behavior. These findings imply that in societies with a relative high degree of altruism, it is beneficial for the production of green products to target an equal distribution with respect to environmental care.

Altruism is also shown to play an important role in the adaption of green electricity. Different contributions in the literature study the motives for adapting green-electricity tariffs, e.g. Rowlands et al. (2003), Kotchen and Moore (2007), Diaz-Rainey and Ashton (2011) and Ozaki (2011). Kotchen and Moore (2007) find that environmental care and altruistic behavior influence the decision on participation in green electricity programs while demographics did not significantly influence the decision. This is in line with the findings of the other three studies which generally find that attitude is the most important factor that decides over the decision to adopt green electricity tariffs, demographics and behavior also plays a significant role but to a lesser extent.

The complexity of which factors motivate green behavior is described by Benabou and Tirole (2011) in a more general setting. They analyze the interaction between “values”, “laws”, and “norms” and how these three approaches in relation with each other shape public policies and private decisions. Individuals’ behaviors shape the norms persisting in a society which together with the valid law influence optimal incentives and policies. Specifically to the issue on preserving the environment, individuals’ attitudes towards green consumerism shape consumers’ behavior by influencing the degree of altruism. This endogenously determined consumer behavior impacts the optimal environmental policy. As already indicated, wealthier countries typically are able to address the issue of environmental damage with more resources than poorer ones which in turn leads to an increased level of environmental regulation. In their theoretical contribution Heyes and Kapur (2010) have shown that altruism alters optimal policies. Thereby, they provide evidence for the existence of the effect through which consumer behavior impacts optimal incentive setting. The incentives in society thus convey information about societal values and changes in private and societal preferences (termed as “values” or also informal institutional innovations) can have the same influence on norms as changes in incentives (formal institutional innovations) have.

An interesting concept by Benabou and Tirole (2011) is also the one of the “social multiplier” which explains the diverse individual’s reactions to the actual societal behavior. An example of such a behavior is again the Toyota Prius. Owning such a car is today seen as a superior characteristic. Thus, as the Prius is relatively expensive and is driven by relatively few people it is likely to be compelling for wealthy people to drive this car and signal their status. This might change with time as the Prius becomes affordable to a wider range of people. More individuals owning such a car might be a reason for the wealthier ones to not own it anymore and instead replace it through a newer status symbol.

4.3.4 Informal Innovations Inducing Green Consumerism

The analysis in Section 4.1 has shown that the development and diffusion of green technologies heavily rely on policies such that without any governmental action investment in environmental R&D is at a suboptimal low level. Policies do not only incentivize innovation directly, but are also expected to increase the consumers’ awareness for green products and thus its demand. In the following, I am going to address these less formal regulations that are implemented in order to incentivize the demand for green products by final consumers.

An individual’s degree of green consumerism is dependent on different factors which characterize the consumer to which belong informal institutional changes including behavioral changes. Such informal institutional changes do not necessarily have to come from the consumers also firms can implement such changes. Among these changes are supporting instrument policies often voluntary implemented by firms which are expected to further induce green consumerism and are of crucial importance in the diffusion phase of the product cycle (see Figure 5). Examples of such instruments are corporate social responsibility (CSR) programs or eco-labeling which are used to convey additional information to consumers and which in the literature are often expected to replace more formal regulations. Heyes and Kapur (2012) challenge this persisting belief that informal regulations which increase firms’ environmental performances can either replace or at least complement more formal ones. The authors argue that such informal regulations might complement the formal regulations under certain circumstances, but that formal regulations are more efficient than the informal ones in incentivizing green firm behavior from a social welfare perspective.

Different studies have recognized the important role of eco-labels in conveying information to uninformed consumers, e.g. Caswell and Mojduszka (1996) and Mason (2006). These studies show that firms can signal the quality of their products credibly as long as the information is certified by a trustworthy third party. Building on these results Mahenc (2009) investigates the role eco-labeling plays when the third party itself is possibly not trustworthy. Only if consumers completely trust the agency, the information can be successfully submitted with a minimum efficiency loss and labeling is useful in solving the adverse selection problem. But the use of eco-labeling to signal a product’s greenness might also bear its problems as eco-labeling can be shown to be non-informative (Mahenc, 2008a). Mahenc (2008b) shows that mainly due to the issue of asymmetric information but also due to the costliness of information eco-labeling is not suited without restrictions to signal a product’s environmental performance. Instead, pricing can be used as the characteristic that signals the product’s environmental performance to uninformed consumers – a method that has been shown to be of empirical relevance as consumers are willing to pay a higher price for cleaner products (altruism and/or signaling). Due to the higher production costs of green products and due to the firms which want consumers to believe their products to be clean regardless of its true environmental performance, green products are priced higher in the market than polluting ones. This implies that cleaner firms forgo less profit due to a price increase than more polluting firms. Thus, firms distort prices upward compared to the case of perfect information in order to signal the environmental performance. In another theoretical study Mahenc (2007) shows that the case in which dirty and clean products are priced the same can exist as well. This might pose a problem as the incentive to produce cleaner and at the same time more costly products is decreased as clean and dirty products sell at the same price which in turn might drive the clean products out of the market. Whether the latter case is empirically relevant is not clear, but the opposite case – green products are priced higher – at least is observable under some circumstances motivated through intrinsic or signaling motivation.

5 Inequality and Eco-Innovations

In this section inequality is introduced. It starts out with the theoretical and empirical evidence that exists on inequality and eco-innovations. The second part of the section discusses the current literature and the implications of the empirical findings made in previous sections in relation with income inequality and their effect on the development and diffusion of eco-innovations.

5.1 Theoretical and Empirical Evidence

Only little theoretical and empirical evidence exits that deals with the impact income inequality has on eco-innovations. On the one hand there is the direct demand effect through which consumers' preferences determine the market size and thus the incentives to eco-innovate and on the other hand there is the indirect effect consumers' preferences have on inducing eco-innovations through the influence on environmental policy.

Though not measuring directly the incentives to eco-innovate Magnani (2000) provides crucial insight into how income inequality affects environmental degradation and thus also might affect green innovations. Her analysis is of theoretical and empirical nature and focuses on high income countries, i.e. those countries with GDP per capita in the downward-sloping part of the environmental Kuznets curve (EKC) and thus those countries which possess a high income-elasticity for the demand of environmental quality. The author introduces two measures, the absolute-income effect and the relative-income effect, which are measured by GDP per capita and within-country income inequality respectively. It is shown that while the former effect on environmental quality is indeed positive as proposed by the EKC literature, the relative-income effect is strongly negative. This implies that for high-income countries in which consumers' care for the environment is high enough, income inequality reduces expenditures on environmental R&D and also reduces environmental regulation such that income inequality impacts the demand for environmental quality negatively. These findings contradict with the EKC such that increasing GDP per capita does not inevitably lead to less pollution. Instead, if the relative-income effect dominates the absolute one environmental degradation might increase with a growth in GDP per capita.

More recently few authors have started to test the relationship between income inequality and the development of environmentally-friendly technologies either theoretically (Vona and Patriarca, 2011, 2012) or empirically by focusing on the renewable energy sector (Vona et al., 2012; Nicolli and Vona, 2012). In their analysis Vona and Patriarca (2011) find that a high level of income inequality is harmful for the development of eco-innovations, especially in rich countries. For poor countries, the effect of inequality is dominated by the low per-capita incomes. Even though the analysis confirms the role of pioneer consumers and the positive adoption externalities they provide on others, it is shown to be relevant only for small income distances in rich countries such that income inequality negatively affects eco-innovations. For poor countries if the median consumer is not wealthy enough even if inequality is low the learning-by-using effect might not induce middle class consumers to consume green goods. From an empirical point of view Vona and Patriarca (2011) confirm their theoretical findings and show that for rich countries inequality harms the development for eco-innovations. An exception to this negative relationship between inequality and the development of green technologies in rich countries are relatively new technologies such as the electric vehicle. In such immature sectors in the early stages of technology development pioneer consumers might play a crucial role in incentivizing innovation for which inequality does not need to be harmful. Vona and Patriarca (2012) extend their analysis by introducing regressive taxes and measuring the tax effectiveness under different levels of income inequality. Thereby, increasing income inequality leads to a lower tax effectiveness which is due to the fact that the higher income gap reduces the positive externality effect of pioneer consumers on less wealthier consumers.

The analyses above rely on assumptions that have shown to be of empirical relevance. Consumers have non-homothetic preferences characterized by hierarchical needs with satiation limits. Once basic needs are satiated, consumers' WTP for goods higher in the hierarchical scale becomes positive. Thereby, environmental quality can be regarded as a normal good higher in the hierarchical scale. This increased WTP is reflected in the direct demand for green products but also indirectly in the demand for a higher degree of environmental regulation. Given the per capita income, lower income inequality (characterized by a richer median consumer) increases the WTP for environmental quality and at the same time supports stricter environmental regulation (Vona et al., 2012; Nicolli and Vona, 2012). These findings are in in line with the ones of Magnani (2000) and Vona and Patriarca (2011).

By empirically studying the determinants of innovation in the renewable energy sector in OECD countries Vona et al. (2012) identify the high importance of income inequality in inducing eco-innovation directly and the relevance of GDP per capita in determining policy stringency. Nicolli und Vona (2012) more specifically study the determinants for renewable energy policy in OECD countries and find that income has a positive effect on policy and inequality a negative one. Thereby, the negative effect of inequality is much stronger in wealthier countries. This is consistent with the previous results and shows that environmental policy is dependent on consumers' preferences and norms persisting in a society as indicated by Benabou and Tirole (2011)

Network externalities such as learning are crucial in the analysis of how income inequality affects eco-innovation. Learning-by-doing is associated with technological progress such that over time production becomes cheaper. Learning-by-using on the other hand emerges on the consumption side. Thereby, pioneer consumers play a crucial role as they can induce green consumption by middle class individuals as long as the income gap is small enough (trickle-down). This trickle-down effect can develop in a way that a critical mass of consumers demand environmental quality and that the good eventually becomes available to the mass. This development can be compared with the "Flying Geese" pattern as identified by Matsuyama (2002) and Foellmi et al. (2009) in their models addressing the issue on how income inequality affects conventional innovations. The pattern describes the development that with increasing income and productivity one product takes off after another and transforms from a luxury into a necessity. The models assume non-homothetic preferences such that the rich consume a variety of high-quality products and the poor fewer low-quality products. Through invention the luxury goods of the rich are turned into mass consumption goods for the poor. This is analyzed by Zweimüller (2000) who shows how the distribution of income determines the level of market demand. At the initial stage, only the rich are able to afford the luxury good, but over time as learning occurs and income grows, the market size increases and an increased number of consumers becomes willing to buy the product which eventually turns into a mass product.

Concepts used in such models are helpful contributions but cannot be completely carried over to apply to green innovations. The positive spillover effect of public knowledge is also present in case of conventional innovation. What is new is the issue of environmental pollution, the associated negative externality and environmental regulation. The development and diffusion of eco-innovations lead to direct private and public benefits of consumption and to complex policy interventions on firms and consumers which are not present in case of conventional innovations. Income inequality thereby directly influences the demand and indirectly impacts policy choices.

5.2 Demand and the Development of Eco-Innovations

The discussions in the previous sections have identified regulation, technology and market factors as the main drivers for the incentives to eco-innovate. Further, it has been shown that different kinds of innovations (incremental vs. radical) or different technologies (mature vs. immature) are differently influenced by these factors.

Studies addressed above have identified crucial differences in the determinants of incremental and radical eco-innovations. To these studies belong the ones of Popp (2003) and Calel and Dechezleprêtre

(2013) who use patent data, but also the ones of Cleff and Rennings (1999), Wagner (2007) and Rave et al. (2011) who use survey and patent data for their analyses. Thereby, it is generally found that environmental regulation plays a crucial role in inducing less innovative eco-innovations which are often characterized by being incremental and less expensive process innovations designed for legal compliance and cost reduction and which possess no direct consumer benefit. At the same time the demand channel seems to play a subordinate role for such incremental innovations which are often times implemented to reduce pollution. The reverse is true for more radical innovations for which the demand is expected to be the key driver and flexible environmental policy solely supports eco-innovative activities. In inducing such innovations the technology stage, which itself is a determinant of the demand, also plays a crucial role. Such innovations are characterized by typically being complex and more expensive product innovations aiming at increasing energy-efficiency and designed for market reasons and thus with a clear direct benefit for consumers.

For any kind of technological innovation the stage of the technology is decisive for identifying the key drivers of eco-innovations as particularly analyzed theoretically by Acemoglu et al. (2012) and empirically by Horbach (2008), Johnstone et al. (2010) and Wangler (2013). Thereby, for less mature technologies which still are in the early stages of the innovation cycle, stricter regulation is required to induce such eco-innovations and is also an important determinant thereof. This does not mean that such innovations are necessarily incremental. Instead, they often time possess a high growth potential as no close substitutes to this technology are available. While being less mature but still radical, strict regulation and the demand play a crucial role in incentivizing innovation in such "new" green technologies. As an example of such a technology the electric vehicle can be mentioned. On the other hand, there are the more mature technologies which typically possess close substitutes (e.g. wind energy). Such innovations are mainly driven by demand and to a lesser extent by regulation as they are already progressed.

5.3 Inequality and the Development of Eco-Innovations

As the literature review has shown the demand impacts eco-innovation through two different channels: Indirectly through policies and directly through the market size. Both of them will be analyzed in the following with a discussion on how the two effects work in developing and developed countries.

5.3.1 Political Economy Effect

The political economy effect works through the preferences for environmental quality of the median consumer through which income inequality negatively influences environmental policy. Thereby, environmental quality is considered a public good such that in a political process an individual can decide on whether to consume a private good with only private benefits or to consume the public good which is associated with public benefits. How many consumers demand the public good and how much of their resources they put into the consumption of the public good are directly dependent on the consumers' preferences for environmental quality in an economy. There is empirical evidence that environmental quality is a normal good and depending on the good under consideration, the time and the consumer's individual preferences might even be a superior one. Under the assumption that an individual's environmental awareness is dependent on his income, the income distribution in a society is responsible for the different proportions of consumers' resources devoted to the public good such that increasing income inequality decreases the contribution of the median consumer. Hence, it is the median voter's income that decides over the degree of environmental policy stringency in the economy. This income is maximized under total income equality. Thus, this political economy effect is negative in any case such that an increase in income inequality reduces the median consumer's income and his demand for environmental quality. This leads to less stricter environmental policy which in turn has a negative effect on the incentives to eco-innovate.

This indirect effect of inequality on eco-innovations is present in developed as well as developing countries but is likely to be bigger in developed ones as empirically identified by Nicolli and Vona (2012) which can be attributed to two reasons. First, environmental quality in developed countries is more likely to be a superior good than it is in developing countries. While in developing countries mostly incremental eco-innovative products are consumed that satisfy the minimal accepted environmental standards, eco-innovative products in developed countries are of both, incremental and more radical nature. The consumption of such radical products in developed countries is often associated with altruism and status symbols. There is empirical evidence that consumers are willing to pay a higher price for an eco-friendly product in order to signal their status (e.g. Ariely et al., 2009; Griskevicius et al., 2010). Further, this income-elasticity of environmental demand is likely to change over time such that with increasing income the elasticity is more likely to exceed unity. Second, the political economy effect works for formal and informal policies. Informal regulation which is voluntary adopted (e.g. labeling, CRS) is only successful if the median consumer's care for environmental quality is high enough. In developing countries this situation does not exist as the negative effect of a low GDP per capita on the demand for environmental quality dominates the positive one of low inequality (Vona and Patriarca, 2011). In contrast, in developed countries which exceed a certain GDP per capita level less formal regulation is successful as long as the degree of inequality is not too high such that a critical mass of consumers is willing to pay a premium for the greenness. In summary, the indirect effect of inequality through policies is unambiguously negative and most likely higher in developed countries than in developing ones.

5.3.2 Market Size Effect

5.3.2.1 Developing Countries

Statistics show that the big majority of eco-innovations demanded in developing countries are low-value incremental innovations often imported and adopted to local conditions (Lanjouw and Mody, 1996; Dechezleprêtre et al., 2011). Regarding the GDP per capita levels these findings are in line with the expectations. Low-income countries with a majority of poor consumers demand incremental process innovations which satisfy only the minimum level required by regulation. Thereby, the demand has shown to play a subordinate role and instead regulation has been identified as a more important driver. Therefore, the effect of inequality on eco-innovations through the market size seems to be negligible in the majority of cases in developing countries. This is due to the low GDP per capita level which dominates the effect of income inequality.

Still, there is the case in which a very high income inequality leads the few wealthy consumers in poor countries demand radical eco-innovations. The pioneer consumer effect - such that innovation trickles down to middle class consumers □does not work since the low GDP per capita level dominates (Vona and Patriarca, 2011). A higher degree of inequality thus has a positive impact in increasing the amount of consumers who are willing to purchase eco-friendly innovative products. This analysis can be applied to poor countries to a certain GDP per capita threshold. As long as a certain fraction of the population is below a critical income threshold, a higher degree of inequality increases the demand for green products and the incentives to eco-innovate as long as it dominates the negative political economy effect.

In developing countries a third case in which income inequality differently affects the incentives to eco-innovate can occur. Frugal innovations, which are characterized by very cheap products that are targeted at the mass in poor countries, turn the analysis upside down such that income inequality negatively affects the incentives to eco-innovate. This situation has not received much attention in the literature until very recently, but is closer discussed by means of the case study of the Tata Nano in Section 6.2.

5.3.2.2 Developed Countries

Similar to the majority of cases in developing countries income inequality is expected not to affect less radical innovations since the demand has shown to play a subordinate role for such incremental changes. In these cases, the negative effect of inequality on eco-innovations through policy is the main force. But with increasing income levels more radical eco-innovations are demanded such that the effect of inequality on eco-innovative activities depends on the impact of the technology. In the case in which the technology is sufficiently progressed such that regulation is not a deciding factor anymore, less inequality increases the median consumers WTP for environmental quality and thus the demand to eco-innovate. Thus, the effect of inequality on eco-innovation is unambiguously negative (the indirect and direct channel work in the same direction). However, this analysis only applies to technologies that have achieved a certain degree of maturity such that the demand is the main driver for inducing eco-innovations (e.g. wind technology). In the case of technologies in the initial stages of the innovation cycle (e.g. electric vehicles), policy has shown to also play a crucial role besides the demand. Middle class consumers might not be willing to purchase highly eco-innovative goods such that - similar to the case analyzed for developing countries – only the wealthiest of the rich demand such advanced green goods. As the analysis of Vona and Patriarca (2011) has shown the pioneer consumer effect might not work such that a higher degree of inequality spurs eco-innovations. Which effect, the indirect negative policy-effect or the direct positive demand-effect, dominates for such immature technologies is not clear. Moreover, over time the technology will develop such that eventually inequality is likely to affect eco-innovation in this technology negatively.

5.3.2.3 *Pioneer Consumer Effect and Learning Process*

The pioneer consumer effect has shown to be crucial in inducing eco-innovations and to be highly dependent on the degree of inequality in countries above a certain income threshold. How fast the learning process is and through which mechanisms it works cannot be analyzed simply considering the degree of inequality. Few insights can be gained from the analysis above, but in order to study the speed of the learning process in more detail it might be useful to analyze the factors that determine the diffusion of eco-innovations - something that has not been discussed in detail in this paper. To the insight gained belongs again the crucial role the technology plays. Learning by the producer (learning-by-doing) is likely to be influenced by the technology’s development stage and might differ across technologies. Learning by the consumers (learning-by-using) on the other side is influenced by the degree of inequality, whereas lower inequality is likely to speed up the learning process. Again, environmental regulation might play a crucial role. This time policy instruments that have been shown to be crucial in the diffusion phase (see Figure 5) might speed up the innovation process. To these instruments belong less formal ones like labeling which are only successful as long as the country is wealthy enough and inequality is not too high such that a critical mass of consumers is willing to pay a premium for the greenness.

5.3.2.4 *Extension to Two Sectors*

While in developing countries mostly incremental eco-innovations are demanded, the composition of eco-innovations (incremental vs. radical innovations) in a rich economy is expected to depend on the degree of income inequality which works through the demand channel. Thus, in case of technological eco-innovations in developed countries it might be useful to adopt a model of multiple sectors as done by Windrum et al. (2009a). Thereby, eco-innovations are either done by adjusting the existing product only marginally and making the same product greener or by developing a new product which offers more environmental benefits. Regulation might help to induce eco-innovation in the ‘old’ product such that a higher degree of inequality negatively affects this development through the political economy channel while regulation might have a negligible impact on the ‘new’ product development.

At the same time a low degree of inequality is likely to spur innovation in the “old” product through the market size effect. This can be explained by looking at a country with completely homogeneous consumers regarding their environmental preferences. In such a country consumers demand the marginally greener product and not the radical new product once current consumption has reached satiation. The consumers only switch to the new product once the demand for the highest quality “old” product is satiated. In this case the market size effect is big and the pioneer consumer effect non-existing. The eco-friendliness of the product depends on the GDP per capita level of the country. The higher it is, the greener the product. In contrast, a high degree of inequality increases the pioneer consumer effect and decreases the market size effect. In this case, incentives to eco-innovate in the “new” product increase. The learning process influenced by the degree of inequality determines how fast consumers adopt.

Taken the two effects together implies that once a certain income level is reached, the incentives to eco-innovate increase with additional income level. More equality leads the “old” product to be greener (market size effect dominates pioneer consumer effect) while more inequality leads to the development of a completely novel greener product (pioneer consumer effect dominates market size effect). When a moderate degree of inequality persists it is not clear which effect dominates, such that the existing product is further developed to be greener and a new green product is invented that satisfies the demand of pioneer consumers. Moreover, moderate inequality might accelerate the learning process compared to high inequality.

6 Case Studies on Transport Sector

Eco-innovations in the transport sector and sectors related to it possess high growth potential and are expected to contribute on the way to a green economy. In Section 3 it has been shown that in developed but also in emerging economies (Europe, North America, and Asia) the personal transport sector has been identified as one of the top three sectors for implementing eco-innovations by 2030 (Table 3). Moreover, technologies related to the development of eco-friendly personal cars such as fuel injection, renewable energy, and electric and hybrid have received a lot of R&D attention (Figure 2) and have grown substantially (Table 4) over the last decade. A fast and substantial improvement of such technologies that allow the personal transport sector to become green is also necessary as statistics and outlooks show. In its technology perspective the International Energy Agency (IEA) (2012) shows that in 2009 the transport sector accounted globally for one-fifth of primary energy use and one-quarter of energy-related CO_2 emissions. Alarmingly is the development over time showing that in between 1990 and 2007 global CO_2 emissions from transport have increased by 45%. In the OECD outlook in the “business-as-usual” scenario that already includes efficiency improvements global CO_2 emissions in the transport sector are expected to increase by 40% from 2007 until 2030 (OECD/ITF, 2010). This increase in global CO_2 emissions is due to the increased demand for mobility which is closely linked to the rise in income and population which both are expected to continue in the future, especially in developing countries.

Within the transport sector, the road sector accounts for the highest volume of CO2 emissions. Hereby, some countries classify CO2 emissions related to road transport into freight and passenger transport. In general (with the exception of China), passenger transport is responsible for about 60-70% of the road sector CO2 emissions (OECD/ITF, 2010). This high share of the road passenger transport on global CO2 emissions shows the high potential the passenger vehicle sector possesses to lower global environmental impact and simultaneously puts pressure on the sector to do so. The IEA has set the ambitious target of cutting global energy-related CO2 emissions by 2050 in half compared to the 2005 level, whereby the transport sector is expected to contribute 23% to the required reductions (IEA, 2010). An important mean to reach this target is the development and widespread introduction of electric vehicles (EVs). The recently published IEA report estimates that 75% of all vehicles sales by 2050 will need to be EVs to reach the ambitious environmental goals (IEA, 2013).

So far, the ongoing development of such energy-efficient cars has been achieved thanks to technological progress in processes and products. Thus, it is the technology that has typically been at the center of the innovation towards a sustainable development in the transport sector. But increasingly eco-innovations in the transport sector become more integrated such that they also include formal and informal institutional arrangements (OECD, 2009). These institutional arrangements can be diverse as they include whole alternative business models (e.g. bike or car sharing), new policies and green lifestyles. Such changes are influenced by a range of complex factors including measures which are difficult to quantify such as institutions, environmental policies, cultural behavior and individuals' environmental awareness and are certainly dependent on the income level but also on the degree of inequality in an economy.

Also when looking at different world regions it is found that income inequality might be a crucial determinant for the demand for environmental quality and thus for the incentives to eco-innovate in the transport sector. North America and Europe still use the most energy which reflects the fact that the energy use in the transport sector has typically been higher in OECD countries, but has been rising faster in non-OECD countries over the last decade. In most economies CO2 emissions from the transport sector have almost increased continuously since 1990. Few countries such as France, Germany, and Japan are exceptions in that they have either stabilized or even decreased road CO2 emissions already before the 2008-2009 recession. Factors to this development are manifold, some are country-specific others are observable in all three countries. Amongst them are changes in fuel taxation (in Germany), a drop in average traffic speeds (in France), better freight truck load factors (in Japan), but also a stabilization or decrease in road passenger traffic and the impact of a better light-duty fuel economy (OECD/ITF, 2010). These findings are in line with the EKC-literature arguing that with a raising income per capita level environmental degradation decreases. Nevertheless, there is no clear consensus in the literature whether this relationship truly holds and which mechanisms work that determine the process of environmental degradation. Magnani (2000) has shown that besides the income per capita level, income inequality is likely to play an important role.

In the following I am going to turn to two case studies dealing with emerging green technologies and product- and process-innovations in the passenger vehicle sector. By means of electric vehicles the first case study addresses the case in which the green product is mainly demanded in rich countries and in which the technology is still at the initial stages of the development process while the second case study looks at the emergence of an ultra-cheap, but still eco-innovative car in developing countries by means of the Tata Nano.

6.1 Case Study I: Electric Vehicles

This case study deals with the question on how income inequality influences the incentives to innovate in the development of electric vehicles (EVs). Technologies related to EVs are shown to be in the early development stages and are expected to improve substantially only in the long-term. This situation is characterized by the fact that environmental policy as well as demand have a high influence in inducing innovation in EV-technologies. Thereby, income inequality impacts the incentives to innovate in such technologies through the political economy effect and the marketsize effect which contradict each other at least in the short- and medium-term.

6.1.1 Technology and Penetration

There exist different types of EVs including battery electric vehicle (BEVs), hybrid electric vehicles (PHEVs), and fuel cell electric vehicles (FCEVs). In its definition the IEA distinguishes the three types of EVs and terms these categories together as “advanced vehicles”. The BEVs are plug-in, battery vehicle which are typically simply referred to as EVs. PHEVs have an internal combustion engine as well as a motor with battery pack, while the FCEVs use a fuel cell system to convert hydrogen into electricity (IEA, 2011). Over the last few years efforts to accelerate the introduction and the adaption of EVs have increased. To these efforts belongs the Electric Vehicles Initiative (EVI) which is a multi-government policy forum introduced in 2010 under the Clean Energy Ministerial. The EVI includes BEVs, PHEVS, and FCEVs in its definition for EVs. Through its widespread investigation that includes 15 governments from four different continents with its member countries accounting for over 90% of the world EV stock in 2012, the EVI provides consistent data which I will use for the following analysis.

In its recent EVI report, the IEA gathered data on its 15 member countries and estimates that these countries will account for 83% of global EV sales between now and 2020. As of the end of 2012, the global EV stock had approximately a size of 180 000 vehicles which is likely to be an underestimate and which represents only 0.02% of total global passenger cars. Table 5 shows the EVI countries listed by the size of their corresponding EV stocks as of 2012. EVI's goal is to increase the global EV stock to 20 million by the end of 2020. This seems to be very ambitious but the recent developments made lead in the right direction. While in 2011 45'000 EVs were sold globally, this number increased in 2012 to 113'000 vehicles. In order to reach the clarified goal the 2011 sales would need to grow 72% compound each year till 2020. Further, this penetration by 2020 is necessary in order to reach the level of 75% of all vehicles sales to be EVs which is needed in order to reach the projected environmental goals (IEA, 2013).

	EV Stock 2012
United States	71'174
Japan	44'727
France	20'000
China	11'573
United Kingdom	8'183
Netherlands	6'750
Germany	5'555
Portugal	1'862
Italy	1'643
India	1'428
Denmark	1'388
Sweden	1'285
Spain	787
Finland	271
South Africa	N/A
World	180'000+

Table 5: EVI countries listed by EV stocks Source: IEA, 2013

Countries participating in the EVI are typically characterized by relatively high absolute GDP levels as well as high GDP per capita levels. Exceptions are the three emerging economies China, India, and South Africa (due to the fact that no data is available for South Africa, I do not further pay attention to it). But China and India are both huge economies with high development potential such that their sizes and their economic outlooks are likely to dominate the effect of low GDP per capita levels. It is not only EVI countries that demand EVs. With approximately 10'000 EVs Norway has the highest EV stock of non-EVI countries. Other non-EVI countries with increasing EV stocks are Canada, Ireland, Switzerland, and Austria (IEA, 2013). Interesting are the common characteristics of all these countries: they are all OECD members, have very high GDP per capita levels and relatively low population sizes. These components make the countries interesting with respect to potential customers, but the absolute sales of EVs are likely to be low due to the tiny market sizes. In general, it can be said that it is mostly developed countries which are responsible for the current demand of EVs while the emerging markets with high market potential cannot be neglected.

Particular hope is put into the diverse national policy initiatives designed to increase the penetration of EVs. These initiatives can be distinguished to be of financial, infrastructural and RD&D-based nature.

Unsurprisingly, due to the newness of the EV market most of the effort is put into the research, development and demonstration (RD&D) sector. Figure 6 represents the RD&D on EVs spending by EVI countries. 2009 shows the high spending due to the U.S. economic stimulus. Even though this was a one-time U.S. investment overall spending remained at a constant high level as in the consecutive years especially Japan, Germany, and China invested increased amounts into the development of EVs which shows the commitment and high expectations put into the EV market. Particularly interesting with respect to the high RD&D efforts is the progress made towards reducing battery cost. As of today, battery costs still account for the largest cost of an EV, but the IEA (2013) argues that these costs are falling rapidly and expects the battery costs to be less than half of the cost of an EV by 2020. Other studies are not as optimistic. Gerssen-Gondelach and Faaij (2012) find that in the medium-term or even in the long-term all with the exception of one battery under consideration are likely not to simultaneously meet all requirements put on them.

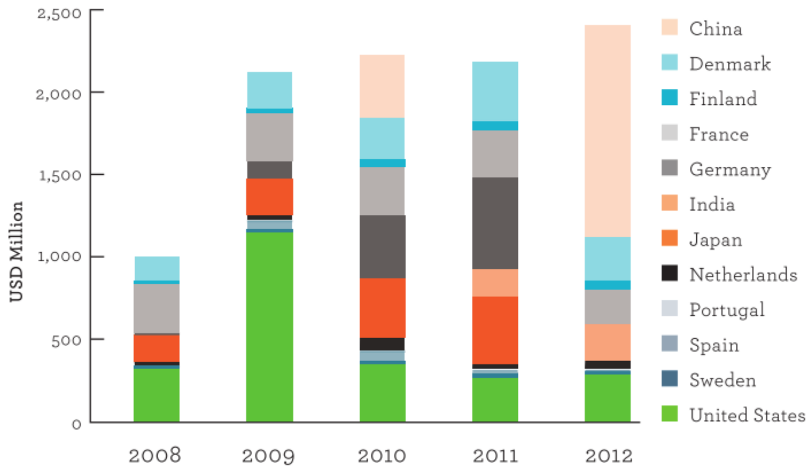

Figure 6: RD&D spending on EVs by EVI countries Source: IEA, 2013, p.16

The current and expected penetration of EVs shows that it is likely to take time such that EVs are available to the mass only in the long-term. This development of EV penetration goes hand in hand with the technology. Surely not in the short-term and optimistically in the medium-term, the technology is going to have achieved a stage that allows the widespread adoption of EVs. How fast this technological development progresses heavily depends on learning-by-doing by technology developers and producers of EVs which in turn is dependent on the incentives to innovate. Thereby, consumer demand and governmental policy both play a crucial role for such technologies early in their development stages.

6.1.2 Environmental Regulation

Different empirical studies have shown that environmental regulation plays a crucial role in the development of eco-technologies at the early stages of the development process (e.g. Rennings and Beise, 2005; Johnstone et al., 2010). While environmental regulation for EV-related technology has mainly focused on innovation policy in the past, a wide range of instruments also from environmental policy such as market-based (tax incentives and subsidies), regulatory (technology standards) or supporting instruments (car labeling) are available designed to increase the incentives to innovate. While many of such instruments target the producer, thus deal with technological progress and are designed to increase the speed of development, fiscal expenditures also include incentives for the consumers to purchase EVs. Such financial incentives have recently been introduced in most EVI countries and are diverse (IEA, 2013). Under this category fall for example direct financial subsidies for the purchase of EVs (e.g. China, India, Japan, Spain, Sweden), exemptions from road taxes (e.g. Denmark and Germany), and tax reductions (e.g. Netherlands, United States). Such subsidies are expected to eventually disappear, but in the early introduction phase of EVs such actions are necessary to stimulate demand. The third dimension of introduced initiatives in EVI countries includes infrastructure spending which has been relatively sparse from the side of the government. As the IEA (2013) argues, the involvement of cities and the private sector in the development of charging stations puts the governments' focus on fiscal an R&D-based actions.

6.1.3 Demand for EVs

The demand for EVs is likely to depend highly on the demand for environmental quality. Besides concern for the environment and the associated environmental policy, other factors such as altruism and signaling, but also the relative cost of driving which depends on the fuel price are further expected to impact the demand of such green cars.

Environmental quality can be regarded as a normal good for which the demand increases with increasing income. Moreover, empirical studies show that depending on the good, the time and the individual environmental quality can be seen as a superior good such that demand for the green good increases more than proportionally with income (OECD, 2008a, 2011a; Diaz-Rainey and Ashton, 2011). This implies that with increasing incomes the demand for EVs is expected to increase. This is supported by the findings of an in 2008 conducted OECD household survey which indicates that in the 10 OECD countries under consideration people owning a hybrid vehicle were more often people in the highest income decile than people who own a conventional fuel-based car (OECD 2011a). Further, the more recent OECD survey shows that EV ownership positively depends on household income and household size and that the household's WTP for an EV is higher for households which display higher environmental concerns (OECD, 2013).

With increasing wealth, altruism and signaling become a crucial motive of purchasing EVs (Maynard, 2007). Signaling wealth which in the past typically has been done through the consumption of luxury goods is slowly getting replaced through the consumption of eco-friendly products such as bio-labels for food or alternative-fuelled vehicles. This can be seen by the trade-off individuals make between a product's price, quality and environmental performance as described by Windrum et al. (2009b). Traditionally consumers' preferences for cars were steered towards high quality characterized by speed, acceleration and size and not towards environmental performance which incentivized producers to focus on high-quality and at the same time high-polluting product development. With time and increasing incomes consumers especially in developed countries have started to shift their preferences to incorporate environmental quality. This development has more recently incentivized more R&D towards eco-friendly technologies in the transport sector. But this transition in consumer preferences away from high-polluting, high-quality towards eco-friendly, lower-quality products is still in its early phase as can be seen by the still high demand for high-quality cars and the relative low attention a car's environmental performance gets in the purchasing decision (OECD, 2013). Nevertheless, the transition away from high-quality products to eco-friendly products to signal wealth is taking place which can be seen by the fact that consumers of eco-friendly goods are more willing to purchase the good if the good is priced higher (e.g. Griskevicius et al., 2010). Displaying altruism has not yet spread to the wide mass, instead it is the wealthiest of the rich who are willing to pay a premium for eco-friendly goods in order to display their altruism. In the OECD household survey in 2011 (OECD, 2013) people who responded that they believe they should not bear some of the cost environmental policies bring about were shown to have a lower average WTP for EVs. Thus, with respect to the wide mass of consumers, the relative price of driving can be identified as another factor impacting the demand of EVs. Increases in fuel prices make driving an EV relatively less expensive and thus increase the demand for EVs and induce innovation in EV-related technologies. Over time increased R&D in turn leads to smaller sales prices which are expected to develop the EV from an exclusive good to a good available to the wide mass.

6.1.4 Income Inequality

Both effects of income distribution on the incentives to innovate in EVs are expected to be big. The indirect effect through environmental policy is expected to be strong because the countries under consideration are typically high income countries associated with a high average demand for environmental quality. In such countries the level of environmental regulation is expected to be relatively high which has empirically been identified by Easty and Porter (2001). Additionally to formal regulations implemented by the government, informal regulations such as eco-labels for cars or CSR are likely to be successful in such economies with a high degree of environmental awareness. Thus, a higher degree of inequality unambiguously decreases policies that are designed to spur the diffusion of EVs. Less regulation translates into less R&D undertaken by producers and developers of EV-related technologies and simultaneously to a decrease of the demand for EVs by consumers.

The direct effect through the demand channel is likely to work the other way around. Higher income inequality is expected to increase the demand for EVs at least in the short- and medium-term. This is due to the fact that the technology is only little progressed such that the middle class in the relatively rich countries under consideration are not willing to give up private benefits for the public benefits the purchase of an EV brings about. Only the wealthiest of the rich are able to afford the advanced product and are willing to pay a premium for it which can be associated with either intrinsic or signaling motivation. Higher income inequality thus implies higher demand and higher incentives to innovate in related green technologies. With increasing demand the learning process is expected to accelerate.

At least as much influence as the demand on the speed of the learning process has the stage the technology is in. In case of EVs it has been shown that the technology needs time to develop that optimistically in the medium-term it reaches a level that makes EVs available to the wide mass. The numbers reflect this fact. In 2012 about 180 000 vehicles or only about 0.02% of all vehicles worldwide were EVs. The goal is to reach a penetration of 20 million EVs by 2020, which would represent roughly about 2% of the current worldwide vehicle stock. Finally by 2050 the demand for EVs is expected to have risen to a reputable level accounting for 75% of the worldwide vehicle stock. These numbers show that in the short-term the positive effect that pioneer consumers have on the middle class consumers seems not to work because technology is not advanced enough. Optimistically in the medium-term, maybe only in the long-term, technology will be progressed enough such that the pioneer consumer effect works and the market size effect induces eco-innovations related to EVs. Thus, higher income inequality can be associated with higher incentives to innovate in EV-related technologies.

Whether the negative political economy effect or the positive demand effect of inequality on the incentives to eco-innovate dominates is not clear. It is likely to depend on the individual country characteristics including market structure and entry barriers, the persisting level of environmental policy as well as the technology stage and the associated learning effects. This is at least true for the short-term and most likely also for the medium-term, but is expected to change over time such that inequality unambiguously decreases the incentives to innovate in EVs once the technology has reached a certain maturity level and even though environmental policy becomes less important.

6.2 Case Study II: Tata Nano

It has been shown that the EV is an environmental innovation that significantly cuts down the release of harmful substances compared to available alternatives by using electricity instead of fossil-fuels as its power source. Per definition not all eco-innovations offer such a clear benefit and lead to such a big reduction of environmental damage. As seen in Section 2.2 any innovation that has environmental benefits compared to available alternatives is classified as an eco-innovation. Thus, another specific innovation also from the passenger vehicle sector that can be regarded as an eco-innovation is the Tata Nano. In the following, I am going to address the characteristics of the product together with the concepts of frugal innovations which is a topic closely related with the Tata's introduction in developing as well as developed markets. In a second part, I am going to discuss the role income inequality plays for the development and diffusion of the Tata.

6.2.1 Tata Nano and its Characteristics

The Tata Nano is an ultra-low cost car developed by the biggest Indian car company Tata Motors and first introduced in the Indian market in 2009 priced at $2 200 (Tiwari and Herstatt, 2011). The special features of the Tata are its simplicity while still meeting performance standards and regulatory requirements and its low cost. Besides being advertised as being big on space, comfortable, and cheap, the Tata also meets the Indian as well as the European emission standards (Tata Motors, 2013). This fuel efficiency moreover makes the Tata the most fuel-efficient car in the Indian market and thus from the perspective of the Indian passenger vehicle market the Tata Nano can be classified as an eco-innovation. The Tata Nano might provide a greener alternative to current available cars on the Indian market, but also to the many two-wheelers currently in use. As the Worldwatch Institute (2013) argues in its article the Tata is likely to pollute less than the motor vehicles from an individual's perspective.

With only 13 cars per 1000 people in 2011 India has one of the lowest car penetration rates among emerging markets (ICRA, 2011). This low car penetration rate together with rising incomes and population should help to the widespread introduction of the Tata in the Indian market and other emerging markets and make it the "people's car". This situation is comparable with the one in the U.S. about a century ago before the introduction of the Ford Model T. Incremental process innovations led to the development of Model T which made the car available to the wide mass in the U.S. (see Foellmi et al., 2009 for a detailed analysis). Central to the analysis is Schmookler's concept of how luxuries transform into necessities:

"*Consumer goods inventions that cut both cost and quality but reduce the former more than the latter, such as the Model T, have historically been an important means for transforming the luxuries of the rich into the conveniences of the poor.*" (Schmookler, 1966)

This transformation is also applicable to the Tata Nano as quality is cut a lot but costs even more. The car as an initially very complex product has been adjusted through incremental innovations such that it can almost not get any simpler and especially not any cheaper anymore. However, there are two important differences to the situation that occurred in developed countries a century ago. First, besides cost and quality, the innovation's environmental performance is also taken into account and thus is associated with environmental regulation. Second, this time the innovation occurs in developing countries and thus has not only already occurred in developed countries at earlier times but also possesses the possibility to spread to such more advanced countries.

In general, incremental eco-innovations are often times driven to a big extent by environmental regulation. This is different for such innovations targeted at markets with a high growth potential that allow a previously luxury good to become available to the wide mass. The motivation of such eco-innovations is often times not the increased environmental performance instead the huge market demand is the key factor of the development that makes luxuries into conveniences. Consumers with typically low incomes do not primarily care about environmental quality, but much more about the affordability of the good. Increased environmental performance of the good occurs as a positive side effect that is on the one hand due to regulation and on the other hand due to learning from the past. Domestic regulations put in place are expected to define a product’s environmental performance. But India as an emerging country with a very low GDP per capita level is likely to have a relatively lax environmental regulation. This hypothesis is supported by Easty and Porter (2001). Besides meeting Indian performance standards, the Tata complies with the European ones. Such regulations are likely to be stricter and are also likely to influence the Tata’s environmental performance as Tata Motors strives to spread the car also to developed countries. Learning occurs through the import and adaption of technologies from industrialized countries and allows emerging countries to develop incremental eco-innovations. There is a positive effect such that the processes and technologies which the emerging countries apply today do not suffer from the same high environmental impact as the ones that had been used in the past by developed countries.

6.2.2 Frugal Innovations

The development of such products like that Tata which are characterized by their simplicity have more recently occurred manifold in emerging economies and have been termed as “frugal”, “disruptive”, “reverse” or “constraint-based” innovations. According to the EIO frugal innovations can be seen as a special category of eco-innovations. The EIO describes frugal innovations its report as “eco-innovations designed to be inexpensive, robust and easy to use. It also means being sparse in the use of raw materials and their impact on the environment” (EIO, 2011, p.62). Besides the Tata examples of such frugal innovations are a fridge (market introduction price of $70), a water purifier ($21), or a tablet PC ($35) which in 2009 were introduced to the Indian market at a fraction of the prices of existing, computing products (Tiwari and Herstatt, 2011). This development is comparable to the introduction of consumer durables (e.g. refrigerators, washing machines, televisions) in developed countries but with the distinction that this time such innovations are targeted at the base of the pyramid in poor countries such that the products impress by their minimal costs and their simplicity. Due to the typically high income inequality in such emerging economies the market size at which such products are targeted is huge.

While the terms “frugal” or “constraint-based” can be associated with the simplicity of the innovation, the terms “reverse” or “disruptive” go back to the diffusion of such simplified green products which have been achieved through innovations in developing countries to more advanced economies. Such innovations often do not only encompass product or process innovations, but also marketing and organizational ones (Tiwari and Herstatt, 2011). This trickling-up of eco-innovations from poor to rich countries reverses the traditional view of innovations in which the innovation typically trickles down from developed to developing countries. More recently R&D which traditionally has been carried out in Europe, Japan, and the U.S. has been rising in the developing world, in particular in East Asia. According to the OECD report on perspectives of the global development (OECD, 2010) the concept of reverse innovation is part of a new business model that emerges from the developing world. This structural transformation of the global economy has started 20 years ago and is expected to continue which is reflected by the high growth rates of China and India during the 2000s which both grew at a rate three to four times of the OECD average.

6.2.3 Income Inequality

The development of the Tata Nano as a reverse innovation characterized through its simplicity, its low environmental impact and above all its low costs is mainly driven by demand and only to a little extent by environmental regulation. These main drivers distinguish the Tata from other incremental innovations as regulations have shown to be an important determinant thereof. At the same time it can be argued that the Tata as a final product is a radical innovation achieved through many incremental innovations not only in processes, but also of organizational and marketing-based nature. From this point of view, the fact that mainly demand determines the incentives to innovate in the Tata is reasonable.

The effect of income inequality on the incentives to eco-innovate through the indirect policy channel is likely to be low to non-existing. High within-country inequality in India and more generally in emerging economies from which the reverse innovations originate would be expected to have a negative effect on the incentives to innovate in green products. But higher foreign regulation standards together with learning that has occurred leads innovations from such developing economies to meet eco-standards but still not to be completely green. In these cases the macro effects on the environment through such eco-innovations is likely to be negative (see Section 6.3 for Rebound Effect and Backfire).

The effect of income inequality on the incentives to eco-innovate through the demand channel in return is all the higher. The income distribution determines the success of the Tata as it is at first specifically targeted at Indian's middle class. High income inequality thereby has a negative effect on the potential market size, while with a complete equal distribution the market size is maximized. The low car penetration rates in emerging economies in general and especially in India show this high potential of the Tata Nano. In such poor countries consumers are not primarily concerned about environmental quality, but enjoy the convenience of owning a car as alternative to a two-wheeler. Increasing incomes and minimal costs of the Tata Nano allows households above a specific income threshold to purchase such a relatively green vehicle. Thus, income inequality within emerging economies has a negative effect on the diffusion of the Tata in such markets.

Additionally to domestic demand, Tata Motors sees market potential in developed countries. Within such rich countries the poorest consumers who do not yet own a car are targeted. This is reasonable as in OECD countries low income is the number one reason for not owning a car and car ownership increases with higher incomes (OECD, 2011a). Again, such consumers are likely to value the ownership of a car higher than the environmental quality. A decrease in the very poor consumers in developed countries thus decreases the market size and a high amount of inequality in such countries is likely to be beneficial for the diffusion of the Tata to such high-income countries.

In summary, the likelihood of success of the introduction of the Tata Nano in emerging economies depends on the income distribution such that a lower level of within-country inequality is beneficial. While for the case that the Tata spreads to developed countries a higher level of inequality in such countries is more encouraging for its success.

The development of the Tata and more generally of frugal innovations are promising for the mass in emerging economies and for the poor in rich countries which enables them to consume previous luxuries. Even though regarded as eco-innovations, this widespread introduction of consumer durables induced by increasing incomes and reverse innovations is likely to be negative with regards to the environmental impact on the macro level. Although this development is not sustainable over the long-run, the poor have the right of car usage and other environmental polluting activities as long as wealthy consumers enjoy the same. This issue is much more complex as different solutions of not only technological nature are needed that rethink the right to pollute (e.g. public transport instead of personal vehicles) and that provide solutions to a zero-impact economy. In the specific case of the transport sector, this incorporates the development of new technologies such as EVs. Such cars with minimal or even zero environmental impact will need to be made available not only to the wealthy consumers but also to the poor ones. Thus, the concept of the Tata Nano is promising but needs to be expanded to vehicles with minimal impact that still are characterized by low price something that as of today poses a real technological challenge.

6.3 Rebound Effect

In relation to both case studies above and more generally to any eco-innovation introduced in the market the so-called rebound effect (RE) is an essential but often times ignored issue. In its most narrow definition the RE describes the effect lower energy cost achieved through increased energy efficiency has on consumer behavior. Lower costs lead to additional usage which at least partially offsets the positive impact on the environment gained through efficiency improvements. If this RE is very pronounced such that the efficiency improvements are more than offset by the increased usage the term backfire is used in the literature. The RE is shown to be heterogeneous over time periods, geographical regions, energy services and individuals and is crucial for any policy implementation.

Even though the mechanism of the RE is widely accepted, it is typically still not taken into account when projecting future energy use and implementing policies. Many countries have established policy programs in order to achieve ambitious environmental goals and international organizations such as the OECD, the IEA, and the UN provide environmental outlooks under different scenarios (e.g. IEA, 2012; OECD, 2012; UNEP, 2012). In these reports governments and organizations assume that the achieved increased energy efficiency completely translates into less environmental impact and neglect any possible REs. A reason for this omission could be the disputable magnitude of any RE which is due to its different appearances but also due to its complexity as it operates through different mechanisms. Different definitions, methodological approaches and data sources used can lead to totally different estimates of the size of the RE, but generally it can be distinguished between the direct, the indirect, and the economy-wide RE as follows (Maxwell et al., 2011):

- The direct rebound effect describes the increased consumption of a product or service that due to an efficiency improvement has become cheaper.
- The indirect rebound effect refers to increased spending on other goods and services through the additional income that has become available due to efficiency improvements.

While the direct and indirect effects occur at microeconomic levels (individual, household, and firm), the economy wide effect represents the sum of the two at the macro level.

- The economy wide rebound effect describes the effect of efficiency improvements at a macroeconomic level. Efficiency improvements lead to increased productivity which in turn spurs economic growth and consumption.

The RE heavily depends on income and substitution effects and can be best estimated by using elasticities. While energy-efficiency elasticities are not easily available, price-elasticities are more commonly used in order to estimate the direct rebound effect (see Sorrell et al., 2009).

Most empirical studies that have been conducted focus on measuring the direct RE of consumer energy services in developed countries. The size of the RE is typically expressed in percentage terms indicating non-realized savings in the resource relative to potential savings from the maximum efficiency improvement. E.g. a direct RE of +20% indicates that 20% of the expected efficiency improvements are lost due to increased usage. Evidence suggests the direct RE for household heating and cooling and personal transport to be in the range of 10-30% and closer to 10% for transport (Greening et al., 2000; Small and van Dender, 2007; Sorrell, 2007; Maxwell et al., 2011). Clearly, households are likely to differ in their responses to a change in prices of energy services such that the size of the RE depends on the income distribution in an economy. Over the last two decades few empirical studies have tried to identify the heterogeneous responses of households to changes in energy prices, mainly investigating household gasoline demand (Kayser, 2000; West, 2004; Small and van Dender, 2007) but also household heating (Milne and Boardman, 2000) in the United States.

The results of the empirical studies are diverse, but generally lead in the direction that price-elasticities of gasoline demand in developed countries today decrease with increasing incomes. The relatively outdated study of Kayser (2000) uses data from 1981 and finds that households with higher levels of income have greater gasoline-price elasticity. These results might be explained by the fact that poorer households already drive as little as possible and thus there is only little room for poor households to adjust to price changes. At the same time the consumption of gasoline by the rich is probably less of a necessity than for the poor, making it easy for rich to adjust to price changes. While this analysis might have been appropriate for data from 30 years ago, incomes have risen and consumption patterns have changed substantially over time such that price-elasticities of different income groups have changed as well. While 30 years ago, wealthier households might have had a moderate demand for gasoline, poorer households did only use their car for the very essential travels. This might have changed over time in a way that wealthier household maximized their car travels such that their demand for gasoline has reached saturation. At the same time poorer households have started to travel more and have increased their gasoline demand. Studies with more recent data then also either find that price-elasticity of gasoline demand decreases with higher income (e.g. West and Williams, 2004; Wadud et al., 2009) or show a U-shaped pattern (e.g. West, 2004; Wadud et al., 2010). This U-shaped relationship might reflect the substitution possibilities of travelling available to different income classes. In response to a price increase poorer households might choose to travel less or to switch to alternative travel modes, while wealthier households might not rely so much on travelling since their travel are not necessities or they simply switch to air travel for longer distances. On the other hand, middle income households are likely to have less substitution possibilities for their travels than households in another income class.

The heterogeneous price-elasticities among different income classes directly translate into different sizes of the RE. Those income classes with the highest absolute price-elasticities consequently have the highest REs as they adjust their usage the most to price changes due to efficiency improvements. Thus, with regards to developed countries low-income households are expected to react the most to price changes as high-income households’ usage has already achieved saturation.

Only few empirical studies have tried to measure the heterogeneity of the RE among different income classes. Small and van Dender (2007) for example measure the RE for motor vehicles in the U.S. between 1966 and 2001 and find an average RE in their sample that decreases with higher incomes. Another interesting finding of their work is that the direct RE has decreased over time. While in the time period from 1966 to 2001 the short- and long-run RE were estimated to be 4.5% respectively 22.2%, the estimates for the time period in between 1997 and 2001 are 2.2% and 10.7% respectively. This difference is remarkable and shows the decreasing RE over time. Another study that estimates the heterogeneity of the RE among households in the private transport sector is the one by Frondel et al. (2012). It analyses household travel diary data between 1997 and 2009 in Germany. With an average RE of 57% to 62% the estimates are substantially larger than the ones obtained by the majority of other studies. This might show the different occurrences of the RE among geographical regions. Empirical evidence suggests the RE in the private transport sector to be in the range of 10% in the U.S., the obtained value of 60% for Germany might indicate the better substitution possibilities for personal transport in Germany compared to the U.S. The results of Frondel et al. (2012) further indicate that it is mainly the driving intensity that is responsible for the differences in the responsiveness of car travelling among German households while income inequality does not play a significant role.

Specifically to the passenger vehicle sector analyzed above a RE might occur due to driving more often or further distances due to the purchase of an EV or a Tata. With respect to the EV a study conducted in Switzerland showed neither a direct nor an indirect RE after the purchase of an EV, but found that expenditures for other environmentally-friendly products were increased (Maxwell et al., 2011). This might indicate that in Switzerland and in general in very wealthy countries personal transportation has reached saturation such that consumers do not react to efficiency increases. Instead, consumers’ awareness for the environment has reached a level that specifically makes them consume green products and also induces them to adopt environmentally-friendlier lifestyles.

Little empirical evidence exists on the RE in developing countries. Additionally, there is no evidence on heterogeneous price-elasticities for the energy demand across individuals. Indeed due to the poor and huge middle class of which most individuals do not own any energy intensive products yet, such an analysis would not provide much insight. Much more interesting is the question of how big the RE due to the introduction of a frugal innovation is which introduces new consumers to the market. When looking at the introduction of the Tata Nano in developing countries, the RE is likely to be big and might even lead to backfire which is due to consumers’ high price-elasticities. This hypothesis is supported by Roy (2000) who empirically studies the RE in India across three sectors including the transportation sector. The high RE is due to the not yet saturated market, rising incomes and population growth. These characteristics of emerging markets leads to enormous growth potential for the Tata and many other eco-innovations which is represented by the large middle class who mostly do not own cars yet. The introduction of the Tata to new consumers is associated with a high RE which might even lead to backfire. Over time, as incomes grow, car penetration rates in emerging markets increase and growth slows down, the RE will decrease as well. This is comparable with the development industrialized countries have undergone in the past which was associated with a decreasing RE.

The RE is crucial for policy implementation and has to be taken into account when introducing any eco-innovation to the market. Empirically it has been shown that the RE differs across energy services, time, incomes and regions. With respect to fuel efficiency in the personal transport sector in developed countries the RE has been decreasing over time, is likely to be substantially higher in the long- than in the short-run, and decreases with higher incomes. In such countries were demand for personal transportation has reached satiation which are typically characterized by high income levels the direct and indirect RE is likely to be close to zero or even negative. This is supported by the fact that consumers in such countries have reached a level at which they are willing to pay a premium for environmental quality. On the other hand, the RE in emerging economies at early development stages is expected to be big and might even lead to backfire as new consumers get introduced to new products. Only over time higher market penetration, increasing incomes and increased environmental awareness will induce the RE to decrease in such countries.

7 Conclusion

This paper has addressed the impact of income inequality on the incentives to eco-innovate in developing and developed countries. Since the available theoretical and empirical evidence in the literature on the issue is scarce, findings from studies dealing with the concept of eco-innovation, the drivers of eco-innovations and the importance and motives of green consumerism have been combined to assess the role income inequality plays in inducing green innovations.

Additionally to the positive spillover effect also present in the case of conventional innovations, eco-innovations are characterized by mitigating the negative environmental externality economic activity brings about. This double-externality problem calls for regulation which combines innovation and environmental policy in order to incentivize green innovations. Through this policy channel income inequality indirectly impacts the incentives to eco-innovate negatively. An increase in inequality reduces the demand for environmental quality of the median consumer, leads to less strict environmental policy and thus has a negative impact on the incentives to eco-innovate. This political economy effect is present in developing and developed countries but is likely to be bigger in developed ones.

In the past research has mainly focused on technological eco-innovations which can be classified into process and product innovations but more recently non-technological eco-innovations have gained increased importance due to their high potential they possess in leading the way to a green economy. In the case of technological eco-innovations income inequality does not only impact process and product innovations to a different extent, the stage of technology and whether the country in consideration is rich or poor also has an influence. The consumer demand which is the second channel through which economic inequality directly impacts the incentives to eco-innovate comes into play. It is shown to be effective mainly in the case of radical innovations, but not for incremental innovations.

As developing countries are mainly responsible for incremental eco-innovations, the market size effect does not play a role for most innovations developed by such emerging countries as the low GDP per capital level dominates the effect of income inequality. It only becomes crucial in two cases. The first case is characterized through a high degree of income inequality such that the few rich in a poor country demand a new eco-friendly product in which case inequality has a positive effect in the development of eco-innovations. In the second case, the huge middle class demands the green innovation. This situation occurs if the newly introduced product possesses the characteristics of a frugal innovation. Thereby, the product impresses by its low costs and its simplicity and is specifically targeted at poor consumers which previously have not been able to afford a similar product. In the case of such frugal innovations an unequal income distribution negatively affects the incentives to eco-innovate as analyzed by means of the case study on the Tata Nano.

In the case of developed countries the market size effect is also of negligible amount for incremental eco-innovations. This is different for more radical innovations. As long as the technology under consideration has achieved a certain development stage, income inequality negatively affects the incentives to eco-innovate. This is due to pioneer consumers who induce middle class consumers to demand green products. But there is also the case of immature technologies for which the pioneer consumer effect does not work and thus high inequality has a positive effect on the demand. In such a case, the market size and the political economic effect play a crucial role and contradict each other such that it is not a priori clear whether inequality increases or decreases the incentives to eco-innovate in such technologies. This case of a new technology in developed countries has been analyzed by means of the introduction of electric vehicles. It seems to support the claim that the GDP per capita level is one of the main determinants of whether electric vehicles are introduced in the market and that inequality positively affects the introduction of such revolutionary technologies as only the wealthiest of the rich are willing to pay for environmental quality at least in the medium-term. This is likely to change over time as technology develops and income rises.

For future research it would be interesting to conduct empirical analyses on the two case studies to test whether the hypotheses on how income inequality impacts eco-innovative activities are also quantitatively supported. Further, since the case studies have been confined to two specific situations it would be worth analyzing the cases not specifically discussed in this paper. Thereby, I think of radical eco-innovations in relation with mature technologies such as the wind industry and less of incremental innovations as the effects of inequality on such latter innovations might be difficult to analyze. It would be interesting to see whether the hypothesis based on the findings from the literature, indicating that in the case of relatively mature technologies less inequality leads to a higher amount of eco-innovations, also holds empirically.

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