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Expanding the Usage of Renewable Energy Through Innovation and Technology Transfer

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Abstract

Moving green growth forward requires acknowledging the well-known carbon dilemma facing all nations: carbon-based economic development versus carbon emission reductions. Switching conventional carbon energy to renewable energy offers a potential win-win solution to tackle this dilemma. This dissertation empirically examines innovation and technology transfer of renewable energy technology at the international level with its three essays. The first essay explores how oil endowments of a country influence its innovation paths, specifically in the automobile sector. I show that a country's oil endowment is a negative driver for alternative technologies, while a positive driver for oil extracting technologies. Depending on their levels of fossil fuel endowment, it appears that countries alter their domestic climate policy to either increase or decrease their dependence on fossil fuels. International climate policy could be designed to incentivize countries with increasing dependence on fossil fuels, and thus reach agreements for more rigorous action on climate change.

However, in smaller developing economies with traditionally low capacity to innovate, technology diffusion is more important than technology innovation. Technology diffusion from wealthier nation to the world's poorest is the fastest way to make the transition to renewable energy at the current state. Hence, the second essay shifts the focus to technology diffusion, exploring how foreign aid helps developing countries increase their capacity to use renewable energy technologies. I find that foreign aid on technical cooperation (transferring intangible knowledge) increases future renewable energy production more than foreign aid on non-technical cooperation. This opens a new window for the on-going discussion of program and policy evaluation in the field of foreign aid, while also contributing to the fields of policy

evaluation and climate change policy, especially for the diffusion of renewable energy technologies.

Having shown the effectiveness of foreign aid in the energy sector, the third essay explores whether aid allocation by bilateral donors responds to the recipient needs in the renewable energy sector. Bilateral donors have been known for allocating their financial assistance based on political interests among recipients such as former colonies and political allies. The recent trends show that they allocate aid aligning more to their commercial interest. The findings support the recent trends of following the donors' commercial interest. Donors select recipients based on their economic interest especially through expanding their market having higher number of recipients. When allocating, physical proximity drives the amount allocated. This sheds some light on future research to explore the potential of multilateral agencies in allocating aid to meet the needs of the poor.

EXPANDING THE USAGE OF RENEWABLE ENERGY THROUGH INNOVATION AND TECHNOLOGY TRANSFER

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DISSERTATION

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Introduction

Discussions on moving green growth forward often emphasize the transition of energy sources away from fossil fuels toward more sustainable resources. Climate change is a complex issue including debates on economic development and energy security. Green growth using sustainable energy sources provides an option to alleviate concerns on climate change and its opposing arguments of economic development and energy security. The major challenge in transitioning to renewable energy is having technologies that use renewable energy sources. There are two mechanisms to obtaining technologies: developing needed technologies and diffusing already developed technologies. Developing technologies involves invention and innovation. Invention refers to the process creating new knowledge, while innovation is transforming the new knowledge into marketable products. Having ready-to-use products is the key to accelerating the transition of energy sources. Thus, innovation receives higher attention regarding developing technologies in this dissertation.

Innovation of renewable energy technologies receives revived attention with the rise of concern on climate change. Unlike short-lived attention on renewable energy in the 1970s, concerns on climate change led the international community to organize an international treaty, the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. Negotiations through UNFCCC soon induced the Kyoto Protocol, which calls for binding actions on reducing greenhouse gases (GHGs) by developed countries. At the domestic level, nations across the world adopt national renewable energy policies that include strategies promoting innovation of renewable energy technologies. For example, France developed a national renewable energy action plan including a clause for 'technical specification.'[1] The clause states incentives are in place to promote development of renewable energy technologies.

Focusing on renewable energy innovation, the first essay of this dissertation examines the link between climate change and energy security in the automobile sector. Measuring energy security by oil endowment of a country and domestic gasoline price excluding tax, the essay analyzes the effect of energy security level on innovation of renewable energy technology.

The second mechanism for obtaining technologies is diffusing the already developed technologies. At the country-level, developed countries have higher capacity to innovate such as existing knowledge, the level of human resources and economy size. Developing countries with large economy, such as China and India, also have innovative capacity but in certain sectors. Although they are now competitive in the international market, these developing countries also had begun building their innovative capacity through diffusion of technologies. In contrast, most developing countries with small economy have a low level of innovative capacity. For these developing countries, diffusion is a better option incurring less cost in having renewable energy technologies than innovation.

Knowing that diffusion is a better measure for obtaining technologies in developing countries, one question is what channel should be used to diffuse renewable technologies to developing countries. A large volume of literature on international technology transfer contributes to examining diffusion channels in the private sector such as foreign direct investments (FDI), licensing and trade. The problem with private sector channels is lower income, developing countries are often overlooked as recipients of technologies. In climate

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[1] Member countries of European Union (EU) are required to develop a national renewable energy action plan and report the progress to EU.

change, lower income developing countries are also in need of renewable energy technologies not only for joining mitigation efforts, but also for adaptation purpose. Including more developing countries demands a diffusion channel more accessible to small income developing countries. In this regard, the second and third essays of this dissertation focus on foreign aid as a diffusion channel specific to developing countries.

The second essay examines the effectiveness of foreign aid as a diffusion channel of renewable energy technologies. Specifically, it focuses on the technological capacity that has potential to raise innovative capacity. The major concern in this essay is how to raise technological capacity of recipient countries. I propose an answer to this by looking at the cooperative aid that involves intangible knowledge transfer such as know-hows.

The third essay also looks at foreign aid as a diffusion channel of renewable energy technologies. However, it examines what determines the flow of foreign aid as a diffusion channel of renewable energy technologies in the first place. By looking at the determinants, I attempt to find out how to increase the diffusion of renewable energy technologies to developing countries.

Overall, the three essays of this dissertation concern how to expand the usage of renewable energy to both developed and developing countries. The first essay focuses on innovation in relation to energy security concerns. The second and third essay focuses on a diffusion channel to developing countries.

Essay I. Energy Security and Climate Change: How Oil Endowment Influences Alternative Vehicle Innovation

1. Introduction

Concerns about combating climate change have led to serious debates on fossil fuel usage; however, those concerned with energy security, with the goal of an economically stable energy supply, often advocate the use of fossil fuels. In the search for a win-win solution to tackle both these pressing problems, technology innovation, especially in alternative energy, provides an opportunity to solve the two problems at the same time by reducing greenhouse gas (GHG) emissions and decreasing countries' dependence on imported fossil fuels. Among the many sectors using fossil fuels, the transportation sector heavily relies on fossil fuel use and is the second largest sector, emitting 23 percent of world carbon dioxide (CO_2) as of 2009 (IEA, 2011). It is a pressing task to analyze the rate and the drivers of technology innovation for climate change mitigation and energy security within the transportation sector. Thus, this paper examines the effect of crude oil endowments, a driver of innovation related to both climate change and energy security, on the patterns of technology innovation in the transportation sector.

As a measure of technological innovation, I constructed a panel of patent data for five different types of automobile-related technologies: oil extraction, oil refining, fuel cells, EHVs and vehicle energy efficiency. A brief look at the patent data indicates different patterns of technology innovation emerge across countries depending on their oil endowment. For example, Germany and Japan, each with low oil reserves, show high levels of patenting in alternative energy technologies compared to other technologies within those countries, while Norway and Canada, each with higher oil reserves, show high levels of patenting in oil extraction technologies. It is obvious the different patterns of patenting in various countries correlates to the presence of industries. The existence of the oil extracting industry, for example, leads to oil extracting patents, while vehicle patents are driven by vehicle industry. However, patterns of vehicle patents vary among countries by oil endowment. Particularly, low oil reserves are associated with high patenting in alternative vehicle technologies. This paper focuses on this relationship between oil endowment and patents in alternative vehicle technologies.

This study contributes to the literature in two ways. First, it fills an important gap in the analysis of energy-related technological change. Although the transportation sector is a key part of most economies, and by far the biggest consumer of oil, almost all of the previous literature on energy and technology innovation focuses on the electricity sector. Second, it connects the energy security and climate change issues by studying technology innovation that provides a vision for a win-win solution for both energy security and climate change mitigation. In doing so, it expands the existing list of the drivers of technology innovation related to fossil fuel use by empirically testing the effect of oil endowment on the patterns of technology innovation. This study shows that decisions to innovate appear to take energy security into consideration, as well as climate change, in sectors using fossil fuel energy.

In the next section, I review previous studies regarding determinants of technology innovation. In section 3, the theory of how country-level oil endowment affects patterns of technology innovation is discussed and in section 4, the patent data in this study are described. Explanatory variables are described in detail in the fifth section followed by the empirical model and its result in section 6. Section 7 will conclude the paper.

2. Literature Review

Studies on the determinants of technology innovation in the energy sector have focused on two main drivers of technology innovation: energy price (Popp, 2002; Newell *et al*., 1999) and government policies (Fischer and Newell, 2008; Popp, 2006; Johnstone *et al*., 2010).[2] The heightened attention on seeking technological solutions regarding climate change led to more recent studies focusing on the power of government policies in inducing clean energy technology innovations (Lanjouw and Mody, 1996; Popp, 2006; Greene, 1990). Contrarily, studies on natural resource scarcity as a determinant to technology innovation are mostly theoretical or based on simulation models (e.g. Bretschger, 2005).

As a determinant of technology innovation frequently studied, government policy emerges in two forms: public R&D and policy measures, such as incentive systems. Public R&D may initiate private R&D. David *et al*. (2000) survey literature on the effect of public R&D on private R&D that led to innovations. A series of empirical studies finds a positive effect, which implies that public R&D can serve as a complement to private R&D. Similarly, Hascic *et al*. (2008) find that governmental public R&D increases environmental technology innovation in environmental pollution abatement.

Government policy measures are another governmental intervention inducing technology innovation (Fischer and Newell, 2008; Popp, 2006; Johnstone *et al*., 2010). Fischer and Newell (2008) examine renewable energy policies in the electricity sector. They find that a portfolio of policy measures is more effective in reducing GHG emissions than a single policy measure. Johnstone *et al*. (2010) look at the effects of both price-based and quantity-based

[2] See Jaffe et al. (2003) and Popp et al. (2010) for more complete lists of literatures

policies on renewable energy innovation from 25 OECD countries.[3] In general, they find that policies have a significant impact on renewable energy innovation. However, price-based and quantity-based policies exhibit different levels of effects on different technologies. Non-financial policies that allow firms to choose technologies stimulate cheaper technologies, whereas financial policies that guarantee a market price promote more expensive technologies (*e.g.* feed-in-tariffs on solar energy).

Regarding indirect measures of energy resource scarcity, several studies empirically test the effects of energy prices on induced innovation. Popp (2002) tests the effects of energy prices on energy efficiency innovation and finds a strong effect of energy price on energy efficient innovation, as measured by patent counts. Newell *et al.* (1999) test both the effects of price and regulation on technology innovation in home appliances. They find that neither price changes nor environmental regulation have a dominant effect on technology innovation. On the other hand, Greene (1990) finds that the Corporate Average Fuel Economy standard has a stronger effect on fuel economy than changes in fuel price.

Regardless of their focus on either price or government policy (or both), these studies frequently look at the electricity sector (Popp, 2002; Fischer and Newell, 2008; Johnstone *et al.*, 2010; Lanjouw and Mody, 1996; Newell *et al.*, 1999). However, Greene (1990) and Van Den Hoed (2007) are the exceptions; they study the automobile industry. Greene (1990) measures innovation through the improvement in fuel economy, which shows the possible results of accumulated knowledge but not the amount of accumulated knowledge. Van Den Hoed (2007) analyzes what factors cause technological change from combustion engine to fuel cell technology in private investment in the automobile sector. He finds that government regulation

[3] OECD is the Organization of Economic Co-operation and Development

coupled with significant technical progress contributes to high investment in the fuel cell technology. Although his analysis provides insights on the fuel cell technology for automobiles, his analysis is mostly descriptive. To fill the gap in the literature, this study empirically examines the effect of oil endowment as another determinant of technology innovation.

3. Theory

Previous studies identify policies (Fischer and Newell, 2008; Popp, 2006; Johnstone *et al.*, 2010) and energy prices (Popp, 2002; Newell *et al.*, 1999) as determinants of energy technology innovation. The literature on technology innovation does not explicitly consider the oil endowment of a country as a direct determinant. However, from the socio-political perspective, resource endowment directly relates to energy security of a country. Reflecting the interconnectedness with energy security, this paper posits that studying technology innovation may include oil endowment as one of its direct determinants and aims to identify the impact of oil endowment on the pattern of innovation in the automobile sector across countries.

In the automobile sector, the connection between oil endowment and automobile technology innovation is not obvious because of the highly integrated world markets for automobiles and oil. Oil and automobile are complementary goods because oil is the dominant energy input for automobiles—oil price and supply highly affect vehicle sales. Customers facing high fuel prices prefer more efficient or alternative vehicles rather than the conventional ones, thereby increasing the demand for efficient or alternative vehicles. Driven by the increased consumer demand, automobile firms decide to invest in innovation for alternative vehicles not only for the domestic market, but also for the foreign market. Because automobile manufacturers target their products to a global market, this results in innovations that do not closely reflect domestic needs unless they are universal.

Similarly, highly integrated world oil markets mean that domestic crude oil prices are loosely linked to domestic oil endowments. Globally traded crude oil prices do not vary by country, yet domestic consumer prices for refined fuels do. The price difference between refined fuels and crude oil is explained by differences in the refining sector, domestic gasoline market structure and government policies by country (EIA, 2013), resulting in country-by-country variations in domestic fuel prices.

Here, one should recognize the difference in response of a country and a firm to energy security. Firms seek opportunities to increase its profit under various risks. Under the energy security concern, firms react to consumer behavior (change in demand for alternative vehicles) and seek for better opportunity (investment in innovation). On the other hand, a country reacts to the welfare of domestic economy by implementing policy measures that secure domestic energy supply in largely three ways: 1) facilitating oil supply through expanding domestic production or foreign policy, 2) regulating consumer fuel price through taxes and 3) promoting alternative innovation through public research and development. Although government employs all three policy measures simultaneously, the focus may vary by the country's oil endowment. For example, a country with a large oil endowment has the capacity to facilitate oil supply domestically, thereby focusing less on the other two policy areas. Contrarily, a country with a small oil endowment has a low capacity of domestic energy supply and therefore, concentrates on the other two policy areas to induce alternative technology innovation.

Additionally, the consumer price of energy can be manipulated by government policies to provide incentives for firms to innovate. Energy and R&D policies in the automobile industry often emerge as tax legislation that either discourages the use of fossil fuels or provides incentives for the use of renewable fuels through tax credits. A gasoline tax is an example of a disincentive that raises gasoline price on consumption. The increased gasoline price promotes innovations to reduce gasoline usage in cars. Firms now innovate to raise the energy efficiency of automobiles or to develop substitutes, such as alternative fuels, that can compete with gasoline.

Adding the socio political aspect to the literature, the theoretical model of this study recognizes automobile technology innovation as having three determinants: oil endowment, the energy price and governmental policies. Equation (1) depicts this relationship, controlling for the industrial characteristics of different countries. Looking more closely, oil endowment and energy price also indirectly cause technology innovation through governmental policies. Government policies are designed to provide incentives and guide technology innovation, given the pre-tax domestic energy price and oil endowment. Hence, the three determinants are better depicted in a system by decomposing the effect of policy to catch the full effects of oil endowment and energy price, as in equation (2). Equations (1) and (2) represent a system of relationships among three determinants on technology innovation.

$$\text{Tech.Inno}_{i,j,t} = f\{\text{Oil.Endow}_{i,t}, \text{POL}_{i,,k,t}, \text{E.Price}_{i,t}, \text{Industry}_{i,t}\} \qquad (1)$$
$$\text{POL}_{i,k,t} = f\{\text{Oil.Endow}_{i,t}, \text{Politics}_{i,,t}, \text{E.Price}_{i,t}\} \qquad (2)$$

Tech.Inno:	Technology innovation in the automobile sector
Oil.Endow:	Oil endowment
POL:	Domestic policy
E.Price:	Domestic energy price
Industry:	Characteristics of industries related to each technology
Politics:	Characteristics of the domestic political situation

* *i*, *j*, *k*, and *t*: country, types of technology, types of policy and year, respectively.

The system estimates the full effect of oil endowment and energy price on technology innovation by aggregating the effects from each equation. The technology innovation for *j* is observed in year t in country *i*. A technology *j* can be either oil-use technology (oil extracting and oil refining) or alternative technology (fuel cell, EHV, and energy efficiency). The decomposed policy equation—equation (2)—includes oil endowment, energy price and politics as the determinants of domestic policy. As mentioned earlier, more oil endowment steers government's policy focus to securing domestic oil supply and away from policy areas inducing alternative innovation.[4] Therefore, the effect of oil endowment in equation (2) is expected to be negative on alternative technologies; whereas energy price and pro-environment politics have a positive and strong effect. In the case of oil-use technologies, the effect of oil endowment is expected to be positive, while energy price and pro-environment politics are expected to have negative effects.

The politics variable represents characteristics of the domestic political and administrative situation that determine the direction of domestic policy. In designing governmental policies, the government's budget restricts or allows the government to act, and it shows the country's preference for government intervention in the economy. Although the budget represents the government's capacity to act on its policies, the government's actions may also be affected by current political conditions. Thus, the financial and political conditions of a government directly affect government decisions on policy-making and eventually influence technology innovation, which is the outcome of energy and R&D policy measures. In the analysis, the politics variable in equation (2) includes both the financial and political conditions of a government.

Unfortunately, difficulties in collecting data for policy variables limit the use of the two-equation system. Because the unit of analysis in this study is a country, data on policy variables need to be comparable country-by-country. Also, a comprehensive collection of policy variables would be needed to adequately estimate equations (1) and (2). Examples of policy variables are gasoline taxes, fuel economy standards and governmental R&D expenditures. However,

[4] Large oil endowment steers government's policy to climate change mitigation as well. However, both types of countries with large and small oil endowment would have mitigation policy because countries with small oil endowment would or already have policy measures reducing the usage of oil.

financial data, such as gasoline taxes and R&D expenditures, are unavailable for some countries or have incomplete time-series. Furthermore, fuel economy standards in countries are so diverse that they are not comparable in a country-by-country analysis. For example, Japan and the United States have mandatory fuel standards, while the European Union, Canada and Australia have voluntary standard programs for CO2 emissions, GHGs and fuel, respectively.[5] Hence, this study adopts the reduced form of the two-equation system, equation (3).

$$\text{Tech.Inno}_{i,j,t} = f\{\text{Oil.Endow}_{i,t}, \text{Politics}_{i,t}, \text{E.Price}_{i,t}, \text{Industry}_{i,t}\} \quad (3)$$

This equation allows for the estimation of the full effects of oil endowment and energy price on technology innovation, and approximates the policy effect by using political variables as proxies for the policy that affect the outcome indirectly. Given the negative effect of oil endowment in equation (1) and (2), oil endowment is expected to have negative effect on alternative innovation in equation (3). Meanwhile, pro-environment politics and energy price are expected to have positive effects on alternative innovation because of their positive effect in both equation (1) and (2). The effects of these variables on oil-using innovation are expected to be the opposite. Thus, the hypothesis being tested is that oil endowment reduces innovation activities in alternative technologies while increasing those in oil-using technologies.

Finally, in the decision to innovate in particular technologies, the industrial capacity of a country is another determining factor because it is tightly linked to innovation capacity. Whether a country has an automobile manufacturing industry or a refinery industry deeply relates to the country's capacity to innovate in automobile engine and fuel technologies. A higher level of technology innovation is expected when the capacity is larger.

[5] See An *et al.* (2007) and An and Sauer (2004) for detailed comparison among countries.

4. Patent Counts of Vehicle-Related Technologies

Patents are often selected as a measure of technological change (*e.g.* Johnstone *et al.*, 2010; Hascic *et al.*, 2008; Popp, 2002). Patent data provide advantages over R&D expenditures and human resources capital because they represent the output of R&D activities (Griliches, 1990), while other measures mostly represent the input. Because the input does not always result in successful output, measures for output provide a higher proximity to technological change. Moreover, the ease of the International Patent Classification (IPC) system and the ample details patent data provides add to the advantage of patent data being a good measure of successful output of R&D activities.[6]

Although not all inventions are patented or patentable (Griliches, 1990), patentable technologies remain constant and will show up in the pool of patented technologies over time within an industry. Thus, restricting the coverage to one industry, or incorporating industry dummies, can reduce such a discrepancy. In addition, a large sample size can resolve the quality of individual patents issues. Griliches (1990) also notes patent renewal data can alleviate the quality problem of the patent.

Despite the disadvantages, the advantages enable patent data to serve as a reasonable measure for technology innovation. In this paper, patent counts represent the magnitude of knowledge production activities by country. For the automobile sector, five types of technologies were identified: oil extraction, fuel refining, fuel cell, EHV and vehicle energy efficiency. These technologies are selected because they relate to the input and the output of automobile use. Except for vehicle energy efficiency technology, the four types of technologies

[6] See Dernis and Guellec (2001) and Dernis and Kahn (2004) for more description on details of new technologies patent data provides and their applications. Patent data also make it easy to identify specific technology with the classification system. Specifically, IPC system provides rich information on different technologies (Popp, 2005). The classification system shows the nature of the patent; therefore, the direction of technological change in certain classes can be traced.

are related to the input (*i.e.* fuel) of automobile use. Energy efficiency technology is related to the output (*i.e.* automobile use). EHV has characteristics related to both the input and output of automobile use. It uses an electric fuel source, while it includes internal combustion engine technologies.

Oil extraction and refining technologies are categorized under fossil fuel-related technology. Fossil fuel-related technology promotes the use of fossil fuel. Oil extraction includes technologies for well development and enhanced oil recovery. Both the technologies directly facilitate the extraction of oil from reserves by building wells in the suspected site of the reserves and by injecting other materials to raise productivity.

Similarly, refining also promotes the use of fossil fuel. In this paper, refining includes hydrocarbon production, reforming, isomerization and alkylation technologies. Hydrocarbon production makes use of fossil fuels that have higher production costs, for instance, oil shale, oil sand and natural gas. These fossil fuel sources are different from crude oil reserves. Reforming, isomerization and alkylation are technologies used at the end of the crude oil refining process. However, these technologies intend to raise the efficiency of the refining process. Thus, in this paper, refining technologies raise the efficiency in using crude oil reserves, which are perceived as cleaner technologies.

Contrarily, fuel cell and EHV are categorized under the alternative technologies for vehicle fuel and vehicle engines, respectively. These two technologies clearly aim to reduce the use of fossil fuels. Fuel cells produce electricity through chemical reactions rather than the combustions used in conventional gasoline fed vehicles.[7] In the vehicle industry, fuel cells often use hydrogen as a fuel. Hydrocarbons can also be used, but with more GHG emissions. The

[7] U.S. Fuel Cell Council: http://www.usfcc.com

produced electricity operates the electric engine. Unlike fuel cell technology, EHV refers to engine and vehicle operating system technologies. The IPC system categorizes EHV as combining two or more types of motors, most frequently the electric engine and the conventional internal combustion engine.[8] EHV may still require the use of fossil fuels, albeit reduced usage.

Energy efficiency technology for vehicles also aims to reduce the use of fossil fuels, but it does not entirely substitute for fossil fuels. Improving energy efficiency in a vehicle often requires redesigning the internal combustion engine (OECD, 2009). In contrast to the fuel cell and EHV technologies, energy efficiency technologies use the conventional engine that burns fossil fuels, rather than replacing it with alternative technologies.

Given the selected technologies, I identified the corresponding code of the IPC system for each sub-group of technologies.[9] The two key criteria constructed for the patent counts are the country of origin and the first application year. A patent represents the embodied knowledge that belongs to the inventor. The other key information is obtained from the information on the patent family. Patent data reveal an array of information regarding the technology, such as the inventor, the applicant, the IPC codes and the patent family. The inventor's information includes: the name, address and the inventor's country of origin. The inventor's country of origin was used as the original country of patent.[10] An inventor can file the same patent in another

[8] http://www.wipo.int/classifications/fulltext/new_ipc/ipcen.html

[9] The World Intellectual Property Organization (WIPO) developed the IPC system as a hierarchical system, using letters and numbers at different levels of technologies. For example, Section B includes performing operations and transporting. Under Section B, items B60-64 list technologies for transportation. Section C includes Chemistry and Metallurgy. Section C10 lists technologies for petroleum products. The lower level of the IPC code was then determined by a keyword search for each sub-technology. This paper uses the IPC sub-class code only if the keyword search returns over 50 percent of the patent numbers for each sub-class. For some sub-IPC classes with more than a 30 percent return, I searched the U.S. Patent Class only. If the USPC returns more than 50 percent of the patents, those patent classes were included in the sample.
The total number of downloaded patents is 286,830. Patents were downloaded through the Delphion research network: http://www.delphion.com/. Included among the downloaded patents are: 21,820 for oil extraction; 18,414 for refining; 57,357 for fuel cell; 160,830 for energy efficiency; 28,409 for EHVs.

[10] Literature using patent data for cross-country analysis notes that almost all patents are first filed in the inventor's country of

country to get protection in the destination country. In such cases, patents in other countries have exactly the same inventions but have different patent numbers. These patents are regarded as family patents.[11] The year and the patent number of the first patent in the family are called the priority year and the priority patent number. After identifying the origin countries and priority years,[12] patents were counted by country and year.[13]

For the descriptive analysis, the counted patent data is limited to data for the 29 OECD and BRICs countries (Brazil, India, China and Russia) from 1981 to 2002. These countries are expected to show higher levels of innovation activities because of their capacity for technology innovation. Table 1 shows the summary statistics for each technology.

[Insert Table I-1 here]

Comparing raw patent counts across countries requires caution. Countries have their own patent registration systems. The difference comes from the institutional framework for intellectual property protection and the industrial composition of each country. For example, Japanese patent counts are much larger than other countries in all technologies except oil extraction. Japan imports crude oil because it has almost no reserves of crude oil, and it develops more efficient technologies because of limited resources. Also, the Japanese patent registration system has a narrower scope than other countries. This enables inventors to apply for several small patents.

Examples of the relationship between oil endowment and technology innovation are found in both developed and developing countries. Among examples from developed countries,

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origin (Dernis and Guellec, 2001). Often, cases show that the inventor and the applicant's country are identical. Given collapsing patent families into the earliest priority patent, inventor's and the applicant's country are the same.

11 Patent families are counted once to avoid double counting.

12 Priority year was used because family patents were recognized and collapsed into one patent in the family with the first priority year, which is the origin year.

13 Data has both panel and count data properties.

Norway is rich in crude oil reserves, while Germany is scarce in oil. Figure I-1 shows the technology innovation patterns, which is measured by the patent count share of the country total, of the two countries. Norway has a high patent count share in oil extraction, whereas relatively low technology development in energy efficiency and other alternative technologies, like fuel cell and EHV. Conversely, oil-scarce Germany has high technology development in energy efficiency technology, while it has low development in oil extraction. In oil-scarce Germany, although the difference is not as wide as in the case of energy efficiency technology, the categories of fuel cell and EHV show high levels of technology innovation. This suggests that the oil endowment of a country positively correlates with higher number of patent counts in oil extraction and refining technologies, whereas it correlates with fewer patent counts in alternative (fuel cell and EHV) and energy efficiency technologies.

[Insert Figure I-1 here]

The strength of this connection varies in developing countries; however, the relationship is still valid. Cases of developing countries are included to support the correlation from the descriptive analysis, but they are excluded in the empirical tests because of low levels of patents and data availability for independent variables. Figure I-2 shows technology innovation in Mexico and China. Mexico is a developing country rich in oil reserves. Although Mexico shows lower levels of technology innovation, the concentration on oil extraction technology is high. At the same time, alternative technologies, like fuel cell and EHV, show very low levels of technology innovation. This is similar to Norway, except that Mexico shows relatively higher levels of technology innovation. On the other hand, China is an example of a developing country with scarce oil reserves. The pattern of technology innovation exhibits higher innovation in energy efficiency technologies.

[Insert Figure I-2 here]

5. Explanatory Variables

1) Fossil fuel endowment

In this paper, the crude oil reserves represent fossil fuel endowment because of their importance to the automobile sector.[14] The data on 'World Proved Crude Oil Reserves' was acquired from the U.S. Energy Information Administration (EIA). The data contains observations from 1981 to 2009. The mean of crude oil reserves in a thousand barrels per capita is depicted by country in Figure I-3. Within the sample, Norway has the most crude oil, followed by Mexico and Russia. Apart from these three countries, Australia, Canada, Denmark, the United Kingdom and the United States have relatively high reserves of crude oil. In contrast, France, Japan, Germany and Italy have low reserves. Developing countries, such as China, Brazil, India and Korea, show low or no crude oil reserves.

[Insert Figure I-3 here]

Despite some variations, the overall patent activities, especially in alternative energy like fuel cell and EHV, appear higher in economies with low crude oil reserves. Table I-2 shows cumulative patent counts for countries during 1981-2002.

[Insert Table I-2 here]

The correlation matrix in Table 3 describes the relationship between oil endowment and automobile technologies. The alternative technologies (fuel cell, EHV and vehicle energy efficiency) have a negative relationship with crude oil reserves. However, conventional energy

[14] In this study, proven crude oil reserves measure oil endowment of a country, which provide the lowest uncertainty in the amount of commercially recoverable oil. It should also be noted that they could vary by technological and political changes (WPC, 2007). For this reason, proved and probable reserves or ultimately recoverable resources might measure a country's oil reserves. However, among the dataset publically available, only proved reserves data can be obtained from the credible source, i.e. US Energy Information Agency (EIA).

technologies exhibit a divergent relationship with crude oil reserves. Oil extraction technology shows a positive relationship with crude oil reserves, as expected. On the other hand, refining technology shows a negative relationship, as with the other alternative automobile technologies. This confirms the prediction of the refining technology in this paper being cleaner than the conventional refining technology, as described in the data collection step.

[Insert Table I-3 here]

2) Other factors for vehicle-related technology innovation

Given the interest in oil and the automobile industry, domestic gasoline price represents the energy price that affects technology innovation within a country. From the data on end-use gasoline price and taxes obtained from the International Energy Agency (IEA), I constructed the domestic gasoline price data without gasoline tax by subtracting gasoline tax from the end-use gasoline price. The constructed price variable includes intermediate costs accruing to refineries, distributors and retail sellers, but does not include government policy on the gasoline price.[15] It enables a test of the pure effect of the domestic price, excluding the policy effect from the tax. Unfortunately, the dataset lacks observations from the BRICs countries. This limits the countries included in the empirical analysis.

The political party, political freedom and total governmental revenues are included as proxies for domestic energy and R&D policies. These variables affect energy and R&D policies, and will eventually affect technology innovation in the automobile sector. The political party and political freedom measure the political situation. They represent the government's approach toward domestic policy-making. The political party of the Chief Executive of a country was

[15] The constructed gasoline price is retail gasoline price before tax. Retail gasoline price includes cost and profit components of intermediary actors such as refineries, distributors, and retail sellers as well as government taxes (EIA, 2013).

extracted from the Database of Political Institutions (DPI).[16] The 'Chief Executive Party' represents the political orientation of the Executive Office. The DPI identifies the political orientation by the party's stance on the economic policy. The left party pursues socialist ideology more than the right party. I constructed the political party variable as a dummy variable for the left party: 1 being the left party and 0 being the non-left party (both right and center parties).[17] The effect of the left party is expected to be positive on alternative technologies because it pays attention to environmental friendly activities in regard to economic policy. However, energy policy is inter-related with economic, environmental and security policies and policy-making itself includes highly complex political negotiation processes. Therefore, this study expects the effect of left party to be weak.

The political freedom data of a country was obtained from the Freedom House.[18] The data gives each country an index scale from 1 to 7, with 1 being the highest and 7 being the lowest political freedom for the public in the country, for every year based on their analysis. Political freedom indicates less authoritative government, which may be important if these governments are more apt to adopt diverse options. Thus, the effect of political freedom is expected to be positive on innovation targeting alternative technologies.

The government's total tax revenues measure the government's overall role in the economy. I collected the raw data from the OECD and constructed a dataset in terms of the percentage of GDP. The total tax revenue is expected to have a positive relationship with

[16] The data used is 2009 version and downloaded from: http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:20649465-pagePK:64214825-piPK:64214943-theSitePK:469382,00.html

[17] According to DPI (Beck, *et al.*, 2001), the left party represents "communist, socialist, social democratic, or left-wing" in regard to the economic policy.

[18] http://www.freedomhouse.org

domestic policy by raising the total amount of the budget, which may also raise government's support for public R&D.

Industrial characteristics in this paper include the vehicle manufacturing industry and refinery industry. As noted, the existence and size of the two industries are representative of the country's innovation capacity. Thus, larger vehicle manufacturing and refinery industries are expected to positively influence the vehicle engine (*i.e.* EHV and energy efficiency) and refining technologies, respectively. The GDP of the vehicle manufacturing industry was collected from the OECD to capture the size of the vehicle manufacturing industry. Similarly, the refinery capacity was captured using 'Crude oil distillation capacity' from the EIA. The data was constructed in terms of one thousand barrels per capita and ranges. The collected data on refinery capacity only includes distillation capacity, which is the primary process for refining crude oil.

The different levels of economic development and innovation capacity were controlled by the GDP per capita and total number of patents within a country, respectively. The data was obtained from the OECD and World Bank. Both the variables are expected to positively influence all the technologies because a country with a higher level of economy or innovation capacity would have more resources to foster innovation.

Table 4 shows the descriptive statistics of the explanatory variables. Unfortunately, the BRICs countries lack several explanatory variables: gasoline price, GDP share of vehicle industry and total government tax revenues. Within the OECD countries, a total of 12 countries were selected, based on the data availability for the explanatory variables. The 12 countries are Austria, Canada, Germany, Finland, France, Italy, Japan, Mexico, Netherland, Norway, the United

Kingdom and the United States. The time series (1990 to 2002) was also selected based on the data availability.

[Insert Table I-4 here]

6. Empirical Analysis

1) The model

To test the effects of oil endowment on patterns of innovation, a panel was constructed from the patent data of five different types of automobile-related technologies: oil extraction, fuel refining, fuel cell, EHV and vehicle energy efficiency. As noted earlier, this study uses the reduced form model in equation (3), which delineates the effect of oil endowment on technology innovation. The detailed model specification is as follows:

$$(\text{Patents})_{i,j,t} = \beta_1(\text{CrudOil}_{i,t}) + \beta_2(\text{Gas.Price}_{i,t}) + \beta_3(\text{Pol.Free}_{i,t}) + \beta_4(\text{Pol.Party}_{i,t}) + \beta_5(\text{Tot.Tax.Rev}_{i,t}) + \beta_6(\text{Refine.Capa}_{i,t}) + \beta_7(\text{Veh.Manu}_{i,t}) + \beta_8(\text{GDP}_{i,t}) + \beta_8(\text{Kstock}_{i,t}) + \alpha_i + \gamma_j + \varepsilon_{i,t} \quad (4)$$

where i = 1, …, 12 for countries, j = 1, …, 5 for technologies, and t = 1990, …, 2002 for the year. The time series starts from 1990 because of the limited time series of government's total tax revenue (Tot.Tax.Rev) and refining capacity (Refine.Capa). The dependent variable, (Patents), is measured by the annual count of patent applications for each of the five technologies. The explanatory variables included in the model analysis are the crude oil reserves ($\text{CrudOil}_{i,t}$) for the oil endowment; the political freedom index ($\text{Pol.Freedom}_{i,t}$); the political party of the Chief Executive ($\text{Pol.Party}_{i,t}$); and total government tax revenues ($\text{Tot.Tax.Rev}_{i,t}$) for politics; the domestic pre-tax gasoline price ($\text{Gas.Price}_{i,j,t}$), for the energy price; the GDP share of the vehicle manufacturing industry ($\text{Veh.Manu}_{i,t}$); the refinery capacity ($\text{Refine.Capa}_{i,t}$) for the industry characteristics; the GDP per capita ($GDP_{i,t}$); and the total patent counts ($Kstock_{i,t}$). The model also includes the error term ($\varepsilon_{i,t}$), the parameter (α_i) for the fixed effect model, and the parameter (γ_j) for the model with multiple technologies.

The analysis used a Poisson regression for panel data, which was developed for count data models. The model follows the Poisson distribution, assuming the mean and the variance of the data are the same. In the case of over-dispersed data, robust standard errors can be used to adjust the over-dispersion, specifically in fitting a fixed-effect model.[19]

2) Empirical results

Both random and fixed effect models were run to estimate the effects of the explanatory variables on each technology. Table 5 lists the estimated coefficients from the random and fixed effect models. The random effect models estimate the effect of crude oil reserves using variations across countries, thus the generalization of the effect can be applied outside of the sample. However, the random effect models potentially suffer the endogeneity problem. The effect of crude oil reserves may have omitted variable problem. Using the fixed effect models helps in solving the endogeneity issue by picking up other country-specific characteristics with the fixed effect term. However, the fixed effect term might pick up the effect of the crude oil reserves in the model as well, because crude oil reserves do not significantly vary over time.

[Insert Table I-5 here]

Despite the different types of explanatory power, the results from random and fixed effect models show very similar effects of independent variables other than crude oil reserves.

[19] See Cameron and Trivedi (2005)

This validates the random effect model as does the effect of crude oil reserves. Thus, I include both the random and fixed effect models in Table 5.

As expected, I found that crude oil reserves encourage innovations in oil extracting technology but discourage innovations in alternative fuel technologies. The coefficient of crude oil reserves has a statistically significant negative effect on refining and EHV technologies, whereas it has significant positive effects on oil extraction and energy efficiency technologies. Given the coefficient on fuel cell being statistically insignificant, a country with more crude oil would invest less in alternative technologies using alternative and new fuels, while investing more on alternative technologies using oil as the main fuel. This suggests having crude oil reserves also steers technology innovation within alternative technology groups as well as between conventional and alternative technologies.

As noted earlier, refining patents collected in this study are for cleaner use of crude oil and raising efficiency of refined fuel production. Given the statistically significant negative effect of crude oil on refining technology, countries with larger reserves have less focus on the cleaner use of crude oil. This country-level pattern is also observable in vehicle use technologies. I find a negative effect of crude oil on EHV but a positive effect on energy efficiency. Crude oil reserves encourage technologies using more oil in both vehicle fuel and vehicle use technologies, while discouraging technologies seeking alternative ways in using less oil.

Regarding the effects of the domestic gas price, countries with higher gas prices have fewer patents in oil extraction, but have more patents in fuel cell, EHV and energy efficiency. Refining is the only technology not significantly affected by gas prices. Higher gas prices encourage the development of alternatives to compete with oil. The fixed effect models confirm significant positive effect of gas price on innovations in fuel cell and energy efficiency; even after the country effects are controlled. This suggests the higher gas price induces more R&D, leading to innovation for alternative technologies.

Between the two variables for industrial characteristics, the refining capacity significantly increases the patent counts for EHV in both random and fixed effect models. It seemingly appears that a larger refining capacity attracts R&D on alternative fuel sources, the electricity. However, this comes from the "Japan effect." Japan has the highest patent counts for EHV among the sample countries. Excluding only Japan's patent counts removes the significance of the effect of refining capacity, implying refining industry has only insignificant effects on vehicle technologies.

In contrast to refining capacity, GDP of the vehicle manufacturing industry has significant effects across all technologies tested. A larger vehicle manufacturing industry will attract investment in vehicle manufacturing R&D, thus raising patent counts of vehicle use technologies. This implies countries with a large vehicle manufacturing industry gear the investment on R&D toward alternative vehicle use technologies rather than fuel source technologies. Interacting vehicle industry with total tax revenue has the same effect. As total governmental tax revenue increases, the effect of GDP of the vehicle manufacturing industry becomes more negative on oil extraction and refining technologies, whereas it becomes more positive on alternative vehicle use technologies.[20]

Political freedom, political party and total tax revenues control for the effect of domestic policies. Political party does not have significant effects on the patent counts across technologies, which infers that having the left party in power does not increase investment in alternative

[20] The regression results including interaction term are provided in the Appendix I. The thresholds of total government tax revenue having vehicle manufacturing effects negative on oil technologies and positive on alternative technologies are: 12% for oil extraction, 20% for refining, and 18% for energy efficiency. The summary statistics show the minimum of total governmental tax revenue as 15%.

technologies. In contrast, political freedom increases investment in technology innovation in general, given the negative signs on oil extraction, EHV and energy efficiency patent counts.

Total tax revenues have negative effects across technologies except energy efficiency technology, suggesting a country with a higher governmental budget invests more on energy efficiency technology rather than other technologies. This implies either a government with more budget capacity values energy efficiency technology higher than others; or the public R&D increased by higher governmental budget is successfully translated into private R&D and the innovation process.

Although I attempted to control for domestic policy, it is hard to identify the policy effect on patent counts because effects are estimated with a reduced-form equation. Also, these variables include highly complex political activities that often diminish the effects of policies, even though the originally intended effects were strong.

GDP per capita and knowledge stock control for the wealth of a country and the size of innovation capacity respectively. GDP per capita has significant positive effects on all technologies except fuel cell. Wealthier countries have capacity for newer and innovative technologies, thus they have higher patent counts of new technologies than poorer countries. Interestingly, knowledge stock has a significant negative effect on energy efficiency technology, while it positively affects fuel cell technology. This suggests more patenting activity steers the vehicle innovation toward using alternative fuel rather than oil.

Grouping technologies into broader categories allows a data set to have a larger number of observations and produce stronger empirical results, in terms of conventional versus alternative technologies. Hence, I conducted pooled model regressions to see the effects of variables on conventional and alternative technologies. Fuel cell, EHV and energy efficiency technologies are grouped together as alternative technologies (AltTech). Refining technology, while it mainly uses fossil fuels, is included separately because of its cleaner technology characteristics. Oil extraction is the omitted category for this pooled model. Table 6 presents the result of pooled models.

[Insert Table I-6 here]

The negative effect of crude oil reserves on alternative technologies persists in the pooled model as well. The joint test also validates the significance of the negative effect of crude oil on alternative technologies in the pooled model. More crude oil induces less patenting activities in alternative technologies in the automobile sector. For the effect of crude oil, year dummies have little effect.

Regarding the price effect, higher gas price induces a larger number of patents in alternative technologies the same as the individual regressions by technology. The pooled model also results in the significant negative price effect on refining technology. The joint test validates the signs of price effects on alternative and refining technology. Overall, the higher gas price attracts more patenting activities in alternative technologies, while reducing the patenting activities in refining technology. This implies the price effect clearly influences fuel source choice.

Refining capacity has a negative effect on alternative technology overall. Countries with higher refining capacity are usually the ones endowed with large oil reserves. This corresponds to the effect of crude oil on alternative technologies. The joint test sustains the significance of the effect on both alternative and refining technology.

In both separate-model regressions and pooled-model regressions, more crude oil reserves cause less innovation in alternative fuel and vehicle use technologies. Although the policy effect still needs to be investigated separately, a smaller oil endowment directs a country's innovation patterns away from oil-intensive technologies.

7. Conclusion

This study tests the effects of oil endowment on the patterns of technology innovation in the automobile sector. Technology innovation was measured by the patent counts in five automobile-related technologies, selected based on the input and the output of automobile use.

The descriptive statistics show correlations between oil endowment and automobile innovation, although the link seems very weak at first. Countries with larger oil endowments have a higher level of patenting activities for oil extraction, while having relatively low patenting activities for alternative technologies (fuel cell and EHV) and energy efficiency. Countries scarce in oil endowment have the exact opposite pattern of innovation: higher patents in energy efficiency and alternative technologies and fewer oil extraction and refining patents. The empirical results confirm the negative effect of oil endowment on alternative technologies.

A possible explanation on the negative relationship between oil endowment and the alternative technologies is that patenting as social behavior also reflects the cultural context of a society. In countries with low fossil fuel endowment, the culture of fuel usage is efficient and saving, *e.g.* Japan's highly energy-efficient economy. Scientists and engineers, as members of the society and the culture, also put their priority on high efficiency in fuel usage, which leads to fuel-saving innovations.

However, we are observing government intervention on this negative relationship between oil endowment and alternative technologies. A government intervenes in the domestic market for energy security and puts in place policy measures to move domestic firms to meet domestic needs. If the interventions were successful in signaling high fuel prices in the future, the demand would increase for energy-efficient and alternative innovations. In fact, we can observe many developed countries using policy measures to promote R&D on alternative vehicle technologies. For example, France launched a national plan for development and deployment of EHVs in 2009 and provides a subsidy in purchasing low-emission cars. Germany also has developed a national plan for developing and deploying EHVs.[21]

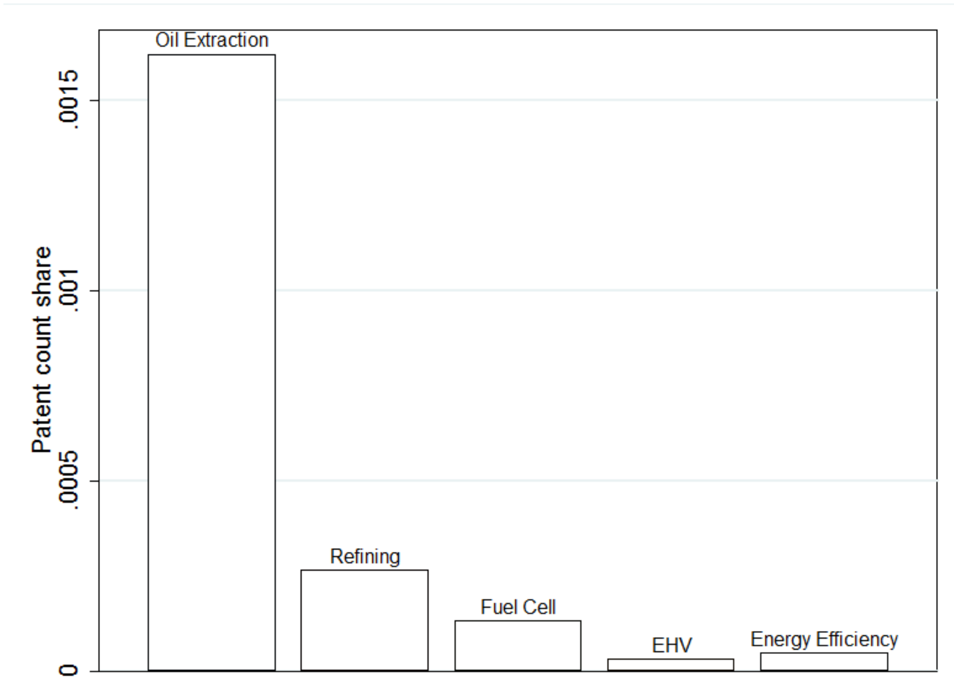
This also has an implication on the international climate change policy. Given the diverse interests from developed and developing countries with high and low oil endowment, it is hard to reach a consensus on actions to intervene in the negative relationship. The difficulty is clearly emerging from negotiations for the next step for Kyoto Protocol, on which the international community still has not reached an agreement.

In the same context, the major concern on climate change agreement lies on devaluation of carbon resources, especially for countries with large oil exports. However, the divergence of technology innovation given fossil fuel endowment may become a factor that hinders reaching agreements on international climate change actions. Countries with large oil endowments continue to develop technologies to explore fossil fuel more efficiently. This makes it more difficult to reduce fossil fuel consumption. In such a case, reaching an agreement may require designing a mechanism that gives incentives to those countries with large oil endowments and a lack of interest in reducing fossil fuel consumption.

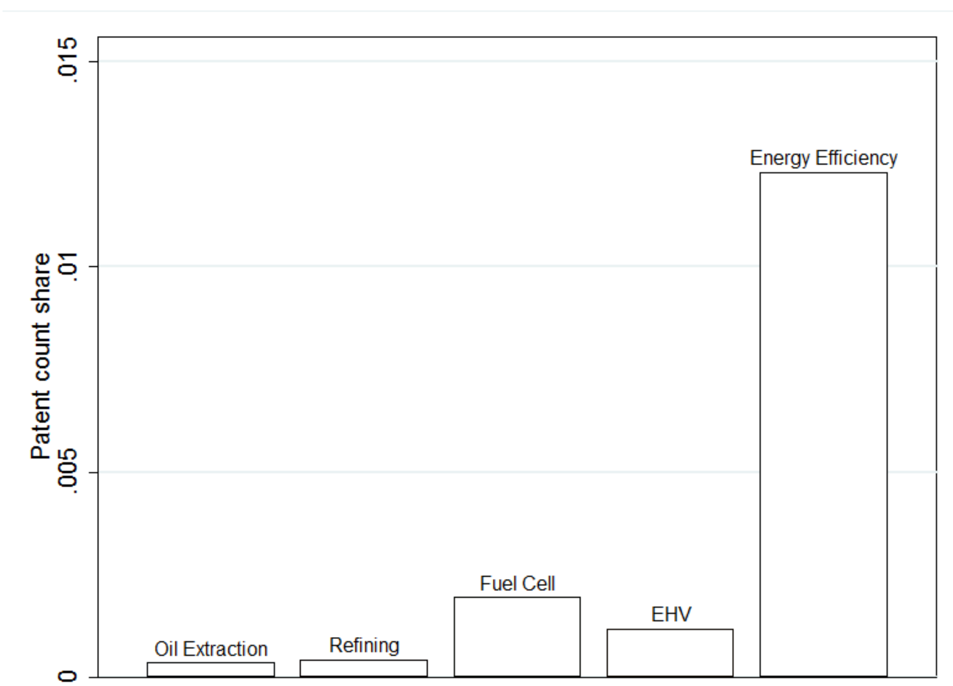
[21] Both the cases from France and Germany are listed in the EU report from the workshop on "European Commissions' and Member States' R&D programs for the Electric Vehicle"

Contrary to oil endowments, the gasoline price shows positive impacts on alternative technologies, including fuel cell, EHV and energy efficiency. An increased domestic gasoline price results in more innovation activities that move energy use away from fossil fuel. To promote alternative or fuel-saving technologies, governmental intervention needs to keep fossil fuel prices high enough to encourage customers to choose substitutes for fossil fuels. However, this is very likely to provoke political controversy. Future work may also look at strategies to alleviate political controversy. Also, if the government decides to intervene the price through the tax system, the design of such a policy needs to include a watchdog mechanism on the government spending translating into private R&D and further to their innovation activities.

Given the accumulated empirical results on the effects of energy policy on technology innovation, future work on testing the effects of fossil fuel endowment on energy policy will make the link more robust, completing the causation flowing from fossil fuel endowment, to energy policy, and to technology innovation. In addition, the effect of economic scale should be examined by adding developing countries in the empirical model. This also addresses the absorptive capacity of the developing countries for technology innovation. When including developing countries, the model should also take into account the difference in the product standards in trade.

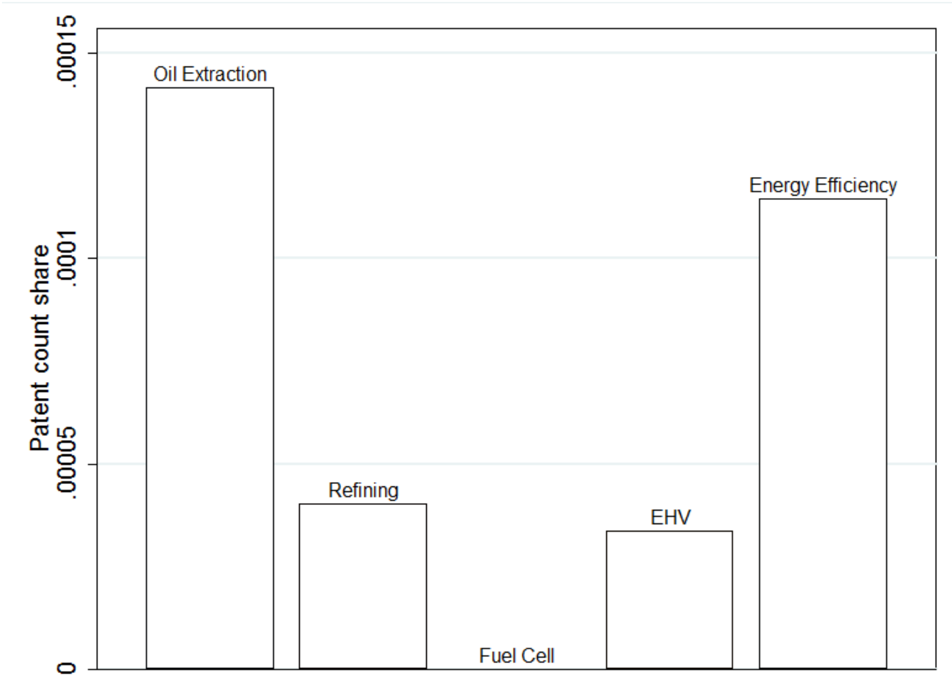


: Norway

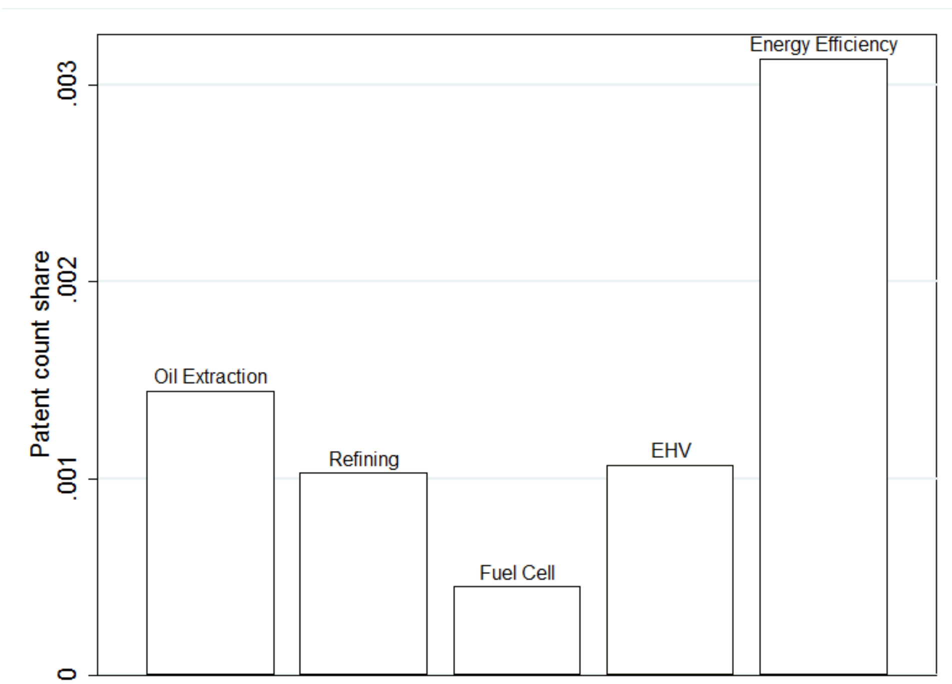


: Germany

Figure I-1. Patent count share, developed countries (1981-2002)



: Mexico



: China

Figure I-2. Patent count share, developing countries (1981-2002)

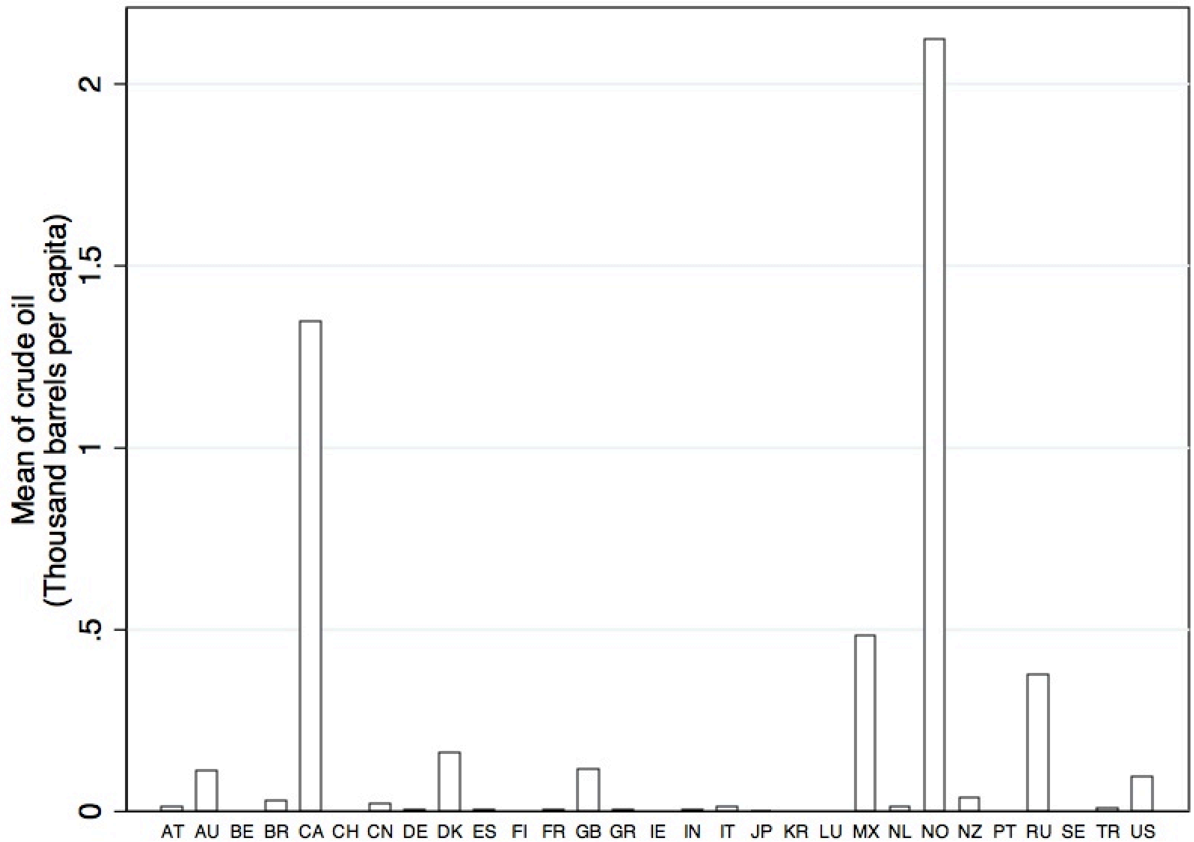


Figure I-3. Oil Endowment by country (1981–2009)

Table I-1. Descriptive statistics of patent count by technology (1981-2002)

Variable	Obs	Mean	Std. Dev.	Min	Max
Oil extraction	622	13.96	43.15	0	307
Refining	622	13.23	33.90	0	218
Fuel cell	622	41.51	201.47	0	2974
EHV	622	20.77	97.04	0	1053
Energy efficiency	622	146.76	545.68	0	4276

Table I-2. Cumulative patent counts for selected countries (1981-2002)

Country	Oil extraction	Refining	Fuel cell	EHV	Vehicle energy efficiency
Brazil	64	30	4	24	224
Canada	379	194	317	59	171
China	677	483	213	501	1467
Germany	398	463	2063	1259	12974
France	322	380	206	361	1236
United Kingdom	413	305	226	162	1555
India	2	20	5	2	13
Italy	49	116	83	69	647
Japan	240	2801	18797	8849	62668
Korea	2	53	311	255	2080
Mexico	21	6	0	5	17
Norway	195	32	16	4	6
United States	4177	2794	3061	1044	6163

Table I-3. Correlation among resource endowments and patents (29 countries)

		Patents by technology				
	Crude oil Endowment	Oil extraction	Refining	Fuel cell	EHV†	Energy efficiency
Crude oil	1					
Oil extraction	0.0441	1				
Refining	-0.0675	0.6025	1			
Fuel cell	-0.0585	0.0843	0.5690	1		
EHV	-0.0621	0.0593	0.5668	0.9121	1	
Energy efficiency	-0.0791	0.0609	0.6821	0.8723	0.8391	1

* Countries: Austria, Australia, Belgium, Brazil, Canada, China, Denmark, Germany, Finland, France, Greece, Ireland, India, Italy, Japan, Korea, Luxemburg, Mexico, Netherland, Norway, New Zealand, Portugal, Russia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States

* Year: 1981-2002

Table I-4. Descriptive statistics of explanatory variables (12 countries for 13 years)

Variable	Obs.	Mean	Std. Dev	Min	Max
Crude oil (thousand bbl per capita)	155	0.257	0.609	0	2.722
Gasoline price without tax (USD PPP per liter)	155	0.218	0.065	0.120	0.404
Political party (dummy)	155	0.529	0.501	0	1 (left)
Political freedom (index)	155	1.206	0.690	1	4
Total government tax revenue (% GDP)	155	36.138	8.433	15.12	47.22
Refining capacity (thousand bbl per capita)	155	0.016	0.007	0.006	0.034
GDP of vehicle manufacturing industry (billion USD)	155	16.646	22.141	0.045	101.362
GDP per capita (thousand USD PPP)	155	30.393	7.340	10.373	46.211
Knowledge stock (total patents in a year)	155	0.065	0.117	0	0.440

* Countries: Austria, Canada, Germany, Finland, France, Italy, Japan, Mexico, Netherland, Norway, United Kingdom, United States

* Year: 1990-2002

Table I-5. Estimated coefficients from the Poisson models

VARIABLES	Oil extraction		Refining		Fuel cell		EHV		Energy efficiency	
	RE	FE	RE	FE	RE	FE	RE	FE	RE	FE
Crude oil	0.703* (0.3385)	0.844*** (0.0621)	-1.792*** (0.4956)	-2.332*** (0.5911)	0.294 (1.1617)	2.112 (2.1303)	-3.195* (1.3628)	-1.181 (2.0817)	4.399** (1.4631)	5.525 (3.7525)
Gasoline price without tax	-2.714*** (0.7040)	-2.551*** (0.6789)	-0.687 (0.6143)	-0.605 (1.3440)	10.102*** (0.3656)	10.102*** (1.0852)	1.881*** (0.4590)	1.862 (1.1832)	3.690*** (0.2016)	3.653*** (1.0977)
Political party	-0.0106 (0.0590)	-0.015 (0.0868)	0.085 (0.0487)	0.055 (0.0580)	-0.011 (0.0287)	-0.022 (0.0576)	-0.073* (0.0355)	-0.076 (0.0998)	0.021 (0.0154)	0.020 (0.0672)
Political freedom	-0.8964** (0.2756)	-0.923*** (0.0878)	0.112 (0.0770)	0.075* (0.0328)	0.025 (0.0389)	0.017 (0.1125)	-0.252*** (0.0527)	-0.252** (0.0769)	-0.113*** (0.0218)	-0.114** (0.0356)
Total tax revenue	-0.069*** (0.0173)	-0.059 (0.0309)	-0.041* (0.0165)	-0.031 (0.0497)	-0.037** (0.0114)	-0.030 (0.0338)	-0.073*** (0.0175)	-0.068 (0.0363)	0.0715*** (0.0082)	0.0736** (0.0283)
Refining capacity	11.097 (29.7539)	6.585 (55.0959)	-12.910 (27.8976)	0.727 (65.3897)	-28.813 (20.3843)	-20.971 (44.0600)	327.117*** (29.2001)	336.606*** (82.2453)	-4.968 (13.7349)	-4.344 (11.1565)
GDP of vehicle manufacturing industry	-0.015*** (0.0039)	-0.0151** (0.0049)	-0.016*** (0.0033)	-0.014* (0.0059)	0.019*** (0.0015)	0.020*** (0.0033)	0.017*** (0.0024)	0.018** (0.0059)	0.011*** (0.0011)	0.012*** (0.0023)
GDP per capita	0.127*** (0.0152)	0.125*** (0.0151)	0.115*** (0.0164)	0.121*** (0.0346)	-0.010 (0.0102)	-0.004 (0.0529)	0.062*** (0.0141)	0.064 (0.0493)	0.050*** (0.0066)	0.051*** (0.0131)
Knowledge stock of the year	1.101 (1.4822)	1.119 (1.3429)	1.189 (1.3203)	-0.063 (1.2521)	4.248*** (0.7015)	3.848 (3.0047)	1.395 (0.9610)	1.177 (1.7777)	-1.737*** (0.4512)	-1.823** (0.6767)
Observations	155	155	142	142	142	142	155	155	155	155

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; constants not reported.
Mexico was dropped from the regression model because of zero patent number for the refining and fuel cell technologies.
Countries: Austria, Canada, Germany, Finland, France, Italy, Japan, Mexico, Netherland, Norway, United Kingdom, United States
Year: 1990-2002

Table I-6. Estimated coefficients from the fixed effect Poisson models

Variables	With year dummies	Without year dummies
Crude oil	0.294	0.527*
	(0.248)	(0.245)
Crude oil *AltTech	-5.666***	-4.745***
	(0.46)	(0.45)
Crude oil *Refine	-0.877***	-0.877***
	(0.102)	(0.099)
Gasoline price without tax	-7.343***	-8.109***
	(0.524)	(0.456)
Gasprice*AltTech	11.77***	13.05***
	(0.436)	(0.434)
Gasprice*Refine	5.871***	6.587***
	(0.523)	(0.527)
Political party	0.0879***	-0.00437
	(0.0173)	(0.0116)
Political freedom	0.0247	-0.105***
	(0.031)	(0.017)
Total tax revenue	-0.0315***	-0.0178***
	(0.007)	(0.005)
Refining capacity	121.9***	207.1***
	(11.43)	(9.28)
Refin_capa*AltTech	-264.6***	-268.5***
	(6.067)	(5.884)
Refin_capa*Refine	-95.07***	-89.98***
	(5.84)	(5.66)
GDP of vehicle manufacturing industry	-0.011***	0.00116
	(0.0014)	(0.0011)
Vehicle GDP * AltTech	0.00770***	0.00747***
	(0.0008)	(0.0008)
Vehicle GDP * Refine	-0.00699***	-0.00725***
	(0.0009)	(0.0009)
Knowledge stock	1.891***	1.201***
	(0.478)	(0.321)
GDP per capita	0.0390***	0.0586***
	(0.006)	(0.005)
Year dummy	Yes	no
No. of Obs.	775	775
Joint Test		
Crude oil + crude oil *AltTech	-5.371***	-4.218***
	(0.507)	(0.496)
Crude oil + crude oil *Refine	-0.583*	-0.351
	(0.27)	(0.266)
Gasprice + gas price*AltTech	4.427***	4.938***
	(0.331)	(0.146)
Gasprice + gas price*Refine	-1.472**	-1.522***
	(0.481)	(0.400)
Refining capacity + Refin_capa*AltTech	-142.6***	-61.43***
	(11.43)	(9.069)
Refining capacity + Refin_capa*Refine	26.87*	117.1***
	(11.59)	(9.365)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Countries: Austria, Canada, Germany, Finland, France, Italy, Japan, Mexico, Netherland, Norway, United Kingdom, United States

Year: 1990-2002

Appendix I-1. Estimated coefficients from the Poisson models with an interaction

VARIABLES	Oil extraction		Refining		Fuel cell		EHV		Energy efficiency	
	RE	FE	RE	FE	RE	FE	RE	FE	RE	FE
Crude oil	0.699*	0.792***	-2.905***	-3.289***	0.178	2.142	-3.018*	-0.957	6.320***	7.818
	(0.3435)	(0.0737)	(0.6646)	(0.4540)	(1.0893)	(2.0134)	(1.3187)	(1.9713)	(1.6142)	(5.1798)
Gasoline price without tax	-2.318**	-2.093**	-0.068	0.020	9.977***	10.060***	1.695***	1.701	3.004***	2.956**
	(0.7245)	(0.7256)	(0.6264)	(1.6889)	(0.3799)	(0.8105)	(0.4731)	(1.3474)	(0.2115)	(1.1152)
Political party	0.041	0.051	0.155**	0.137*	-0.019	-0.025	-0.087*	-0.087	-0.012	-0.013
	(0.0629)	(0.0899)	(0.0504)	(0.0581)	(0.0295)	(0.0545)	(0.0366)	(0.1054)	(0.0157)	(0.0609)
Political freedom	-0.819**	-0.861***	0.116	0.085*	0.025	0.017	-0.253***	-0.252**	-0.103***	-0.100*
	(0.2754)	(0.0702)	(0.0780)	(0.0426)	(0.0387)	(0.1147)	(0.0527)	(0.0801)	(0.0219)	(0.0441)
Total tax revenue	-0.024	0.001	0.086**	0.107**	-0.054**	-0.036	-0.100***	-0.093	-0.009	-0.006
	(0.0257)	(0.0440)	(0.0261)	(0.0335)	(0.0183)	(0.0429)	(0.0241)	(0.0666)	(0.0106)	(0.0257)
Refining capacity	17.948	18.259	10.703	24.898	-35.344	-23.383	315.849***	325.706***	-32.963*	-33.158
	(30.480)	(45.563)	(29.164)	(29.994)	(20.714)	(54.194)	(30.019)	(74.835)	(14.145)	(31.972)
GDP of vehicle manufacturing industry	0.0122	0.020	0.0623***	0.0725***	0.011	0.017	0.002	0.005	-0.0361***	-0.0357*
	(0.0119)	(0.0127)	(0.0128)	(0.0159)	(0.0072)	(0.0241)	(0.0097)	(0.0247)	(0.0041)	(0.0140)
Interaction term (total tax revenue & vehicle GDP)	-0.001*	-0.001**	-0.003***	-0.003***	0.0003	0.0001	0.001	0.001	0.002***	0.002**
	(0.0004)	(0.0004)	(0.0005)	(0.0007)	(0.0003)	(0.0008)	(0.0003)	(0.0010)	(0.0001)	(0.0006)
GDP per capita	0.1274***	0.1269***	0.1427***	0.1513***	-0.013	-0.005	0.0573***	0.060	0.0333***	0.0351*
	(0.0153)	(0.0201)	(0.0173)	(0.0324)	(0.0106)	(0.0603)	(0.0144)	(0.0542)	(0.0068)	(0.0159)
Knowledge stock of the year	1.126	1.081	-0.303	-1.564	4.447***	3.920	1.696	1.490	-0.329	-0.399
	(1.4892)	(1.2820)	(1.4157)	(1.3507)	(0.7105)	(3.5359)	(0.9792)	(1.9812)	(0.4648)	(1.0047)
Observations	155	155	142	142	142	142	155	155	155	155

* $p < 0.05$, **$p < 0.01$, *** $p < 0.001$; constants not reported.
Mexico was dropped from the regression model because of zero patent number for the refining and fuel cell technologies.
Countries: Austria, Canada, Germany, Finland, France, Italy, Japan, Mexico, Netherland, Norway, United Kingdom, United States
Year: 1990-2002

Essay II. Does foreign aid increase recipient's technological capacity? Empirical evidence from renewable energy aid

1. Introduction

A decade of international climate change negotiation has intensified the well-known dilemma of developing countries: they rely on using carbon fuels for economic development while being challenged to reduce usage for emission reductions. Although technology offers a solution to tackle the dilemma, developing countries have low levels of technological capacity, which refers to a nation's capacity to use and innovate advanced technologies. This has prevented some developing countries from benefitting from advanced technologies. Given the heightened pressure on developing countries, the Bali Action Plan (UNFCCC, 2008) recognizes the importance of environmentally-sound technology transfer for actions on climate change and calls for more action from developed countries. The Action Plan also emphasizes that technology transfer is more effective in recipients' capacity building if it includes environmentally-sound technologies.

Literature has recognized technological capacity as a determinant of technology transfer (Keller, 1996) and diffusion (Keller, 2004; Mancusi, 2008). Not many studies pay attention to whether technology transfer increases a recipient country's technological capacity. Technology transfer accumulates external knowledge within the recipient country. However, the accumulation do not automatically increase the capacity. To better understand the link between technology transfer and capacity building, this study explores the effect of technology transfer on the recipients' ability to generate renewable energy.

International technology transfer (ITT) refers to technology transfer between countries, typically flowing from developed countries to developing countries. Most ITT occurs in the private sector through ITT channels such as foreign direct investment (FDI) and licensing. However, lower income developing countries with small markets are less likely to attract FDI and licensing. Therefore, foreign aid becomes a potential channel of ITT for developing countries with small economies.

According to Kim et al. (2013), misalignment of technologies supplied and demanded in ITT also suggests foreign aid is a better fit for developing countries with smaller economies, rather than other channels in the private sector. Their study compared Technology Need Assessment (TNA) and technologies in Clean Development Mechanisms (CDM). TNA is a list of needed technologies developing countries identify by themselves and submit to the UNFCCC. Lower income developing countries frequently requested efficient household technologies such as increased lighting or improved stoves. However, limited markets for these technologies discourage developed countries' private sectors from innovating and transferring such technologies. In contrast, foreign aid belongs to the public sector, thus it provides an opportunity to reduce the misalignment.

This study limits its context to climate change and energy technology and focuses on the technological capacity to generate renewable energy. In the foreign aid literature, many studies focus on the education (Michaelowa and Weber, 2007; Asiedu and Nandwa, 2007; Dreher et al., 2008), health (Walt et al., 1999; Williamson, 2008), and agriculture (Norton et al., 1992; Kherallah et al., 1994) sectors. However, foreign aid studies focusing on the energy sector are rare (e.g. Kretschmer et al., 2010) and those that do exist focus mainly on the effect of FDI on energy consumption (Perkins and Neumayer, 2009; Mielnik and Goldemberg, 2002; Hubler and Keller, 2010). Kretschmer et al. (2010) investigate both the effect of overall and specific (energy and industrial sector) foreign aid on reducing energy consumption and carbon intensity. They find that sector-specific aid in energy and industry hardly affects either energy or carbon intensity. However, they did not pay attention to the effect of hands-on assistance in aid transferring technological knowledge.

Foreign aid aims to enable the recipients to sustain their economic development (Rosenstein-Rodan, 1961). In this light, foreign aid may aim for capacity building in the energy sector. Hence, I focus on the technological capacity of the recipients, by examining the effect of foreign aid on the power generation capacity of renewable energy. The empirical results show that foreign aid with technical cooperation increases the renewable power generation capacity of recipients in the longer term with higher magnitude than foreign aid with only financial transfers. This suggests foreign aid effectively works with technical cooperation.

This study contributes to the literature in two ways. First, it tests whether foreign aid increases recipients' ability to invest in renewable energy. This study is one of the first attempts to examine foreign aid as a channel of hands-on knowledge transfer. Previous studies treat foreign aid as a channel of financial transfer that increases physical capital stock. Second, it revisits capacity building in foreign aid with a specific focus on the renewable energy sector. Foreign aid community emphasizes capacity building to let recipients raise their standard of living by themselves in the long-term. However, studies on aid effectiveness often focus on the end result of economic development than recipients' ability to support themselves. This study refocuses the end goal of aid as promoting recipients' sustainability rather than meeting their needs temporarily.

The rest of the paper is organized in the following way. The next section describes the theoretical framework that motivates this study. The third section describes electricity generation from non-hydro renewable energy in developing countries, the dependent variable.

The fourth section outlines foreign aid the main independent and control variables. The fifth section presents the empirical models and concerns in using the models, followed by the results in sixth section. Finally, this study concludes with discussions and policy implications on the foreign aid.

2. Theoretical framework

Studies on the effectiveness of foreign aid often ask about the influence of absorptive capacity. They frequently identify human resources (Rosenstein-Rodan, 1961; Adler, 1965; Chenery and Strout, 1966: recited from Guillaumont and Chauvet, 2001; Lensink and White, 2001) and domestic policy and governance (Hadjimichael et al., 1995; Durbarry et al., 1998; Hansen and Tarp, 2000; Hansen and Tarp, 2001; Collier and Dollar, 2002; Clemens et al., 2004; Dalgaard et al., 2004) as components of absorptive capacity.

Specifically, human resources are a critical factor in low-level development. According to Rosenstein-Rodan (1961), technical assistance enables the recipient to use the incoming financial resources. Technical assistance typically provides expert services to the recipients. When experts from overseas are involved in an aid project, they are not familiar with the domestic environment outside of the project. Therefore, when a local environment changes, domestic human resources can better manage the project. In this circumstance, technical assistance to lower-income developing countries is better when it enhances domestic human resources.

This study defines technological capacity a national trait enhanced by external knowledge. As discussed in the literature, absorptive capacity is a limiting factor of technology transfer.[22] However, external knowledge through technology transfer increases the absorptive capacity for future technology transfer. Thus, technological capacity in foreign aid includes limiting factors for a successful aid project as well as latent factors that influence the process of internalizing external knowledge.

Specific to renewable energy, technological capacity in this study refers to the ability to enhance renewable energy with the transferred knowledge. The acquisition of new knowledge occurs through ITT projects, in which recipients (countries rather than firms) become active in absorbing the inflow of transferred technology.[23] Having developing countries as recipients, the World Bank's report on Science, Technology and Innovation (STI) capacity building (Watkins and Ehst, 2008) emphasizes capacity building at the country level. The report defines STI capacity building as: 1) the capacity "to acquire and use existing knowledge" (p. 11) and 2) the capacity "to produce and use new knowledge" (p. 11). Following the World Bank's emphasis, this study also highlights the country-level capacity building, having country as the unit of analysis.

Accumulated external knowledge adds to a recipient's ability to use advanced technologies. In the electricity sector, this study measures technological capacity increase with the increase in electricity generation. The enhanced ability to expand renewable energy allows the recipient to reproduce the transferred energy technology, expanding the electricity generation. Therefore, the electricity generation of renewable energy represents the use of transferred renewable energy. To capture the increased ability, it is more logical to examine the effect of technology transfer on the growth of technological capacity rather than on the level of

[22] For foreign aid, see Clemens, M. and S. Radelet (2003); for general technology transfer, see Keller (1996).

[23] Literature focuses on firms' behaviors in identifying useful new knowledge from external sources (Zahra and George, 2002). Examples of studies focusing on a country as their unit of analysis are Mowery, D. C. and J. E. Oxley (1995); Keller, W. (1996); Liu, X. and R. S. White (1997); Watkins, A. J. and M. Ehst (2008).

technological capacity. Hence, this study examines the effect of foreign aid in the energy sector on the change in the electricity generation from renewable energy.

How knowledge is transferred

In an ITT project, the input is the transferred knowledge, which includes: physical capital such as equipment and tangible innovations, and knowledge capital that is disembodied from physical capital—what Polanyi (1958) describes as tacit knowledge. While embodied knowledge is transferred through the physical capital, disembodied knowledge capital is often transferred through human resources (Quah, 2001). When successfully transferred, the knowledge results in increasing the recipient's technological capacity by increasing physical capital or enhancing domestic human resources.

Similar to the World Bank's STI capacity building, the effects of successfully transferred knowledge in ITT may emerge in two ways. First, the transferred knowledge increases the recipient's technological capacity to use and apply the knowledge to other similar projects. This type of capacity uses the infrastructure of the recipient country to assimilate the transferred knowledge and use it. For example, a wind turbine is transferred and needs to be connected to the electricity grid to use the electricity generated from the turbine. Second, the transferred knowledge may increase the recipient's technological capacity to design and improve the technology. This will increase the domestic manufacture of the equipment with improved features; for example, more efficient wind blades for wind turbines. This type of capacity may lead to the export of improved products. However, as a channel for ITT, foreign aid transfers knowledge only to limited extents because of the low levels of absorptive capacity in recipient countries. Hence, this study limits its scope to the technological capacity to use and apply the transferred knowledge. The limited scope presents the first hypothesis to test.

HP1: Foreign aid transfers knowledge and enhances recipient's technological capacity to use and apply.

The effect of the transferred knowledge is also connected to the mode of technology transfer. The types of knowledge transferred determine the mode of transfer: transfer of embodied technology only, transfer of both embodied and disembodied technology and transfer of disembodied technology only. A foreign aid project limited to financial transfer delivers only embodied knowledge to recipients by procuring physical capital. Depending on the recipient's level of absorptive capacity, the recipient will take some time to figure out how to build the equipment, or the recipient might never figure out the disembodied knowledge. This mode of transfer increases the stock of physical capital; however, it is unclear whether this mode increases the technological capacity of the recipient.

The second mode of technology transfer includes both embodied and disembodied knowledge. In such cases, a recipient of foreign aid receives both the equipment and the know-how to build the equipment, or the knowledge to use the equipment. This type of aid project includes the donors' cooperation with hands-on technical assistance. A common example of hands-on technical assistance is the donor providing experts and volunteers. This brings new disembodied knowledge to the recipient country, increasing the intangible knowledge stock. However, the newer knowledge transferred needs to be internalized to make the increase permanent or at least to have long-term effects. This mode of transfer increases the technological capacity of the recipient, specifically in using and applying knowledge. The recipient can reproduce similar projects on its own. An example of benefitting from disembodied knowledge transfer is Bangladeshi textile industry in 1970s-80s. The workers for a South Korean company observed how the company created and kept the documents of exports and the logistics, and later created their own company (Easterly, 2002). The unintentionally transferred knowledge enabled the recipient to reproduce. This mode of technology transfer—disembodied knowledge transfer—is the main focus of this study by looking at the effect this type of transfer has on the recipient's technological capacity.

The last mode of transfer only includes disembodied knowledge. The disembodied knowledge includes documented and undocumented knowledge. Documented disembodied knowledge consists of blueprints such as patents, while undocumented disembodied knowledge refers to know-how transferred only through human interaction. In either type of knowledge, this mode increases the technological capacity for designing and improving transferred knowledge. Given the lack of physical capital in transfer, complete knowledge on technology requires examining the detailed structure of the equipment and the process of building it. This requires high-level technological capacity, whereas almost all recipients of foreign aid only have a low level of capacity. Thus, this mode of transfer is not viable through foreign aid.

The type of knowledge transferred, embodied or disembodied, also determines the level of capacity-increase. Hands-on assistance of foreign aid transfers disembodied knowledge to the recipients through activities such as training and providing human capital, feasibility studies and joint research. By categorizing foreign aid into aid with and without technical cooperation, I attempt to capture the effect of disembodied knowledge transfer on the capacity increase in a recipient country.[24] Transferring both embodied and disembodied knowledge increases capacity to use and apply the transferred knowledge. Assuming foreign aid brings physical capital to the recipient, transferring disembodied knowledge along with physical capital escalates the increase of technological capacity. The recipient is now able to apply the transferred knowledge to projects requiring similar knowledge. Thus, I expect the magnitude of capacity increase is higher

[24] OECD defines technical cooperation as 1) grants flowing to recipient countries for education or training; and 2) salaries to experts from donor countries providing services in the recipient countries.

in aid with technical cooperation than in aid without technical cooperation. Given the expectations in the outcomes, the second hypothesis of this study to test is:

HP2: Technical cooperation signifies the effect of foreign aid in increasing technological capacity. In the context of renewable electricity generation, technical cooperation in foreign aid has higher and longer impacts on changes in renewable electricity generation of recipient than foreign aid without technical cooperation.

3. Dependent variable: Changes in electricity generation from NHRE

Changes in electricity generation, specifically from renewable energy sources, measure changes in technological capacity for renewable energy affected by the influx of foreign aid. It captures the outcome of change in investment put into renewable energy. Changes in installed capacity are a better measure for technological capacity for electricity generation. However, data on comparable installed capacity for developing countries are not yet complete to use in long-term time-series. Thus, the output of the renewable electricity generation is used as the next best measure because it represents the output of major renewable energy activities.[25] Using data obtained from the U.S. Energy Information Administration (EIA), I constructed data for annual changes in renewable electricity generation.[26]

[Insert Figure II-1]

Developing countries share 19 percent of NHRE electricity generation of the world.[27] Figure II-1 shows the NHRE electricity generation by energy sources and in China, Brazil, India, Philippines and Indonesia from 1980 to 2008. These are the top five countries with the largest increase in NHRE electricity generation over the sample period. Comparing the two graphs in Figure II-1, patterns of this generation follow the main NHRE source in each country. The

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[25] Other renewable activities include (not exhaustively) heat generation and fuel conversion.

[26] NHRE includes biomass, geothermal energy, ocean power, power generation from renewable sources, solar energy and wind power.

[27] The 19 percent is author's own calculation from the EIA data on world electricity generation. For total electricity generation, developing countries share 42 percent of generation during the sample period from 1980 to 2008.

divergence of renewable energy in countries comes from different renewable energy strategies. For example, Brazil has promoted biomass energy from its sugarcane industry, and the Chinese government has pushed wind energy by mandating wind turbines to be locally produced. Although countries have a different focus on renewable energy, this study analyzes aggregated NHRE electricity generation, which provides a reasonable number of observations for analysis from the countries in the sample.

4. Independent variables

1) Foreign Aid on Renewable Energy

OECD's Development Assistance Committee (DAC) defines foreign aid as transactions by official agencies that primarily aim to promote the "economic development and welfare of developing countries." [28] In light of cleaner development and welfare, this study focuses on foreign aid in the renewable energy sector and collects data from the OECD's Creditor Reporting System (CRS).[29] The database provides basic information on each aid flow/project, such as the donor and recipient countries, the type and amount of aid committed and disbursed, the project's sector, and purpose of the project. This study uses the amount of aid disbursed to measure foreign aid flow. Commitments are officially written obligations by the donor, whereas disbursements are what have already been spent on a recipient or a project. Because creditors report the amount of aid committed and disbursed in the database, commitments seemingly make a better measure of aid. However, there is a chance not all commitment money has been delivered to the recipient (Michaelowa and Weber, 2007; Dreher et al., 2008), especially when it

[28] In this study, foreign aid refers to both Official Development Assistance (ODA) and Official Aid (OA). The definition provided is on ODA; however, it also applies to OA because ODA and OA only differ in the list of recipient countries. ODA is given to developing countries included in Part I of the DAC's recipient list, whereas OA is given to more advanced developing countries that are in transition and included in Part II of the DAC's recipient list.

[29] CRS includes both ODA and OA with time series dating from 1973 for some countries; other countries include a shorter time series.

comes to measuring technical cooperation. This makes disbursements a better measure than commitments for this study.

Energy aid represents about 5 percent of the total foreign aid disbursements captured by CRS from 1995 to 2009. Energy aid has grown gradually with a sharp increase around 2000, while the number of NHRE projects has continually increased since the mid-1990s. This implies donors' growing interest in providing renewable energy assistance to recipients as the world's energy focus has shifted to renewable sources. The project duration was calculated by subtracting the last disbursement year by the first appearance of an aid project in the CRS. It should be noted that the last appearance is captured as disbursement, while the first appearance can be captured as either commitment or disbursement. The average duration for post-1994 NHRE projects is 2.3 years.[30] The fact the project can last after the last disbursement is installed gives flexibility in capturing the project duration.

[Insert Figure II-2]

A closer look at the NHRE aid in Figure II-2 shows aid donors are more interested in solar and wind energy. Projects on solar and wind energy had already started to take off in the mid-1990s, following a heightened concern on climate change since the enactment of the Kyoto Protocol. However, the financial capital started to visibly flow into projects on these types of energy in the mid- to late 2000s, implying donors started implementing projects with a substantial size since the mid- to late 2000s. A possible explanation is that the cost of solar and wind energy substantially decreased in 2000. According to the U.S. Energy Information Administration (EIA, 2011), O&M costs for 'Gas Turbine and Small Scale' in the United States

[30] Given the average lag between commitment and disbursement being over 7 months, the average duration for post-1994 NHRE projects would be from 2.3 years to 3 years.

was 9.79 $/MWh in 1999 and decreased to 7.19 $/MWh in 2000.[31] In comparison, O&M costs for electricity from fossil fuels was 4.62 $/MWh in 1999 and 4.59 $/MWh in 2000. The bigger drop in costs for generating electricity from solar and wind energy is a potential factor for donors actually implementing more sizable solar and wind aid projects from 2000.

As previously stated, technical cooperation is a key feature of foreign aid investigated in this study. A foreign aid project with technical cooperation transfers both physical capital and disembodied knowledge, whereas an aid project without technical cooperation includes only financial installments, limiting its delivery to physical capital. However, transferring physical stocks sometime includes experts' assistance in installing or simulating the equipment or machines. This portion of aid in non-technical cooperation projects is captured as 'investment-related technical cooperation (irtc)' in CRS data. Thus, in constructing technical cooperation and non-technical cooperation aid variables, I add the irtc portion of financial transfer in aid projects without technical cooperation to aid on technical cooperation (TC). The rest of financial transfer in aid projects without technical cooperation is constructed as aid on non-technical cooperation (noTC).

[Insert Figure II-3]

In energy aid disbursements, most aid does not include technical cooperation. Figure II-3 pictures the share of disbursements on technical cooperation (TC) and disbursements on non-technical cooperation (noTC) in the NHRE sector. Disbursements on technical cooperation share less than 5% of NHRE disbursements, indicating a low level of technical cooperation. This supports the argument of developing countries asking for more technical cooperation from developed countries in the international climate change meetings.

[31] Gas Turbine and Small Scale includes gas turbine, internal combustion, photovoltaic (solar energy) and wind plants.

For empirical analysis, I use the CRS data on energy aid from 1995 to 2009. OECD notes that pre-1995 CRS data is not reliable to analyze sectoral data. Because this study only uses aid on the energy sector, the time series is limited to data from 1995. Using only energy aid introduces potential selection bias because the sample includes only those countries receiving energy aid. However, the countries not receiving energy aid share less than 1% of total aid flows. The sample covers all countries receiving energy aid including countries receiving energy aid but not NHRE aid. This validates the use of the current sample. Appendix 2 presents the lists of 121 recipient countries included in the sample for empirical analysis. The list represent the restriction from the availability of control variables.

2) Control variables

As discussed, renewable energy production involves relatively newer technologies. Recipient countries have different ability to handle advanced technologies. I use tertiary education, total electricity generation, GDP per capita and FDI to control for the difference. The tertiary education enrollment data measures the level of domestic human resources. Focusing on newer renewable energy technologies, higher level of human resources matters when absorbing knowledge transferred via technology cooperation.[32] Thus, I use the enrollment rate for tertiary schooling of a country obtained from World Development Indicator of World Bank. Changes in the total electricity net generation measure investments on the total power production. Investments on the power industry fuel economic growth of a country. As the economy advances, a country can absorb newer technologies. I construct data on total electricity generation by subtracting NHRE electricity net generation from the total electricity net generation, then calculate year-by-year change in electricity net generation. In the same line,

[32] Norton et al. (1992) is an example of controlling available human resources in sectoral analysis, specifically on agricultural sector. It includes both available population for agriculture and schooling in the analysis.

GDP per capita measures the size of domestic economy. Almost all studies on the effectiveness of foreign aid, regardless of their sectoral focus, include GDP per capita as a control variable.[33] FDI controls for the other type of technology transfer through the private sector.

For empirical analysis, I construct an unbalanced country-year panel from 1995 to 2009. The panel is unbalanced because of different introduction times of renewable energy in recipient countries. Table II-1 presents the descriptive statistics of variables included in the empirical model.

[Insert Table II-1 here]

5. Empirical models

The main interest of this study is to find the effect of technical cooperation in foreign aid on the change in NHRE electricity generation. First, I examine the aggregated effect of foreign aid in the NHRE sector to test the first hypothesis. The empirical model is expressed as:

$$dy_{it} = \alpha + \sum_{j=1}^{L} \beta_j X_{i,t-j} + \delta Z_{it} + \nu_t + \gamma_i + \varepsilon_{it} \tag{1}$$

where dependent variable *dy* is the change in NHRE electricity generation in country *i* at time *t*, $X_{i,t-j}$ denotes foreign aid to recipient country *i* in distributed time *t* from the previous year *t-1* back to year *t-L*, and $Z_{i,t}$ refers to control variables. Year fixed effects, υ_t, controls for the time-varying effects common to all countries. Time-invariant country specific effects are captured by γ_i addressing potential endogeneity of unobserved variables (e.g. renewable resource

[33] To name a few, Michaelowa and Weber (2008), Asiedu and Nandwa (2007), Dreher et al. (2008) include GDP per capita; Burnside and Dollar (2000), Collier and Dehn (2001), Hansen and Tarp (2001) include log of GDP per capita for aid in total. See Roodman (2007) for the complete listing for aid in total. In renewable energy literature, cross-country analysis controls for GDP per capita. An example is Popp et al. (2010).

endowment). The aggregated effect of aid represents the combined effect of aid on technical cooperation and non-technical cooperation. The long-term effect of aid on technical cooperation and the short-term effect of aid on non-technical cooperation might cancel out the effects of the other. Thus, the expected effect of aggregated aid is weakly positive in the short-run and diminishes in the long-run.

The intent of this study is to test the gap in the effects between of two types of knowledge foreign aid transfers to the recipient countries: physical capital through non-technical cooperation and tacit knowledge through technical cooperation. To test this, I set another model with disaggregated foreign aid as:

$$dy_{it} = \alpha + \sum_{j=1}^{L} \beta_j [TC]_{i,t-j} + \sum_{j=1}^{L} \beta_j [TCno]_{i,t-j} + \delta Z_{it} + \upsilon_t + \gamma_i + \varepsilon_{it} \tag{2}$$

the vector of aid X is now separated into two vectors [TC] and [TCno], referring aid on technical cooperation and aid on non-technical cooperation respectively.

Technical cooperation transfers tacit knowledge. It involves learning process that requires longer time to result in outcome. Whereas, non-technical cooperation results in immediate outcome with the increased physical stock. Both types of knowledge increase the technological capacity of the recipient countries. However, learning tacit knowledge enables the recipient applying the learned knowledge to other projects. Thus, the magnitude of long-term cumulative effects is expected to be larger when aid transfers tacit knowledge than not.

To determine the optimal lag length, the preliminary estimations were performed from one-year-lag up to four-year-lags for equation (1) and up to eight-year-lags for equation (2) only for the foreign aid variable. I exclude current year's aid because aid at the end of year cannot contribute to changes in NHRE electricity generation in the same year.[34] The foreign aid literature often uses 4-year lags in estimating the effect of aid on economic growth (Clemens et al., 2004). I first follow the convention of the literature, then use Akaike information criterion (AIC). For the first model in equation (1), the combined effect of technical and non-technical cooperation in NHRE aid would minimize the expected long-term positive effect of technical cooperation. Thus, I followed the conventional lag of four years in estimating the effect of aggregated NHRE aid. To capture longer than the immediate effect of four years for technical cooperation of aid, I double the conventional lag length up to 8-year lags in estimating the second model in equation (2). Once AIC is estimated for models up to 4- and 8-year lags, a model with the smallest AIC score was selected as a best fit because it indicates a minimum information loss in the estimation.

Empirical concerns

I use the first differencing (FD) estimator to eliminate the time-invariant country-specific unobserved variables (υ_i). In general, fixed-effect (FE) and FD estimators are used to eliminate the time-invariant unobserved effects. An important assumption using these estimators is explanatory variables are strictly exogenous, uncorrelated with error terms in any time periods. I ascertain the assumption by using a distributed lag model. The distributed lag model allows for solving the lack of strict exogeneity by the presence of correlation between the error terms and lagged explanatory variables. Provided that the strict exogeneity assumption holds, the choice between the FE and FD estimator hinges upon the assumptions about the error terms. The FE

[34] Excluding the current year also prevents the reverse causation. Changes in electricity generation this year cannot affect the amount of aid coming in this year. However, aid disbursements follow only after commitments have been made. Using disbursements prevents a concern on reverse causation, which is another advantage in using disbursements than commitments.

estimator is more efficient than the FD estimator when assuming no serial correlation and homoskedasticity in error terms. However, making these two assumptions may be too strong. The FD estimator assumes the first differenced error terms are serially uncorrelated and have constant variance. If the first differences of the error terms are serially uncorrelated, the FD estimator is most efficient among the estimators depending on the strict exogeneity assumption (Wooldridge, 2010). While the difference between the two requirements is subtle, the latter requirement may be less restrictive and more likely to hold.

Moreover, a unit root test of panels in the data reject the null hypothesis of all panels contain unit roots. The alternative hypothesis states at least one panel is stationary. I also find some evidence of a unit root. In this case, FD estimator provides consistency by removing any unit roots (Wooldridge, 2010) holding the strict exogeneity assumption. Therefore, I use the FD estimator given the model used in this study entails multiple time periods. For statistical inference, I correct for the possible heteroskedasticity and serial correlation in the error terms.

Although FD estimator eliminates the time-invariant unobserved heterogeneity, there may be other potential endogeneity problems that are time-variant and country-variant unobserved effects. An example is changes in the details of renewable energy policy in recipient countries. However, this kind of endogeneity problem is very rare especially in the developing world context. Renewable energy policies in developing countries are very recent and thus not likely to have substantial changes. Nevertheless, I include instrument variable (IV) estimator to check this potential endogeneity in the Appendix. I use IV estimator with the distributed lag structure and FD estimator. The result is only suggestive with very few statistical significance, showing the overall patterns of short- and long-term effects of aid stay very similar to the FD estimator.

6. Results

The first model estimates the effect of aggregated NHRE aid disbursements on the change in NHRE electricity generation. The model with up to four-year lags provides the least information loss with the smallest AIC score among the models with different lag structure. Table II-2 includes models with different lag structure using the FD estimator. The result is somewhat striking. None of the estimated coefficients are statistically significant. It is only suggestive that the estimated effect of aid is the highest from 2-year lag aid and quickly dissipates thereafter. The cumulative effects have the same pattern of being suggestive with a peak from 2 years ago.[35]

[Insert Table II-2 here]

As Clemens et al. (2004) note, the effect of aid on its output becomes clearer when we disaggregate aid into two categories: aid having short-term effects and aid having long-term effects. In this study, aid on technical cooperation is expected to have a long-term effect, while aid on non-technical cooperation is expected to have a short-term effect. Thus, I consider separately the impact of aid with technical cooperation and without technical cooperation. Table II-3 presents the results from disaggregated NHRE disbursements. Because of the expected longer-term effect of technical cooperation, I extend the lag length up to the doubled lag of eight years. AIC score informs the model with lags up to eight years the best fit among models with different lag structure.

[Insert Table II-3 here]

The distinction between aid on technical cooperation and aid on non-technical cooperation is obvious across all models. The estimated effect of aid on technical cooperation

[35] The result is available upon request.

takes off three years after the inflow of aid and increases as cooperation matures. The result of the model with lags up to eight years is in column (3). For the individual short-term effect of each lag, effects of cooperative aid are statistically significant from aid three years previous and stay statistically significant and positive. More importantly, the magnitude of effects is much larger for cooperative aid than for non-cooperative aid. The estimated effects of non-cooperative aid are statistically significant from aid two years previous at the 1 percent level. The non-cooperative aid has very short-term impacts on NHRE electricity generation, which dissipates very quickly. Given the project duration of 2.3 to 3 years, the non-cooperative aid results in immediate and short-lasting effect on renewable power generation. Column (1) and (2) have statistical significance from lag 5 for non-cooperative aid; however, the significance level is at 5% and the magnitude of the effect is very low compared to cooperative aid. The smallest estimated effect of individual lagged aid comes from aid disbursed six years earlier for cooperative aid. In column (3), the coefficient n column (3) is .3827. In comparison, the persistent statistical significance for non-cooperative aid is aid disbursed two years earlier with the coefficient .0158. The cooperative aid has about 24 times higher effect than the non-cooperative aid.

To put the magnitude into context, consider the eight-year lag model in the column (3). From non-cooperative aid with a short-term effect, one million USD aid spent on wind power projects in China would produce 15.8 gigawatt hours per year on average. This is about the same as the current level of production rate per cost: 14.3 gigawatt hours per year.[36] Taking the .3827 of cooperative aid from six years ago, one million USD cooperative aid put toward wind power projects in China would produce 382.7 gigawatt hours per year. This is more than 25 times the current production rate per cost. Moreover, this is the smallest effect among different lagged aid.

[36] A Chinese wind power project from Clean Development Mechanisms (CDM) costs an average of 70 million USD per megawatt hour (Tang & Popp, 2014). In other words, a one million USD investment in a Chinese wind power CDM project will produce 14.3 gigawatt hours per year on average.

As the tacit knowledge internalized after its transfer through technical cooperation to the recipient country, it raises the recipient's long-term capacity to generate NHRE electricity yielding higher outcome. In contrast, changes in physical capital stock through financial resource transfer produce immediate results that are comparable to the current state of power projects, not raising sustainable long-term capacity of the recipient.

As a robustness check for the long-term impact of cooperative aid, I impose a different lag structure for the two types of aid. If the current model is appropriately developed, difference in lag length of non-cooperative aid would not affect the magnitude and long-term impact of cooperative aid. Based on the theory of this paper, cooperative aid is expected to have longer-term effect on the renewable energy generation. Thus, the lag for cooperative aid is set for eight years, while the lag for non-cooperative aid is set to vary from one to eight years. The result indicates that the estimated coefficients of cooperative aid from lag three to eight are both statistically and economically significant across different lag structures of non-cooperative aid. At the same time, the statistical significance at lag two of the non-cooperative aid stays the same regardless of the length of lags for non-cooperative aid. This confirms the short-lasting, immediate effect of non-cooperative aid as well as the long-lasting lagged effect of cooperative aid in Table II-3. The result is included in Appendix 1.

[Insert Table II-4 here]

Moving to long-term cumulative effect of lagged aid, Table II-4 includes the sum of estimated effects for lagged aid and the statistical significance level from the joint test of the sum. The statistical significance takes off after three years of aid disbursement continues to be positive thereafter. This is the same as in the case of the individual effect in Table 3. To illustrate, Figure II-4 shows the effects of a one million USD increase, *ceteris paribus*, in each disbursement type on the change in NHRE electricity generation from the eight-year lag model. We can observe a clear divergence between technical cooperation and non-technical cooperation. For the cooperative aid, the long-term effect of lagged aid increases as the number of lag increases. It supports my argument that cooperative aid transfers tacit knowledge and helps it internalize. Once internalized, the knowledge leverages the effect of aid as the knowledge matures within the country in time. In contrast, transferring only embodied knowledge fails to internalize the knowledge and has immediate and a very short-term effect that lasts for two years.

[Insert Figure II-4 here]

It is also interesting to see that the statistically significant and positive effect takes off in different times between the cooperative and non-cooperative aid. Cooperative aid takes one more year to have its effect on the renewable power generation than non-cooperative aid. The embodied knowledge transferred through non-cooperative aid can take effect immediately two years after the aid coming in following by the construction of a facility, but instantly dissipates its effect. In contrast, the transferred tacit knowledge takes its effect three years after the aid coming in, which lasts and grows as time accumulates. This suggests that cooperative aid increases the local capacity to produce renewable energy, which aids the recipient country to better use and produce renewable energy on its own in the future.

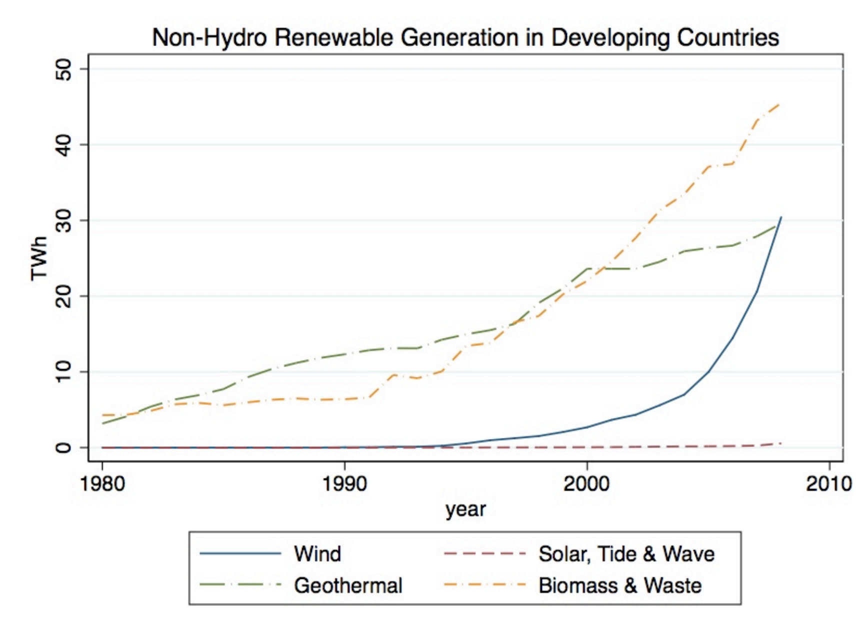
7. Conclusion

This study examines the effect of foreign aid on recipients' capacity to produce renewable energy. The findings indicate that foreign aid with technical cooperation has a substantial and significant long-term effect on the renewable capacity of recipients, whereas foreign aid without technical cooperation brings immediate but short-term effects. Although having a delayed effect, donors' hands-on assistance extends the effectiveness of aid, increasing recipients' capacity for renewable energy. As tacit knowledge is internalized, recipients sustain themselves for an extended time.

However, transferring only tacit knowledge has limitations in technology transfer and in foreign aid in particular. The level of knowledge transferred through foreign aid is restricted mostly to the knowledge that can contribute to raising capacity of using and applying, rather than designing and improving the transferred knowledge. Thus, in foreign aid, tacit knowledge transfer is attached to the physical capital transfer. A question for future research is then what level of technical cooperation and non-technical cooperation maximizes the aid effectiveness.

In answering this question, future studies can also address the importance of the cooperation types. For example, technical cooperation in emerging economies and technical cooperation in least developed countries would take different forms. China might have the capacity to manufacture the wind turbine, but most of the other small developing countries are better off having the knowledge of how to conduct a feasibility study for a potential wind farm. In this light, the optimal mix of technical and non-technical cooperation will raise the aid effectiveness as well as the optimal design of technical cooperation customized to the recipient. This point is expected to enlighten the international aid community finding technical cooperation as an important factor for capacity building contributes to evaluating how truly effective aid is to the recipients.

Another way to optimize technical cooperation is by delivering technical cooperation through different channels of aid: bilateral or multilateral. This suggests changes in the design of foreign aid in donor countries. Multilateral agencies involve various donor nations. Ideally, they have high level of transparency to aid the donor nations make an informed decision (Easterly and Pfutze, 2008). Moreover, Dollar and Levin (2006) found that multilateral donors are more selective than bilateral donors in choosing recipients with better governance. It is more likely that projects implemented in the recipient countries with better governance reach the project goal more fully than in countries lacking good governance. This would reduce the burden of bilateral donors by allowing them to reduce the cost of monitoring and evaluating projects.



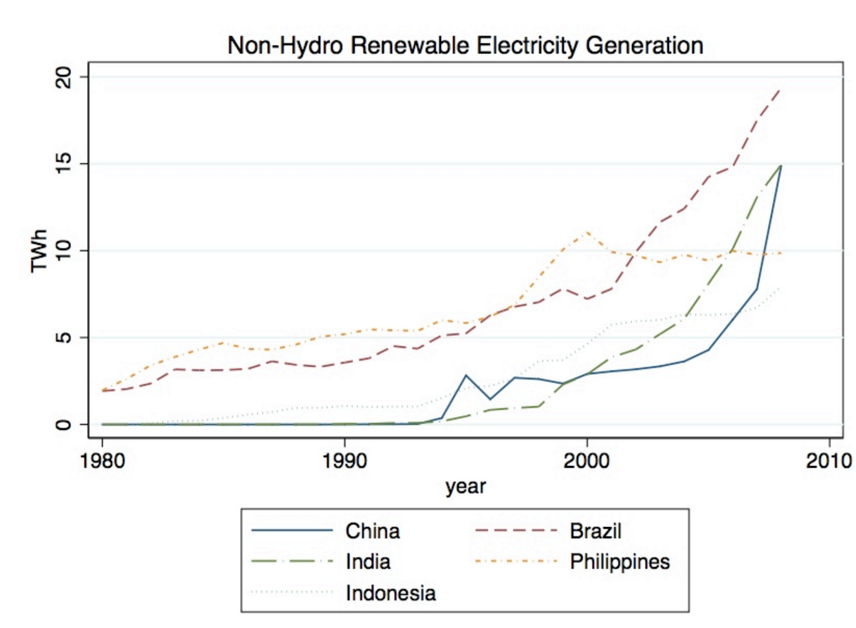
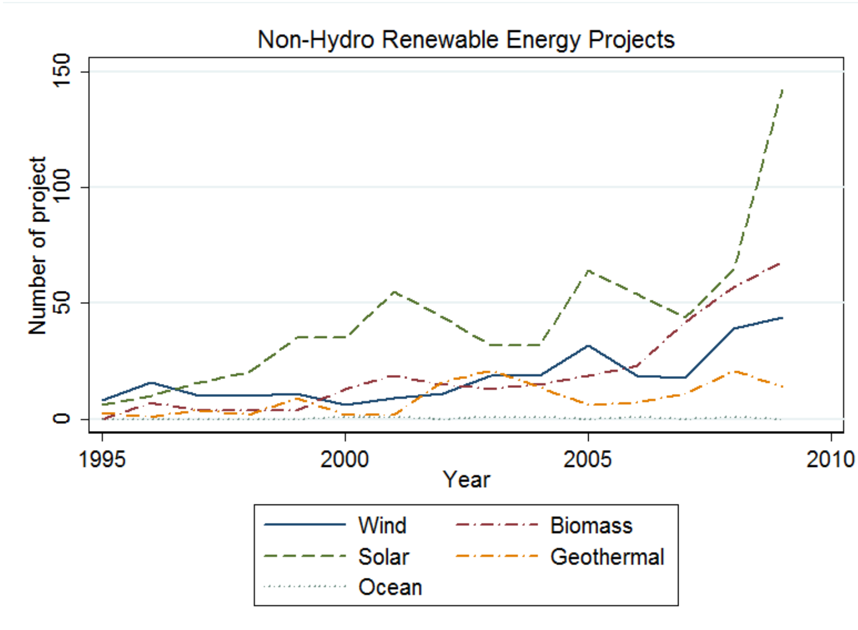


Figure II-1. NHRE electricity generation in developing countries



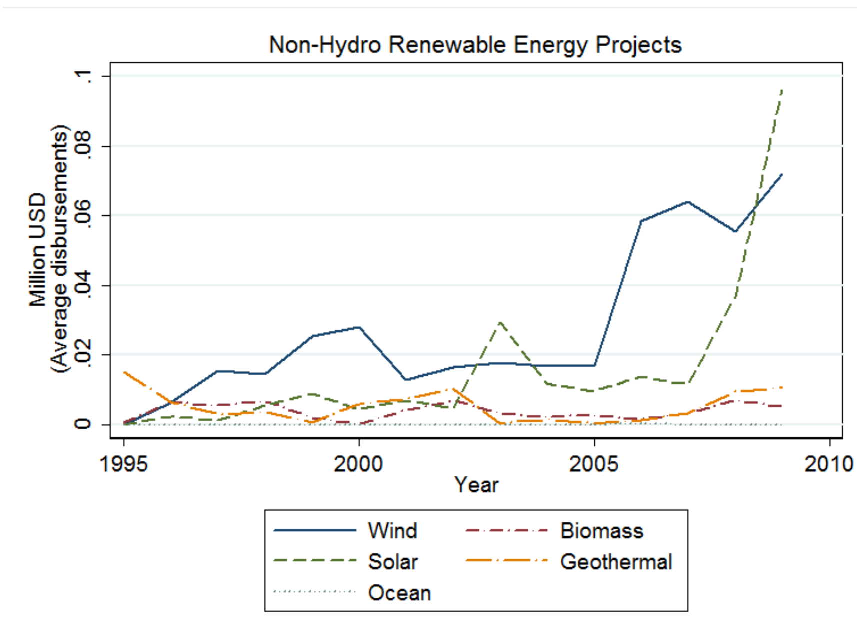


Figure II-2. NHRE projects by technology

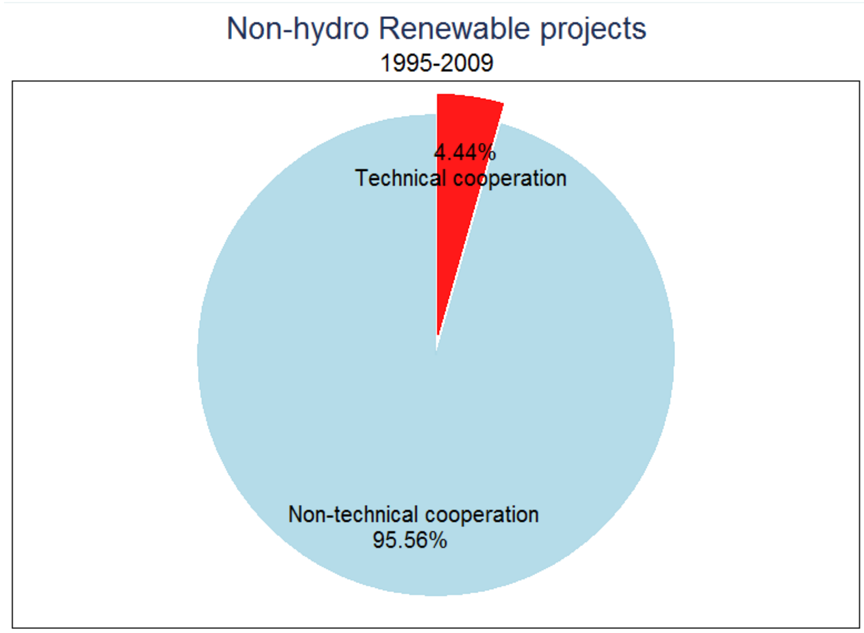


Figure II-3. Foreign aid projects on energy by technical cooperation

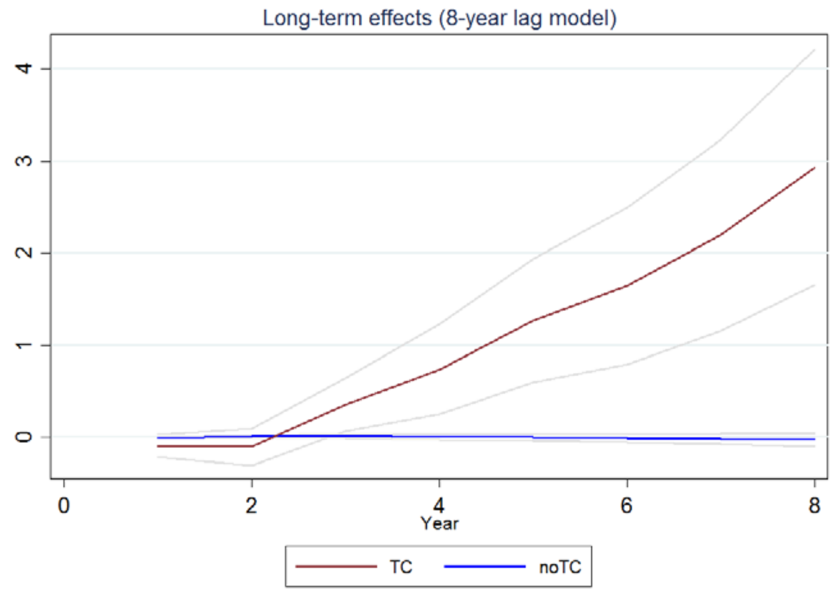


Figure II-4. Long-term effects of increase in aid disbursements on the change in NHRE electricity generation – 8-year lag model of FD estimator

Table II-1. Descriptive statistics

Variable	Number of observations	Mean	Standard Deviation	Min	Max
Total NHRE electricity net generation (TWh)	1404	0.06	0.49	-2.10	13.05
Disbursement on NHRE projects (million 2008 USD)	1404	2.03	11.02	0	158.99
Disbursement on NHRE projects with technical cooperation (million 2008 USD)	1404	0.12	0.48	0	6.43
Disbursement on NHRE projects without technical cooperation (million 2008USD)	1404	1.91	10.84	0	158.40
Total electricity net generation (TWh)	1404	34.18	174.12	0.00	3445.99
Tertiary education enrollment (% gross)	1404	14.10	15.33	0	121.51
GDP per capita (USD per million capita)	1404	0.0018	0.0024	4.83E-05	0.023
Foreign direct investment (billion 2008 USD)	1404	2.0016	9.41	-3.72	171.54

Table II-2. Estimated effects of total disbursements on NHRE projects from FD model

Dependent variable: Change in NHRE net generation

	Up to 3 lags (1)	Up to 4 lags (2)	Up to 5 lags (3)
Lag 1	0.004	0.0035	0.0008
	(0.0031)	(0.0032)	(0.0036)
2	0.0091	0.0088	0.0101
	(0.0081)	(0.0080)	(0.0083)
3	0.004	0.0019	0.003
	(0.0042)	(0.0039)	(0.0045)
4		-0.0041	-0.0012
		(0.0057)	(0.0064)
5			0.0098
			(0.0064)
Control variables	V	V	V
Observations	968	859	750
Number of country	118	116	112
AIC	874.748	854.235	841.92

*** p<0.001, ** p<0.01, * p<0.05

Year dummies are included. FD model. Robust standard errors are reported in parenthesis.

Table II-3. Estimated effects of different aid types from FD model

Dependent variable: Change in NHRE net generation

	Up to 6 lags (1)	Up to 7 lags (2)	Up to 8 lags (3)
Disbursements on NHRE projects with technical cooperation			
Lag 1	-0.0214	-0.0587	-0.0906
	(0.0723)	(0.0619)	(0.0585)
2	0.0395	0.0359	-0.0106
	(0.1060)	(0.0833)	(0.0765)
3	0.4187*	0.5348***	0.4581***
	(0.1737)	(0.1485)	(0.1055)
4	0.3113	0.3444**	0.3871**
	(0.1866)	(0.1334)	(0.1285)
5	0.4118*	0.4643**	0.5276***
	(0.1852)	(0.1423)	(0.1512)
6	0.1736	0.3369**	0.3827**
	(0.1362)	(0.1197)	(0.1300)
7		0.5007***	0.5509***
		(0.1426)	(0.1620)
8			0.7421***
			(0.2090)
Disbursements on NHRE projects without technical cooperation			
Lag 1	-0.0023	-0.0036	-0.0013
	(0.0036)	(0.0033)	(0.0032)
2	0.0162	0.0235***	0.0158**
	(0.0088)	(0.0070)	(0.0051)
3	0.0055	-0.0028	0.0033
	(0.0056)	(0.0064)	(0.0062)
4	-0.001	-0.0094	-0.0124
	(0.0036)	(0.0055)	(0.0076)
5	0.0133*	0.0117*	0.0015
	(0.0065)	(0.0046)	(0.0072)
6	-0.0003	-0.0022	-0.0124
	(0.0062)	(0.0057)	(0.0066)
7		-0.0015	-0.0119
		(0.0073)	(0.0107)
8			-0.0044
			(0.0120)
Control variables	V	V	V
Number of obs.	645	542	442
AIC	642.2	511.1	406.0
Number of country	110	106	103

*** p<0.001, ** p<0.01, * p<0.05

Year dummies are included. FD model. Robust standard errors are reported in parenthesis.

Table II-4. Long-term effects from the model with up to 8 years lag from Table 3
Dependent variable: Change in NHRE net generation

	Disbursements on NHRE projects with technical cooperation	Disbursements on NHRE projects without technical cooperation
Lag 1	-0.0906	-0.0013
	(0.0585)	(0.0032)
1+2	-0.1012	**0.0145*** **
	(0.1)	(0.0057)
1+2+3	**0.3569*** **	0.0178
	(0.1425)	(0.0099)
1+2+3+4	**0.744** **	0.0053
	(0.2421)	(0.0145)
1+2+3+4+5	**1.2716*** **	0.0069
	(0.3356)	(0.0176)
1+2+3+4+5+6	**1.6543*** **	-0.0055
	(0.4253)	(0.0207)
1+2+3+4+5+6+7	**2.2053*** **	-0.0174
	(0.5196)	(0.0283)
1+2+3+4+5+6+7+8	**2.9474*** **	-0.0219
	(0.6407)	(0.0367)

*** p<0.001, ** p<0.01, * p<0.05

Appendix II-1. Estimated coefficients from models with different lag structure for technical cooperation and non-technical cooperation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Disbursements on NHRE projects with technical cooperation								
Lag 1	-0.0037	-0.0327	-0.0368	-0.103	-0.0697	-0.0826	-0.0966	-0.0906
	(0.0683)	(0.0695)	(0.0677)	(0.0635)	(0.0575)	(0.0581)	(0.0605)	(0.0585)
2	0.1841	0.1528	0.017	-0.0364	0.0028	-0.0153	-0.0195	-0.0106
	(0.1101)	(0.1012)	(0.1061)	(0.0930)	(0.0810)	(0.0816)	(0.0777)	(0.0765)
3	0.5541***	0.5644***	0.5054***	0.5172***	0.5320***	0.5022***	0.4504***	0.4581***
	(0.1532)	(0.1259)	(0.1106)	(0.1108)	(0.1117)	(0.1141)	(0.1050)	(0.1055)
4	0.6320**	0.5208***	0.5789***	0.5237***	0.4741***	0.4629**	0.3831**	0.3871**
	(0.2123)	(0.1543)	(0.1568)	(0.1353)	(0.1386)	(0.1416)	(0.1280)	(0.1285)
5	0.7852***	0.6794***	0.6849***	0.5519***	0.5693***	0.5704***	0.5244***	0.5276***
	(0.2386)	(0.1808)	(0.1655)	(0.1460)	(0.1514)	(0.1569)	(0.1484)	(0.1512)
6	0.7151**	0.7111***	0.5938***	0.4581**	0.4770**	0.4887**	0.3923**	0.3827**
	(0.2330)	(0.1999)	(0.1535)	(0.1463)	(0.1521)	(0.1530)	(0.1335)	(0.1300)
7	0.6248**	0.7742***	0.7137***	0.6640***	0.6407***	0.6948***	0.5677***	0.5509***
	(0.2150)	(0.2174)	(0.1836)	(0.1691)	(0.1747)	(0.1790)	(0.1711)	(0.1620)
8	0.7112**	0.6294**	0.8474***	0.7351***	0.6723***	0.7203***	0.7738***	0.7421***
	(0.2470)	(0.2201)	(0.2377)	(0.1954)	(0.1868)	(0.1927)	(0.2154)	(0.2090)
Disbursements on NHRE projects without technical cooperation								
Lag 1	0.0057	0.0052	0.0034	-0.0001	-0.0011	-0.0014	-0.0015	-0.0013
	(0.0039)	(0.0046)	(0.0041)	(0.0035)	(0.0036)	(0.0033)	(0.0031)	(0.0032)
2		0.0149*	0.0188**	0.0195**	0.0230**	0.0208**	0.0167**	0.0158**
		(0.0059)	(0.0061)	(0.0064)	(0.0070)	(0.0069)	(0.0060)	(0.0051)
3			0.0193**	0.0121	0.0111	0.009	0.0041	0.0033
			(0.0067)	(0.0071)	(0.0065)	(0.0063)	(0.0066)	(0.0062)
4				-0.0136*	-0.0081	-0.0074	-0.0109	-0.0124
				(0.0064)	(0.0077)	(0.0078)	(0.0080)	(0.0076)
5					0.0078	0.0039	0.0036	0.0015
					(0.0044)	(0.0041)	(0.0045)	(0.0072)
6						-0.0057	-0.0116*	-0.0124
						(0.0032)	(0.0056)	(0.0066)
7							-0.009	-0.0119
							(0.0064)	(0.0107)
8								-0.0044
								(0.0120)
Tertiary education	-0.0120*	-0.0111*	-0.0106*	-0.0100*	-0.0093*	-0.0096*	-0.0084*	-0.0086*
	(0.0054)	(0.0045)	(0.0044)	(0.0043)	(0.0042)	(0.0042)	(0.0039)	(0.0040)
Change in total electricity	-0.0042	-0.0015	-0.0043	-0.0122	-0.0126	-0.0097	-0.0102	-0.0078

generation	(0.0064)	(0.0070)	(0.0060)	(0.0070)	(0.0065)	(0.0071)	(0.0070)	(0.0119)
GDP per million capita	53.6797*	41.4892*	32.8405	32.3561	30.2589	31.1047	22.4985	20.5344
	(26.6423)	(20.7262)	(19.5793)	(19.5039)	(19.7825)	(19.6635)	(18.5998)	(20.1404)
Foreign Direct Investment	-0.0106	0.0023	0.0177	0.0116	0.0191	0.019	0.0228	0.024
	(0.0160)	(0.0145)	(0.0152)	(0.0176)	(0.0195)	(0.0196)	(0.0196)	(0.0216)
Constant	0.1903	0.1407	0.1632	0.1731	0.1876	0.2138	0.2138	0.2123
	(0.1851)	(0.1732)	(0.1653)	(0.1664)	(0.1685)	(0.1728)	(0.1656)	(0.1669)
Number of obs.	442	442	442	442	442	442	442	442
AIC	479.431	454.726	432.418	417.715	412.669	410.174	**406.203**	407.508

*** p<0.001, ** p<0.01, * p<0.05; Year dummies are included. FD model. Robust standard errors are reported in parenthesis.

Appendix II-2. List of Recipients included in the empirical analysis by their time series

1995-2009
Algeria
Brazil
Burkina Faso
China
Kazakhstan
Pakistan
St. Lucia

1995-2008
Armenia
Azerbaijan
Bangladesh
Burundi
Cambodia
Cameroon
Cape Verde
Central African Republic
Chad
Chile
Colombia
Comoros
Congo, Dem. Rep.
Congo, Rep.
Cuba
Djibouti
Dominica
Ecuador
Egypt
El Salvador
Eritrea
Ethiopia
Ghana
Guinea
Guyana
Honduras
Indonesia
Iran
Jamaica
Jordan
Kenya
Kyrgyz Republic
Laos
Madagascar
Malaysia
Mali
Mauritania
Mauritius
Mexico
Mongolia
Morocco
Niger
Panama
Philippines
Rwanda
Senegal
St. Kitts and Nevis
Thailand
Tunisia
Turkey
Uganda
Uruguay
Venezuela
Zimbabwe
Namibia
Gambia

1995-2007
Argentina
Bolivia
Cote d'Ivoire
Guatemala
India
Malawi
Paraguay
Togo
Yemen

1995-2006
Angola
Benin
Botswana
Guinea-Bissau
Lesotho
Peru
Swaziland

1995-2004
Dominican Republic
Nepal
Tonga

1995-2003
Nicaragua

1995-2002
Sierra Leone
Slovenia
Suriname

1995-2001
Samoa
Vietnam

1995-2000
Equatorial Guinea
Liberia
Sudan
Zambia

1995-1999
Gabon
Papua New Guinea

1996-2008
Croatia
Georgia

1996-2004
Albania

1996-2002
Iraq

1997-2008
Macedonia
Moldova

1998-2009
Uzbekistan
Costa Rica
Fiji
Mozambique
Nigeria
Tanzania
Trinidad and Tobago

1998-2008
Tajikistan

1998-2004
Vanuatu

2000-2008
Afghanistan

2001-2009
Oman

2001-2008
Lebanon

2002-2008
Belize
Bhutan

2002-2006
Maldives

2004-2009
East Timor

2004-2007
Saudi Arabia

2005-2008
Belarus

2006-2008
Bosnia and Herzegovina
Serbia

Appendix II-3. IV analysis

I use the IV estimator to check the unbiased coefficients of the FD estimator in the presence of the other types of endogeneity other than omitted variable bias. I instrument the aggregated aid on NHRE for the model (1) and the disaggregated aid on NHRE (TC and TCno) in the model (2). For the aggregated aid, the excluded variable is the total aid excluding the energy aid. The key for a good instrument is having correlation with the instrumented variable (the aid in this study) and no correlation with the dependent variable (the renewable electricity generation). Thus, I excluded environmental aid that might have correlation with renewable energy. Running the IV model for disaggregated aid on NHRE, I instrumented the disaggregated aid by disaggregated aid in other sectors: [37] I combined IV and the FD estimator with robust standard errors correcting for heteroskedasticity and serial correlation.

Table II-A. IV estimates using the FD estimator

Dependent variable: Change in NHRE net generation

	Disbursements on NHRE projects with technical cooperation	Disbursements on NHRE projects without technical cooperation
Lag 1	-0.6337*	0.0064
	(0.3076)	(0.0069)
2	-0.356	0.0133*
	(0.2218)	(0.0055)
3	0.2361	-0.0014
	(0.1611)	(0.0066)
4	0.1943	-0.0223*
	(0.1548)	(0.0092)
5	0.3377*	-0.0049
	(0.1688)	(0.0076)
6	0.2189	-0.0159*
	(0.1508)	(0.0064)
7	0.6399***	-0.0117
	(0.1894)	(0.0108)
8	0.7589***	0.0008
	(0.1863)	(0.0128)
Control variables	✓	
Observations	442	
First stage F statistics	5.93	11.03
Number of country	103	

*** p<0.001, ** p<0.01, * p<0.05; Year dummies are included. FD model. Robust standard errors are reported in parenthesis.

[37] For disaggregated aid, instruments are technical cooperation and non-technical cooperation aid in banking and financial services; communications; other commodity assets; and trade policies and regulations.

Except for the estimated coefficients from lag 7 and 8 for technical cooperation, the statistical significance is reduced or disappeared compared to the results from the FD estimator in Table II-3. This is partly because of the noise added by using IV strategy because the IV estimator requires more variables to be included in the model. The weaker first-stage F statistics support the added noise in the IV estimator. Instruments are strong for non-technical cooperation and somewhat weaker for technical cooperation. Although the statistical significance mostly disappears, estimated coefficients for cooperative aid from lags 7 and 8 stays the same regarding the statistical significance and have very similar magnitude from the first differencing model in Table II-3. The delayed effect of cooperative aid is robust.

Essay III. Renewable energy aid: Do those in need receive it?

1. Introduction

Concerns on climate change have highlighted cleaner energy options for developing countries to tackle both climate and developmental challenges. As one channel to help developing countries, foreign aid increasingly recognizes renewable energy as a sector to address the needs of the poor. Since the start of the Kyoto Protocol (KP) in 1997, foreign aid on renewable energy has continually increased. OECD's assessment (2010) on energy Official Development Assistance (ODA) reveals that donors increased aid for renewable energy on average 16 percent annually between 2003 and 2008. However, findings from previous studies on general aid suggest aid allocation addresses donor interests rather than the needs of the poor. Specific to the renewable energy sector, this study investigates what factors determine the aid flow in this sector and whether sectoral aid serves the needs of the poor.

The work by McKinley and Little (1979) first introduced a typology of aid determinants: donor interests and recipient needs. Since their work, studies found that donor interests, including political and commercial interests, are the major aid determinants rather than recipient needs (McKinley & Little, 1979; Maizels & Nissanke, 1984; Alesina & Dollar, 2000; McGillivray, 2003). More recent studies add good governance to the aid allocation typology (Collier and Dollar, 2002; Neumeyer, 2003). Motivated by findings in aid effectiveness literature (e.g. Burnside and Dollar, 2000), they examine the effect of good governance in recipient countries on aid received. However, their results send mixed signals on whether good governance matters for donors in aid allocation.[38] Most recently, another stream of studies on aid allocation emerged. This group of studies adopts the gravity framework of international

[38] For a more comprehensive list of literature, see Neumeyer (2003).

trade flow (Clist et al., 2012; Duchesne, 2012). These studies add physical and social proximity to the typology of aid determinants.

Historically, aid studies have analyzed general aid. Thiele et al. (2006) point out the need for more sectoral analysis on aid. Highlighting foreign aid can also achieve the poverty-reduction goal using other means instead of economic growth (McGillivray, 2003). Moreover, the flow of aid is not solely the donor's choice. Both the donor's decision and recipient's agreement on the aid contract determines the aid flow. From the recipient's viewpoint, the ultimate goal (of goodwill) in receiving aid is to obtain needed technologies and be able to manipulate them without continuing assistance from donors so the recipient develops a sustainable economy and increases exports in the future. Recipients seek donors who can provide technological expertise if possible. However, recipients cannot select donors. The only time recipients can shape aid flow is when negotiating aid project agreements. During the negotiation, recipients can align the donor intention with their own intention, distributing aid among sectors.

Renewable energy reduces poverty by providing more of the population with access to energy. Nevertheless, only a small group of studies focused on aid allocation at the sector level: for example, food aid (Neumeyer, 2005; Duchesne et al., 2012), emergency aid (Fink & Redaelli, 2011), and sectors linked to Millennium Development Goals (MDG) (Thiele et al., 2006). This limited focus on sectoral aid has resulted in energy aid not receiving much attention in the aid literature. This study fills this gap by examining the patterns of aid flow in the renewable energy sector and contributes to the literature by empirically studying determinants of this aid flow.

Methodologically, I adopt the gravity model of international trade to describe the aid flow from a donor to a recipient following Duchesne et al. (2012). I model aid flow as proportional to the outcome of aid in a donor and a recipient, and inversely proportional to the distance between them. I use four categories of determinants from the existing literature: donor political interests, donor commercial interests, recipient needs and good governance. In many cases, aid determinant literature analyzes total aid flow. Subsets of total aid are expected to have similar effects of determinants with variation in magnitude. Because renewable energy aid is a subset of the total aid, I hypothesize all four categories have some level of positive impact on aid flow in the renewable energy sector.

In the next section, I review aid allocation literature and provide a theory of determinants for aid allocation in the renewable energy sector. In section 3, I describe foreign aid flow—the dependent variable—in the renewable energy sector. I then visit independent variables and provide how to measure them in section 4. Section 5 introduces the empirical model used in this paper. Results are presented in section 6, followed by the conclusion.

2. Background

In aid allocation literature, McKinley and Little (1979) set up the framework of donor interests and recipient needs exclusively determining aid allocation. However, later studies used more hybrid approaches in assessing aid allocation (e.g. Bethelemy, 2006; Clist et al., 2012). The literature generally finds that donor interests weigh heavier than recipient needs, specifically donor political interests (Alesina and Dollar, 2000; Radelet, 2006; Ali and Isse, 2006) and donor commercial interests (Ali and Isse, 2006; for aid-trade literature see McGillivray, 2003; Wagner, 2003; Osei et al., 2004). Recently, some studies argue that donor sensitivity has increased on recipient needs in allocating aid after the Cold War (Classens et al., 2007; Clist et al, 2012).

Borrowing from aid effectiveness literature, studies on aid allocation focus on donors' selectivity regarding governance and policies after the end of the Cold War era. Good governance is to protect the human, political and civil rights of the public in a country

(Neumeyer, 2003). Studies often proxy good governance with, for example, democracy (McKinley and Little, 1979; Neumeyer, 2003), political stability (McKinley and Little, 1979), political rights (Wall, 1995; Svensson, 1999; Alesina and Dollar, 2000), or corruption (Neumeyer, 2003).[39] Most studies on good governance argue that donors allocate aid to recipient countries who perform better governance or have better policies than others, and empirically found the argument valid (Neumeyer, 2003; Dollar and Levin, 2006; Berthelemy, 2006).[40] On the other hand, some studies argue that donors allocate aid to recipient countries with bad policies so an aid project results in policy reform, thereby raising aid effectiveness (e.g. Svenssen, 2003). The diverted arguments produce mixed results on the effect of good governance. Nevertheless, the policy reform is induced from the aid, which aims to restructure a recipient's economy. Hence, good governance in recipients attracts more attention from donors.

A newly observed group of studies incorporates gravity framework of international trade flow (Dollar & Levin, 2006; Clist et al., 2012; Duchesne et al., 2012). The gravity model describes international bilateral trade as proportional to products of trade from each partner and inversely proportional to the distance between the two partners (Duchesne et al., 2012). Literature typically used the gravity model when examining the effect of aid on trade rather than studying determinants of aid allocation. However, Dollar and Levin (2006) and Clist et al. (2012) use the concept of gravity, although not using the gravity model itself. Dollar and Levin (2006) used distance between a donor and a recipient when examining aid selectivity on recipient's governance. Clist et al. (2012) categorized determinants of aid allocation into four categories: Poverty, Population, Policy and Proximity. The concept of the Proximity factor is close to the resistance to trade in trade literature using the gravity model. Clist et al. (2012) specifically used

[39] For more detailed description of literature, see Neumeyer (2003)
[40] However, Alesina and Weber (2002) found no evidence of aid allocation favoring less corrupt governments.

a dummy variable for the same official language between a donor and a recipient to examine general aid allocation. Comparably, Duchesne et al. (2012) used the gravity model in examining food aid allocation. They included distance between a donor and a recipient to measure the gravity effect. However, Duchesne et al. (2012) focus on the food aid. Thus, this study will be one of the first studies that analyzes aid allocation in the renewable energy sector using the gravity model.

Aid flow in the renewable energy sector

Aid literature has not focused on renewable energy aid because it makes up only a small fraction of total aid. However, global actions on climate change move donors to increase renewable energy aid (OECD, 2010). The global community is increasingly pressing developing countries to participate in the mandatory climate change actions. Efforts to attract developing countries into the action at the multilateral level emerged as newly created climate change funds.[41] In line with these efforts, bilateral donors also increased aid on renewable energy in the last decade. However, it is unclear why bilateral donors provide renewable energy aid—whether they align their motivation with the global efforts or their own interests. If donors follow their own interests, bilateral aid would overlook recipient needs. This will decreases aid effectiveness on achieving poverty reduction. In this regard, discovering motivation of bilateral donors in giving renewable energy aid sheds light on raising the effectiveness of renewable energy aid.

The attention on renewable energy revived after the late-1990s when the KP was ratified. As mentioned earlier, the post-Cold War environment diluted donor political interests in providing aid. However, donor political interests emerged in a different form. Specific to climate change, donors invest in developing countries to induce their participation in the mandatory

[41] Examples are: Adaptation Fund, Green Climate Fund, Special Climate Change Fund and Least Developed Countries Fund.

greenhouse gas (GHG) reduction targets. Therefore, donors strategically give renewable energy aid to recipients. This might signal a reduced burden in climate change action to the recipient countries.

Another frequently considered donor interest that significantly emerged in the Post-Cold war era is of the commercial nature; it is one that seeks economic opportunities for the donors' own countries in giving aid. (Claessens et al., 2007). Dollar and Levin (2006) also support this change in donor focus from political to economic. The commercial interest of donors is extensively studied in relation to international trade (e.g. Wagner, 2003; Nelson and Silva, 2008), by maintaining the donor-recipient relationship with trade partners (Lloyd et al., 2000; Wagner, 2003). Donors give aid to a country that imports their goods and services expecting continued exports to the recipient. Therefore, the recipient buys goods and services from the donor to secure future aid from them. In other words, donors secure their exports while recipients secure the income of foreign aid.

Martens (2005) suggests another view on commercial interests. He argues donors use foreign aid to position commercial firms of the donor's home country in the global market. In this case, donors transfer aid to as many recipient countries as possible to set the technological standard. Becoming a widely used standard suggests more markets for their products, i.e. increasing exports. Thus, donors expand their commercial influence in many recipient countries. Furthermore, having more recipient countries also expands donors' political influence over wider regions.

In the case of the renewable energy sector, donors prefer expanding the list of recipients because renewable energy technologies are emerging technologies in the global market. As donors assist many recipient countries with their own renewable technologies, there is higher chance of becoming the global standard. Considering the first-mover advantage, being a global standard is a strong economic incentive for donors in giving aid.[42]

Together with commercial interests, the end of the Cold War and the rise of globalization re-highlighted good governance and better policy in recipient countries. As stated previously, weaker donor political interests after the Cold War made donors refocus on aid effectiveness. Donors seek good governance in recipients for the most output given the aid they input. Recipients with good governance provide a better environment in aid use by avoiding corruption and having transparency. Thus, good governance sends a signal to donors that the recipient country has a willingness to solve its developmental problems. Similarly, a country with better political rights pursues the needs of its people. Hence, donors allocate their aid to recipients with better governance (Neumeyer, 2003). Previous studies examined good governance on general aid allocation. Given the same process in general and sectoral aid distribution, this good governance argument is also valid for the renewable energy sector.

Similar to the good governance, sector-specific domestic policies show the willingness of a recipient country in solving developmental problems in the specific sector. In the renewable energy sector, a better policy environment signals donors that a recipient country is an effective candidate for their renewable energy aid if allocated. However, presence of such policies does not guarantee they are well practiced and donors recognize that policy effectiveness is unclear. Unfortunately, donors cannot gauge the effectiveness of policies until long after aid has been disbursed. Thus, the presence of policy is what donors must use to measure recipients' effectiveness at best.

[42] From the recipients' perspective, aid is most effective when it supports neglected technologies that are not viewed as profitable by firms in developed countries, but needed in developing countries. In this case, being a global standard is not as strong of an incentive for donors because of the low market potential of supported goods. However, in practice, it is unclear that renewable energy aid supports the neglected energy technologies.

In theory, aid flow reflects recipient needs in the renewable energy sector because of both donor strategic interests (to include developing countries in the binding agreement) and recipient needs (energy needs for development). Hence, I examine what determines aid flow in the renewable energy sector and attempt to answer which donor interests and recipient needs are the stronger driver of renewable energy aid.

3. Dependent variable: Foreign aid on renewable energy

Data on foreign aid flowing into the NHRE sector is constructed from OECD's Creditor Reporting System (CRS) from 1995 to 2009. OECD notes that CRS data at the sector level are reliable only after 1995 when the reporting was improved. Because previous studies note that bilateral and multilateral aids are different and better to be analyzed separately (Alesina and Dollar, 2000; Maizels and Nissanke, 1984), this study limits its scope to bilateral aid using commitment data, which represent donor's willingness and interest in a recipient country (Neumeyer, 2003).[43]

[Insert Figure III-1 here]

This study focuses on foreign aid for the non-hydro renewable energy sector. Figure III-1 plots the number of bilateral NHRE projects starting each year and the amount of commitments on bilateral NHRE projects in the pipeline each year. During the sample period of 1995-2009, the number of projects continuously increases by almost 8 fold, implying donors' increasing attention on NHRE use in developing countries. The fast increasing attention on NHRE is supported by the upward trend of donors' commitments starting from late 1990s, when the global community became more serious on combating climate change. For example, the KP was

[43] Commitments are the amount of financial resources donors promise to give to recipients. A comparable concept is disbursements that are the amount of financial resources already spent in implementing aid projects.

signed in 1997 with binding reduction targets of developed countries.[44] The fast increase motivates to study why donors give aid in the NHRE sector and whether they give it to those in need.

Breaking down to donor-to-donor aid, Japan and Germany are the two biggest bilateral donors in NHRE aid.[45] Table III-1 shows top recipient countries in total energy and NHRE aids from Japan and Germany. There are different trends of each donor in aid allocation. For Japanese aid, African and Southeast Asian countries appear at the upper rank in both total energy and NHRE aid. German aid mostly flows into Central Europe and South Asia such as Serbia, Armenia, Turkey, Pakistan and Nepal. The regional concentration sheds some light on the physical proximity driving the aid allocation. This motivates the use of the gravity model in this study.

[Insert Table III-1 here]

The difference in regional concentration by donors supports the argument of donors' political and economic interests. If the aid allocation is solely on the imperatives of the recipients, virtually all donors would allocate their resources following very similar regional distribution. However, the diverse regional concentration of donors indicates the aid allocation process is strategic. The next section presents what are the potential factors in this strategic donor behavior.

[44] CRS data, by definition, does not include financial flow for the Clean Development Mechanisms (CDM) of the KP. However, actual data include some of feasibility studies for CDM projects. I follow the definition of CRS data and regard observations for CDM feasibility studies as noise in the data.
[45] USA is ranked at 2nd for total energy aid but at 10th for NHRE aid among 25 donor countries during the sample period 1995-2009. Author's own calculation.

4. Aid determinants

Drawing upon the determining factors of aid in previous studies, the aid flow model includes four determinants: donor political interests, donor commercial interests, recipient good governance, and recipient needs. Because energy aid is a subset of total aid, previously identified factors of aid allocation at the aggregated level determine allocation of energy aid. However, sectoral determinants are not to be overlooked. The aid flow model thus includes energy sector-specific determinants in each category of determinants. Using a gravity equation, I add potential determinants of aid allocation from the gravity equation as well.

Political interests

Political interests were a strong driver of aid allocation, especially during the Cold War era. Considering that the majority of donors were western democracies, the motivation of aid giving was to keep the recipients on their political side. After the Cold war, donor political interests became focused on maintaining established political influence and practicing their foreign policy strategies with the recipients.

Previous studies identified political interests a strong driver of aid allocation by bilateral donors (Alesina and Dollar, 2000; Radelet, 2006; Berthelemy, 2006; Clist, 2011). They measured political interests with former colonies (Alesina and Dollar, 2000) and UN allies (Alesina and Dollar, 2000; Hoeffler and Outram, 2011). Aid giving to donor's former colonies clearly indicates donor interests in maintaining political influence of the recipient's domestic affairs and being UN allies assumes to have the same geopolitical interests between a donor and its aid recipients. However, the inference is unclear whether being UN allies induces aid allocation or if aid recipients become UN allies. Considering this unclear inference link, I use the former colonial link downloaded from the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) to measure donor political interests.

More directly than being UN allies, donor political interests in a particular recipient are developed through migrants from the recipient country. Bermeo and Leblang (2010) argue that migrant interest groups lobby for more aid allocation to their country of origin and found the argument statistically sustained. Borrowing from them, I use immigrating population from a recipient country to a donor's country to measure donor's political interest through migrant interest groups. Increased immigration from a recipient country makes the interest group for the population politically stronger. The interest group with political strength succeeds in lobbying for more economic assistance to their country of origin. Hence, the effect of immigration is expected to be positive on aid flow in general, thus positive for the renewable energy sector as well.

Specific to energy, aid to recipients with crude oil or natural gas endowment measures donor geopolitical interests. Donors allocate aid to recipients in an attempt to continue imports of energy resources from the recipients. Thus, I use imports of crude oil and natural gas rather than the endowment to measure donors' geopolitical interests. The imports indicate that a donor-recipient pair has a historical relationship regarding energy resources as well as donors' dependence on recipient's energy resources. Donors give aid to their partners to maintain their relationship and to secure the energy supply. The geopolitical interests determine donors' decision on the overall aid distribution rather than on the sectoral aid. Although loosely related, more imports of energy resources are expected to have a positive effect on NHRE aid flow.

Regarding climate change, donors strategically give aid to recipients to recruit developing countries in the binding GHG reduction targets. Donors with high interest in climate change and renewable energy would be active in international climate change accord and impose renewable energy policy. Thus, I measure donor strategic interest with commitment to the KP, share of electricity from renewable energy and patents on renewable energy technologies of donor countries. Having committed to the KP clearly shows donors' strategic interest in recruiting recipients in the binding targets. Commitment to the KP is a binary variable being a unity if a donor signed the KP and did not withdraw.[46] Both the share of electricity from renewable energy and patents on renewable energy technologies are the outcome of the renewable energy policy, which measures the stringency and effectiveness of renewable energy policies in donor countries. Data for these two variables were obtained from World Bank and OECD respectively. As donors commit to climate change action and renewable energy policy, they have high incentive to attract developing countries. The expected effects of these variables are positive on providing renewable energy aid.

Commercial interests

Post-Cold War, donor motivation in aid allocation appeared to re-focus on development goals. However, the accelerating globalization led donors to be more interested in commercial benefits than political ties. Commercial interests bring the economic profits back to donor countries. One way to realize this commercial interest is giving aid to their trade partners in the expectation of continuous exports to the recipients. Previous studies measure this trade interest by as export share (Dollar and Levin, 2006; Clist, 2011) and as trade flow (Hoeffler and Outram, 2011). Given the donor interest in continuing and expanding exports, I use a recipient country's share of total exports from the donor country. This measures the importance of the recipient as a market to the donor.

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[46] A donor who signed the KP has value of 1 from 1998 and after; 0 before 1998.

Specific to the emerging technologies, a wide coverage of a donor's technology increases the opportunity of becoming the global standard (Martens, 2005). Renewable energy technologies are relatively newer technologies in the energy sector. Thus, giving aid to as many countries as possible might be a donor strategy to become the global standard. The number of recipient countries receiving aid from a donor measures donor intention to spread its technology, expecting the effect to be positive. I calculate the number of recipients per donor as the number of total recipients receiving aid from a donor minus one so it excludes the recipient country in a donor-recipient pair.

Good Governance

Recent studies on foreign aid find that the effectiveness of aid is conditional on good policies (Burnside and Dollar, 2000; Collier and Dollar, 2002) or good governance (Neumayer, 2003). In a donor's strategy, allocating aid in recipient countries with good policies/governance would raise the effectiveness of aid. In this study, I used the level of democracy (Alesina and Dollar, 2000; Neumayer, 2003; Dollar and Levin, 2006; Clist, 2011) measured by political rights index and civil liberty index from Freedom House. I expect good governance to have a positive impact on NHRE aid, consistent with the findings from the literature.

Specific to renewable energy, the *willingness in sustainability* is important in implementing renewable energy projects. A recipient more willing to implement renewable projects will seek funding sources from domestic sources to foreign assistance. Thus, higher willingness would draw more aid in the renewable energy sector. A dummy variable for renewable energy policy is constructed from the IEA's renewable energy policy for the willingness in sustainability of recipient countries.

Recipient needs

Poverty reduction is the foremost goal of foreign aid. The literature measured the poverty level of recipients using national income. Although this study particularly focuses on the energy sector, poor countries often suffer from energy poverty as well. Hence, poverty would increase the amount of aid on renewable energy received (especially in terms of selection). In this study, GNI per capita measures the level of poverty in a recipient country, which is expected to have a negative impact on aid with its inverse relation to poverty.

Energy need is a sector-specific factor of recipient needs in this study. This variable is also directly related to the main goal of foreign aid, poverty reduction. Intuitively, people in extreme poverty are the ones without proper access to energy, disabling their everyday activities such as cooking, washing and transporting. Thus, energy needs ultimately meet the aim of general aid. I use the actual value of each per capita residential electricity use and per capita energy consumption to measure the energy need of a recipient country.[47] According to IEA (2010), per capita residential electricity use denotes the reliability of electricity supply and the residents' ability to pay for electricity. Per capita energy consumption denotes the level of economic development of a country. OECD (2010) states that high-income developing countries consume more energy from more diverse energy sources than low-income developing countries. Thus, lower energy use indicates higher energy needs of the country. Given the inverse relationship, I expect the energy use has negative impact on foreign aid on renewable energy.

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[47] To measure the energy need, IEA developed the Energy Development Index (EDI). The index is calculated by using four indicators: *Per capita commercial energy consumption, per capita electricity consumption in the residential sector, share of modern fuels in total residential sector energy use and share of population with access to electricity*.[47] However, I did not use EDI because the index only covers time series from 2004.

The gravity model in international trade describes bilateral trade flow proportional to the product of trade, which is Gross Domestic Products. In this study, I also use Gross Domestic Products as the product of aid, measuring economic advancement of a country. Bilateral aid aims to promote economic development of a recipient country, while the commercial interest signified with the globalization would also result in economic development of a donor country.

The gravity model of international trade describes the bilateral trade inversely proportional to the distance between the two countries. Following this, the gravity model of bilateral aid also describes bilateral aid inversely proportional to the distance between the donor and the recipient. Especially in the renewable energy, procurement of physical equipment is necessary. Thus, physical distance indicates the level of transportation costs. Also, geopolitical relations make donors more likely to give aid to nearby recipients to enhance their regional political influence. The distance between two countries is acquired from the CEPII website.[48] The effect of distance is expected to be negative because longer distance would hinder aid transactions because of high transportation costs and low geopolitical interests.

Given the data collected, I constructed an unbalanced donor-recipient pair-year panel from 1995 to 2009.[49] The panel is once limited to the availability of commitments, then to the availability of migration data.[50] Table III-2 presents variables to measure each determinant of NHRE aid flow and their descriptive statistics. Population of recipients is added to control for the size of recipient countries.

[Insert Table III-2 here]

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[48] Nelson and Silva (2008) used the same dataset. http://www.cepii.fr/anglaisgraph/bdd/distances.htm
[49] See appendix for lists of donors and recipients included in the analysis
[50] For some donor-recipient pairs of immigration, missing values are not zero immigration but just not recorded. Thus, I limit the panel having donor-recipient pairs with consecutive observations on immigration.

5. Empirical Model

After the Cold War, donors began diverting their selection criteria from political interest. Donors changed their aid giving behavior to a philanthropic focus. To begin investigating renewable energy aid distribution patterns, I examine bilateral aid on renewable energy at the donor-recipient pair level.

I adopt the gravity model of international trade to investigate the determinants of aid flow. Trade literature typically specifies the gravity model as a log-linear regression and adds more independent variables affecting trade flow (Liu, 2007). Regarding foreign aid, the simplest gravity model describes the aid flow (*A*) proportional to economic advancement (Y) of both a donor (*i*) and a recipient (*j*) and inversely proportional to the distance (*D*) between the two.

$$A_{ij} = \gamma \frac{Y_i Y_j}{D_{ij}} \quad (1)$$

Taking the log-linear form and adding other independent variables, the final specification to estimate is:

$$\ln\left[A_{ijt}\right] = \alpha + \beta_1 \ln\left[Y_{it}\right] + \beta_2 \ln\left[Y_{jt}\right] + \beta_3 \ln\left[D_{ij}\right] + \beta_4 X_{ijt} + \beta_5 Z_{it} + \varepsilon_{ijt} \quad (2)$$

where X is a vector of the donor interests including political and commercial interests, Z is a vector of the recipient-related variables, recipient's good governance and the recipient needs, and ε is an error term.

Given a number of zero observations in the data, literature used diverse estimating techniques to estimate consistent effects of independent variables: OLS, Tobit and Poisson models in trade literature using the gravity equation (Liu, 2007) and OLS, Tobit, Heckman's two stage model, and two-part model in aid allocation literature controlling for selection process (Berthelemy, 2006). Given the selection process built in the aid allocation, OLS estimator will produce biased coefficients. The second option is a Tobit estimator that does not model the selection and allocation process of donors in theory. The estimator treats independent variables having the same effect on both selection and allocation processes. With the same reason, the Poisson model does not provide theoretical ground in estimating two stages of aid distribution.[51]

The third option in aid literature is the Heckman model with a two-step process for selection and allocation, modeling the real-world more closely. The estimator treats the censored data as having an omitted variable problem, requiring an additional variable that is correlated to the selection process but not to the allocation process. Finding such an excluded variable is difficult in practice (Neumayer, 2003; Clist, 2010). Thus, I turn to the fourth option, two-part model.

The two-part model separates the selection process and the allocation process. The selection process is estimated by logit or probit, modeling being selected or not. Then, the allocation process is estimated by linear regression conditional on the selected group, receiving positive aid amount in this case. The assumption of the two-part model is the errors in the selection process and the allocation process are independent of each other. If the assumption is true, the model does not need an excluded variable for selection process. Even if the assumption fails, Manning et al. (1987) found that introduced bias is small in most common situations.[52] Based on the merit, I mainly use two-part model in estimating the model (2).

[51] Additionally, the Poisson model is not appropriate estimating aid flow (the monetary observations as a unit of analysis) because the model works with dependent variable being count data (i.e. integer), which is not the case here.

[52] See Neumayer (2003) and Clist (2011) for more detailed description of the two-part model.

6. Results

I report the estimated coefficients from the selection and allocation stages separately. Table III-3 summarizes the results of the selection stage using logit and probit estimators. The first column reports the results of fixed effect logit estimator conditional on pairs. The second and the third columns report the results of random probit estimator with donor specific effect and both donor and recipient specific effects, respectively. Having pair-fixed effect, the conditional logit estimator in column (1) omits pair-specific variables, the distance between capitals and being a former colony index. Compared to probit estimators in columns (2) and (3), the conditional logit estimator has higher coefficients. However, the relative values among the variables within an estimator are similar both in the logit and probit estimators.

[Insert Table III-3 here]

Because the unit of analysis is a donor-recipient pair, the statistical significance indicates two types of selection processes. First, an independent variable of donor characteristics drives the decision of donors to be a donor when statistically significant. The second type of selection process is an independent variable of recipient characteristics drives the decision of donors in selecting recipients. In all three columns, the gravity effect and donors commercial interest drive selecting into a donor-recipient pair: donors decision to give aid on NHRE projects and donors decision on choosing recipients.

The donors' commercial interest is a major driver for being a NHRE aid donor. In all three models, the number of recipients is statistically significant. Controlling for donors' wealth, having more recipients represents donor's commercial interest of expanding their markets as well as their political influence. NHRE is a newer and growing technology in the energy sector.

Being the first comer would benefit donors in the future market of NHRE. In contrast, being a major trade partner does not guarantee receiving NHRE aid from a donor.

Regarding the gravity effect, donors choose to give aid to nearby recipients (distance of a pair). This donor behavior becomes more intense when controlling for recipient specific effect in column (3). This physical proximity offers donors reduced transaction costs that come with aid giving.[53] Transportation of physical capital or human resources costs less if they choose recipients close by. Because donors bare most of the costs related to aid giving, they minimize the costs in choosing recipients.

The wealth of a donor does not affect a donor's decision to be a donor (donor GDP). However, the wealth of a recipient might affect a donor's decision to provide aid. In column (2) without recipient fixed effect, the wealth of a recipient is statistically significant and influences the decision of a donor in choosing wealthier recipients. Connecting to the donor's commercial interests, wealthier recipients have higher buying potential, thus have higher market potential than the poor. Meanwhile, it also indicates that donors seek recipients with better capacity to receive aid in terms of economic activities. Similarly, the size of recipients' population matters when choosing recipients. In columns (1) and (3), recipient specific effects wipe out the statistical significance of population in selecting recipients. Column (2) indicates populous recipients have higher odds of being selected to receiving NHRE aid. However, the magnitude of the effect is very small, implying that donors' first attempt to meet their commercial interests.

In contrast to the above factors, donor political interests and recipients' good governance do not influence the decision of being a donor and of choosing recipients in the NHRE sector.

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[53] Gravity model literature regards distance between two countries as a loose proxy for transaction costs. See Gomez-Herrera (2013).

The diluted effect of donors' political interests is expected given the sample period being the post- Cold War era. We can observe donors are more interested in their commercial benefits post-1995. Even the strategic interest directly related to renewable energy turns out to have statistically equal to zero effects.

Surprisingly, good governance in recipients has statistically zero effect. This result is against what Dollar and Levin (2006) note as donors increasingly condition on good governance when they choose recipients. The rationale behind it is good governance in a recipient country would raise the effectiveness of aid. However, limiting recipient countries in terms of good governance might fail to help those in serious need. As Clist (2011) states, donors are not sensitive to recipients' governance. The results in Table 3 indicate good governance does not determine donor decision in giving aid to a recipient in the renewable energy sector.

Recipient need also has statistically zero effect in receiving NHRE aid when controlling recipient specific effects. However, proxies of recipient need do not vary over time significantly. Including time-invariant recipient specific effects takes statistical significance away. GNI and residential electricity use are statistically significant at only the 5 percent level in column (2). Although weak, the signs are as expected. Poorer (lower GNI) recipients and recipients in higher energy poverty are more likely to receive NHRE aid. In addition, population also shows statistical significance only in column (2) not controlling recipient specific effects. When selecting recipients, donors focus more on their commercial interests and reducing transaction costs than on the need of recipient or the effectiveness of aid from good governance.

Having selected recipients, donors now decide how much to allocate their financial resources among the recipients. The estimated effects are in Table III-4 from random effect models in column (1) with donor fixed effects and (2) with donor and recipient fixed effects, pair fixed effect model in column (3), and Tobit model in column (4). At first, donors emphasize more on selecting recipients than allocating the amount of aid among the recipients. Donors consider more categories in selecting recipients than in allocating aid. However, having recipient fixed effect reduces the statistical significance or drops the time-invariant recipient characteristics in columns (2) and (3) respectively. Counting different model specification, donors allocate NHRE aid among recipients based on the physical proximity and the recipient need.

[Insert Table III-4 here]

As found in the selection stage, physical proximity drives the amount of aid given to a recipient. In random effect models in column (1) and (2), the coefficients of logged distance is around -.35. This indicates if a donor-recipient pair is 10 percent closer than the other, the recipient will receive 3.5 percent higher aid on NHRE. For example, Washington DC is 6147 km from Rabat, Morocco and 6792 km from Algiers, Algeria. Rabat is about 10 percent closer to DC in distance than Algiers. Thus, Morocco would receive 3.5 percent higher aid on NHRE than Algeria, all others being equal.

Contrary to the selection process, donors do care about recipient needs when allocating the amount of aid among the recipients. More importantly, donors seem to care about the sectoral needs of renewable energy use in recipients when allocating aid. The use of renewable energy hardly changes in recipient countries, thus dropping statistical significance.

As a robustness check, I included the estimated results of Tobit model in column (4). The results follow both the selection and allocation stages. Wealth of a recipient, physical proximity, the number of recipients and population are all statistically significant as in the selection stage. Whereas, Tobit estimator does not have statistical significance of renewable energy use in recipients as found in the allocation stage of the two-part model. Tobit model seems to better estimate the selection process than the allocation process because it includes all available donor-recipient pair regardless of being selected. In contrast, two-part model only includes donor-recipient pair selected by donors. Thus, two-part model can better estimate the allocation process with less noise from the data.

7. Conclusion

This paper examines what drives aid distribution. From the results, it is obvious that donors have separate priorities in selecting recipients and allocating the amount of aid among the recipients. First, donors select recipients based on their self-interests, specifically by their commercial interests. Even the political interests of energy security closely relates to supporting donor's economic activities. In addition, richer donors are more willing to be a donor in the NHRE sector. Fortunately, donors are not always selfish. Once recipients are selected, they do care who needs aid. Although donors would still seek the opportunity to reduce transaction costs through physical proximity, they allocate resources based on the sectoral need.

From the policy perspective, it seems natural that bilateral donors make their decision based on their interests. A finding in this study is donors' interests have changed from political to commercial, confirming findings in literature. Future researches picking up this topic should look into multilateral donors. Finding out whether they really base their decision on the recipient needs will shed light on the delivery of aid for better serving the poor. However, multilateral donors may focus more on the overall domestic situation in recipient countries than sectoral needs. An interview with a former consultant of aid project reveals donors condition their aid commitment on reframing recipients' policy structure, which would delay serving the individual poor. In this regard, future research can also investigate the interactions among policies when giving aid.

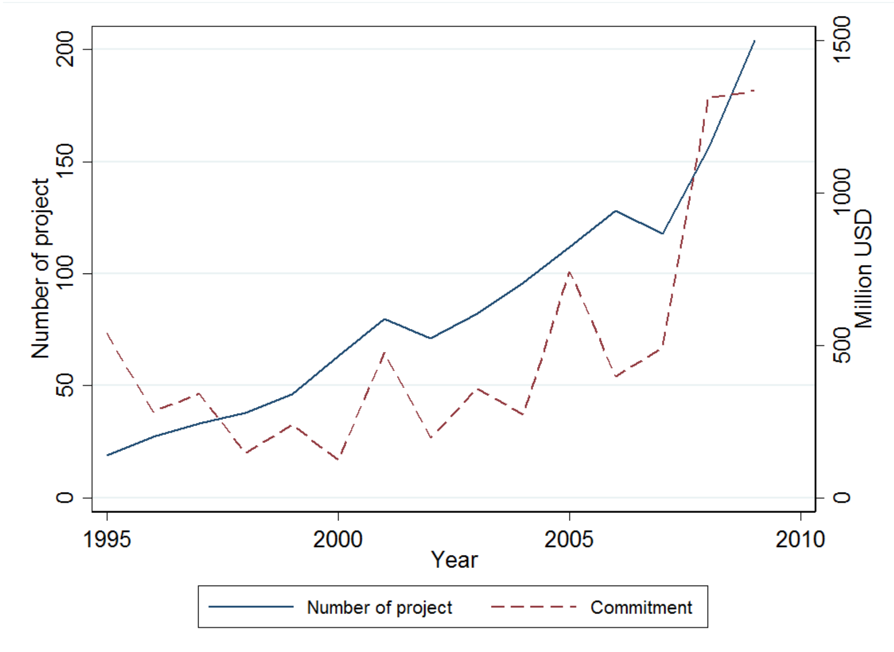

Figure III-1. Non-hydro Renewable energy aid from bilateral donors
Figure shows the number of projects starting in a year (solid line) and the amount committed in the pipeline in a year (the dashed line) during 1995-2009. The number of projects is on the left axis, and the amount of USD committed to NHRE aid is on the right axis.

Table III-1. Top 20 recipients of Japanese and German aid (1995-2009)

	Japan		Germany	
	NHRE	Total Energy	NHRE	Total Energy
1	China	India	India	India
2	Indonesia	Indonesia	Egypt	Egypt
3	Egypt	Vietnam	Brazil	Pakistan
4	Philippines	China	Morocco	Serbia
5	Brazil	Philippines	Pakistan	China
6	Vietnam	Malaysia	China	Nepal
7	Morocco	Iraq	Chile	Morocco
8	Tunisia	Sri Lanka	Turkey	Bangladesh
9	Sri Lanka	Bangladesh	Croatia	Indonesia
10	Uruguay	Azerbaijan	Bangladesh	Georgia
11	Maldives	Thailand	Namibia	Brazil
12	Yemen, Rep.	Pakistan	Serbia	Armenia
13	Djibouti	Peru	South Africa	Chile
14	Palestinian Adm. Areas	Egypt	Uganda	Sri Lanka
15	Mongolia	Syria	Nepal	Albania
16	Micronesia, Fed. States	Kenya	Afghanistan	South Africa
17	Marshall Islands	Uzbekistan	Bosnia and Herzegovina	Afghanistan
18	Belize	Nepal	Mongolia	Croatia
19	Palau	Paraguay	Indonesia	Philippines
20	Nigeria	Armenia	Senegal	Kenya

Table III-2. Descriptive statistics

	Variable	Obs	Mean	Std. Dev	Min	Max
Dependent variable						
	NHRE aid commitments (Million USD)	2090	0.81	9.24	0	287.132
Independent variables						
Political interests	Former colony (dummy)	2090	0.12	0.33	0	1
	Immigrants from recipient to donor (Million)	2090	0.16	0.84	0	11.74
	Import of natural gas from recipient (Million tonnes)	2090	0.008	0.12	0	2.68
	Import of crude oil from recipient (Million tonnes)	2090	0.82	6.08	0	81.78
	Number of patents for NHRE technologies	2090	66.83	166.36	0	1190.58
	Share of electricity generation from NHRE sources (%)	2090	5.06	4.94	0.20	27.61
	Commitment to Kyoto Protocol (dummy)	2090	0.75	0.43	0	1
Commercial	Share of exports with a recipient in a donor's total exports	2090	0.002	0.007	0	0.11
	Number of recipients receiving a donor's aid	2090	6.38	7.38	0	44
Good Governance	Political rights (index)	2090	3.96	1.89	1	7
	Civil liberty (index)	2090	3.95	1.36	1	7
	Renewable energy policy (dummy)	2090	0.40	0.49	0	1
Recipient need	Recipient GNI (Million USD per capita)	2090	0.002	0.002	0.00011	0.013
	Renewable energy consumption in the commercial and public sectors (ktoe per million capita)	2090	356.96	1253.87	0	6334.19
	Electricity consumption in residential sector (ktoe per million capita)	2090	2761.86	5978.66	0	41900.6
Gravity factor	Recipient GDP (Million USD per capita)	2090	0.002	0.002	0.0001	0.014
	Donor GDP (Million USD per capita)	2090	0.027	0.008	0.013	0.042
	Distance between capitals (km)	2090	7711.31	3228.47	277.88	17836.2
Control variable	Population of recipient (Million)	2090	179.48	362.56	1.65	1331.38

Table III-3. Estimated effects in the selection stage (DV: log of NHRE aid commitment)

	Fixed logit (1)	Random probit (2)	Random probit (3)
Gravity factor			
Log of recipient GDP	1.768	0.157**	0.17
	(2.022)	(0.054)	(0.217)
Log of donor GDP	7.088	0.773	0.833
	(4.428)	(0.4561)	(0.459)
Log of distance between capitals		-0.043**	-0.100***
		(0.015)	(0.028)
Political interests			
Colony		0.003	-0.013
		(0.029)	(0.034)
Immigrants	-0.579	0.012	-0.003
	(0.486)	(0.026)	(0.028)
Natural Gas import	0.858	0.041	0.130
	(1.483)	(0.056)	(0.075)
Crude oil import	-0.098	-0.001	-0.00006
	(0.062)	(0.004)	(0.004)
NHRE patents	0.001	0.00009	0.0001
	(0.0006)	(0.0001)	(0.0001)
Share of NHRE	-0.048	-0.007	-0.008
	(0.040)	(0.004)	(0.004)
Kyoto Protocol	-1.872	-0.153	-0.146
	(1.245)	(0.117)	(0.119)
Commercial interests			
Number of recipient	0.244***	0.029***	0.030***
	(0.021)	(0.002)	(0.002)
Share in donor trade partners	19.514	-2.141	-2.509
	(29.257)	(1.736)	(1.929)
Good governance			
Political rights	-0.054	0.004	-0.005
	(0.121)	(0.010)	(0.015)
Civil liberty	-0.148	-0.007	-0.008
	(0.209)	(0.015)	(0.023)
Renewable energy policy	0.079	0.030	-0.003
	(0.255)	(0.019)	(0.028)
Recipient need			
GNI	-0.497	-0.034*	-0.072
	(0.497)	(0.016)	(0.060)
Renewable Energy use	0.032	-0.001	0.004
	(0.037)	(0.002)	(0.004)
Electricity use in residential sector	0.015	-0.0015*	0.002
	(0.016)	(0.0006)	(0.002)
Population	-0.002	0.0001***	0.00003
	(0.005)	(0.00002)	(0.0005)
Year dummy	∨	∨	∨
Donor dummy		∨	∨
Recipient dummy			∨
Pair fixed effect	∨ (156)		
Number of observations	1,898	2,144	2,090

*** p<0.001 ** p<0.01 * p<0.05; Robust standard errors in parentheses; marginal effect is reported for probit models

Table III-4. Estimated effects in the allocation stage (DV: log of NHRE aid commitment)

	Random effect (1)	Random effect (2)	Fixed effect (3)	Tobit (4)
Gravity factor				
Log of recipient GDP	0.163	-2.260	-1.961	0.712*
	(0.295)	(1.782)	(1.926)	(0.330)
Log of donor GDP	0.565	1.214	0.296	4.944
	(3.675)	(3.899)	(4.587)	(2.589)
Log of distance between capitals	-0.350***	-0.343**		-0.302***
	(0.105)	(0.130)		(0.091)
Political interests				
Colony	-0.146	-0.019		-0.098
	(0.168)	(0.179)		(0.185)
Immigrants	0.122	0.094	1.854	0.068
	(0.134)	(0.248)	(1.741)	(0.158)
Natural Gas import	-0.252*	0.167	0.081	0.096
	(0.107)	(0.139)	(0.237)	(0.326)
Crude oil import	-0.009	-0.012	-0.125	-0.011
	(0.021)	(0.042)	(0.083)	(0.021)
NHRE patents	-0.0003	-0.0002	-0.0002	0.0004
	(0.0003)	(0.0004)	(0.0005)	(0.0004)
Share of NHRE	0.025	0.014	0.008	-0.027
	(0.041)	(0.048)	(0.046)	(0.022)
Kyoto Protocol	-0.168	-0.585	-0.243	-0.694
	(0.551)	(0.692)	(0.715)	(0.537)
Commercial interests				
Number of recipient	0.003	0.011	0.026	0.135***
	(0.015)	(0.017)	(0.019)	(0.012)
Share in donor trade partners	-11.765	-15.484	97.127	-3.095
	(18.429)	(19.319)	(95.503)	(12.606)
Good governance				
Political rights	0.060	0.071	0.094	0.040
	(0.062)	(0.087)	(0.110)	(0.055)
Civil liberty	-0.030	-0.143	-0.196	-0.053
	(0.083)	(0.133)	(0.155)	(0.081)
Renewable energy policy	0.140	0.165	0.191	0.141
	(0.129)	(0.231)	(0.247)	(0.104)
Recipient need				
GNI	-0.052	0.162	0.432	-0.163
	(0.075)	(0.558)	(0.523)	(0.098)
Renewable Energy use	-0.017**	0.001	0.003	-0.010
	(0.005)	(0.023)	(0.017)	(0.010)
Electricity use in residential	-0.005	-0.0002	0.004	-0.008*
	(0.003)	(0.007)	(0.021)	(0.003)
Population	0.00024	-0.004	-0.009	0.0006***
	(0.000157)	(0.003)	(0.006)	(0.000162)
Constant	1.624	-0.627	1.851	-17.426
	(12.886)	(13.091)	(13.628)	(8.964)
Donor dummy	V	V		V

Recipient dummy	∨	∨		
Pair fixed effect			∨	
Number of observations	395	395	395	2,161
Log likelihood			-378.047	-1081.901
Number of donor-recipient pair	159	159	159	249

*** p<0.001 ** p<0.01 * p<0.05; Robust standard errors in parentheses; year dummies not reported

Appendix III-1. List of donors and recipients in the sample pairs

Table III-A. Bilateral aid donors in the sample

Australia
Austria
Belgium
Canada
Denmark
Finland
France
Germany
Italy
Netherlands
New Zealand
Norway
Spain
Sweden
United Kingdom
United States

Table III-B. Bilateral aid recipients in the sample

Albania	Dominican Republic	Nicaragua
Algeria	Ecuador	Pakistan
Argentina	Egypt	Peru
Armenia	Eritrea	Philippines
Azerbaijan	Ethiopia	Senegal
Bangladesh	Guatemala	Slovenia
Belarus	Honduras	South Africa
Benin	India	Sri Lanka
Bolivia	Indonesia	Tanzania
Bosnia and Herzegovina	Iran	Thailand
Botswana	Jordan	Togo
Brazil	Kazakhstan	Tunisia
Cameroon	Kenya	Turkey
Chile	Malaysia	Ukraine
China	Mexico	Venezuela
Colombia	Morocco	Vietnam
Costa Rica	Mozambique	Yemen
Croatia	Namibia	Zimbabwe
Cuba	Nepal	

Conclusion

The three essays in this dissertation ponder how to expand the usage of renewable energy technologies to all corners of the world. The results from the first essay suggest that energy supply security influences innovation of renewable energy technologies. Specifically, the domestic oil endowment influences shaping the innovation pattern of a country. Oil is a commodity traded in a global market; it is not expected to have an impact on domestic activities. The findings contradict an expectation from the traditional economic theories and imply there are political economic factors to technology innovation in the renewable energy sector. Further studies on this notion will contribute to methods for shaping a sustainable path in the energy and climate change sector.

The second essay demonstrates foreign aid is an effective diffusion channel of renewable energy technologies to developing countries. The results suggest that intangible knowledge substantially increases technological capacity of recipient countries. However, intangible knowledge transferred through foreign aid is often attached to the physical capital transfer. In other words, foreign aid is often a mix of cooperative aid and non-cooperative aid. Future research is needed to explore the optimal mix of cooperative and non-cooperative aid in raising aid effectiveness. In addition to the optimal mix, another question for future research is the design of cooperative aid. Technical cooperation is different depending on the recipients' existing technological capacity. Although China has the capacity to manufacture physical capitals, small and low income developing countries are better off learning how to conduct a feasibility study for potential renewable energy projects. Thus, customizing the cooperation design to individual countries will raise the aid effectiveness when combined with the optimal fraction of cooperative aid.

The third essay presents how developed countries select aid recipients based on their commercial interests but allocate the amount of aid based on the recipient need among the selected recipients in the renewable energy sector. Findings on selecting aid recipients illustrate how to sell diffusion of renewable energy technologies to developed countries; it brings them commercial benefits. On the other hand, findings on allocating aid raise a topic for future researches: multilateral aid. As more aid regarding climate change is flowing through multilateral agencies, comparing determinants of bilateral and multilateral aid elucidates a better delivery of aid in serving the poor. Combining with the results from the second essay, these findings shed light on the design of future assistance to diffuse renewable energy technologies in terms of cooperative level (the second essay) and marketing strategy to bilateral donors (the third essay).

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