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Explaining the diffusion of renewable energy technology in developing countries

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ABSTRACT

In this paper we study the diffusion of non-hydro renewable energy (NHRE) technologies for electricity generation across 108 developing countries between 1980 and 2010. We use two-stage estimation methods to identify the determinants behind the choice of whether or not to adopt NHRE as well as about the amount of electricity to produce from renewable energy sources. We find that NHRE diffusion accelerates with the implementation of economic and regulatory instruments, higher per capita income and schooling levels, and stable, democratic regimes. In contrast, increasing openness and aid, institutional and strategic policy support programs, growth of electricity consumption, and high fossil fuel production appear to delay NHRE diffusion. Furthermore, we find that a diverse energy mix increases the probability of NHRE adoption. Finally, we find a weak support for a positive influence of the Kyoto Protocol on NHRE diffusion and no evidence for any influence resulting from financial sector development.

1. Introduction

The growth of global carbon emissions is nowadays largely driven by the increasing volume coming from within developing countries (IEA, 2010). Consequently, in 2008 the aggregate energy-related CO_2 emissions of developing countries surpassed those of industrialized and transition countries for the first time in history (IEA, 2010). The positive growth prospects for emerging economies make this trend likely to continue for the foreseeable future, especially given that – particularly in the initial stages of development – the demand for energy increases as the economy grows (Chow et al., 2003; Jakob et al., 2012). Curbing the future increase of carbon emissions from developing countries is, therefore, indispensable to the achievement of ambitious climate targets (IPCC, 2011).

Currently, the electricity sector constitutes a major source of energy-related CO_2 emissions, accounting for 41% of global CO_2 emissions (IEA, 2010). This reality clearly makes the reduction of emissions from electricity generation an essential ingredient in any climate change mitigation strategies (GEA, 2012; IPCC, 2011). Alongside increasing energy efficiency, the rapid diffusion of renewable energy technologies (RET) is considered to be the second – though equally most effective – option for reducing carbon emissions while simultaneously meeting humanity's ongoing need for energy provision (GEA, 2012). The widespread adoption of RET – including hydroelectric power, geothermal, solar, biomass and wind – would not only help to avoid the negative environmental and social effects associated with conventional (i.e., fossil fuel) energies, but also has the potential to create substantial additional socioeconomic benefits — such as, for example, reducing local air pollution and safety risks, increasing energy access and improving energy security (GEA, 2012; IPCC, 2011; Martinot et al., 2002; Owen, 2006).

The research and development in RET is primarily done in industrialized countries (Dechezleprêtre et al., 2011; Popp et al., 2011). The key challenge for developing countries is, therefore, to secure the international transfer of these climate-friendly technologies. The adoption of RET in developing countries not only slows down global carbon emissions in the short term but also offers them the opportunity to "leapfrog" over developed countries, as a result of environmentally benign power production technologies being harnessed before a lock-in into conventional energy resources occurs (Popp, 2011; Watson and Sauter, 2011). Nevertheless, it is common knowledge that many governments and firms still continue to invest in old technologies even though the new ones are more cost-effective, which underlines that the diffusion of energy technologies is at least as equally costly and

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difficult as is their invention (Del Río González, 2009; Jaffe and Stavins, 1994; Jaffe et al., 2002; Popp et al., 2011). Against this backdrop, we thus study the adoption and diffusion of RET for electricity generation in developing countries.

The main contribution of this paper to the literature is twofold.

First, although investments in energy-saving or environmentally friendly technologies have received considerable attention in the field of environmental and energy economics,[2] to date few studies have focused specifically on the diffusion of RET, and these studies consider almost exclusively developed countries. For example, Johnstone et al. (2010) use patent counts in a cross-section of 25 OECD countries to show that public policies encourage innovation in RET. Also using patent-based data, Popp et al. (2011) find that increased knowledge has a robust, albeit small, effect on renewable energy investments across 26 OECD countries. In contrast, we model and evaluate the adoption of RET across 108 developing countries between 1980 and 2010, assessing a wide range of potential drivers of, and barriers to, RET diffusion. As such, our study is related to a recent work by Brunnschweiler (2010), who presents evidence of financial sector development having a positive effect on renewable energy development, with special attention given to non-OECD countries. Our study is different however, in that: we explicitly model the decision about whether or not to adopt RET; we focus on non-hydropower; and we consider the potential role of additional possible drivers of RET adoption — including specific energy policies, the energy mix, trade and the official development assistance (ODA) provided.

Second, we first propose and then use an econometric approach to deal with two methodological problems in this area of study that have been somewhat overlooked so far. The main problem is the large number of zero-valued observations included in our dependent variable, because many countries do not yet, or have only recently begun to, invest in (non-hydro) renewable electricity production. Moreover, we might have a potential sample selection problem — the zero-valued observations may reflect either no investment in RET or the fact that off-grid electricity production is not included in the available data, and thus may differ systematically from the positive values of the potential outcome.[3] We deal with these two methodological issues by using two-stage estimation methods, in which we explicitly model the choice of whether or not to adopt RET as well as the decision about the amount of electricity to produce from renewable energy sources. To this end, we employ both the two-part model (2PM) of Duan et al. (1984) and Heckman's (1979) two-step selection model (TSM).

We find that the diffusion of non-hydro renewable energy (NHRE) technologies for electricity generation accelerates with the implementation of economic and regulatory instruments, higher per capita income and schooling levels and with stable, democratic regimes. In contrast, increasing trade intensity, higher levels of foreign direct investment (FDI) and ODA, institutional and strategic policy support programs, growth in electricity consumption and a high level of fossil fuel production appear to delay the diffusion of NHRE. Furthermore, we find that a large share of hydropower lowers the probability of NHRE being adopted but nevertheless stimulates the amount of NHRE electricity produced, while the opposite is true when there is a diverse energy mix. Finally, we find a weak support for a positive influence of the Kyoto Protocol on NHRE diffusion and no evidence at all for any influence resulting from financial sector development.

The remainder of this paper is organized as follows: In Section 2 we present some stylized facts regarding the role of RET in global electricity production, and we discuss our data in relation to the existing literature dealing with the factors that determine technological adoption. In Section 3 we introduce and specify our empirical methodology. Section 4 presents the baseline results of our analysis. In Section 5 we provide additional results, with special attention given to the general drivers of technology adoption and to the role of the energy mix. Section 6 summarizes and concludes by offering some suggestions for possible future research in this field.

2. Data, background and stylized facts

As a measure of RET adoption – our dependent variable – we use electricity generation measured in the amount of kilowatt-hours (kWh) per capita obtained from the following renewable resources: biomass, geothermal, solar, and wind. We exclude hydroelectric power generation from our definition, because large hydropower projects are increasingly viewed as being unsustainable sources of power generation due to their often serious negative environmental and social externalities.[4] Also, we exclude (traditional) biomass because of its negative impact on agricultural (food) production, as demonstrated by the rising price of grain as well as of other foodstuffs. We use data on electricity generation from non-hydroelectric sources provided by the United States Energy Information Administration (EIA) for the period 1980–2010. While the EIA data can be considered to be comprehensive, electricity generation may be underestimated, as off-grid activities do not seem to be included in the data. We use data for 108 developing countries (see Appendix A, Table A1).

According to the 2012 report *Global Energy Assessment — Toward a Sustainable Future*, the contribution of RET (including hydropower) to the world's electricity generation in 2010 was roughly 3800 terawatt-hours (TWh), equivalent to about 19% of total global electricity consumption. Renewable power capacity additions now represent more than one-third of all global power capacity additions (GEA, 2012). Based on our data, Table 1 presents key statistics regarding the growth of NHRE between 1980 and 2010. It is evident that the share of NHRE in total electricity production in developing countries is small but rapidly increasing: since 1980 it has more than doubled, and now comprises over 2%. Moreover, Table 1 shows that while Brazil, Russia, India, China and South Africa (BRICS) initially lagged behind they are now leading the group of developing countries. Figs. 1 and 2 below illustrate that NHRE, especially during the last decade, has experienced high annual growth rates, particularly in the BRICS countries. Finally, both the relatively high shares and growth rates of NHRE in developed countries demonstrate that the RET adoption process is, as previously noted (still) being led by rich countries.

To identify the factors and barriers that may affect RET adoption, we make use of insights from both the broader economic literature as well as from the environmental and energy economics literature.[5] One of the main stylized facts regarding technological change is that new technologies often initially complement older technologies, and only subsequently – and often slowly – replace older technologies (see, for example, Dosi, 1997; Gruebler et al., 1999; Mokyr, 1990; Rosenberg, 1982; Ruttan, 2001; Stoneman, 2002; Young, 1993). The gradual nature of this technology diffusion can be explained from the fact that technologies differ not only in terms of their productivity (vertical dimension), but also with respect to other qualities (horizontal dimension). Consequently, agents face returns to diversity in that they explicitly attach value to using both new and old technologies at the same time.

As regards the vertical dimension, broad historical evidence shows that new technologies tend to be initially inferior to more mature technologies due to the fact that they temporarily reduce expertise and, thereby, capital productivity. This leads to the gradual adoption of new technologies, and results in the coexistence of old and new

[2] See Popp et al. (2010) for an excellent overview of this literature.

[3] Off-grid electricity production from renewable sources is potentially important, given the installation of isolated photovoltaic (PV) of mini-hydro systems in remote rural areas.

[4] Unfortunately, our cross-country dataset does not allow one to consistently distinguish between large and small hydropower projects.

[5] For a review of the broader economic literature see, for example, Keller (2004) or Comin and Hobijn (2004). For a review of the technology adoption research in environmental and energy economics to date, see Popp et al. (2010).