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Adoption of solar and wind energy: The roles of carbon pricing and aggregate policy support

Rohan Best*, Paul J. Burke

Arndt-Corden Department of Economics, Australian National University, Acton ACT 2601 Australia

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ABSTRACT

This paper analyzes the roles of policies and preferences in national adoption of solar and wind energy technologies. We use cross-sectional and panel regressions for both the European Union and a broader international sample. We find that countries that price carbon emissions have gone on to adopt more solar and wind energy. The aggregate level of policy support, measured in euros per megawatt hour, appears to have been important for solar energy adoption. We also find that solar energy adoption has been larger in countries with higher proportions of people concerned about climate change. In addition, we assess the effects of other key explanators including financial system size and income levels.

1. Introduction

Rapid cost reductions mean that solar and wind are likely to play an increasingly important role in the world's energy system. For example, modelling suggests that it would be feasible for solar photovoltaics and wind to contribute around 90% of annual electricity demand in the Australian National Electricity Market (Blakers et al., 2017), with hydroelectricity and biomass providing the remainder.

A key advantage of solar and wind energy is that they avoid carbon dioxide emissions. This provides an opportunity for energy system transformation to make a major contribution to a climate change mitigation goal of keeping anthropogenic global warming below two degrees Celsius (DDPP, 2015; OECD/IEA and IRENA, 2017). An increase in renewable energy share can also help to reduce local pollution, diversify energy mixes, and ameliorate energy security risks arising from reliance on fossil fuels sourced from geopolitically unstable countries.

Increasing reliance on solar and wind energy comes with challenges, although these are surmountable. One is that solar and wind face intermittency issues without adequate storage solutions or the use of other dispatchable energy sources. Frequency disturbances, when there is insufficient inertia in electricity systems, can also be important to manage. Solar and wind energy sources have been more costly than established energy sources until recently (IEA, 2015, 2016). This has motivated policy intervention, which has then provided a favorable environment for cost reductions through learning-by-doing.

There is considerable variation in renewable energy adoption across countries. For instance, Denmark has high levels of wind energy use, but combined solar and wind energy use per capita was between 10 and 40 times lower in five other European Union (EU) countries in 2015. Germany had solar energy use per capita that was between 20 and 120 times greater than five other EU countries in 2015, including some with more abundant sunshine.

This paper examines the factors that have been important for the early adoption of solar and wind energy. We consider many variables that could potentially be relevant, including policies, preferences, and financial systems. We use cross-sectional and panel regression approaches for renewable energy adoption up to 2015 for two groups of countries: a group of EU countries, and a larger international sample. The advantages of solar and wind energy provide strong motivation for our study. The paper furthers understanding of the factors that promote solar and wind energy and whether frequently-recommended policies have been associated with successful outcomes.

The paper makes a number of contributions relative to the existing literature. We separately consider solar photovoltaic (PV), solar thermal, and wind energy, identifying the factors that have been important for the adoption of each energy type. We also consider a number of underlying or indirect factors that have not been prominent in the previous empirical literature. We assess the impact of carbon pricing, an efficient policy approach that has not received as much attention in the empirical literature as other policies such as feed-in tariffs or renewable energy certificates. Another feature of our approach is our use of a cardinal, holistic policy support variable from an Ecofys (2014) report on subsidies and costs of energy for the European Commission. We refer to this variable as aggregate policy support.

The paper proceeds as follows. Section 2 reviews the previous literature. Section 3 explains our method and data. The results are

* Corresponding author.
E-mail address: rohan.best@mq.edu.au (R. Best).

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presented in Section 4. Section 5 provides brief case studies. The final section concludes.

2. Literature review

2.1. Current methodologies in the literature explaining solar and wind energy use

There are many previous studies using various panel regression approaches to assess the determinants of renewable energy use. Zhao et al. (2013) used the Poisson pseudo-maximum likelihood estimation technique for a global panel, finding that renewable electricity policies are important in promoting renewable electricity use. Carley (2009) found that renewable portfolio standard implementation is not a significant predictor of the renewable electricity share of total generation of US states from 1998 to 2006, based on fixed effects vector decomposition estimates. Pfeiffer and Mulder (2013) used a two-stage approach to separately consider the adoption of and quantity of renewable energy used by a panel of developing countries. Basher et al. (2015) note that the renewable energy share of electricity generation is not stationary in many OECD countries, which poses a challenge for empirical studies that focus on time-series variation.

Survey-based techniques have also been used to assess renewable energy deployment. For example, Friebe et al. (2014) used a qualitative approach to identify key factors for project investment decisions on wind farms and then use a quantitative survey approach ("maximum difference scaling") to further evaluate the importance of these key factors. Eleftheriadis and Anagnostopoulou (2015) surveyed renewable energy experts to identify barriers to renewable energy diffusion. Murakami et al. (2015) used a choice experiment to quantify the willingness to pay for renewable electricity by US and Japanese consumers.

Simulation models and scenario analysis are other alternatives. Hirth and Steckel (2016), for example, use a techno-economic power system model to show the combined effect of the weighted average cost of capital and carbon prices on the renewable energy share.

2.2. Factors that may affect early adoption of solar and wind energy

Policymakers could theoretically use one policy instrument to target the adoption of renewable energy. In practice, multi-dimensional policy approaches are often employed. Jaffe et al. (2005) note that the interaction of combined market failures associated with pollution externalities and diffusion of new technologies provides a rationale for a portfolio of public policies that aids adoption of environmentally beneficial technology. Sener and Fthenakis (2014) discuss the need for a holistic approach to policy for large-scale solar PV in the United States. We use an aggregate policy support variable from a report by Ecofys (2014) for the European Commission, as described in Section 3, to account for aggregate policy support in multi-dimensional policy frameworks. We expect that the aggregate policy support variable has had a positive impact on renewable energy use.

Our use of an aggregate policy variable complements prior studies that focus on specific policies. Using an instrumental variables approach, Smith and Urpelainen (2014) find that feed-in tariffs have been effective in increasing renewable electricity take-up. Baldwin et al. (2016) find that renewable electricity policy impacts differ by country income group. Polzin et al. (2015) note that feed-in tariffs are more effective for less mature technologies, whereas renewable portfolio standards appear more effective for mature technologies. Policies are not always successful; Aguirre and Ibikunle (2014) conclude that policies involving voluntary participation appear to have a negative relationship with renewable energy investment, possibly as a result of uncertainty over government policy changes. Studies also find mixed results depending on the type of policy support. Pfeiffer and Mulder (2013) show negative impacts of institutional and strategic policy support measures from the IEA/IRENA Global Renewable Energy Policies and Measures Database, but positive impacts from economic and regulatory instruments.

Carbon pricing is another specific policy that could influence renewable energy adoption. Carbon pricing can promote cost-effective emissions abatement by providing incentives for private agents to exploit low cost abatement opportunities (Aldy and Stavins, 2012). A carbon price gives producers and consumers an incentive to consider the external costs that their emissions impose on others, promoting socially-efficient resource allocation by addressing the market failure resulting from these externalities. The idea of charging agents for the external costs that they impose on others dates back to Arthur Pigou in the early 20th century (Mankiw, 2009). More recently, there has been a growing number of carbon pricing initiatives around the world, and plans for more (Hepburn, 2017). Yet not many empirical studies have considered the impact of carbon pricing on renewable energy adoption. For instance, the paper by Basher et al. (2015) includes a table (Table 1) that summarizes empirical studies on the impact of policy on renewable energy diffusion. The table mentions feed-in tariffs and renewable portfolio standards, but not carbon pricing. We expect a positive impact of carbon pricing on renewable energy use, as carbon pricing provides an advantage to renewables by making fossil-fuel alternatives more costly.

Various aspects of governance could be relevant for the adoption of renewable energy. Best and Burke (2017) find that general government effectiveness has been important for electrification in low- and middle-income countries in recent decades, and similar may perhaps be true for adoption of modern energy sources. Governments that are more involved in global political processes may also be more likely to promote renewable energy to contribute to international climate goals.

Policy measures focusing on innovation could also affect renewable energy adoption. Countries with a greater focus on innovation could be faster to adopt new technology such as solar energy. Johnstone et al. (2010) show that various policies can spur innovation: feed-in tariffs appear to increase patent numbers for solar, while renewable energy certificates appear to be important for increasing wind energy patent numbers. Popp et al. (2011) analyze the impact of patents on investment in renewable energy capacity and find that technological advances do increase investment to some extent. Together, these two studies indicate that policy can foster innovation, which can increase renewable energy investment. Veugelers (2012) surveys the empirical literature, citing success in environmental policies inducing clean technology innovation, while also noting that there are fewer studies on the adoption of clean technologies.

It may well be the case that there is greater adoption of solar and wind energy when citizens have had stronger preferences for these energy types and when they are more concerned about climate change. This can occur via increased demand for use of these technologies. Another mechanism is that stronger preference for renewables may make it less likely that policy support for renewables would be wound back in the future, reducing uncertainty. The negative impact of policy uncertainty on renewable energy investment has been noted for the United States (Barradale, 2010).

We also investigate if the size of financial sectors is important for solar and wind energy adoption. Countries with greater access to financial capital may adopt more capital-intensive energy types such as solar and wind (Brunnschweiler, 2010; Best, 2017; Lin and Omoju, 2017). Larger quantities of financial capital would lower the cost of capital, all else equal, benefitting solar and wind energy generation, which is capital intensive and sensitive to the cost of capital.

Financial sector composition could also be important. The banking sector has been a key source of finance for energy investment in the past (IEA, 2014), but faces financial regulations that discourage long-term energy finance (Kaminker and Stewart, 2012; Ng and Tao, 2016). Private investors, including pension funds, will increasingly be the source of capital for renewable energy due to high government debt in many countries (Della Croce et al., 2011; Kaminker and Stewart, 2012).