Energy Policy 111 (2017) 58–67

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Non-renewable and intermittent renewable energy sources: Friends *and* foes?☆

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ARTICLE INFO

JEL:
D22
D24
Q41
Q42

Keywords:
Renewable energy production
Natural gas
Factor complementarity
Electricity production

ABSTRACT

This paper studies the links between non-renewable and intermittent renewable energy sources in the production of electricity. Using U.S. state-level data from 1998 to 2015, we find that the relationship between the price of natural gas and investments in solar and wind capacity is non-linear and can be represented by an inverted U-shape. Hence, for relatively low natural gas prices, the two modes of production are substitutes. After a price threshold is reached, the two are complementary. A theoretical explanation argues that this stylized fact is the result of a trade-off between two characteristics of these modes of production: the high degree of flexibility of electricity production using natural gas as an input and the low marginal cost of renewable energy sources.

1. Introduction

As the world struggles to address climate change, renewable energy is becoming an increasingly important electricity source. However, non-renewable sources of energy are still relevant. While moving forward with investments in wind and solar power projects, it is important to consider the relationship between renewable energy and non-renewable energy sources such as natural gas. Natural gas is a direct competitor to renewable energy in both the contract and spot bulk power markets. At the same time, the operational flexibility of gas-fired generation makes it a promising resource to offset natural fluctuations in sunlight and wind.

Natural gas and intermittent renewables are mostly seen as substitutes, both in the economic literature and the policy arena. Indeed, considering their intrinsic technical substitutability within power generation, it is quite natural to assume that an increase in the price of natural gas will increase incentives to invest in renewable energy generation. However, the intermittency and the comparative advantage in terms of the input price of renewable energy undoubtably provide some scope for complementarities. This is particularly true for natural gas, due to its high degree of flexibility in electricity production. Natural gas generators can almost instantaneously supply the market when renewables do not produce.

Other have analyzed the complex relationship between natural gas and intermittent renewable energy. However, the economic literature on the interplay between natural gas and renewable energy is relatively new. The theoretical literature has largely focused on the technological assumption that fossil fuels and renewables can substitute one for another. Most theoretical analysis explain how choices (in terms of capacity or inputs) between conventional and intermittent generation technologies are made. Some studies provide a social point of view, such as the partial equilibrium analysis in Ambec and Crampes (2012) or the general equilibrium framework in Schwerin (2013). Other studies look for strategic market-based explanations, such as Bouckaert and De Borger (2014) and Aflaki and Netessine (2017). All these studies consider thermal-based primary energy sources and intermittent ones to be substitutes, in that a rise in fuel prices eventually leads to increased investment in renewable energy.

However, some nuances to the substitutability between renewables and fossil fuels have been identified in the literature. For example, Bouckaert and De Borger (2014) show that from a strategic point of view, capacity choices between conventional dispatchable and intermittent generation technologies (in a duopolistic setting) may be strategic complements when intermittent generation conditions are

☆ The authors thank Benoit Mulkay, Mathieu Lefebvre, Scott Savage, François Salanié, Daniel Kaffine, Vicenzo Verardi, Stefan Ambec and participants at various presentations in Montpellier, Paris, Rennes, Louvain-la-Neuve and Turin for early comments. Any remaining errors are our own.
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http://dx.doi.org/10.1016/j.enpol.2017.09.018
Received 26 April 2017; Received in revised form 1 September 2017; Accepted 7 September 2017

unfavorable. But they remain net substitutes at the equilibrium, considering capacity cost effects. Using an electricity peak-load pricing model, Chao (2011) concludes that "the wind generation capacity generally substitutes the investment in combined cycle GT capacity but complements the investment in gas turbine units." In the same vein, Garcia et al. (2012) analyze optimal versus equilibrium mix of renewable and non-renewable technologies and state that "renewable capacity should be seen as a substitute to baseload technologies and complementary to peak generation technologies." Recently Ambec and Crampes (2015) have studied the optimal energy mix when renewables are used and find that capacities installed for the purpose of balancing intermittent sources can be lowered when environmental damages (or carbon taxes) go over a certain level. This can be interpreted as a complementary relationship between intermittent sources and fossil fuels when the impacts of different public policies that aim to decarbonate electricity production are considered.

These conclusions have also been acknowledged in the policy literature. For instance, Lee et al. (2012) argues that a complementary relationship between natural gas and renewable energy sources can be established. Technical, environmental, political and economic considerations explain this claim. From an economic point of view, the energy sources have different risk profiles, so they may be complementary portfolio options. Lee et al. argue that natural gas price volatility would be balanced by stable (near zero) generating costs of renewable energy investments and, on the flip-side, natural gas plants' low up-front costs counterbalance inherent risks due to the intermittency of renewable generation plants.

This complementary relationship is also studied in the empirical literature on the determinants of investment in and production of renewable energies (see Delmas and Montes-Santo, 2011; Fabrizio, 2013; Hitaj, 2013; Polzin et al., 2015, among others).[1] These papers mainly focus on the impact of various policy tools (such as feed-in tariffs or renewable portfolio standards) using aggregate data. In some of these studies, the price of natural gas or other fossil fuels is used as a control variable. Using European data, Marques et al. (2010) find a *positive* relationship between the share of contribution of renewables to the energy supply and the natural gas price, i.e. substitutability. Using U.S. data, Shrimali and Kniefel (2011) find a significant *negative* relationship between the share of renewable (wind, solar, biomass and geothermal) capacity and the total net generation, i.e. complementarity. Using their own words, "The flexible natural gas based plants are used for overcoming the intermittency issues inherent in renewable power generation — in particular wind, the dominant renewable source." (Shrimali and Kniefel, 2011, p.4737).

The aim of our analysis is to consider, both from an empirical and theoretical point of view, the extent of *gross substitutabilities or complementarities* between intermittent renewables sources and natural gas. For this purpose, we rather study the indirect price effect of a flexible input onto an investment decision than the technological relationship between inputs or the strategic link between supply decisions. We follow this approach because renewable energies are must-run technologies. Hence, the strategic decision happens at the investment rather than at the production stage.

In a first step, using U.S. state-level data from 1998 to 2015, collected from the U.S. Energy Information Administration, we look at the empirical link between the renewable energy and the natural gas market. We use a panel Tobit model to study the determinants of capacity investments in intermittent renewable energy. We focus mainly on renewable energy investment's relationship with the price of natural gas, using various socioeconomic, electricity market, policy and tax factors as control variables. Hence, we follow a macro approach in the sense that we use aggregate yearly data at the state level. In contrast with the literature, we allow for a non-monotonic relationship between our two main variables of concern. As confirmed by various empirical specifications, we find that this relationship is best represented by an inverted U-shape.

In a second step we develop a model that reproduces and explains what is at stake behind this empirical fact. Using a simple theoretical framework, we find that for relatively low prices of natural gas, they are substitutes, as the absence of an input cost for renewable production is less valued. On the other hand, for relatively high natural gas prices, they are complementary, as the flexibility of a fossil fuel energy source can circumvent the intermittency of renewable energy sources (as they cannot be stocked and are not perfectly predictable).

Our analysis has some implications for policymakers. It suggests a need for more comprehensive policies in the energy sector. Our paper highlights how various policy changes could have a wide impact, as the markets composing the energy sector are intertwined in a more complex manner than originally thought. For example, the Trump administration has recently decided to ease drilling rights and investments in new pipeline projects to boost the U.S. production capacities (Goldberg, 2017). Other examples like increasing political tensions between Russia, the world's biggest exporter of natural gas, and European countries or the signing of bilateral free trade agreements between importing and exporting nations will not only have an influence on the natural gas market. These changes will also have an impact on investments in renewable energies, depending on the prevailing market conditions and, more specifically, the price of natural gas. Hence, caution is needed when anticipating the consequences of these changes.

2. Empirical evidence

We first study the empirical link between non-renewable and renewable electricity markets. More precisely, we focus on the relationship between investments in renewable energy sources and the input price of a non-renewable technology, in our case, natural gas. Fig. 1 shows the relationship between the natural gas price and renewable capacity investments for 49 U.S. states between 1998–2015, as well as a quadratic fit (only considering strictly positive investments). The graphic suggests that a non-linear relationship is more plausible than a linear one. In what follows, we show that this suggestive evidence is robust to various empirical approaches.

2.1. Data

2.1.1. Dependent variables

Our analysis focuses on capacity investments, as opposed to accumulated investments, market share or generation to better highlight the outcome of our investment decision, net of previous years and independently from unpredictable weather conditions. Finally, in line with our theoretical model, we focus on investments in two sources: solar and wind. They are both non-flexible intermittent and renewable sources of production that don't create negative externalities through their capacity installments, the production of electricity or the supply of inputs. We use state-level data rather than data at the level of power pools. The main reason is that power pools are a rather new phenomena and are not present in many states. Hence, state-level data allows us to consider a bigger and more representative set of observations. More control variables are also available at the state level which is a coherent entity with respect to the energy policies implemented.

Our data comes from U.S. Energy Information Administration (2017) where state-level data on both renewable capacity investments and natural gas prices is available (via the EIA-860 form). To consider both the increasing number of units producing electricity and the increase in productivity observed over time, we multiply the number of generators installed by their nameplate capacity (i.e. maximum output of a generator expressed in megawatts). As our dependent variable is heavily right-skewed and has a non-normal kurtosis, we apply the

[1] There is also a substantial literature that estimates the energy cross-price elasticities based on applied production theory. See Stern (2010) for a survey.