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# The positive feedback cycle in the electricity market: Residential solar PV adoption, electricity demand and prices

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ABSTRACT

Micro renewable energy systems (MRES) such as Photovoltaic (PV) are an increasingly important element of National energy strategies. However, the success of these installations has given rise to a positive feedback cycle whereby increased customer adoption results in reduced demand from Utility providers. This leads to price increases and further incentives customers to adopt MRES. This paper investigates the existence of a positive feedback cycle by developing a theoretical model based on simultaneous equations and estimating it using the three stage least squares approach using data from the UK, Australian and Irish Markets. Results indicate strong support for the idea of a positive feedback cycle. This reinforces the need for stakeholders to consider this issue in framing future energy policies to ensure that the adoption of solar PV is supported in a sustainable way, while not punishing non-adopters with higher electricity rates.

## 1. Introduction

Micro renewable energy systems are small scale energy systems which generate small amounts of energy when compared to traditional centralized power plants. Micro renewable energy systems have now made it possible for home owners to retrofit their premises to generate their own electricity and/or heat, thus becoming more self-sufficient. Allen et al. (2008) references a study where it was predicted that electrical micro renewable energy systems could provide 30–40% of the United Kingdoms' electricity needs by 2050.

Governments worldwide have included strategies to stimulate the growth of micro renewable energy systems at the residential level as part of their overall energy policy aimed at combatting climate change. Governments have used a variety of support mechanisms to achieve their targets which include Feed-in Tariffs (Fit), point of sales rebates including Renewable Energy Certificates (REC), and tax benefits. These policies have been successful in increasing the number installations particularly that of solar photovoltaic systems in the residential sector in countries like the United States of America, Australia and the United Kingdom (Allen et al., 2008; Chapman et al., 2016).

Though, the increasing popularity of residential solar photovoltaic systems in electricity markets has led some to suggest that it has created a positive feedback cycle or loop. Simply put a positive feedback cycle is a situation where, action A generates more of action B which in turn generates more of action A. In economics, a positive feedback cycle results in a systemic risk to the system (Cai et al., 2013; Rodrigues et al., 2016; Sahu, 2015).

There has been a vast amount of literature on the economic impact of renewable energy systems; however, the literature has mainly been focused on renewable energy systems at a macro level (Payne, 2010; Salim et al., 2014; Shafiei and Salim, 2014). A new line of literature has begun to investigate the economic repercussions of increasing number of micro-generators, particularly that of residential solar photovoltaic (PV) systems and the effects on countries electricity markets which may result in a positive feedback cycle which could possibly lead to a utility 'death spiral'. This scenario is a result of residential electricity customers adopting solar photovoltaic systems due to high electricity prices will therefore reduce their consumption from the electricity grid. In response to falling sales electrical utilities will have to raise their prices as the costs[1] associated with the generation of electricity do not decrease in proportion to the decrease in electricity demanded. The increase in price by electrical utilities thus incentivises more of the remaining electricity customers to adopt solar photovoltaic systems. Increasing penetration levels of residential solar photovoltaic systems onto a grid could further accelerate the positive feedback cycle and could have several implications. The increasing electricity prices will be borne by low and medium income households who cannot afford solar photovoltaic system and in a worst case scenario where electricity price

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[1] This is because the electrical utilities have to pay for transmission and distribution infrastructure and these fixed costs are recovered over decades.

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increases will be futile in raising sufficient revenues to cover their total costs could potentially force electrical utilities into a death spiral (Costello and Hemphill, 2014; Felder and Athawale, 2014).

Of the literature that empirically investigates the topic of a positive feedback cycle in the residential electricity market caused by an increasing number of solar PV, has thus far mainly focused on the American experience. Therefore, this paper will be the first to extend the ideas from the existing literature on the American experience to a newly selected group of countries, Australia, Ireland and the UK. To address this issue, this paper firstly models the positive feedback cycle caused by consumers in the residential sector by deciding to adopt solar photovoltaic systems and the resulting implications on demand and pricing in the residential electricity market. Following this, a three stage least squares regression is performed for the panel of countries to investigate whether a positive feedback cycle is being experienced. Our findings show support for: (1) increasing residential electricity prices leading to higher installation rates of residential solar photovoltaic, (2) residential solar photovoltaic installations lead to higher residential electricity prices, (3) residential solar photovoltaic installations negatively affect residential electricity demand.

The results attained in this paper will be used to inform and support policy makers as they consider potential changes to residential electricity rates that could affect solar photovoltaics role in advancing policy objectives and not to punish non-adopters with higher electricity rates.

The paper is organised as follows: Section 2, is the material and methods sections; provides details on the model development, the estimation technique, data specifications and a descriptive statistics subsection. In Section 3, the results of the three stage least squares regression of our simultaneous equation model are presented and discussed. Section 4 contains the concluding remarks and policy implications.

## 2. Literature review

The earliest reference to the positive feedback cycle as a result of micro-RES the author could find was by Severance (2011), however these terms aren't used in the study. Severance notes that utility managers have an “unspoken fear” of a death spiral scenario due to “on-site power” and the collection of higher and higher rates from poorer and poorer customers. Others studies (Nelson et al., 2011, 2012) raise concerns about the impact of favourably tariffs for micro-RES are having.

The hypothesis of a positive feedback cycle induced by residential solar PV, has motivated a new line of research into the interactions between residential solar PV adoption rates and electricity prices and demand. Arthur (1990) first wrote about the influence of the positive feedback on economic systems. In his paper, the author saw the positive feedback cycle as the driving force in determining which of competing technologies would dominate a market. He concluded that at the start, markets are unstable and small increases to a new technologies market share can expand its growth exponentially (Ruth and Hannon, 2012).

Studies examining the impact of electricity retail rate structure on solar PV are not new, however, most of them have stopped short of investigating whether it would lead to a positive feedback cycle (Darghouth et al., 2011; McLaren et al., 2015; Mills et al., 2008). In a paper by Chew et al. (2012) for Pacific Gas & Electric Company, the authors acknowledge that a positive feedback cycle is in effect and conclude that electric utilities must adapt their rate-making procedures to ensure that both solar-PV adopters and non-adopters are fairly charged for their cost of service. To do this the authors presented a model that could be used by electrical utilities to estimate the impact of various policies proposals will have on cost shifts and residential rooftop solar PV systems. In Cai et al. (2013), the authors investigate how the adoption of solar PV systems by households leads to a positive feedback cycle via increasing electricity rates. They modelled solar PV adoption for a specific investor owned utility, subject to rate-of-return regulation in California. The results from their model illustrate that the feedback cycle reduces the time it takes for solar PV capacity to reach 15% of peak demand by up to 4 months and has a greater impact in later years. Costello and Hemphill (2014) investigate whether the ‘death spiral’ facing electrical utilities due to increases in distributed generation[2] is a reality or overstatement. The authors conclude that electrical utilities are in for some tough times ahead, but it is due to several factors not just distributed generation. Moreover, it is in the interests of policy makers to ensure electrical utilities avoid entering a death spiral as this outcome would hurt customers in the long run, since they will have to rely on the grid on occasions. A similar conclusion is presented by Laws et al. (2017) where they investigate how many electric utilities are changing their pricing structures to address the rapidly-growing market for residential solar PV systems. The authors note that there is little knowledge about how changes to utility pricing structures would affect the adoption rates of solar PV systems, as well as the ability of utilities to prevent widespread grid defection. Laws et al. (2017) carry out simulations on a system dynamics model to predict how changes to the retail price of electricity impact on the adoption rates of residential solar PV. A sensitivity analyses is also conducted to investigate the likelihood of a utility ‘death spiral’. Their results indicate that a utility ‘death spiral’ requires a perfect storm of high intrinsic adoption rates, rising utility costs, and favourable customer financials. Eryilmaz and Sergici (2016), investigate the price-responsiveness of the residential customers with increasing residential solar PV penetration and projected future electricity sales to the residential sector considering various future solar PV penetration scenarios. Their results show that increasing residential electricity prices are associated with an increase in residential solar PV installations and using their findings for the estimated elasticity values, they project the share of utility electricity sales reduction due to solar residential sector between 2013 and 2020. In a future scenario where there is a 25% residential solar PV penetration by 2020, about 1.2% of the projected growth of the electricity sales to the residential customers will be taken over by rooftop solar PV.

The literature published on the topic of a positive feedback cycle due to residential solar PV adoption to date has focused on the American experience. This paper extends the ideas from the literature to a selected group of countries, Australia, Ireland and the UK, to investigate whether residential solar PV adoption in these countries has led to the existence of a positive feedback cycle.

## 3. Material and methods

### 3.1. Data specifications

We consider monthly data spanning the period from 2010 to 2015, for three countries: Australia, Ireland and the United Kingdom in this study. The three countries can be seen to represent micro-RES at three different stages of growth; infancy, intermediate and mature respectively. One reason for the different levels of penetration between the countries is government support mechanisms. A possible reason for the slow residential solar PV uptake in Ireland when compared to the other countries is weak government support mechanisms. In Ireland, the ESB networks and Electric Ireland (formally known as ESB Customer Supply) ran a ‘pilot scheme’ from 2009 till 2014 for micro generators of electricity. Under this ‘pilot scheme’, micro-generators where offered a support package of a free installation of an import/export meter and support payment of 10 cent/kW h for the duration of their contract (the last of these contracts expire in 2017). For micro-generators who missed

[2] Distributed generation refers to the generation of energy close to the place where energy issued. It can mean a range of generator sizes; from residential households to community or district-level.