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Has the Fukushima accident influenced short-term consumption in the evolution of nuclear energy? An analysis of the world and seven leading countries

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ABSTRACT

In 2013 registered nuclear power consumption in several countries, including France, Germany, and other OECD members, declined. In this paper, we focus on nuclear consumption leaders and explore, through diffusion models, whether and to what extent Fukushima accident had a short-term effect on these countries' consumption dynamics. Safety checks, performed after the accident caused temporary shutdowns in production but not all of them were significant enough to modify nuclear energy evolution. Then, we compared the evolutionary behavior estimated through the entire time series and that obtained by excluding the last three observations (2011–2013): what would the forecasts have been before Fukushima? Significant short-term effects were identified in 2011–2013 at the global level, for France, and South Korea, while they have not been identified for the US, Germany, and Russia. About the medium-term evolution predicted by the models, we identified countries with declining consumption (the US, France, Germany and South Korea) and with increasing consumption (China, Russia, and Canada). At the global level a declining trend is predicted.

1. Introduction

Of all the forms of energy used to generate electricity, nuclear is probably the most concerned with safety issues. The history of commercial use of nuclear fission dates back to the 1950s and has been characterized by three major accidents. The first one, occurred in 1979 at Three Mile Island (USA), fortunately had a limited effect, since the amount of radioactivity was under the safety limits. However, the accident received much media attention (Csereklyei, 2014). Conversely, the accident that produced catastrophic consequences for nuclear fallout in Western Union of Soviet Socialist Republics (USSR) and Europe was Chernobyl in 1986. The Chernobyl disaster is considered the worst ever and has been classified at Level 7 on the International Nuclear Event Scale (INES) (maximum level): the accident was due not only to flawed reactor design but also to dramatic human errors (Villa, 2008). The other accident classified at Level 7 is the one that occurred in Fukushima (Japan) in March 2011.

After the Fukushima accident Japan, from being the world's third largest nuclear power generator, fell down to the 18th position between 2010 and 2012 due to the shutdown of all its reactors (Schneider and Froggatt, 2014). According to the IAEA-Pris database (IAEA PRIS, 2014) in Japan 11 reactors currently have been shutdown, while 48 are still "operational", even though 46 are classified as "suspended operation" and have not generated electricity for years. The disaster changed Japanese public opinion about this energy source. In Esteban (Esteban and Portugal-Pereira, 2014), it is reported that a recent opinion poll revealed that 70% of Japanese are in favor of a nuclear power phase-out. Since the Fukushima disaster the Japanese government has launched various measures to update the electricity sector and diversify the energy mix: before 2011, the energy policy in Japan was essentially led by large power companies that persuaded people about the security of nuclear power (Esteban and Portugal-Pereira, 2014).

As emphasized in Huenteler et al. (2012), the Japanese energy strategy was focused on nuclear power as "a (nominally) cheap, quasi-indigenous and low-carbon power source", while renewables played a secondary role. However, in Huenteler et al. (2012), it is also underlined that the Fukushima accident shed light on the importance of a decentralized and resilient energy supply system: in particular, photovoltaic energy seems doomed to play a prominent role in the future of this country (Huenteler et al., 2012). The BP-Statistical Review of World Energy (2014), reported a dramatic increase in photovoltaic (PV) installed power for 2013 ($\Delta\%_{13/12} = 75.4\%$). More impressive is the annual absolute installed photovoltaic power in megawatts: 6900 (2013), 1829 (2012), 1296 (2011) and 991 (2010), which denotes a rapid shift toward a decentralized technology.

Outside Japan, it is argued that the disaster was responsible for reconsideration of nuclear power policy in many countries. In particular, many questions raised about the prevailing decision to implement the

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uprating process, which consists of technical alterations and lifetime extensions of existing reactors. As reported in Schneider and Froggatt (2014), the main reason for reactor uprating is the economic advantage with respect to building new ones, even though this strategy implies a lower level of security. Alternatively, small modular reactors (SMRs) have been proposed as a possible solution to the problems characterizing nuclear power, namely economics, safety, waste and proliferation (Deutch et al., 2003). In Ramana and Mian (2014), the basic features of this technology are discussed and the authors concluded that the four key problems characterizing nuclear power (cost, safety, waste and proliferation) cannot be solved by this technology simultaneously. In particular, each challenge requires driving the technology in different and sometimes conflicting directions (Ramana and Mian, 2014).

Safety concerns forced national decisions on nuclear energy. For instance, four days after the accident in Japan, the German government ordered the shutdown of eight reactors that had started up before 1981 and other countries, such as Belgium and Switzerland, reconsidered previous decisions to extend lifetime of reactors. In Italy, a referendum rejected a plan to build new reactors (Hayashi and Hughes, 2013). Thus, the Fukushima accident appears to have affected the energy policies outside Japan. In 2013, the BP-Statistical Review of World Energy (2014) reported a decline in nuclear power consumption in several countries, although it increased in others.

In Table 1, we summarize the situation as of 2013 for the seven leading countries, the US, France, Russia, South Korea, China, Canada and Germany. Together, these countries generate about 75% of all nuclear electricity in the world. Various percentage changes are outlined in Table 1, in order to appreciate the differences between countries: for instance, the only country that has exhibited a steady growth is China. Conversely, a decrease is observed in Germany, France and South Korea. Focusing on the percentage change from 2012 to 2013 there has been a decrease in France, Russia, South Korea, and Germany and an increase in consumption has been reported for the US, China, and Canada. Should we consider the decline as a post-Fukushima outcome? Was growth slowed by the accident? To answer these questions we cannot simply refer to the change observed in more recent years; we must instead analyze the complete history of nuclear consumption in these countries (see Fig. 1).

The main purpose of the paper is to evaluate, in quantitative terms, the effect of the Fukushima accident on the consumption dynamics of nuclear power in the seven leading nuclear-consuming countries. In particular, this analysis is aimed at recognizing the short-term effects (3 years) of the accident compared to the medium-term trend (almost a decade, until 2020), whose behavior may depend on historical, economic, social and technological aspects, which are generally country-specific. In fact, in Hayashi and Hughes (2013), it is highlighted that in addition to short-term effects in Japan, the accident could have had short-to-medium term effects in other countries, that invested or not in the nuclear option. In particular, in Hayashi and Hughes (2013), the authors maintain that the Fukushima accident occurred during a growth phase for nuclear power, often termed as “nuclear renaissance” (Nuttall, 2005; World Nuclear Association, 2014a). However, as reported in Csereklyei (2014), a body of literature questions whether this renaissance really occurred. Among others, Glaser (2011), Guidolin and Guseo (2012), Schneider and Froggatt (2014) and Thomas (2012) argued that the nuclear renaissance had ended before Fukushima due to economic and technological problems. Partially building on this literature, we reach conclusions on the impact of Fukushima on nuclear consumption at a global and country level: in investigating this issue, we adopt a statistical approach, to identify the existence and intensity of short-term effects, by separating them from the medium-term dynamics of consumption. In particular, we model the time series of annual consumption of nuclear power for the world and the seven countries of Table 1 with innovation diffusion models. Such choice relies on an increasing literature that uses innovation diffusion models in the energy context, as will be clarified in Section 2.

Table 1
Nuclear power consumption: annual nuclear consumption (TWh), 2013 share of total for the 7 consumption leaders, and percent changes.

	TWh	2013 share of total	$\Delta\%_{13/12}$	$\Delta\%_{13/11}$	$\Delta\%_{13/07}$	$\Delta\%_{10/07}$
US	830.5	33.4	2.6	−0.2	−2.2	0.1
France	423.7	17.0	−0.4	−4.2	−3.8	−2.8
Russia	173.0	6.9	−2.5	0.1	8.1	6.4
South Korea	138.8	5.6	−7.7	−10.3	−2.9	4.0
China	110.6	4.4	13.6	28.1	78.0	18.9
Canada	102.1	4.1	6.6	7.7	10.0	−3.4
Germany	97.3	3.9	−2.2	−9.9	−30.7	0.1

The paper is structured as follows. In Section 2 we present the diffusion models we used in our analyses. In particular, we propose a new approach that combines in one model aspects that exist in literature, which are dynamic market potential (Guseo and Guidolin, 2009), heterogeneity of agents (Guseo et al., 2015), and external interventions (Bass et al., 1994), allowing for a more flexible parametric structure. Moreover, whenever necessary, in order to capture the behaviors of countries with non-homogeneous regimes, we expand a single-cycle approach by proposing a two-wave model, that generalizes the work of Guseo (2011) and Guseo and Guidolin (2015), and provides a more flexible parameter structure between the two waves. In Section 3, we discuss the results of our analysis at the global level and for the seven leading countries in energy consumption and evaluate the effects of the Fukushima accident on the countries' energy policies from short and medium-term perspectives. Conclusions are presented in Section 4.

2. Diffusion models: exogenous shocks, dynamic market potential, heterogeneity, and two-wave regimes

The pioneering work of the physicist Cesare Marchetti (see for instance Marchetti, 1980) provided a crucial contribution to the understanding of historical dynamics of energy systems. Starting with the hypothesis that society as a whole is a system made of interconnected individuals who share knowledge and generate collective expectations, he theorized that energy sources are comparable to new commercial products that compete to be accepted by society, whose learning behavior may be characterized by logistic-like functions. Under this hypothesis, primary energy functions may be considered innovations, whose diffusion process has its own speed and degree of uncertainty depending on technological, socio-economic and institutional aspects. For instance, Usha Rao and Kishore (2010), reported that nuclear fission was used for the first time in a reactor to produce commercial power 40 years after the discovery. Thus, the adoption of a new energy may be a very slow process due to a high degree of uncertainty and public policies may be an efficient mean of reducing it, by stimulating market formation (Gallagher et al., 2012).

However, despite the fundamental contribution of Marchetti's theories since the 1980s, the development of studies that combine innovation diffusion models, mostly introduced in quantitative marketing, with energy themes is quite recent. In fact, typical applications of diffusion models have concerned traditional marketing sectors, such as durable goods, information and communication technologies, pharmaceuticals, and services (for comprehensive reviews of the literature, see for instance Meade and Islam, 2006; Peres et al., 2010).

More recently, we have witnessed increasing interest in the use of these models in the energy sector to forecast the evolution of different energy sources, with growing attention paid to renewable energy technologies (RETs): for instance, Dalla Valle and Furlan (2011) studied the diffusion of wind energy; Dalla Valle and Furlan (2014) the diffusion of nuclear energy in some developing countries; Davies and Diaz-Rainey (2011) analyzed the pattern of international diffusion of wind energy; Guidolin and Guseo (2012) applied diffusion models to the diffusion of nuclear power and parallel reactor start-up process; Guidolin and Mortarino (2010) modeled the growth of photovoltaic energy; Guseo