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The capacity for adopting energy innovations in Portugal: Historical evidence and perspectives for the future

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ABSTRACT

This paper investigates the speed of adoption of energy technologies in a traditionally innovation importing country, Portugal, as compared with countries where these technologies first started. Data were collected on the growth of eight energy-related technologies, both energy supply (e.g. natural gas plants, wind turbines) and end-use (e.g., motorcycles). The analysis is done in terms of the evolution of the number of units and installed capacity, indicating possible scale effects. The results show an average adoption lag of one to two decades relatively to "Core" countries. However, the growth rate increases when a technology arrives at Portugal, confirming the hypothesis that adoption accelerates when technology reaches new markets. Additionally, the duration of diffusion in Portugal is less constrained by the final scale of diffusion, contrasting with previous observations for the Core. The data also uncover the successful diffusion of wind energy in Portugal, showing that growth took off less than a decade after the diffusion in the Core, and achieving similar levels of intensity. The analysis suggests that this was supported by the improvement in the adoption capacity, associated with the development of a wind energy innovation system. These findings open new perspectives for the spatial diffusion of sustainable innovations.

1. Introduction

The deployment of new energy technologies in large scale is needed in the next decades in order to overcome current societal challenges (e.g. environmental problems, security of supply) (IPCC, 2014). Historical experience reveals that the emergence and diffusion of energy technologies are slow and marked by a series of barriers (Grubler et al., 2012; Grubler, 2012; Fouquet, 2012). One of the reasons for this slowness is the extent of institutional and organizational changes that are often necessary for the emergence and dissemination of a new technology (Bergek et al., 2008; Jacobsson; Bergek, 2011). However, the analysis of international patterns of technology diffusion shows an acceleration of growth as the technology moves from pioneer countries and reaches new regions (Grubler, 2012, 1998; Bento, 2013). A possible explanation for this empirical regularity is the presence of externalities (i.e., "spillovers") from the technology development in pioneer countries, which supports its faster dissemination in subsequent markets (Jaffe, 2005; Perkins and Neumayer, 2005). The positioning of each country in the sequence of international diffusion depends on internal conditions, including the ability to absorb and use new technologies (Cohen and Levinthal, 1989, 1990).

The adoption of foreign technology is a key element in the convergence of the less developed economies with more advanced countries (Fagerberg and Godinho, 2008; Godinho, 1995). The notion of "latecomer advantage" has been put forward to explain the technological dynamism of less advanced countries over more developed ones (Gerschenkron, 1962). It is argued that the technological backwardness of the former allows them to absorb the most recent innovations developed in the latter, without having to bear the high initial costs of development (Perkins and Neumayer, 2005). In addition, they are not encumbered by the so-called vintage capital, which is known to be a factor that delays the transition to new technologies in pioneer countries, by creating stranded costs due to the previous investments in human capital and infrastructure (Unruh, 2000; Clark and Wrigley, 1997; Frankel, 1955). This line of reasoning can explain why the transition to new energy systems tends to take less time in follower countries, which benefit from both the experience gained from the diffusion in pioneer countries and a cheaper technology (Grubler, 2012). Wilson (2009) shows evidence of the acceleration of diffusion in late adopters for several energy supply and end-use technologies. The marketing and management literature also finds the same effect of faster diffusion in countries that adopt a given product innovation later, what has been called the "lead-lag effect" (see a review in Peres et al., 2010).

Portugal is an intermediate economy and a typical case of "follower" of technological changes initiated in the more advanced economies (Godinho, 2007; Godinho and Caraça, 1988). A few studies analyze the

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recent evolution of innovative and institutional capacity in Portugal (e.g. Conceição and Heitor, 2005; Fagerberg and Godinho, 2008). In general economic terms, there is evidence of convergence (i.e. "catching up") with the most advanced economies, given the low initial levels of innovation as well as a growing dynamics in some areas (Lains and Silva, 2013; Lains, 2003). But, this process has been associated with a persistent deficit in the technological balance of payments, which can be seen as an indicator of investment in the adoption of foreign technology. This emphasizes the role of technology transfer[1] in the convergence process (Godinho, 2007, 1995). In fact, technology transfer, in its various forms (trade, foreign direct investment or licenses), is an instrument that allows absorbing knowledge spillovers from abroad (Keller, 2010). However, the conditions that permit to absorb eventual spillovers and how the evolution of these conditions relates to the rate of diffusion more recently are still poorly understood, particularly in the case of energy technologies.

It is therefore important to assess the pace at which energy technologies have historically diffused in new markets and understand the mechanisms at work in the cases in which such diffusion was faster. Portugal is chosen as the case study because of the spectacular progression that new renewable energy technologies knew lately. Instead of assuming that an eventual acceleration in the import and adoption of foreign technologies is an automatic result of technical progress (driven by some external influence), the article examines how technology characteristics affect the rate of diffusion and to what extent the diffusion is influenced by factors related to changes in the adoption context. The latter concerns particularly the role played by internal factors ("enablers") associated with changes in the country's institutional environment that improved the technological capacity to adopt more recent innovations such as wind power.

The paper starts by presenting the analytical framework that summarizes some lessons from the theoretical and empirical literature on the dynamics of innovation systems. Then it compares the adoption of energy technologies in Portugal with their diffusion in the countries where the technology was first developed, in terms of the timing of adoption, pace and scale. This approach not only provides a measure of the innovative performance of the energy sector, but also provides an empirical ground for discussion on the factors that accelerate technology adoption. The results of this analysis can contribute to inform the formulation of more empirically-based strategies to stimulate the diffusion of sustainable energy in follower contexts.

2. Technology formation in the core and the process of spatial diffusion: theoretical framework

2.1. Determinants of the rate of diffusion of technologies

Empirical research on the drivers of past technological transitions have identified a set of factors that influence the market penetration of new technologies and are likely to accelerate or delay their rate of diffusion (Grubler, 2012, 1998; Rogers, 2003): relative advantage, size of potential market, disruptiveness and existence of antecedent markets, technological complexity and infrastructure needs.

The relative advantage of a technology refers to the way it performs better a particular task, is more efficient or cheaper than rival technologies. The higher the relative advantage, the faster the market penetration (Fouquet, 2012). The size of the potential market (scale of diffusion) is another important factor, as high market penetration is likely to require more time to prepare the technology and organize the production (Wilson, 2012, 2009; Wilson and Grubler, 2011). The existence of antecedent markets determines the disruptiveness of the innovation. Technology disruptiveness can be assessed on the extent to which its diffusion depends on novel service provision, new supporting institutions or user practices (Rogers, 2003). The prior existence of a market and the nature of innovation — incremental or substitute vs. radical or rupture — imply different levels of uncertainty and therefore can introduce specific constraints in the rate of diffusion (Freeman and Perez, 1988).

The complexity of the technology, i.e. the extent to which its commercialization depends on challenging unit scaling or on the development of other technologies, also slows down the diffusion process (Grubler et al., 1999). For instance, the development of steam locomotives was only possible when more powerful steam engines became available in the 19th century (Rosenberg and Trajtenberg, 2004). Finally, the needs in terms of infrastructure may severely delay the market introduction and growth of a certain technology. This was the case of transportation systems, such as railways, or energy sources, such as natural gas, which took several decades to develop and reach the current extent (Geels, 2005).

The factors listed above may also impose contextual requirements that affect the duration of the diffusion process. For example, new environmental technologies that are not yet competitive are likely to have longer diffusion times, because of the need to create internal conditions, such as supportive regulatory frameworks or education and R&D investment. The more contextual points are discussed next.

2.2. Formative phase and mechanisms of spatial diffusion

The processes at action in the emergence of new technologies are addressed by two streams of literature. A more empirical approach that studies the regularities of technology diffusion and of systemic technological change (e.g. Grubler, 1998; Wilson, 2009; Wilson and Grubler, 2011a), and a more theoretical approach that examines the emergence and growth of technological innovation systems through the constitution of the structure and fulfillment of key innovative processes or functions (e.g. Markard et al., 2012; Bergek et al., 2008; Hekkert et al., 2007; Jacobsson and Lauber, 2006).

Recent empirical research analyzes the diffusion from the standpoint of the increase in the scale of production as well as the commercialization of even larger technologies (Wilson, 2012, 2009; Wilson and Grubler, 2011). Historical evidence has shown that the expansion of energy technologies depends on both factors and that the diffusion has evolved in a process of three sequential phases (cf. Wilson, 2012): the establishment of a productive base during the formative stage; upscaling at unit level; and the growth and generalization of the technology. Furthermore, the innovation was found to occur first in the central countries ("Core"), where it is developed and begins to be experimented in order to reach sufficient maturity for market commercialization, and then spills over to other geographic areas (Grubler, 1998, 2012).

The analyzes of international diffusion patterns suggest that diffusion accelerates as technology reaches new regions (Bento, 2013; Grubler, 2012; Wilson, 2009). This acceleration may reflect the existence of external effects ("spillovers") from earlier technology deployment in the Core (Jaffe, 2005; Cappelli et al., 2014). In fact, follower countries do not bear the original R&D costs, and can take advantage of the learning processes previously conducted by firms from the center, who have invested to improve performances and reduce costs — by increasing cumulative installed capacity when this was more expensive in order to advance in the "learning curve" (Perkins and Neumayer, 2005). This permits to solve the main technical problems and refine the technology, generating knowledge that is potentially available to other countries (except when protected by patents). Consequently, the access to cheaper and superior models boosts the rate of diffusion in

[1] We follow the definition of international technology transfer proposed by Keller (2010) who considers technology as "knowledge required for production" and thus technology transfer as the deliberated movement of technological knowledge between different countries. Technology diffusion is only one element of this general movement. This concept refers to the impact of a new technology on the national level which is likely to be measured in quantitative terms (units or equivalent capacity, MW). The form taken by this transfer (FDI, acquisition or licensing) is important for the final result, but it is not the focus of our investigation.