Investing in Smart Grids: Assessing the Influence of Regulatory and Market Factors on Investment Level

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ABSTRACT

This paper explores how market and regulatory factors affect stakeholders´ investments in smart grid projects in Europe. Distribution System Operators (DSOs), universities, and technology manufacturers are leading investors, with a cumulative 2286 M€ financed since 2002. Statistical tests were conducted on these groups´ investments in smart grid projects in the EU-28, Norway, and Switzerland from 2008–2015, to evaluate the influence of the following factors on investment: the level of distribution sector concentration, the regulatory mechanism in place, and the existence of innovation stimulus mechanisms. The level of distribution sector concentration did not significantly influence investments by these three groups. Market-minded stakeholders, such as DSOs and technology manufacturers, invested more in countries that employed hybrid, incentive, or innovation-stimulus mechanisms; meanwhile, collaborative knowledge-seeking institutions, such as universities, were not swayed by these factors. Taking these findings into consideration will help policy makers design adequate incentives for stakeholders.

Keywords: Smart Grids, Smart grid regulation, Smart grid investment

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1. INTRODUCTION

Countries around the world are committing to combat the effects of climate change in order to reach a low-carbon future. This effort is demonstrated by the worldwide support of the 2015 Paris Agreement, of which 184 of the 197 Parties invited to the convention have ratified the agreement in their countries (United Nations 2018). Europe in particular has been incredibly focused on these goals, which is highlighted by their aim to become a global market leader in the clean energy transition.

In 2015, The European Union (EU) set lofty energy goals, pledging to reduce carbon emissions by 40%, increase renewable energy penetration by 27% and increase energy savings by 27% by 2030 (European Commission 2015b). In November of 2016, the European Commission (EC) presented the Clean Energy for all Europeans package, a piece of legislation whose three-fold goals include: increasing energy efficiency, leading in the deployment and integration of renewable en-

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ergy, and maintaining a fair deal for consumers (European Commission 2016a). Through this package, the EU plans to mobilize both private and public investments to 177 billion euros per year by 2021 (European Commission 2016a).

Reforming the electricity sector has become a key part of the EU's transition to a clean energy future. Central to this goal is the need to invest in, and upgrade, the electricity grid in order to increase the share of Renewable Energy Sources (RES) from 21% today to 45% by 2030 (European Commission 2015a). Smart grid technology allows for an increased flexibility of distribution grids so that they are able to handle the influx of RES, along with their variable loads, and are a central technology in achieving EU energy goals (European Commission 2006). While this technology addresses many challenges that come with the clean energy transition, cost is a major barrier, and heavy investment is needed (Marques, Bento, and Costa 2014). Tailored regulations can create the framework to incentivize these investments (Cambini et al. 2016; Marques, Bento, and Costa 2014).

The objective of this study is to assess how market and regulatory factors influence stakeholders' investments in smart grid technology in Europe. We focus on investments by Distribution System Operators (DSOs), universities, and technology manufacturers because they are the leading investors in smart grid projects, with a cumulative 2286 million euros invested since 2002 (Gangale et al. 2017). Furthermore, they represent diverse stakeholder interests, as they each have different structures, goals, and relationships with the electricity sector. In order to fulfil this objective, we first provide an analytical review of existing methodologies in the literature; and then apply a selected methodology to compare a dataset of direct investments by these three groups in the EU-28, Norway, and Switzerland from 2008–2015. The work aims at evaluating the relationship between market mechanisms and investments by DSOs, universities, and technology manufacturers to determine how to best design policies to incentivize smart grid investments.

The outline of the paper is as follows: Section 2 provides an overview and definition of smart grids, investment trends, and regulatory policies, along with a review of the existing literature on regulation and smart grid investments. This is followed by the chosen methodology and application of data and statistical tests in Section 3. In Section 4 the analysis and discussion of the results is provided, and Section 5 concludes with some policy recommendations.

2. SMART GRIDS

The traditional electricity grid is made of a large network connecting generation (power stations), transmission, distribution, retailers, and end users. In order to integrate more RES, the grid will have to be updated to be able to handle increased and variable load, and smart grid technology has the potential to upgrade the traditional grid to achieve just that.

While there is no one global definition of what a smart grid is, the literature points to the technology as a modernization of the traditional electricity grid (Connor et al. 2014; Elzinga 2015). The International Energy Agency (IEA) defines smart grids as "an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience and stability," (Elzinga, D., Heinen 2011, 6).

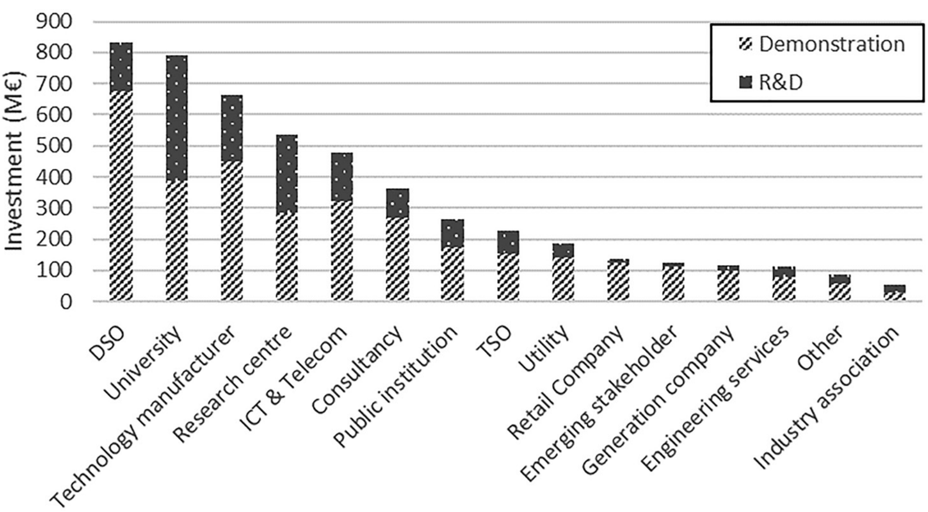
This definition of the smart grid demonstrates a key shift from the traditional grid in the sense that it stresses the importance of technology in facilitating communication and efficiency to better serve the environment. While the traditional grid has no feedback loops, the smart grid allows for an exchange of information from end users back to the grid operator, allowing for an increase in grid efficiency and access to real time prices (Zame et al. 2017). According to the IEA, smart grid technologies are deployed in all stages of the electricity network and include technology areas such as (but not limited to): information and communication integration, distribution grid management, and advance metering infrastructure (Elzinga, D., Heinen 2011). In order to upgrade to the smart grid, there will be many infrastructure changes, thus, a heavy focus on investment on these technologies is necessary (Marques, Bento, and Costa 2014).

2.1 Smart Grid Investment in Europe

The EU has been increasing its focus on smart grids, investing €4.97 billion in 950 projects since 2002 (Joint Research Centre 2018). Due to investment priorities, market-size, and availability of co-funding, there is a wide geographical distribution of investment by different member states (MS): Germany leads with 809 M€ invested over 303 projects, followed by the United Kingdom (UK) with 774 M€ in 197 projects, and France with 680 M€ in 159 projects (Gangale et al. 2017). Investments range from innovative projects to improve the technology, to replacements and upgrades of the physical infrastructure of the grid, to the integration of Information Communications Technology (ICT) infrastructure in distribution (Cambini et al. 2016). According to the Joint Research Center (JRC) database, of the 950 smart grid projects, 540 of them have been Research and Development (R&D) projects and 410 have been Demonstration projects, which fall under the main domains of: smart network management, demand-side management, integration of distributed generation and storage, e-mobility, integration of large scale RES, and others (Joint Research Centre 2018; Gangale et al. 2017).

Figure 1. presents the investment in smart grid projects per stakeholder category. Of these investors: Distribution System Operators (DSOs) have invested the most with €833 million, followed by universities (€790 million), and technology manufacturers (€663 million) (Joint Research Centre 2018).

Figure 1: Stakeholders´ investments in smart grids 2002–2015 (based on Gangale et al. (2017)).



The fact that DSOs are the leading investor-groups in smart grid projects in the EU is quite unsurprising, considering that smart grid technology will directly affect the distribution segment of the electricity industry, and will require massive changes that will influence the role and operations of DSOs (Pereira, da Silva, and Soule 2018). Smart grid technology is important for DSOs because they equip them with the ability to be flexible, which in turn will allow them to keep electricity reliable, affordable, and create more active consumers (Eurelectric, 2014). Universities are also extremely relevant stakeholders because as thought-leaders, their investment interests will fall in line with innovative technologies in their field of study. Smart grids have held a focal interest in the energy space, which explains why universities have invested so much in R&D and demonstration projects in this area. Finally, technology manufacturers have a significant interest in this technology because of the hardware that will need to be developed in order to support smart grids.

Regulations can create a framework that incentivizes investment in smart grid projects (Marques, Bento, and Costa 2014; Cambini et al. 2016). Nevertheless, the cost is still an important obstacle for the transformation of the current electricity system into a smarter one. Regulation can have an important role in setting up a favorable framework that fosters investments. Thus, it is important to understand what regulations are currently in place in Europe related to smart grid technology.

2.2 Smart Grid Regulation in Europe

Because the electricity market is not a traditionally competitive market (only generation and retail are truly competitive, while transmission and distribution are still considered natural monopolies), the regulator holds a very important role in maintaining the balance of these markets. In the EU, each member state is responsible for creating their own energy policy, while the regulator is responsible to create a framework enabling "the integration of new services in the electricity network while apportioning any extra costs in a fair way among stakeholders who benefit from the solutions" (Crispim et al. 2014, 88).

The EU provided a general policy framework for member-states to follow in terms of smart grid deployment. In 2007, the EU created the Strategic Energy Technology Plan (SET), whose focus was to develop the technologies that Europe needed to achieve their 2020 goals (Crispim et al. 2014). Included in the SET plan is to "enable a single, smart European electricity grid, able to accommodate the massive integration of renewable and decentralized energy sources" (European Commission 2007). In an effort to help coordinate these goals, in 2009, the EU set up the Smart Grids Task Force (SGTF), which is made up of five expert groups whose role is to advise on smart grid development and deployment and shape policies (European Commission 2018b). Besides the SGTF, several programs have been created throughout the EU such as: the EU 7th Framework Programme (FP7), Horizon 2020, and The European Electricity Grid Initiative (EEGI), all of which have a focus area in smart grid development (Crispim et al. 2014). The EU TEN-E regulation identified smart grid deployment as one of the 12 Projects of Common Interest (PCI) in 2013, which allows for the possibility for the co-financing of these projects by the Connecting Europe Facility, as well as inclusion in 10-year network development plans (Vasiljevska, Julija; Lucas 2015).

Among the provisions of the Third Energy Package, are stipulations regarding smart meter rollout. The 2009 Directive set provisions regarding smart meter deployment and required MS to replace 80% of electricity meters with smart meters by 2020 (European Commission 2009). Based on EC guidelines, MS conducted cost-benefit analysis (CBA) to evaluate the cost-effectiveness of these programs. While cost estimates vary across member states, the findings from the CBAs found that smart meters can deliver benefits per metering point of €160 for gas and €309 for electricity and an average 3% energy savings (European Commission 2014b). The EC continued to drive smart meter rollout with a 2016 proposal (COM/2016) that stated that all consumers should be entitled to request a smart meter from their suppliers (European Commission 2016b).

The most recent regulatory concern centers around data protection and privacy, especially since the General Data Protection Regulation (GDPR) was passed in 2016 (European Parliament and Council of the European Union 2016). Expert Group 2 of the SGTF published its first recommendations on data protection privacy in 2014 (European Commission 2014a), and finally accepted and adopted a final template of these rules in 2018 (European Commission 2018a).

At the national level, each member-state has their own regulatory mechanisms in place. These can be characterized into three main models which can be coupled with innovation-stimuli: incentive-based, cost-based, and hybrid. An incentive-based model is defined as one in which profits depend on performance factors co-determined by the regulator and the firm; in these schemes, the regulator takes advantage of the information advantage of the firm and delegates certain performance-related decisions to the firm. Berg (1998) defines three essential components of incentive regulation: (1) the use of rewards and penalties to motivate performance, (2) use of the firm's information advantage in setting performance targets (3) the ability of the firm to set their own goals. The incentive-based approach has manifested into several types of regulations such as: "price-caps, rate case moratoria, profit-sharing, banded rate of return regulation, yardstick regulation and menus" (Vogelsang 2001, 3). A cost-based model is defined as one that uses the cost of production to determine prices, independent of demand, that would have been the result of a "competitive" pricing situation. Finally, hybrid models are defined as the combination of cost-based and incentive-based models, the most common application of which sees a cost-based approach with the treatment of capital expenses (CAPEX) and an incentive-based approach with the treatment of operating expenditures (OPEX) (Cambini et al. 2016; Vogelsang 2001; Jerry A. Hausman 2000).

The EU is interested in deploying smart grid technology in order to help attain their sustainability goals. Furthermore, it is evident that there are high levels of investment in this type of technology. Because of the changing nature of the electricity sector in Europe, it is important to understand to what extent the current regulatory framework is facilitating investments (and therefore growth) in smart grid technology. The present study contributes to existing literature by providing an analytical review of different methodologies that look at this relationship between regulations and investment level, and then applies one to a dataset of direct investments by key stakeholders in smart grid technology.

2.3 Prior Work on Smart Grid Investment and Regulations

Various scholars approach the impact that regulations have on smart grid investment through different lenses. Some authors take a micro-economic approach, creating theoretical investment models showing how different regulations affect the decision to invest or not (Agrell, Bogetoft, and Mikkers 2013; Costa, Bento, and Marques 2017; Marques, Bento, and Costa 2014). Others choose a case-study approach, demonstrating different applications of regulation and investments in different countries throughout Europe (Müller 2011; Crispim et al. 2014; Connor et al. 2014). A third approach is through a macro-economic perspective on the question or regulations and investments, but limiting the focus to just considering the role of the DSOs (Ruester et al. 2014; Cambini et al. 2016). Table 4 in the Appendix provides a summary of the approaches, and the following subsections describe the works in detail.

2.3.1 Micro-economic Approaches

Agrell, Bogetoft, and Mikkers (2013) review regulatory solutions for smart grid and Distributed Energy Resource (DER) investments and conclude that the traditional paradigm for network regulation is outdated, so they built an analytical framework to represent regulated investment under private information from a generator or DSO using standard principal agent theory. In their model, they represent three possible scenarios: the first where the DSO is able to make direct investments in DER activities, the second where the regulator contracts with the DSO and delegates the coordination of DER investments to the DSO, and the third where only the regulator coordinates DER investments via centralized investments. Their model tries also to predict under which circumstances investments would be made, and from there, provide policy recommendations that would best incentivize investments. The authors conclude with two policy recommendations. The first, that there should remain high incentive regulation, with the DSO being a key investment driver. The second addresses the question of unbundling the electricity sector. The authors argued that while ownership unbundling has become a key objective to promote competition, this leads to "negotiated agreements" in network regulation and could result in under investment in the technologies (Agrell, Bogetoft, and Mikkers 2013).

Marques, Bento, and Costa (2014) also ascertain that the current regulatory scheme is outdated for the development of smart grid technology, so, they proposed an alternative theoretical regulatory model and applied it to Portugal as a case study. The authors describe a paradox related to smart grid incentives: the more that smart grid technology decreases operational cost, cost-plus regulation becomes less effective while incentive-based regulation increases its effectiveness. Although this paradox exists, the authors conclude that incentives should not risk conventional investments, thus, they propose more research be done on incorporating efficiency obligations and performance regulation, which may be the key for creating a favorable framework for the deployment of smart grids (Marques, Bento, and Costa 2014).

Finally, Costa, Bento, and Marques (2017) demonstrate how different regulations change a firm's interest to invest in smart grid technology, by developing a theoretical investment model evaluating incentives for a firm to invest in projects that have the potential to reduce both OPEX and CAPEX (such as in the case of smart grid technologies). Their model indicates that investment in smart grid technology is more attractive with incentives that put risk-premiums on the technology and increases on expenditures that accrue to the Regulated Asset Base (RAB), while investors will react negatively when cost-saving is passed to the consumer; and, that uncertainties in smart grid technology lead to lower investment opportunities because of increased financial risks. Furthermore, the authors found that a project becomes a more attractive investment as the duration of the time period between regulatory revisions increases, "as less frequent revisions lower the firm's risks of losing the gains realized with investments in cost reduction" (Costa, Bento, and Marques 2017).

The studies focusing on regulations and investments from a micro-economic perspective testify that the current regulatory structure must be upgraded with the changing technology, and while the impact that these new schemes will have on investments is still unknown, the authors generally acknowledge that a more incentive-based approach (rather than a cost-based one) is more attractive.

2.3.2 Case Study Approaches

Müller (2011) presents international case studies of countries (UK, Italy, Norway, and the Netherlands) that increased regulatory measures towards investments in "dynamic efficient" technology (including smart grids). The four case studies demonstrate intense measures and instruments that were implemented in order to stimulate investments, however, an evaluation of empirical data showed no causalities between the type of regulation and investment level (Müller 2011).

Lo Schiavo et al. (2013) explores the case of Italy to describe the evolution of regulatory interventions committed to promoting innovation within the domains of smart grids, smart metering, and electromobility. This analysis demonstrates how regulation on smart grid investment was evolving as the technology was developing. In order to keep up with the changing landscape, network regulation moved from research (to acquire the necessary knowledge), input-based incentives (to add a competitive nature to the demonstration of projects), to deployment of only selected projects; all the while gaining the experience and knowledge to develop a more sophisticated regulatory instrument for smart grid deployment. The Italian regulatory experience demonstrates that innovative regulations, such as output-based regulations based on performance indicators, can facilitate the successful deployment of these projects (Lo Schiavo et al. 2013).

Connor et al. (2014) look specifically at the policies and regulations for the UK related to smart grid technology. The authors demonstrate the innovative policy mechanisms that the UK has employed such as: funding mechanisms, performance-based regulation, and specific distribution and transmission operator incentives (Connor et al. 2014).

Crispim et al. (2014) compare and contrast the UK, Italy, and Portugal as three countries that have implemented smart regulation for smart grid technology development. The authors found that different regulatory approaches are determined by respective market structures, with the UK using flexible regulation mechanisms to create incentives such as RIIO (Revenue = Innovations + Incentives + Outputs), Italy drawing on institutional knowledge and creating incentives for sustainable solutions through rate of return increases, and Portugal basing incentives on the potential benefits of the solution through price caps and efficiency increases (Crispim et al. 2014).

These authors provide valuable lessons on how regulation has been applied in various countries in order to incentivize the deployment of smart grid technology. By focusing on the (more) successful cases of deployment, they serve as a base of comparison for theoretical models described in section 2.3.1.

2.3.3 Macro-economic Approaches

Ruester et al. (2014) focus on distributed energy resources instead of smart grids in particular, to provide insights on how regulation should be adjusted for the DSOs, as they are the regulated body that will feel these changes the most. The authors propose a revision of allowed remuneration to account for increasing cost of distribution and infrastructure investments and to incentivize active system management, along with a distribution network tariff design to guarantee full cost recovery and convey efficient economic signals for the different agents that may connect to the distribution grid. They conclude that the roles of the DSO (vs. Transmission System Operators) must be clearly defined and that the EU should keep a minor role in regulatory requirements by just setting minimum requirements and publish regulatory guidelines (Ruester et al. 2014).

While Ruester et al. (2014) provides a descriptive landscape of current and future DSO regulation, Cambini et al. (2016) analyzed investment data from 2008–2013 for projects in which Distribution System Operators were involved in, considering a compilation of key factors associated with the regulation of electricity distribution networks. Cambini et al. (2016) classified each country the EU-28 (plus Norway and Switzerland) by different regulatory factors and mechanisms: distribution sector concentration, regulatory schemes, and whether or not they employed innovation-stimulus mechanisms. Based on these three classifications, the team ran statistical tests to see if there was a correlation between these market factors and the level of investment. Unlike Müller (2011), Cambini et al. (2016) found three key enablers of smart grid investments: "(1) lower market concentration in the distribution sector, (2) incentive-based regulatory schemes and (3) the adoption of innovation-stimulus mechanisms".

These authors provide both a descriptive perspective of the macro-economic forces at play in determining regulations and investments, and then a practical application of how that theses regulatory factors come into play and affect overall investments.

3. METHODOLOGY

This section describes the research objectives, followed by a preliminary summary of the data, and an overview of statistical methods used.

3.1 Research Objectives

The objective of this paper is to assess the relationship between market mechanisms and the level of smart grid investment by DSOs, technology manufacturers, and universities in Europe, with the aim to assess the design of adequate policies to encourage stakeholder investment. Through statistical analyses, we test the impact of three independent variables (applied to each member state) on stakeholder investments: (1) the level of distribution sector concentration, (2) the regulatory mechanism applied, and (3) the existence of innovation stimulus mechanisms for smart grid investments.

We apply and expand upon the methodology proposed by Cambini et al. (2016) in order to answer this question and provide a macro-level analysis of different stakeholders´ investments considering the European regulatory landscape. This methodology was chosen because it provides a clear way to classify market and regulatory mechanisms to allow for causal statistical analysis, given a small dataset. We expand on the work by considering multiple stakeholder groups and a larger dataset, in order to provide verifiability and a new perspective. We consider data on direct investments by DSOs, technology manufacturers, and universities, further advancing on the existing literature that only considered investments in smart grid projects in which DSOs were involved in.

3.2 Data

The JRC of the EC has collected one of the most comprehensive database of smart grid projects across the EU and published their most recent findings in 2017 in their fourth Smart Grid Outlook report (Joint Research Centre 2018; Gangale et al. 2017). For the present study, investment data from the JRC Smart Grid Outlook Database was used for time period of 2008–2015 (Joint Research Centre 2018).

The investment data extracted from the database corresponds to direct investments by DSOs, technology manufacturers, and universities from 2008–2015 for the EU-28, Norway, and Switzerland. The data was normalized to investments per capita (€/capita) and investments per million Euro GDP (€/M$€_{GDP}$) of each country analyzed. The population and GDP data were obtained from the Eurostat database (Eurostat 2018b, 2018a). Average values for population and GDP from 2008–2015 were used when performing the normalizations. While the JRC provides investment data from 2002, we did not consider data between 2002–2007 because investment level was low at this time, and the data in that period is considered unreliable as there is a high probability that some investments are not listed in the database (Joint Research Centre 2018; Cambini et al. 2016; Gangale et al. 2017).

Following Cambini et al. (2016), the 30 European countries studied were grouped into three regulatory characteristics: distribution-sector concentration (level of market concentration in the electric power distribution sector), regulatory mechanisms (capacity of regulatory scheme to provide incentives), and innovation-stimulus mechanisms (schemes designed by regulators to encourage project implementation). These three regulatory characteristics are considered to be an accurate portrayal of the regulatory panorama in Europe at this time.

For the distribution sector concentration grouping, each country was assigned a concentration of: "low," "medium," or "high:" (1) countries with one distribution system or one system that distributes 99–100% of power were classified as "high", (2) countries where one dominant DSO serves 80% of distributed power or the three largest providers together deliver 60% of the power were classified as "medium," and (3) countries where the three largest DSOs deliver 50% of distributed power were classified as "low". This indicator takes into consideration the number of distribution systems and their share to the overall capacity of the distribution market in each country. The regulatory mechanisms were characterized as incentive-based, cost-based, or hybrid models. Finally, each a country was assigned as either having or not having innovation-stimulus mechanisms in place (Cambini et al. 2016).

A summary of the data classification, as well as the normalized investment values, are provided in Table 5 in the Appendix. Additionally, the descriptive statistics are presented in Table 6, Table 7, and Table 8 in the Appendix.

3.3 Statistical Analyses

In order to determine the appropriate statistical test to be used to compare these samples, three assumptions must be addressed: normality, independent observations, and homogeneity of variances (Cambini et al. 2016).

To determine if a parametric or non-parametric test is to be used, normality must first be addressed (Razali and Wah 2011). In this study, a Shapiro-Wilks test was conducted, which according to the literature, it is considered one of the most powerful normality test available (Shapiro and Wilk 1965; Royston 1982). The results of the normality tests are presented in Table 9 in the Appendix, which show that only a few data points were considered normal. Therefore, both parametric and non-parametric statistical tests were performed for this data set.

The independence assumption is satisfied, since none of the observations in one group overlap with another, in other words, investments in country A do not overlap with investments in country B (Cambini et al. 2016).

The Levene's test was used to test for heteroscedasticity (non-homogeneity of variances) given the non-normal data distribution (Levene 1960; Glass 1966; Field 2009). The results are presented in Table 10 in the Appendix, where most of the points verified homoscedasticity except for the tests on the means for regulatory mechanisms for DSOs, and the values for innovation stimulus mechanisms for technology manufacturers considering the normalization value of €/M€ of GDP. Thus, for all cases except these two mentioned, equal variances can be assumed.

Following the assumptions presented above, both parametric and non-parametric tests were used to check for differences in means among the country groups in terms of investments. For the normally distributed data, a Student T-test was used considering equal variances (except for the cases that did not fit the assumption of homoscedasticity), while for non-normally distributed data a Mann-Whitney U-Test was used.

For the statistical analyses, one-tailed tests were done for the following null and alternative hypotheses:

$$\textit{Null Hypothesis}: H_0 = \mu_1 - \mu_2 = 0 \leftrightarrow \mu_1 = \mu_2 \quad (1)$$

$$\textit{Alternative Hypothesis}: H_1 = \mu_1 - \mu_2 > 0 \leftrightarrow \mu_1 > \mu_2 \quad (2)$$

This implies that under the null hypothesis, the mean values that reflect the level of smart grid investment by the groups of countries, are unchanged by the difference in values of the regulatory factor, in other words, $\mu_1 = \mu_2$ (Cambini et al. 2016).

We performed the Hausman test for endogeneity of the explanatory variables: distribution sector concentration, regulatory mechanism, and innovation stimulus mechanisms (J A Hausman 1978). Each variable was regressed against one other exogenous variable and a selected instrumental variable (the reduced form), obtaining the residuals. These were then added to the structural equation to test for the significance using an Ordinary Least Squares (OLS) regression. All variables were found to be exogenous, therefore confirming no endogeneity problems.

4. RESULTS AND DISCUSSION

The results of the tests to check for differences in means among the country groups in terms of investments, are summarized in Tables 1 to 3. In this section we will go over the results for each factor.

4.1 Results for "Distribution Sector Concentration"

The results for the impact that distribution sector concentration has on investment level are presented in Table 1.

For DSOs, there is not a big change in investment level based on distribution sector concentration and if any, there is a slightly higher investment between medium to high and between low and high, but significance values are too low to make any concrete statements. For both technology manufacturers and universities, there seems to be higher investment in countries with low distribution sector concentration compared to medium and high, with no difference when comparing the level of investments between medium and high concentrations. This only seems to be the case when considering the normalization of €/Capita and does not hold true under the normalization of €/M€ of GDP.

Our analysis on DSO investment deviates from the findings of Cambini et al. (2016), who concluded that the lower the distribution concentration sector, the higher the investment. Cambini´s

Table 1: Average Investment in Smart Grid by Distribution-Sector Concentration

		High		Medium		Low		P-Value T-Test			P-Value U-Test		
Organization		$\overline{X}_H$	n_H	$\overline{X}_M$	n_M	$\overline{X}_L$	n_L	$\mu_L > \mu_M$	$\mu_M > \mu_H$	$\mu_L > \mu_H$	$\mu_L > \mu_M$	$\mu_M > \mu_H$	$\mu_L > \mu_H$
DSO	€/Capita	0.511	7	1.992	15	1.127	8	0.319	0.225	0.139	0.825	0.106	0.152
	€/M€$_{GDP}$/Capita	23.375	7	42.901	15	16.804	8	0.181	0.287	0.363	0.357	0.162	0.397
TM	€/Capita	0.490	7	0.710	15	2.540	8	0.0002***	0.324	0.003***	0.001***	0.185	0.006***
	€/M€$_{GDP}$/Capita	24.070	7	31.180	15	36.006	8	0.372	0.364	0.332	0.591	0.185	0.152*
UNI	€/Capita	0.816	7	2.660	15	4.500	8	0.321	0.313	0.091*	0.002***	0.630	0.014**
	€/M€$_{GDP}$/Capita	40.284	7	62.350	15	44.150	8	0.334	0.323	0.383	0.776	0.581	0.536

Note: * $p \leq 0.1$, ** $p \leq 0.05$, *** $p \leq 0.01$, - $p \geq 0.1$

findings follow the logic that the unbundling of the electricity sector will lead to an adoption of smart grid technology in order to address different challenges of distributed generation (Lopes Ferreira et al. 2011). Thus, the less concentrated a distribution system is, the more incentives there will be to adopt smart grid technology, because it can handle many of the complexities of distributed generation.

Based on our findings, we cannot support the claim that there is a positive correlation between countries with low concentrated distribution sectors and level of smart grid investment. This could be attributed to the point drawn in Agrell, Bogetoft, and Mikkers (2013), that while the unbundling of the electricity sector provides many benefits in terms of competition, it also presents more actors, which leads to more negotiations that at the end of the day, result in compromises that could lead to under investment. Another possibility is that smart grid investment is associated with positive externalities throughout the entire electricity sector, and the benefits are not necessarily appropriated solely by the investor (Costa, Bento, and Marques 2017). Because of this, larger firms or firms under higher concentration may suffer less from free riding when compared to ones with a lower concentration. For DSOs, there is a high significance level between investment in countries employing incentive-based compared to cost-based mechanisms, and a small significance between those implementing hybrid compared to cost-based regulations, with no difference between hybrid and incentive-based schemes. Considering technology manufacturers, countries with hybrid regulatory mechanisms tend to invest more than in cost-based, and there is little difference between other mechanisms. With universities, there does not seem to be any significant difference in the investment level between any of the regulatory mechanisms.

4.2 Results for "Regulatory Mechanism"

The results for smart grid investments based on regulatory mechanism are presented in Table 2.

For DSOs, there is a high significance level between investment in countries employing incentive-based compared to cost-based mechanisms, and a small significance between those implementing hybrid compared to cost-based regulations, with no difference between hybrid and incentive-based schemes. Considering technology manufacturers, countries with hybrid regulatory mechanisms tend to invest more than in cost-based, and there is little difference between other mechanisms. With universities, there does not seem to be any significant difference in the investment level between any of the regulatory mechanisms.

Our results suggest that countries that employ incentive-based or hybrid regulatory mechanisms will spur smart grid investment for market-minded stakeholders, such as DSOs and technology manufacturers. When considering DSOs, our results align with Cambini et al. (2016), who suggest that incentive-based regulation, when compared to cost-based regulations, may better promote

Table 2: Average Investment in Smart Grid by Regulatory Mechanism

		Cost		Hybrid		Incent.		P-Value T-Test			P-Value U-Test		
Organization		$\overline{X}_C$	n_C	$\overline{X}_H$	n_H	$\overline{X}_I$	n_I	$\mu_H > \mu_C$	$\mu_H > \mu_I$	$\mu_I > \mu_C$	$\mu_H > \mu_C$	$\mu_H > \mu_I$	$\mu_I > \mu_C$
DSO	€/Capita	0.199	6	1.053	9	2.119	15	0.069^{*}	0.269	0.171	0.066^{*}	0.599	0.008^{***}
	€/M€$_{GDP}$/Capita	6.532	6	27.354	9	43.745	15	0.125	0.294	0.132	0.145	0.558	0.036^{**}
TM	€/Capita	0.450	6	1.490	9	1.210	15	0.135	0.347	0.117	0.050^{**}	0.682	0.178
	€/M€$_{GDP}$/Capita	11.980	6	43.500	9	30.680	15	0.093^{*}	0.290	0.205	0.050^{**}	0.318	0.235
UNI	€/Capita	1.800	6	2.600	9	3.120	15	0.366	0.389	0.357	0.456	0.347	0.424
	€/M€$_{GDP}$/Capita	33.80	6	47.800	9	62.400	15	0.315	0.351	0.291	0.529	0.907	0.424

investment in smart grid. This idea is also consistent with Marques, Bento, and Costa (2014) who argued that cost-based regulations may not spur investments in a technology such as smart grid, as it is not a capital-intensive technology and can limit its operation cost.

We did not see a difference in investment level in countries employing hybrid versus those with incentive-based models for any of the stakeholders. This can be explained by the fact that most common application of the hybrid approach in Europe is a cost-based approach with the treatment of CAPEX and an incentive-based approach with the treatment of OPEX (Cambini et. al., 2016). Thus, the difference between the two approaches is not very significant, so it would be difficult to find these two mechanisms producing different results when compared to each other.

We found that technology manufacturers, and to a lesser extent, DSOs, tend to have higher investments in countries with hybrid compared to cost-based schemes. This may be attributed to the fact that smart grid technologies do not require an incredibly high capital investment and can save on operational costs (Marques, Bento, and Costa 2014). Thus, a hybrid scheme could be better suited when compared to a cost-based scheme because they take a mixed approach.

In contrast to technology manufacturers and DSOs, universities´ investments were not sensitive to the type of regulatory mechanism in place. One reason of this could be that the universities are more focused on R&D. While universities invest nearly the same amount in both R&D and demonstration projects, other stakeholders mostly invest in demonstration (Gangale et al. 2017). As knowledge seeking institutions, one hypothesis is that universities´ investments are following more the interest of the scientific community rather than regulatory policies or the market. In contrast, DSOs and technology manufacturers are more susceptible to regulatory changes because they are more market-motivated by nature.

4.3 Results for "Innovation-Stimulus Mechanism"

The mean values for smart grid investments based on innovation-stimulus mechanism are presented in Table 3.

Our results confirm a higher investment level by both DSOs and technology manufacturers in countries with innovation stimulus mechanisms in place. With universities, there does not seem to be any significant difference in the investment level between the countries employing and not employing these mechanisms.

The outcomes for DSOs and technology manufacturers suggest that countries that employ an innovation-stimulus regulatory framework encourage more investment in smart grid technology. Our results are consistent with Cambini et al. (2016), who found that the level of smart grid investment was higher when specialized incentives were provided for DSOs. This also aligns with expert opinions that highlighted the importance of shifting DSOs business models so that they participate in building innovative regulatory frameworks to benefit their future business strategy (Pereira, Pereira da Silva, and Soule 2018).

Our results are also consistent with ideas surrounding the risk of investing in a new technology. Using a novel technology is inherently riskier than using an older, but more tested and verified one. Because of higher levels of uncertainty, investors appreciate a higher rate of return for investments in novel technologies. Smart grids, are such a novel technology. Costa, Bento, and Marques (2017) accounted for technological uncertainty in smart grid technology by assuming that investors in this risky new technology would justify a higher remuneration rate. Thus, providing a greater risk premium to incentivize investments. Our results corroborate this assumption in the

Table 3: Average Investment in Smart Grid by Innovation-Stimulus Mechanism

		Yes	No	P-Value T-Test		P-Value U-Test	
Organization		$\overline{X}_Y$	n_Y	$\overline{X}_N$	n_N	$\mu_Y > \mu_N$	$\mu_Y > \mu_N$
DSO	€/Capita	1.621	8	1.341	22	0.382	0.063*
	€/M€GDP/Capita	61.569	8	20.409	22	0.036**	0.012***
TM	€/Capita	2.130	8	0.787	22	0.007***	0.010***
	€/M€$_{GDP}$/Capita	61.930	8	19.490	22	0.041**	0.008***
UNI	€/Capita	3.420	8	2.400	22	0.365	0.118
	€/M€$_{GDP}$/Capita	54.800	8	51.400	22	0.392	0.237

authors´ model, as countries that had implemented innovation stimulus mechanisms drove more investments towards smart grid projects.

We can also substantiate our results by considering real scenarios. In Italy, which is the sixth largest country investor in smart grid projects, the most innovative smart grid demonstration projects were given an additional remuneration of capital cost (2% extra WACC along with original returns) if selected (Lo Schiavo et al. 2013). In Portugal, the regulator, Entidade Reguladora dos Serviços Energéticos (ERSE), has established incentives for projects related to smart grid technology, whereby the DSO is allowed a 1.5% premium return on smart grid investments if the project is projected to provide gains in efficiency (Crispim et al. 2014). As a result of this incentive, Portugal launched the InnovGrid project, where the DSO partnered with other groups to promote interaction between energy companies and customers by installing smart meters (the "EDP Box") that allowed for monitoring of consumption, which was eventually developed into a larger scale project where the DSO installed 31,000 smart meters in Évora (Crispim, 2014). Finally, the UK, which is the largest investor in smart grid projects after Germany, serves as another exemplary case. Since 2015, the UK has implemented the RIIO, a dynamic holistic approach that determined revenue based on innovations, performance based incentives and related outputs (Revenue = Innovations + Incentives + Outputs), which has served a strong incentive towards investing in smart grid projects (Costa, Bento, and Marques 2017; Connor et al. 2014). These are just a few examples of how countries have taken advantage of innovation-based incentives to encourage the development of smart grid projects.

The outcomes of this analysis again place universities´ investment trends in contrast with those of DSOs and the technology manufacturers. Our results suggest that universities´ investments are not spurred by whether or not there are innovation stimulus packages in the country. One reason for this could be the role of the university as a collaborator. According to Gangale et al. (2017), the universities act as the stakeholder that collaborates the most on projects with other stakeholders. Because of this, the level of investments by universities may be more motivated by the different projects they collaborate on, independent of market mechanisms.

5. CONCLUSION

As cost is an important barrier to implementing smart grids, a high level of investment will be necessary in order to further stimulate the development of this key technology. Already, the EU has invested almost €5 billion in these projects, and the pace of development seems to be increasing (Gangale et al. 2017). It is important to understand which organizations are leading the charge in investing in smart grid technology, and how regulatory factors can affect these investments.

This study explored to what extent regulatory factors had an effect on the top three stakeholders investing in smart grid technologies in Europe: DSOs, technology manufacturers, and universities. In order to answer this question, we conducted statistical analyses comparing the level of investment by these groups to three regulatory and market mechanisms: distribution sector concentration, regulatory mechanism, and whether or not innovation stimulus mechanisms were present.

We found that stakeholders reacted differently to these variables. Distribution sector concentration did not seem to significantly and consistently influence investments by the three stakeholders. In terms of DSO investments, this finding diverges with the results of Cambini et al. (2016), who had found that a lower market concentration in the distribution sector enables smart grid investment by this group.

In terms of regulatory mechanisms, market-minded stakeholders, such as DSOs and technology manufacturers, invested more in countries with hybrid or incentive-based regulatory schemes, than those with cost-based models. Furthermore, countries that adopted innovation-stimulus mechanisms were seen to encourage more investments with these two groups. Meanwhile, the level of investments from collaborative knowledge-seeking institutions, such as universities, were not influenced by these factors. These results suggest that future studies should focus on how different stakeholders react to regulatory and market mechanisms depending on their role in the market.

Policy makers should consider these results when designing adequate incentives to each stakeholder involved in smart-grid R&D and/or deployment. Whilst the development of any new technology is based on R&D at universities, technology providers somehow support this R&D and deploy pilot/demonstration projects to be of interest to market operators, such as DSOs. Therefore, policies should address specifically each stakeholder group in accordance with the development/implementation phase of smart-grids in each country. Despite not being empirically tested, from our results we can speculate that there is complementarity between stakeholder investments and regulatory and market mechanisms. For example, incentives could be re-directed to R&D at universities. Development made can then be passed through to technology manufacturers and cascade into DSOs.

We acknowledge the limitation that our dataset only considered direct investments by the three stakeholders, a more robust study could be done with data that considers investments in all projects that stakeholders were involved in.

This paper adds an additional perspective to the question of how regulatory factors affect different stakeholders´ investment level on smart grid technology. Further studies could explicitly look at the relationships between investments within these stakeholder groups. Along with that, other work could be added that take either a more micro or country level approach. On the micro-level, these findings could be further explored using the theoretical investment models presented by Costa, Bento, and Marques (2017), such as considering the unbundling of the electricity sector as a factor affecting investment level. On the country-level, one could expand on previous studies, such as Crispim et al. (2014), and include a deeper look at the specialized incentives, addressing the question of how they affect investment level.

As we attempt to transition to a cleaner energy economy, major updates will need to be done on our electricity sector. The smart grid is one key technology that will be incredibly important in this energy transition, and further mechanisms that encourage investments in these projects should be explored.

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APPENDIX

Table 4: Summary of Previous Works

Approach	Author	Year	Main Findings
Micro-economic	Agrell	2013	High incentive regulations and DSO as a driver leads to higher investments in SG.
	Marques	2014	Cost-plus is less effective than incentive-based regulation, high potential for efficiency and performance regulation to create favorable deployment of SG.
	Costa	2017	Investments higher with incentives that add risk-premiums, lower when cost-saving is passed to consumer. Uncertainties in technology lead to lower investment opportunities.
Country Case Studies	Muller	2011	How UK, Italy, Norway and the Netherlands increased regulatory measures towards SG investments, details instruments, no causality between regulation and investment level.
	LoSchavio	2013	Italian regulatory used 3 step strategy (research, pilot, and roll-out) to incentivize SG.
	Connor	2014	UK used innovative policy measures to deploy SG such as funding mechanisms, performance-based regulation, and DO and TO incentives.
	Crispim	2014	Different regulatory approaches are determined by respective markets; case studies of UK, Italy and Portugal.
Macro-economic	Ruester	2014	Proposed revision to DSO regulatory scheme to incentivize DER.
	Cambini	2016	Lower DSO market concentration, incentive-based regulations and innovation-stimulus mechanisms enable smart grid investments.

Table 5: Normalized SG investments and analyzed regulatory factors for 30 European countries (EU-28, Norway & Switzerland).

Country	Country Code	DSO Investment (€/M€$_{GDP}$)	DSO Investment (€/Capita)	TM Investment (€/M€$_{GDP}$)	TM Investment (€/Capita)	UNI Investment (€/M€$_{GDP}$)	UNI Investment (€/Capita)	Distribution-sector concentration	Regulatory mechanism	Innovation-stimulus mechanism
Austria	AT	22.36	0.83	63.30	2.36	39.23	1.46	Low	Incentive	Adj. Rev.
Belgium	BE	29.25	1.01	49.82	1.72	68.74	2.38	Low	Cost	None
Bulgaria	BG	6.42	0.07	0.00	0.00	12.02	0.13	Medium	Incentive	None
Switzerland	CH	0.00	0.00	9.68	0.76	96.33	7.59	Low	Cost	None
Cyprus	CY	0.00	0.00	0.00	0.00	9.77	0.22	High	Cost	None
Czech Republic	CZ	7.77	3.06	0.87	0.34	0.61	0.24	Medium	Hybrid	None
Germany	DE	25.16	0.85	51.92	1.75	50.25	1.69	Low	Incentive	None
Denmark	DK	1.48	0.50	14.82	4.99	51.25	17.27	Low	Hybrid	Adj. Rev.
Estonia	EE	0.00	0.00	60.92	0.80	87.33	1.14	Medium	Hybrid	None
Greece	EL	9.95	0.18	12.42	0.23	26.52	0.49	High	Cost	None
Spain	ES	85.57	1.96	38.69	0.89	49.77	1.14	Medium	Hybrid	None
Finland	FI	47.00	1.72	86.70	3.17	37.92	1.39	Low	Hybrid	Adj. Rev.
France	FR	51.48	1.63	70.11	2.22	31.46	1.00	Medium	Incentive	None
Croatia	HR	0.00	0.00	0.00	0.00	1.86	0.15	High	Cost	None
Hungary	HU	0.16	0.48	0.00	0.00	0.06	0.17	Medium	Incentive	None
Ireland	IE	26.29	1.09	16.28	0.67	40.75	1.69	High	Incentive	Adj. Rev.
Italy	IT	36.07	0.98	15.20	0.41	17.72	0.48	Medium	Hybrid	Extra WACC
Lithuania	LT	0.00	0.00	0.00	0.00	67.85	0.73	High	Incentive	None
Luxembourg	LU	170.87	14.40	0.00	0.00	341.73	28.81	Medium	Incentive	None
Latvia	LV	0.00	0.00	40.92	0.43	136.38	1.43	Medium	Hybrid	None
Malta	MT	0.00	0.00	0.00	0.00	0.00	0.00	High	Cost	None
Netherlands	NL	29.53	1.15	36.86	1.43	26.29	1.02	Medium	Incentive	None
Norway	NO	2.90	1.66	5.36	3.08	3.10	1.78	Low	Incentive	None
Poland	PL	5.09	0.21	6.86	0.28	5.25	0.22	Medium	Hybrid	None
Portugal	PT	63.21	1.05	127.19	2.12	44.50	0.74	Medium	Hybrid	Extra WACC
Romania	RO	8.50	0.25	22.95	0.67	1.87	0.05	Medium	Incentive	None
Sweden	SE	6.28	2.45	6.45	2.51	6.42	2.50	Low	Incentive	None
Slovenia	SI	127.39	2.30	139.84	2.53	135.24	2.44	High	Incentive	Adj. Rev.
Slovakia	SK	10.09	0.13	15.14	0.20	108.19	1.43	Medium	Incentive	None
United Kingdom	UK	168.75	4.50	32.10	0.86	72.20	1.92	Medium	Incentive	Adj. Rev.

Table 6: Descriptive statistics for Distribution System Operators

		€/Capita				€/M€$_{GDP}$			
Factor	Groups	$\overline{X}$	σ	Max/Min	Obs.	$\overline{X}$	σ	Max/Min	Obs.
Distribution-sector concentration	High	0.51	0.88	2.3/0	7	23.37	46.89	127.3/0	7
	Medium	1.99	3.66	14.4/0	15	42.90	57.63	170.8/0	15
	Low	1.12	0.77	2.4/0	8	16.80	16.85	47/0	8
Regulatory mechanisms	Incentive	2.11	3.59	14.4/0	15	43.74	60.23	170.8/0	15
	Hybrid	1.05	1.03	3.06/0	9	27.35	31.97	85.56/0	9
	Cost	0.19	0.40	1.01/0	6	6.53	11.81	29.24/0	6
Innovation-stimulus mechanisms	None	1.34	3.05	14.40/0	22	20.40	39.52	170.8/0	22
	Implemented	1.62	1.28	4.49/0.49	8	61.56	57.41	168.7/1.4	8

Descriptive statistics: mean, standard deviation, maximum/minimum values (Max/Min) for the country-groups for each regulatory factor considered in the analysis.

Table 7: Descriptive statistics for Technology Manufacturers

		€/Capita				€/M€$_{GDP}$			
Factor	Groups	$\overline{X}$	σ	Max/Min	Obs.	$\overline{X}$	σ	Max/Min	Obs.
Distribution-sector concentration	High	0.49	0.93	2.5/0	7	24.07	51.5	139.8/0	7
	Medium	0.71	0.71	2.2/0	15	31.18	34.6	127.1/0	15
	Low	2.54	1.26	4.99/.762	8	36	30.9	86.7/5.3	8
Regulatory mechanisms	Incentive	1.2	1.10	3.07/0	15	30.6	38.2	139.8/0	15
	Hybrid	1.49	1.63	4.9/.28	9	43.5	41.8	127.1/.86	9
	Cost	0.45	0.68	1.7/0	6	11.9	19.3	49.8/0	6
Innovation-stimulus mechanisms	None	0.78	0.92	3.07/0	22	19.49	22.9	70.1/0	22
	Implemented	2.13	1.52	4.9/.41	8	61.9	51.1	139/14.8	8

Table 8: Descriptive statistics for Universities

		€/Capita				€/M€$_{GDP}$			
Factor	Groups	$\overline{X}$	σ	Max/Min	Obs.	$\overline{X}$	σ	Max/Min	Obs.
Distribution-sector concentration	High	0.81	0.91	2.4/0	7	40.2	48.2	135.2/0	7
	Medium	2.6	7.2	28.8/0.05	15	62.3	87.9	341/0.05	15
	Low	4.5	5.5	17.2/1.3	8	44.1	30.6	96.3/3.09	8
Regulatory mechanisms	Incentive	3.1	7.1	28.8/0.05	15	62.4	86.8	341/0.05	15
	Hybrid	2.6	5.4	17.2/.21	9	47.8	42.5	136.3/.61	9
	Cost	1.8	2.9	7.5/0	6	33.8	39.8	96.3/0	6
Innovation-stimulus mechanisms	None	2.4	6.09	28.8/0	22	51.4	76.4	341.7/0	22
	Implemented	3.4	5.6	17.2/.48	8	54.8	35.8	135/17.7	8

Table 9: Shapiro Wilks Test – Testing for Normality

	Factor	Distribution Sector Concentration			Regulatory Mechanism			Innovation Mechanism	
Organization	Group	High	Medium	Low	Incentive	Hybrid	Cost	None	Yes
DSO	€/Capita	0.002	0	0.876*	0	0.324*	0	0	0.018
	€/M€ GDP	0	0.001	0.225*	0	0.056*	0.003	0	0.143*
TM	€/Capita	0.001	0.18*	0.703*	0.05	0.011	0.024	0.001	0.465*
	€/M€ GDP	0	0.01	0.162*	0.003	0.22*	0.008	0.001	0.107*
UNI	€/Capita	0.126*	0	0	0	0	0.005	0	0
	€/M€ GDP	0.106*	0	0.705*	0	0.268*	0.165*	0	0.022

Note: Considering an alpha of 0.05, $p > 0.05$ data normally distributed (denoted by a *), $p \leq 0.05$ non-normally distributed data set.

Table 10: Levene's Test –Testing for Homoscedasticity

		€/Capita				€/M€ of GDP			
		Levene Statistic		Significance		Levene Statistic		Significance	
Organization	Factor	Mean	Median	Mean	Median	Mean	Median	Mean	Median
DSO	Distribution-sector concentration	1.837	0.937	0.179*	0.404*	2.399	0.833	0.11*	0.446*
	Regulatory mechanism	1.807	0.949	0.183*	0.399*	4.029	1.331	0.029	0.281*
	Innovation-stimulus mechanism	0.46	0.215	0.503*	0.646*	2.199	1.687	0.149*	0.205*
TM	Distribution-sector concentration	0.953	0.828	0.398*	0.448*	0.249	0.02	0.781*	0.98*
	Regulatory mechanism	2.862	0.917	0.075*	0.412*	1.346	0.886	0.277*	0.424*
	Innovation-stimulus mechanism	2.011	1.776	0.167*	0.193*	12.835	7.918	0.001	0.009
UNI	Distribution-sector concentration	0.993	0.319	0.384*	0.73*	1.458	0.707	0.25*	0.502*
	Regulatory mechanism	0.145	0.034	0.866*	0.967*	0.881	0.432	0.426*	0.653*
	Innovation-stimulus mechanism	0.081	0.011	0.778*	0.918*	1.439	0.996	0.24*	0.327*

Note: Considering an alpha of 5%, p> 0.05 data has equal variances (homoscedasticity, denoted by a *), p ≤ 0.05 variances between groups are different (heteroscedasticity).