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SCHOOL OF ECONOMICS, BUSINESS AND INTERNATIONAL STUDIES

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ESSAYS ON

ECONOMIC GROWTH, RADIATION AND ENERGY IMPACT: THE EFFECT OF THE INSTITUTIONAL FACTORS

Ph.D. Thesis

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Piraeus, 2020

I would like to dedicate this thesis to my loving grandfathers Thodoris and Filippos who inspired me to love reading and always learning...

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Abstract

This dissertation consists of five chapters and studies the relationship between the economic growth, radiation and the energy imprint in a framework featuring the effect of institutional factors on three levels: national, European and worldwide. The first chapter describes the motives related to the main subject of the PhD Thesis. The second chapter investigates mainly the relationship between the electric power consumption externalities and economic growth in worldwide level. The third chapter examines the relationship between the total cost of services for radioprotection and the health outcomes in regions of Greece and how regions may be affected. The fourth chapter studies the spillovers of a sequence of shocks to the GDP per capita and Ionizing Radiation Therapy Equipment (IRTE) growth. The last chapter contains useful outcomes of all previous chapters.

The second chapter studies the possible link between economic growth and electric power consumption externalities in a worldwide framework for 89 countries from the period 1990 to 2014. For this purpose, a spatial econometric approach is supported by the results of several statistical tests on the presence of either a spatially lagged dependent variable and/or spatially lagged residuals. Therefore, geographical and economic effects are examined in order to discover patterns of localization of emissions. The results validate the effect of regional externalities of energy consumption pattern on the GDP growth, using spatial, economic, electric and environmental neighboring spillovers. The reasoning behind such externalities is basically the consumption or production patterns between countries caused by energy consumption as well as emissions. The externalities compensate the mechanisms of decreasing returns to scale to capital accumulation within each economy. From this observation, it is increasingly imperative establishing a mechanism for an accurate prediction of energy demands that could contribute with useful information for making decisions on

energy generation and purchase and would have surely a significant impact on preventing overloading and allowing an efficient energy storage.

The third chapter presents spatial hedonic models for environmental hazards and health results. The aim of the chapter is to address the linkages between the total cost of services for radioprotection and the health outcomes in Greece from the period 2010 to 2016 based on a unique dataset of Greek Atomic Energy Commission (EEAE). A spatial analysis is conducted in a hedonic price framework in order to investigate the impact of total service cost Nuts 1 level in Greece. The incorporation of geographical as well as economic and health personnel effects was selected for this study on account on the basis of testing for the existence and magnitude of interregional externalities in conjunction with healthcare expenditure, medical capital investment and examinations MRI. The evidence robustly indicates that the interregional externalities affect regions of economic linkages suggesting strong cross-sectional spillovers than geographical ones. The chapter concludes with the impact segregation of each service for radioprotection, provided by EEAE, to scope out the effect of each one in the total cost services. As anticipated, our findings prove that services for non-ionizing radiation has the strongest influence among the others.

The fourth chapter aims to shed light on spillovers due to a sequence of shocks to the GDP per capita and Ionizing Radiation Therapy Equipment growth concerning 15 European countries over the period 2000 - 2014. A recent method focuses on a convergence between a spatial and global vector autoregression model (GVAR). The specific approach was selected in order to measure the spillovers and a sequence of shocks, conditional on model limitations. Interestingly, the analysis from impulse responses depicts different results for IRTE and GDP per capita from financial and technological shocks respectively. The direct effects exert major impact on the growth of these two variables based on the parameters of the spatially lagged variable. The single most striking observation to emerge from indirect effects is not only the positive sign of a financial shock but also the greater magnitude from a technological one. In contradiction with the earlier findings, the significant spill-out effects across variables of IRTE growth shock in other countries are greater than a GDP per capita growth shock.

Περίληψη

Η διατριβή αποτελείται από πέντε κεφάλαια που εξετάζουν τη σχέση μεταξύ της οικονομικής ανάπτυξης, της ακτινοβολίας και του ενεργειακού αποτυπώματος σε ένα πλαίσιο που χαρακτηρίζεται από την επίδραση θεσμικών παραγόντων σε τρία επίπεδα: εθνικό, ευρωπαϊκό και παγκόσμιο. Το πρώτο κεφάλαιο περιγράφει τα κίνητρα που σχετίζονται με τα κύρια θέματα της διδακτορικής διατριβής. Το δεύτερο κεφάλαιο ερευνά κυρίως την σχέση μεταξύ των διαχύσεων της ηλεκτρικής κατανάλωσης ενέργειας και της οικονομικής ανάπτυξης σε παγκόσμιο επίπεδο. Το τρίτο κεφάλαιο εξετάζει τη σχέση μεταξύ του συνολικού κόστους για τις υπηρεσίες ακτινοπροστασίας και τις επιπτώσεις υγείας στις περιφέρειες της Ελλάδας και πως αυτές μπορεί να επηρεαστούν. Το τέταρτο κεφάλαιο μελετά τις διαχύσεις από μια ακολουθία σοκ στην ανάπτυξη του ΑΕΠ κατά κεφαλήν και του εξοπλισμού θεραπείας ιοντίζουσας ακτινοβολίας. Το τελευταίο κεφάλαιο περιέχει χρήσιμα συμπεράσματα από όλα τα προηγούμενα κεφάλαια.

Το δεύτερο κεφάλαιο μελετά την πιθανή αλληλεπίδραση μεταξύ της οικονομικής ανάπτυξης και των διαχύσεων κατανάλωσης ηλεκτρικής ενέργειας σε παγκόσμιο πλαίσιο για 89 χώρες την χρονική περίοδο από 1990 έως 2014. Γι' αυτό το σκοπό, εφαρμόζεται χωρική οικονομετρική προσέγγιση, ενισχυόμενη από αποτελέσματα στατιστικών τεστ για ύπαρξη είτε μιας χωρικής υστερημένης εξαρτημένης μεταβλητής και/ή χωρικών υστερημένων καταλοίπων. Επομένως, χωρικές και οικονομικές επιδράσεις εξετάζονται για εύρεση πιθανών μοτίβων για την τοπικοποίηση των ρύπων. Τα αποτελέσματα επιβεβαιώνουν την ύπαρξη επιδράσεων των περιφερειακών εξαπλώσεων του μοτίβου της κατανάλωσης ενέργειας στην οικονομική ανάπτυξη, εφαρμόζοντας χωρικές, οικονομικές, ηλεκτρικές και περιβαλλοντικές γειτονικές διαχύσεις. Η αιτία των διαχύσεων αποτελείται κυρίως από την κατανάλωση ή παραγωγή μοτίβων μεταξύ των χωρών προκαλούμενες από την κατανάλωση ενέργειας καθώς και των ρύπων. Οι διαχύσεις εξισορροπούν τους μηχανισμούς μείωσης των

αποδόσεων σε κλιμακωτή συσσώρευση κεφαλαίου σε κάθε οικονομία. Από αυτή την παρατήρηση, καθίσταται ολοένα και πιο επιτακτική η καθιέρωση μηχανισμού για την ακριβή πρόβλεψη των ενεργειακών αναγκών που θα μπορούσαν να συμβάλουν με χρήσιμες πληροφορίες για τη λήψη αποφάσεων σχετικά με την παραγωγή ενέργειας αλλά και αγοράς και θα είχαν σίγουρα σημαντικό αντίκτυπο στην πρόληψη υπερφόρτωσης και στην αποδοτική συγκέντρωσης ενέργειας.

Το τρίτο κεφάλαιο παρουσιάζει χωρικά ηδονικά μοντέλα για περιβαλλοντικούς κινδύνους και αποτελεσμάτων υγείας. Ο σκοπός του κεφαλαίου είναι να αναφέρει τις συνδέσεις μεταξύ του συνολικού κόστους υπηρεσιών για ακτινοπροστασία και των αποτελεσμάτων υγείας στην Ελλάδα τη χρονική περίοδο από το 2010 έως το 2016 σύμφωνα με τη βάση δεδομένων της Ελληνικής Επιτροπής Ατομικής Ενέργειας (ΕΕΑΕ). Εφαρμόζεται χωρική ανάλυση σε ένα ηδονικό πλαίσιο τιμών προκειμένου να διερευνηθεί ο αντίκτυπος του συνολικού κόστους υπηρεσιών σε επίπεδο Nut 1 στην Ελλάδα. Η ενσωμάτωση γεωγραφικών επιδράσεων καθώς οικονομικών και προσωπικού υγείας επιλέχθηκαν σε αυτή τη μελέτη βασιζόμενοι σε τεστ για την ύπαρξη και το μέγεθος διαπεριφερειακών διαχύσεων σε συνδυασμό με τις δαπάνες υγείας, ιατρικού κεφαλαιουχικού εξοπλισμού και εξετάσεων MRI. Τα στοιχεία υποδεικνύουν έντονα ότι οι διαπεριφερειακές διαχύσεις επηρεάζουν περιφέρειες οικονομικών συνδέσεων υποδηλώνοντας πιο ισχυρές αλληλεπιδράσεις από γεωγραφικές. Το κεφάλαιο ολοκληρώνεται με το διαχωρισμό υπηρεσιών ακτινοπροστασίας που παρέχονται από την ΕΕΑΕ, ώστε να απομονώσει το μέγεθος επίδρασης της καθεμίας στο συνολικό κόστος υπηρεσιών. Όπως αναμενόταν, τα ευρήματα μας αποδεικνύουν ότι οι υπηρεσίες μη ιοντίζουσας ακτινοβολίας έχουν την ισχυρότερη επιρροή συγκριτικά με τις υπόλοιπες υπηρεσίες.

Το τέταρτο κεφάλαιο στοχεύει να ρίξει φως σε διαχύσεις έπειτα από μια ακολουθία σοκ στην αύξηση του ΑΕΠ κατά κεφαλήν και τον Εξοπλισμό Ιοντίζουσας Ακτινοβολίας για θεραπεία σε 15 ευρωπαϊκές χώρες τη χρονική περίοδο 2000 - 2014. Μια πρόσφατη μέθοδος επικεντρώνεται στη σύγκλιση μεταξύ χωρικού και διανυσματικού αυτοπαλίνδρομου μοντέλου (GVAR). Η συγκεκριμένη προσέγγιση επιλέχθηκε προκειμένου να μετρήσει τις διαχύσεις και την ακολουθία των σοκ, υπό κάποιους περιορισμούς στο μοντέλο. Είναι ενδιαφέρον ότι η ανάλυση από αιφνίδιες αντιδράσεις απεικονίζουν διαφορετικά αποτελέσματα για τον Εξοπλισμό Ιοντίζουσας Ακτινοβολίας για θεραπεία και το ΑΕΠ κατά κεφαλήν από οικονομικά και τεχνολογικά σοκ αντίστοιχα. Οι άμεσες επιδράσεις ασκούν σημαντική επίδραση στην αύξηση των δύο μεταβλητών βάσει των παραμέτρων της χωρικής υστερημένης μεταβλητής. Η πιο εντυπωσιακή παρατήρηση που προκύπτει από τις έμμεσες επιδράσεις δεν είναι μόνο το θετικό πρόσημο ενός οικονομικού σοκ αλλά επίσης και το ισχυρότερο μέγεθος από ένα τεχνολογικού αντίστοιχα. Σε αντίθεση με τα προηγούμενα ευρήματα, τα σημαντικά αποτελέσματα διάχυσης σε όλες τις μεταβλητές του Εξοπλισμού Ιοντίζουσας Ακτινοβολίας για θεραπεία σε άλλες χώρες είναι μεγαλύτερα από ένα σοκ ανάπτυξης του ΑΕΠ κατά κεφαλήν.

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Chapter 1

Introduction

The present thesis investigates on economic growth, radiation and the energy imprint on three levels: national, European and worldwide. The second chapter concentrates on the link between economic growth, energy consumption and energy emissions on a worldwide level. The third chapter focuses on the relationship between the total cost of services of a national authority responsible for radioprotection in Greece and various external factors related to healthcare. The fourth chapter examines the spillover effect of a sequence of shocks to the global GDP per capita and Ionizing Radiation Therapy Equipment and vice versa in a European framework.

1.1 Motivation

Energy is considered as one of the major components of the fundamental aspect of growth because various production and consumption activities require energy as a primary input (World Economic Forum & IHS CERA, 2012). It is indicated as an important sector of the economy that creates jobs and value by extracting, transforming and distributing energy goods and services throughout the economy. Modern economies are characterized by economic productivity and industrial growth, in which energy is the main operational factor. In recent years there has been extensive interest in a detailed relationship between these parts. Therefore, the relationship between energy and economic growth has been the topic of thorough research and of great interest to economists and policy makers. It is argued that energy drives at least half the industrial growth in a modern economy while representing less than one tenth of the cost of production (Barney & Franzi, 2002). Understanding the link between the economic growth and energy consumption is key to energy policies but the direction of this relationship is not always clear. In many countries, the flow of energy is usually taken for granted but price shocks and supply interruptions can shake whole economies. Advanced economies with high living standards acquire a relatively high level of energy use per capita. According to International Energy Agency, major transformations are depicted in Figure 1.1 that are underway for the global energy sector, from growing electrification to the expansion of renewables, upheavals in oil production and globalization of natural gas markets. Therefore, there will be surely mixed signals on the pace and direction of change not only in energy consumption but also in the economic growth of the continents and countries respectively.

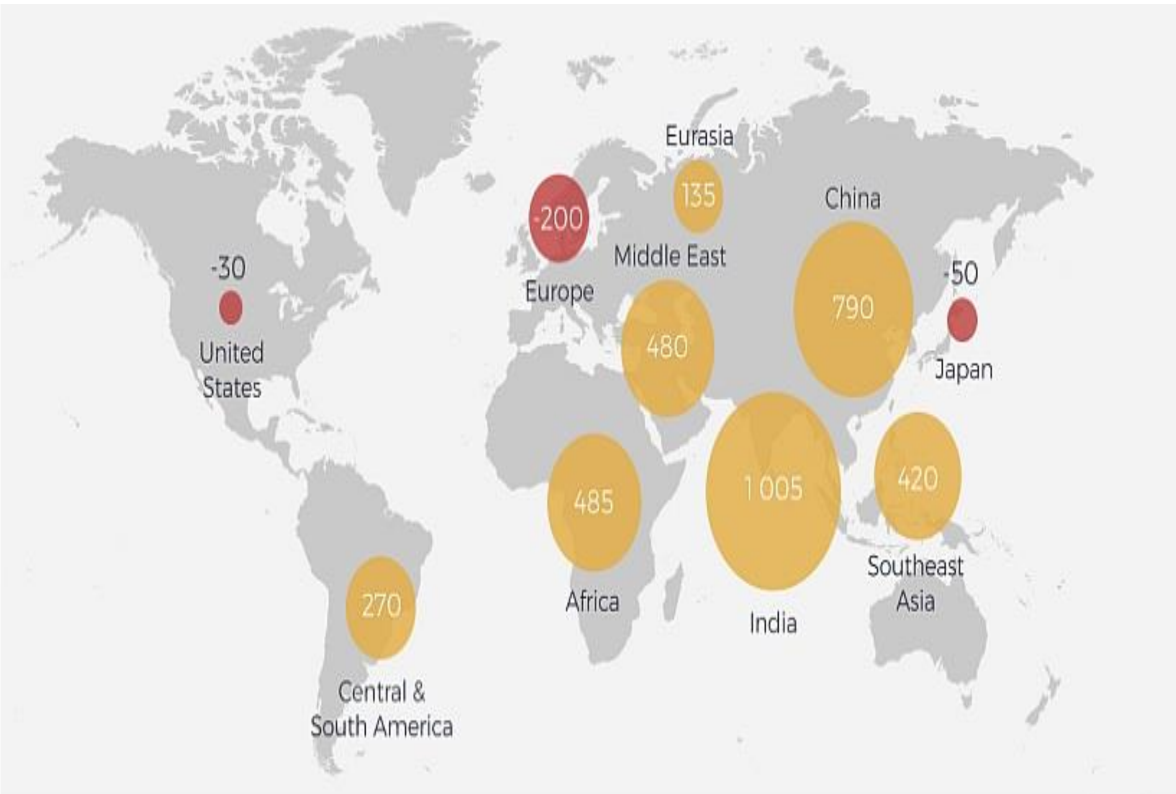

Figure 1.1 - Change in primary energy demand, 2016-2040 (Mtoe)

Towards achieving these high living standards, several negative side-effects of the energy constitute as inhibitory burdens. The most known is various kinds of emissions like carbon dioxide or sulfur that can harm the environment. The vast of the literature validates the positive relationship between the economic growth and the emissions either in short-run or in long-run or both (Dogan & Seker, 2016; Balsalobre-Lorente, et al., 2018; Cowan, et al., 2014). Furthermore, the causality of these two factors differs in the literature reporting not only one-way but also bilateral relationship.

Moreover, many attempts have been made with the purpose of including also an additional factor in this nexus which is electricity with ambiguous results. Electricity consumption is an imperative driver for economic growth and is also related with emissions. However, most studies focus on the relationship on these variables in national, continental or worldwide level and there is a gap in literature for produced spillovers. Externalities depict possible geographically or economically effects of neighboring cities, countries and continents respectively and show the flows of the variables that can provide us useful information.

Expanding the definition of energy in a more detailed level, we meet the term of radiation, which in all modern societies is broadly used in medical applications (medical equipment) for diagnosis and treatment, industry, scientific research and training etc. Radiation is classified in two categories depending on energy and its effect on matter: ionizing and non-ionizing radiation. It performs an important role not only in society but also in various sectors of economy such as public sector, telecommunications – energy, industry – commerce and healthcare. Therefore, the contribution to the society and economy is substantial and multifaceted. Many researchers concentrated on the relationship between nuclear power and economic growth underlining the major importance of this link. According to the statistics for European Union, 507.4 billion Euro in EU GDP were generated by nuclear sector, which is equal to a 3-3.5% share of 2019 EU GDP. In the United States the nearly 100 reactors generate substantial domestic economy value in electricity sales and revenues, which is around $40-$50 billion each year. Focusing on the imperative relationship between medical equipment using ionizing radiation and economic growth was something that no one has ever dealt with it.

Economic performance and healthcare performance are two terms interconnected. Healthcare performance is strongly dependent on the economy, but also on the health systems themselves. Investment in health is not only a desirable, but also an essential priority for most societies. It is compelling for countries to ensure the financial sustainability of health systems, while making a positive contribution to macroeconomic performance. Wealthier countries have healthier populations for a start. Therefore, it is a basic truth that poverty, mainly through infant malnourishment and mortality, adversely affects life expectancy. Based on data from National Accounts, 85% of capital spending in healthcare concerns construction of healthcare facilities and new medical equipment (OECD, 2015). Medical device industry influences directly and indirectly the economic situations in each country (Maresova, et al., 2015). It has been also suggested the validation of the opposite causality of this relationship denoting that the growth of medical device industry is driven by the growing income in countries (Pammolli, et al., 2005). But health financing, through out-of-pocket expenditures, is inequitable and can expose populations to huge cost burdens that block development and simply perpetuate the poverty trap. On the other hand, health systems need financing and investment to improve their performance, yet this need cannot in turn impose an unfair burden on national spending or competitiveness.

A common element of the above subjects is the possible spillover effect that refers to the impact that seemingly unrelated events in one nation can have on the economies of other nations/regions. The term of spillover effect is applied not only for positive impacts but also for negative ones. In an economy, in which some markets fail to clear, such failure can influence the demand or supply behavior of affected participants in other markets, causing the effective demand or effective supply to differ from their unconstrained demand or supply. Such interactions can be considered between the economic growth and the energy consumption, healthcare sector respectively. The diffusion of knowledge is imperative and related with the technology of each sector and contributes to the acceleration of innovations and patents.

Overall, it is considered crucial issue for every company and government organization to be able to predict their financial activities by related variables and datasets. Furthermore, companies and government organizations operate in multiple dynamic environments nowadays that can affect directly the way of operation and the level of difficulty for achieving their goals. In these circumstances, businesses are urged to use several different methods for predictions but in the end, they fall into one of two overarching approaches: qualitative and quantitative. Forecasts and researches are necessary not only for planning ahead their needs and improving the possibilities not to stay behind competitors in the market but also remain financially healthy. Therefore, better decisions by firms and governments improve the behavior of economy as a whole.

Chapter 2

Growth, Electric Power Consumption Externalities and Patterns of Localization of Emissions

2.1 Introduction

The climate change and the global warming are the main greatest causes of environmental pollution. Carbon dioxide (CO_2) is the main source of the greenhouse impact among with oil, coal and fossil fuels. The last three decades the CO_2 emissions have almost doubled their ratio from 17,8Gt in 1980 to 32,1Gt in 2015 according to International Energy Agency (IEA). The threat of increasingly CO_2 emissions is an imperative issue, which concerns the countries' governments universally. According to World Bank, Figure 2.1 shows that the largest countries have the biggest energy consumption per capita in 2013. Furthermore, exhaustible natural resources put in danger the future of energy market and the turn in renewable energy sources is incumbent in the following years. In 1997, the international treaty "Kyoto Protocol" was signed by 37 industrialized countries and the European Community with specified national emissions targets for each country in order to deteriorate the greenhouse gases. Figure 2.2 depicts the top 20 countries in highest electricity generation in 2014. As expected, this specific concern became subject of intense research in economic literature and show that increased CO_2 emissions are related with the global rapid industrialization in order to achieve economic growth. However, results show in Sweden that there is potential to improve energy efficiency for fuel and electricity use in all sectors; energy intensity is not an appropriate proxy for energy efficiency. (Lundgren, et al., 2016)

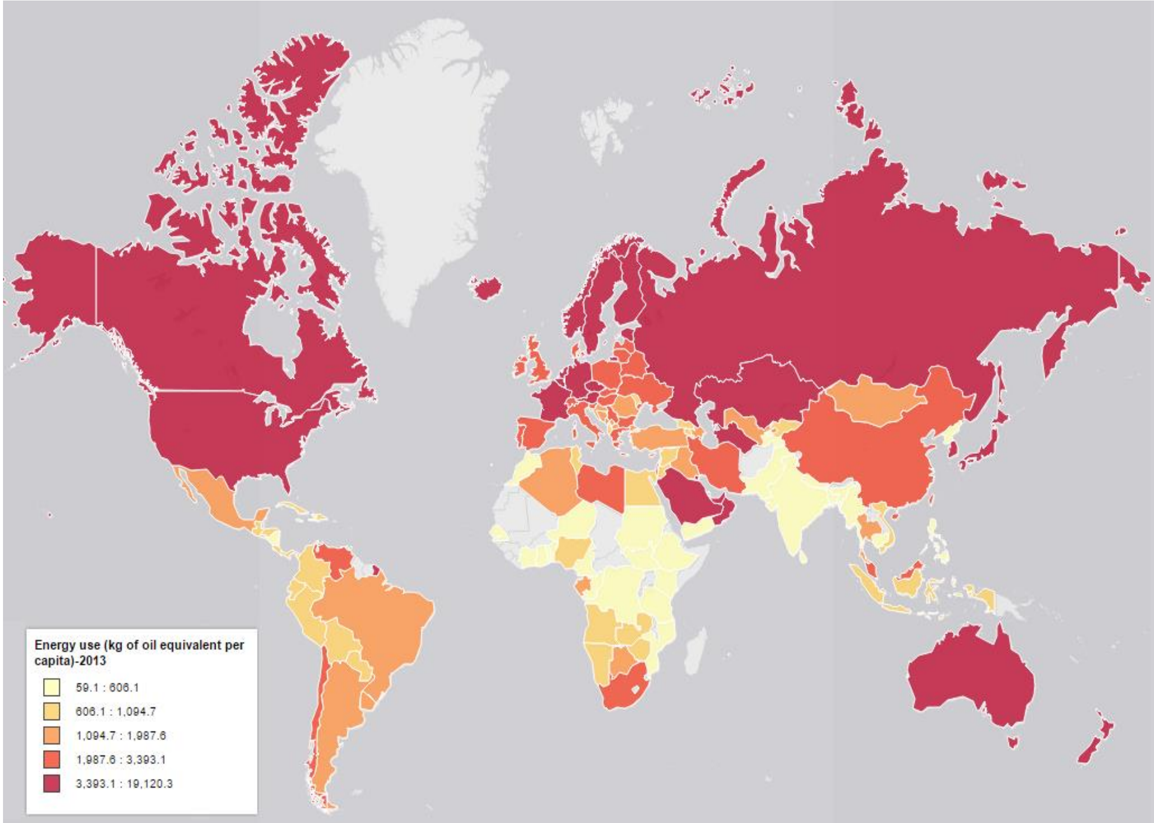

Figure 2.1 - World energy consumption per capita based on 2013

Generally speaking, the relationship between electricity consumption and economic growth can be categorized into four testable causal hypotheses: 1) Growth hypothesis assumes that electricity is a necessary factor of economic growth. 2) Conservation hypothesis postulates a causality running from economic growth to electricity consumption. Yildirim & Aslan used data for 17 highly developed OECD countries and Narayan uncovered the conservative hypothesis for 90 developing countries in a set of 135 countries during 1984-2010 (Yildirim & Aslan, 2012; Narayan, 2016). 3) Feedback hypothesis emphasizes the interdependence between electricity consumption and economic growth. 4) Neutrality hypothesis assumes no causal link. Karanfil and Li considered 160 countries for 1980-2010 and found no evidence for growth hypothesis in anyone income level (Karanfil & Li, 2015). In the long run, the majority of samples provide feedback hypothesis and in short run the conservation and the neutrality hypothesis are implied depending on the region group. Omri surveyed 48 papers related to EG and EC nexus and claimed that 29% support growth hypothesis, 27% feedback hypothesis, 23% conservation hypothesis and 21% neutrality hypothesis (Omri, 2014). Payne categorized 99 papers into these four hypotheses and concluded that there is no homogeneity in a group of countries due to various factors (Payne, 2010).

In order to make proper policy suggestions, it is necessary and essential to clarify the relationship and the direction of causality between them. The purpose of the present paper is to complement and extend the previous literature that has investigated the causal relationship between economic growth and electricity consumption, which has so far provided conflicting results. To do so, we add cross sectional dimension to increase the power of various tests in a multivariate framework, which addresses the problem of omitted variable bias and accounts for different characteristics across countries. A spatial econometric framework is employed to measure the above dimensions.

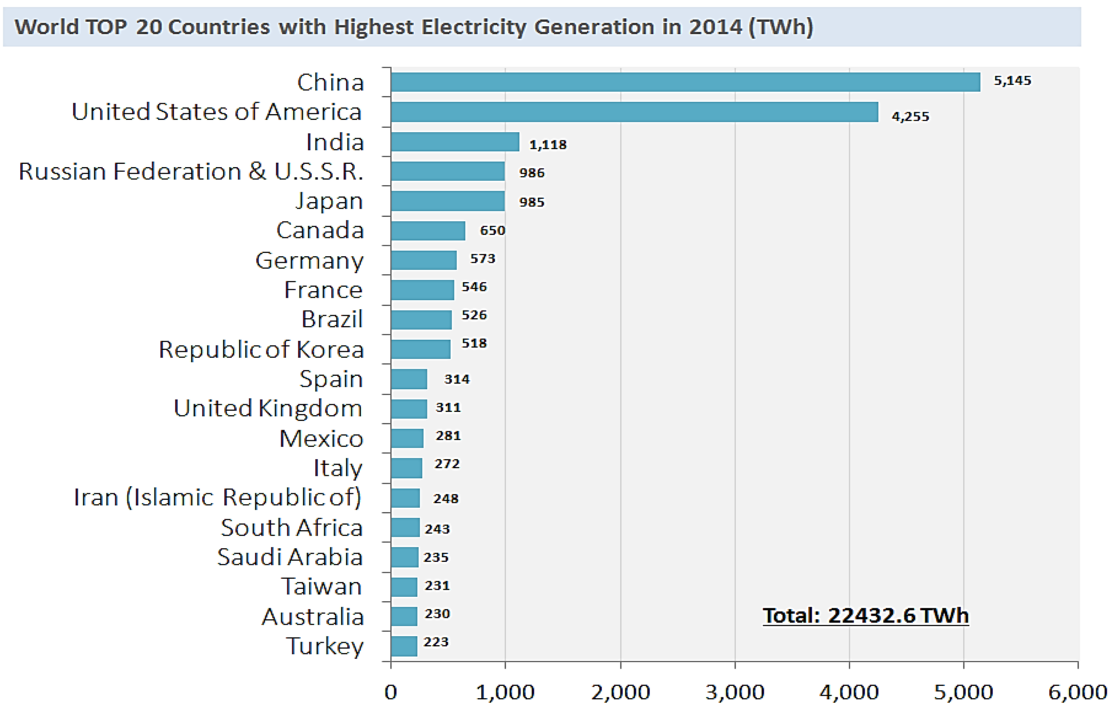

Figure 2.2 - World Top 20 Countries with Highest Electricity Generation in 2014

As a result of this many researchers published a large amount of empirical studies to explain the causal relationship between economic growth and energy consumption. However, the results varied due to different variables, countries and econometric methodologies. More specifically, several studies proposed the existence of an inverse U-shaped relationship between economic activity and the environmental quality, the well-known Environment Kuznets Curve (EKC). The EKC proposed that economic development at the beginning leads to a decline in the environment, but after a specific point of economic growth, a society begins to enhance its relationship with the environment and levels of environmental degradation mitigates. The existence of any direction of this relationship plays a significant role for countries because it can demonstrate policies for the CO_2 emissions and development of the economy depending on the stage and the characteristics of it.

The purpose of this paper is to examine the relationship between the energy consumption, CO_2 emissions and economic growth in 89 countries for the 1990 - 2014 period by using spatial econometric model. The decision to estimate our empirical model using a spatial econometric approach is supported by the results of several statistical tests on the presence of either a spatially lagged dependent variable and/or spatially lagged residuals. For instance, we used several Lagrange multiplier tests proposed by Baltagi and the results of these tests confirm the presence of both spatial effects (Baltagi & Long, 2008; Baltagi, et al., 2003).

The main contribution of this paper is that we elaborate on the dimensions of Electric Power Consumption (EPC) and the patterns of localization. More specifically, we decompose consumption patterns among of geographical and economic effects.

The organizational structure of the paper is divided into four sections: Section 2 we summarize the theoretical and empirical literature on economic growth models. Section 3 provides the data and the methodology. Section 4 discusses about the empirical results and Section 5 provides the conclusions and policy implications.

2.2 Economic growth models through energy consumption with respect to geographical and economic effects

Over the past three decades, many researchers have intensively analyzed the nexus economic growth (EG), environment (EN), energy consumption (EC) reporting ambiguous results. The majority of their studies dealt with the referred nexus in a bivariate framework. Some studies referred to the possibility of omitted variable bias due to bivariate analysis (Lütkepohl, 1982; Zachariadis, 2007). In addition, Zachariadis applied bivariate energy-economy causality tests for G-7 countries concluding that large samples and multivariate models are preferred in order to provide reliable and consistent results. Following that, we have considered significant to involve in our study variables as urbanization, CO_2 emissions, urban population, energy investments with private participation and Foreign Direct Investments (FDI).

The theoritical literature most closely related to our work lies within the relationship and the causality between energy consumption (EC) and economic growth (EG). A study suggested bidirectional causality for PIGST countries (Portugal, Italy, Greece, Spain, Turkey) for 1965-2009 between EG and EC in both short run and long run applying ARDL bounds (Fuinhas & Marques, 2012). A different approach pointed out the significant unidirectional both linear and non-linear causality running from EC to EG in Greece during 1960-2008 using time series data (Dergiades, et al., 2013). An increasing number of studies applied vector error correction model (VECM). An approach used data for 20 net energy importers and exporters for 1971-2002 and found EC causes EG in short run in developing countries (Mahadevan & Asafu-Adjaye, 2007). Moreover, another study revealed bidirectional causality for 38 UFM (Unions for the Mediterranean) in short and long run in developed and developing countries from 1980 to 2010 (Esseghir & Khouni, 2014). It has been suggested a long equilibrium for 12 European countries over 1970-2007 between EC-EG controlling energy prices (Ciarreta & Zarraga, 2010). More recent study uncovered a bidirectional causal relationship for 14 Middle East and North Africa countries between EC and EG, a unidirectional causality from EC to CO_2 emissions and a bidirectional causal relationship between EG and CO_2 emissions for 1990-2011 (Omri, 2013).

A growing body of literature has examined income level as economic and geographical criteria for causal difference. It has been suggested revealed no causal relationship for 82 countries between the variables for low-income level, positive unidirectional causal relationship for below middle and upper-middle income level from EG to EC but negative single direction for high-income level during 1970-2002 (Huang, et al., 2008). Another study demonstrated evidence based on 51 countries over 1971-2005 that there is long-run unidirectional causality from GDP to EC for low-income and bidirectional causality for middle-income but no strong relation for all income groups (Ozturk, et al., 2010). Another attempt highlights the differentiation of income levels for 44 Sub-Saharan Africa countries using country-level time series data during 1980-2007, proving the existence of strong causality in both directions in long run and no causality in short-run in low-income level (Kahsai, et al., 2012).

In recent years there has been considerable interest in the Environmental Kuznet's Curve (EKC) based on the EC-EG relationship. Back in 2010, it has been proposed the outcomes on the long run and the short run equilibrium and at the same time they examined BRIC countries for 1971-2005 (except Russia for 1990-2005) (Pao & Tsai, 2010). A same year study examined the EKC for 43 developing countries based on the short and run-long income elasticity in five regions during 1980-2004. They revealed considerable variation and the long-run income provided less to CO_2 emissions for 35 % of the countries (Narayan &

Narayan, 2010). Another approach used time-series data for 1975-2014 in four countries (Tanzania, Guatemala, China and USA) which represent each income level (low, lower middle, upper middle, high). Specially, they examined the long and short run elasticity and confirmed the validity of EKC hypothesis for low and lower middle-income level (Azam & Khan, 2016).

Increasingly studies examined the relationships between CO_2 emissions, energy consumption and economic growth. A study has suggested a bidirectional causality running from GDP to CO_2 emissions and electricity consumption in China for 1981-2006 (Chang, 2010). Along the same lines a similar study used panel data for 28 provinces in China for 1995-2007. They proved bidirectional causality between CO_2 emissions and energy consumption together with energy consumption and economic growth suggesting the existence of a U-shaped curve between economic growth and CO_2 emissions (Wang, et al., 2011). Focusing on 30 Chinese provinces positive cointegration between real GDP per capita and energy consumption from 1985-2007 estimating a 1% increase of GDP per capita will increase CO_2 between 0,41%-0,43% (Fei, et al., 2011). Another study for China demonstrated linear and nonlinear tests providing evidence of a unidirectional causality from CO_2 emissions to GDP and a bi-directional causality between energy consumption and CO_2 emissions for both tests during 1978-2012 (Wang, et al., 2016). In Turkey, it was concluded that carbon emissions cause energy consumption over 1960-2000 (Soytas & Sari, 2009). In Russia was stated also that there is a strong bi-directional causality between output, energy use and emissions in 1990-2007 while output exhibits a negative significant impact in emissions and does not support EKC hypothesis (Pao, et al., 2011). It has been suggested evidence of bi-directional causality between income, energy consumption and emissions in Brazil during 2008-2013 (Pao & Tsai, 2010). The same year, a study used panel data for eight Asia-Pacific countries from 1971-2005 uncovering long-run equilibrium between EC-EG-

EN (Niu, et al., 2011). Some preliminary work was carried out for 106 countries categorized by income level using PVAR over the period 1971-2011. They found the existence of bidirectional causality between economic growth and energy consumption. In the contrary, the authors claimed that there was no evidence that renewable energy consumption is conducive to economic growth and that developed countries may actually grow-out of environmental pollution (Antonakakis, et al., 2017).

The inclusion of additional variables to the tripartite nexus presents an interesting subject for discussion, especially in terms of economic and environmental development. Trade openness and urbanization were selected for newly industrialized countries (NIC) from 1971-2007. He showed that when EC increases, CO_2 emissions also are increasing, polluting the environment (Hossain, 2011). Capital formation was included for G7 countries and revealed that capital formation and EC caused real GDP in the long run (Narayan & Smyth, 2008). A recent study included capital and urban population and revealed unidirectional causality running from GDP to energy consumption and from energy consumption to carbon emissions in the long run in China during 1960-2007 (Zhang & Cheng, 2009). One year ago, other researchers used annual time series data for Middle East countries for the period 1974-2002 including exports. They estimated that a 1% increase in exports increases GDP by 0,17% and a 1% increase in the GDP, increases electricity consumption by 0,95% (Narayan & Smyth, 2008). FDI was selected for BRIC countries during 1980-2007 (except Russia 1992-2007). Results support the EKC hypothesis and the existence of a bi-directional long-run causality between emissions and FDI with unidirectional causality from energy consumption and real output to emissions and FDI (Pao & Tsai, 2011). Several studies have been carried out by applying the STIRPAT model revealed that urbanization affects the energy consumption and CO_2 depending on the income level of each country (Poumanyvong & Kaneko, 2010; Li & Lin, 2015). Urbanization decreased EC in low and below-income category with significant results. The first study used a panel dataset of 99 countries over the period 1975-2005 while the second introduced a panel dataset of 73 countries during 1971-2010. Analysis from a recent study, using data for 177 countries for 1985-2010, shows FDI could not prove a specific result due to the variance of development, type of energy of each country (Shahbaz, et al., 2016). The impact of renewable energy, combined with macroeconomics policies in 34 countries of OECD during 1990-2010, showed that the economic welfare of a country is not harmed and the advantages of this policy enhance the environmental conditions. A 1% increase of renewable EC will increase GDP by 0,105% and GDP per capita by 0,10% (Inglesi-Lotz, 2016).

An innovative and imperative aspect of the paper is the spatial and economic interactions between countries. According to Tobler's first law of geography, "everything is related to everything else, but near things are more related than distant things". Therefore, the law proves that the variables are dependent and contradicts with the classical econometric model (Tobler, 1970). Geographical location plays a significant role on policy making because a country's policy may environmentally affect regions of neighboring countries. It is crucial to take into consideration the spatial effects as this can lead to model misspecification and biased estimators. Two useful approaches studied the factors in 30 provinces in China with spatial effects. The first study demonstrated the influence of CO_2 emissions with spatial panel data models and came up with that there is significant spatial dependence in CO_2 emissions during 1991-2010, while the second estimated the carbon productivity combined with other factors over the period 2005-2012, based on significant positive spatial dependence and spatial spillover effects with spatial panel data models (Zhao, et al., 2014; Long, et al., 2016). Furthermore, a study in U.S.A. for 48 contiguous states during 1970-2009 revealed that economic radius plays a decisive role between the U.S. states in intra and inter-state CO_2 emissions with positive economic spillovers and negative price spillovers to state-level emissions (Burnett, et al., 2013). Focusing on China, the relationship between economic factors and four gas pollutants was examined and two of them with significant positive spillover effect. Economic growth and urbanization are the key determinants of CO_2, dust and NO_x emissions, while energy efficiency and industrialization do not appear to play a role (Li, et al., 2016). There are potential important forces in the world economy– working through International Technology Diffusion (ITD) – that pull individual countries to advance energy technology, ensuring cross-country convergence in the growth rates of energy technology (Jin & Zhang, 2016).

The objective of this paper is to investigate the causality relationship between the electric power consumption externalities and economic growth trying to discover patterns of localization of CO_2 emissions.

2.3 Data and Spatial Econometric Modelling

Our data source is World Bank's database (2016) and includes 89 countries according to data availability for the 1990-2014 period. All variables are employed with their natural logarithms form to reduce heteroscedasticity. This study examines these countries under four income groups and four regions (Europe, Australia, North & South America, and Asia). According to the World Bank country classification[1], these 89 countries are classified as low income countries (Nepal), lower middle income countries (Armenia, Bangladesh, Bolivia, Georgia, India, Indonesia, Moldova, Pakistan, Philippines, Syrian Arab Republic, Ukraine, Uzbekistan, Vietnam, Yemen Rep.), upper middle income countries (Albania, Azerbaijan, Belarus, Bosnia and Herzegovina, Brazil, Bulgaria, China, Colombia, Costa Rica, Ecuador, Iran Islamic Rep., Iraq, Jamaica, Jordan, Kazakhstan, Lebanon, FYROM, Malaysia, Mexico, Mongolia, Panama Paraguay, Peru, Romania, Thailand, Turkey) and high income (

[1] https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

Argentina, Australia, Austria, Bahrain, Belgium, Canada, Chile, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong SAR, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea Rep., Kuwait, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Qatar, Russian Federation, Saudi Arabia, Singapore, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Arab Emirates, United Kingdom, United States, Uruguay and Venezuela RB). Table *2.1* provide descriptive statistics of the variables employed in each estimation method, while Table 2.3 and Table 2.4 show level estimations and include all regions and countries to study both local and country neighbouring effects.

Table 2.1 - Summary Statistics

Variables	**No of Observations**	**Mean Value**	**Standard Deviation**	**Min**	**Max**
Energy use	1992	4.911	0.494	3.704	6.818
Electric Power Consumption	2044	7.975	1.201	3.569	10.882
CO2 emissions	1835	-1.196	0.580	-3.567	0.804
Energy investments pp	506	19.752	1.824	13.122	24.357
GDP pc 2011	2126	9.632	0.957	7.089	11.807
Urban population	2225	4.161	0.360	2.181	4.605
FDI out	1712	-0.732	2.415	-16.937	4.962
High Income	2225	0.539	0.499	0.000	1.000
Upper Middle	2225	0.292	0.455	0.000	1.000
Lower Middle	2225	0.157	0.364	0.000	1.000
Europe	2225	0.461	0.499	0.000	1.000
South America	2225	0.112	0.316	0.000	1.000
Asia Australia	2225	0.360	0.480	0.000	1.000

In Table *2.2* we use several estimation methods for the model in order to check robustness and to see if there is different sign or magnitude depending on each estimation method. Ordinary Least Squares (OLS) is the simplest estimation method and minimizes the sum of squares of errors. In order to be the best estimator of the relationship between variables, several conditions like Gauss-Markov's have to be met. Weighted Least Squares (WLS) yields more efficient estimates (OLS with robust standard errors works properly using asymptotic methods but is not the most efficient estimator) if the variances of the error terms for all observations are known (to within a constant multiple). Feasible Generalized Least Squares (fGLS) is based on finding an estimator which has the same properties as the true GLS. The model can be estimated by finding the estimated standard deviation for each group by doing the OLS regression, getting the residuals, then using this estimated standard deviation to carry out weighted least squares. Fixed-effects (FE) is suitable for analyzing the impact of variables that vary over time. FE explore the relationship between predictor and outcome variables within an entity, which each one has its own individual characteristics that may or may not influence the predictor variables. Random effects (RE) assume that the entity's error term is not correlated with the predictors which allows for time-invariant variables to play a role as explanatory variables. It is necessary to specify those individual characteristics that may or may not influence the predictor variables. RE allows to generalize the inferences beyond the sample used in the model. Xtabond is appropriate for dynamic panel-data models (models in which there are lagged dependent variables) and can produce the one-step, one-step robust, and two-step Arellano–Bond estimators. Xtabond can handle predetermined covariates, and it reports both the Sargan and autocorrelation tests derived by Arellano and Bond. Generalized Methods of Moments (GMM) enter moment equations. The moment-evaluator method provides greater flexibility in exchange for increased complexity that calculates the moments based on a vector of parameters passed to it.

In this paper, we explicitly address the effect of regional externalities of energy consumption pattern on the GDP growth. The reasoning behind such externalities is basically the consumption or production patterns between countries caused by energy consumption as well as emissions. The externalities compensate the mechanisms of decreasing returns to scale to capital accumulation within each economy. Concretely, economic growth in a given economy may be affected by GDP per capita, Electric Power Consumption (kWh per capita), CO_2 emissions (kg per 2011 PPP$ of GDP) in neighboring economies in terms of geographic criteria or economic criteria. Actually, we focus on spatial and economic externalities by using the following equation:

$$\mathrm{logGDP}_{i\tau} = \eta_i + \lambda \sum_{\substack{j=1 \\ j\neq i}}^{m} w_{ij}\mathrm{GDP}_{j\tau} + \mu \sum_{\substack{j=1 \\ j\neq i}}^{m} c_{ij}\mathrm{EC}_{j\tau} + \nu \sum_{\substack{j=1 \\ j\neq i}}^{m} c_{ij}\mathrm{EM}_{j\tau} + \nu X_{i\tau} + \omega_{i\tau} \qquad (2.1)$$

where, $i = 1, \dots, m$ denotes a region, and $\tau = 1, \dots, k$ a time-period (Lee, 2002). Spatial weights[2] are denoted by w and economic weights by c. Therefore, W and C constitute the respective weight matrices and X is a vector of independent variables that includes energy use (kg of oil per capita), Foreign Direct Investments (% of GDP), investment in energy with private participation (current US$), urban population (% of total).

Consequently, we allow for economic spillovers, in addition to standard geographic ones, and in particular the elements c_{ij}, to depend on the similarity of their economic characteristics in terms of GDP per capita (Lee & Yu, 2010; Le Sage & Pace, 2009). The GDP connectivity matrix differs from any distance matrix in two notable ways. First, the GDP matrix consists of weights where the importance of another country *j* for country *i* is given by the relative magnitude of GDP per capita. Second, the GDP connectivity matrix weighs high-type partners much more heavily than low-type partners, whereas in the distance matrix, any neighbor of *i* must always have *j* as a non-trivial neighbor (Benos , et al., 2015;

[2] For alternative specifications of weight matrices see (Anselin, et al., 1996).

Fotis, et al., 2017). Therefore, the elements of the GDP per capita connectivity matrix are defined as

$$\mathrm{c_{ij}} = 1 - \left|\frac{\mathrm{GDP_j} - \mathrm{GDP_i}}{\mathrm{GDP_j} + \mathrm{GDP_i}}\right| \tag{2.2}$$

and by construction, this index ranges from 0 to 1. If GDP per capita is the same between two countries, then $c_{ij} = 1$. The elements of the GDP connectivity matrix take the value of 0 if the magnitude of GDP per capita of country *j* is dissimilar with country *i*, should the difference in GDP values is really significant. Note that this definition of similarity is symmetric in that $c_{ij} = c_{ji}$ and do not vary over time. We construct this similarity matrix on the basis of the distribution of regional GDP per capita. There is also a substantial variability in the average similarity of any given country's GDP with that of all the other countries in our sample (Yu, et al., 2008).

Our second departure from the standard framework is that the elements of the economic weight matrix, c_{ij}, are not constants but an estimable function of economic distance. In particular, we assume that $c_{ij} \propto e^{-\theta c_{ij}}$ where c_{ij} is economic distance between distance regions i and j and θ is an unknown parameter. Thus, our general specification framework includes more parsimonious specifications or specifications with alternative weights for the border effects. Each variant of eq.(2.1) has been estimated in two different ways. In the first approach, consistent estimates of the parameters are obtained using a non-linear regression methodology, with a bound on the parameter space that imposes a positive value for the exponential decay parameter θ (note that this parameter enters with a negative sign in the econometric model). A negative (zero) value of the parameter would imply that characteristics of a region have a bigger spillover effect the further away they are (are independent of distance). Hence, this parameter is, or should be, positive for significant spatial effects. For the same reason, a test of whether θ is different than zero is not meaningful. Therefore, standard errors are obtained via bootstrapping based on our estimation routine and, by construction, the confidence intervals do not include zero. Asymptotic standard errors, being symmetric in nature, could possibly use confidence intervals that cover zero. This would formally lead to the implication that one cannot reject the hypothesis that the exponential parameter is zero or of the wrong sign, a conclusion that would simply be an artifact of the way symmetric standard errors are computed. The bootstrap standard errors do not suffer from this weakness, but they are asymmetric as a result. However, this first approach does not take into consideration the possible spatial correlation of the disturbance term, resulting in bias of unknown sign in the standard errors. Similar approach is followed, should we define electric or environmental weights by using the latter methodology.

The Model above involves the Maximum Likelihood (ML) estimation[3] of the parameters and asymptotic standard errors in order to account for the possibility of spatial correlation in the error structure. However, the ML estimates are conditional on the consistent estimate of θ, as obtained under the first estimation approach. In other words, the weight matrix is fixed under the ML approach, but not fixed arbitrarily: it is fixed at a consistent estimate (this is reminiscent of what was known in the cross-section literature with non-spherical errors as "feasible GLS"). The use of an estimated θ for the calculation of the weight matrix understates the ML standard errors. It is necessitated by the fact that the standard ML estimation procedures for spatial models consider fixed weight matrices, but it has the incidental benefit that it sidesteps the issue of the confidence intervals for θ possibly covering zero. It is worth keeping in mind though, that this approach still dominates current practice,

[3] For further details, see (Brueckner, 2003).

in which the weight matrix is not only taken as fixed, but also fixed arbitrarily (Keller, 2002).

2.4 Empirical Findings

This section presents the estimates of each method we studied. Table *2.2* presents 10 different estimation methods on 89 countries in order to examine the impact of neighboring GDP growth on regional externalities of energy consumption pattern, using spatial neighboring criteria. The impact of electric power consumption is significantly positive in all estimation models in line with the literature (Squalli, 2007). Ordinary Least Squares (OLS) and Weighted Least Squares (WLS) both present the higher estimate of 0.568 and Arellano-Bond dynamic panel-data estimation (Arellano-Bond1) with one lag appears the lowest at 0.365. Energy use of oil per capita has a negative impact in all methods. As pointed out by Yang the negative impact may be due to the variable used to measure real gross domestic product (Yang, 2000). Apart from WLS all methods create significant results at the 1% level. OLS exhibits the weakest impact (-0.23) while feasible Generalized Least Squares (fGLS) and fGLS with robust present the strongest impact (-0.88). Foreign Direct Investment out (FDI_out) has significantly positive impact on GDP growth using all methods. At the same time, FDI_out presents the lowest impact on Arellano-Bond1, Arellano-Bond2 and GMM methods. Hansen & Rand (2006) also revealed the positive relationship between FDIo and GDP growth even though there was ambiguity with respect to the direction of causality. Investment in energy with private participation has significantly negative influence on GDP growth applying fGLS and fGLS with robust methods at the 1% level of significance. While using Arellano-Bond1 and Arellano-Bond2 the investment in energy appears significant at

Table 2.2 - Baseline Models

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variables	**OLS**	**WLS**	**Feasible GLS**	**Feasible GLS (robust)**	**Fixed Effects**	**Fixed Effects (robust)**	**Random Effects**	**Arellano-Bond (1,2)**	**Arellano-Bond (2,2)**	**GMM**
GDP(pc)_2011 lag1								0,406***	0,504***	
								(0,36)	(0,57)	
GDP(pc)_2011 lag2									-0,103*	
									(0,45)	
Electric_consumption(pc)	0,568***	0,568***	0,483***	0,483***	0,472***	0,472***	0,494***	0,365***	0,367***	0,562***
	(0,31)	(0,32)	(0,25)	(0,49)	(0,29)	(0,74)	(0,27)	(0,3)	(0,31)	(0,73)
Energy_use	-0,235***	-0,235	-0,881***	-0,881***	-0,496***	-0,496***	-0,433***	-0,267***	-0,261***	-0,476***
	(0,69)	(0,17)	(0,6)	(0,78)	(0,57)	(0,112)	(0,54)	(0,36)	(0,38)	(0,19)
FDI_out	0,027***	0,027***	0,031***	0,031*	0,017***	0,017**	0,018***	0,004*	0,003*	0,003*
	(0,7)	(0,7)	(0,4)	(0,12)	(0,2)	(0,5)	(0,2)	(0,1)	(0,1)	(0,1)
Energy_inv(pp)	0,039***	0,039***	-0,038***	-0,038***	0,007**	0,007	0,008**	0,003*	0,003*	0,006***
	(0,8)	(0,11)	(0,6)	(0,9)	(0,2)	(0,3)	(0,2)	(0,1)	(0,1)	(0,1)
CO_2 emissions	-0,242***	-0,242	0,451***	0,451***	-0,234***	-0,235*	-0,263***	-0,010	-0,013	-0,134*
	(0,61)	(0,149)	(0,58)	(0,68)	(0,5)	(0,92)	(0,49)	(0,29)	(0,3)	(0,65)
Urban_population	0,313***	0,313***	0,425***	0,425***	0,328***	0,328	0,280***	0,123	0,154	0,286
	(0,69)	(0,62)	(0,5)	(0,76)	(0,87)	(0,273)	(0,82)	(0,95)	(0,1)	(0,342)
constant	3,751***	3,751***	9,619***	9,619***	6,268***	6,268***	5,962***	3,466***	3,342***	-
	0,52	1,12	0,43	0,49	0,42	0,99	0,41	0,37	0,38	-
N	354	354	306	306	354	354	354	261	260	262
F	251,418	459,060	612,811	917,384	541,475	82,134				
R squared	0,812	0,812	0,924	0,924	0.912	0,912				

Notes: Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors (Sharma, 2011). Also, *, **, and ***, respectively, indicate statistical significance at the 0.10, 0.05, and 0.01 levels.

the 0.10 level, FE and Random effects (RE) reach the 0.05 level moreover the rest of the methods set significant results at the 0.01 level. CO_2 emissions (kg per 2011 ppp $ GDP) has significantly positive impact for fGLS and fGLS with robust estimation methods (Sharma 2011) while OLS, FE, robust FE, RE and GMM turn up significantly negative coefficients. The sign of CO_2 emissions usually depends on the developing phase or income level (Acaravci & Ozturk, 2010; Wang, 2012; Choi, et al., 2010).

Finally, the variable urban population (% of total) has a positive impact on OLS, WLS, fGLS, fGLS with robust, FE and RE method. A recent study explained this positive result might be associated with the fact that when the economy increases, the size of urban core and population rise too, accompanied with important indirect effects (Deng, et al., 2010). The estimated coefficient of the variable urban population ranges from 0.425 (fGLS/fGLS with robust) to 0.123 (Arellano-Bond1).

The next task is to examine Table *2.2* vertically presenting the results of each estimation method. OLS and fGLS both present the lower p-value (below 0.01) for all variables. FE and RE estimation methods have exactly the same impact on each variable with almost all of them to be significant at the 0.01 level. fGLS with robust errors estimates each variable at 0.01 significant level apart from investment in energy with private participation which appears significant at the 0.10 level. FE with robust errors gives CO_2 emissions significant at the 0.10 level, FDI_out at the 0.05 level and for the rest significant ones at the 0.01 level. Arellano-Bond1 and Arellano-Bond2 produce almost the same results regarding the direction and the significance of each variable. Finally, applying GMM estimation method, it reveals FDI_out and CO_2 emissions significance at the 0.10 level while electrical power consumption, energy use of oil and investment in energy with private participation turn also significant at the 0.01 level. This particular estimation method exhibits greater coefficients in contrast with Arellano-Bond1 and Arellano-Bond2.

In Table 2.3 we examine the relationship between geographical, electric and environmental neighboring effects. In column 2, we exclude geographical and environmental neighboring effects, so that we can identify electric's proximity unique impact. Columns 3-5 mix both spatial and electric as well as environmental effects. These specifications assume that neighboring regions with similar electric or environmental structure are closely linked with each other through e.g. energy investments, urban population, foreign direct investments. In column 6, geographical, electric and environmental criteria are included simultaneously and we may identify their distinctive influence and provide insight about their contribution to economic growth.

When only electric proximity is employed (Column 2), the electric impact is strongly positive and significant (0,731). When environmental proximity is used (Column 3), the CO_2 emissions effect is also positive and significant (0,112). In addition, when geographical and electric criteria are included (Column 4), then the electric effect seems statistically significant with less magnitude than the case of column 3 (0,731), while geographical proximity has no effect at all. If environmental neighboring effect is applied instead of electric together with geographic (Column 5), then geographical proximity does not affect significantly while environmental proximity is positive and significant (0,086). In the case, where environmental and electric criteria in conjunction with geographical proximity are involved (Column 6), the electric effect is once again strongly positive than the environmental one (0,474 vs. 0,102) which strengthens compared to the previous case (0,086), indicating the importance of the electric effect.

Furthermore, urban population boosts in Column 1 in which only geographical proximity is applied and has a significant impact in the whole sample ranging from 0,096 to 0,552, while Foreign Direct Investments and CO_2 emissions do not affect at all in all possible models. Moreover, energy use affect negatively neighboring countries in all cases as their coefficients lies from -0,107 to -0,135). This confirms the results of the country-level estimations, although the range of estimates is once narrower. Given baseline estimations, energy investments with private participation ranges from -0,003 to 0,039, while when we use spatial, electric and environmental effects, the contribution ranges from -0,078 to -0,043. Therefore, the variable has negative contribution when using spatial, electric, environmental, economic effects as Table 2.3 and Table 2.4 show. Electric consumption per capita has a strong and positive influence in each column compared to the rest variables ranging from 0,311 to 0,462.

In Table 2.4, we replace geographical proximity with economic in all possible models. When only economic proximity is applied (Column 1), the economic effect of neighboring countries is positive and significant (0,082). When electric proximity is only employed (Column 2), the electric effect of adjacent countries is strongly positive and also significant (0,731). In the last combination with a unique proximity, environmental effect is estimated (Column 3), showing that this particular effect is also positive and significant. When economic and electric criteria are used (Column 4), the economic effect of neighboring countries triple its power while the electric effect is more than halved (0,352). If environmental effect is applied instead of electric together with economic proximity (Column 5), the economic correlation weakens a bit (0,198) compared to the previous case (0,247) while environmental neighbors appear to have positive and significant influence (0,163). Additionally, should economic, electric and emission criteria are all employed (column 6), then all three coefficients are positive and significant, while electric and environmental effects appear to have the lowest impact compared to all columns (0,309 and 0,077 respectively).

Table 2.3 - Spatial, Electric, Environmental Neighboring Effects

	Types of weights					
	Spatial No Electric and No Emissions	No spatial, Electric and No Emissions	No Spatial, No Electric and Emissions	Spatial, Electric and No Emissions	Spatial, No electric and Emissions	Spatial, Electric and Emissions
Model	(1)	(2)	(3)	(4)	(5)	(6)
λ lngdp	0,021 (1,453)			0,009 (1,934)	0,115 (1,472)	0,095 (1,043)
μ lnelectric		0,731* (0,316)		0,504* (0,284)		*0,474** (0,228)
ν lnemissions			0,112* (0,051)		0,086* (0,046)	0,102* (0,055)
GDP(pc)_2011 (spatial)	0,08 (1,223)			0,07 (0,841)	0,08 (0,931)	
GDP(pc)_2011 (energy)		0,775* (0,310)		0,705* (2,140)		0,675* (1,990)
GDP(pc)_2011 (emissions)			0,539* (0,298)		0,494* (1,950)	0,384* (1,820)
Electric_consumption(pc)	0,311** (0,110)	0,405* (1,760)	0,388* (0,210)	0,396* (1,950)	0,462* (1,750)	0,441* (1,690)
Energy_use	-0,119* (0,081)	-0,135* (1,890)	-0,109* (2,010)	-0,108* (1,740)	-0,107* (1,820)	-0,114* (1,690)
FDI_out	0,009 (0,887)	0,003 (1,045)	0,216 (0,996)	0,457 (1,235)	0,592 (0,741)	0,288 (1,425)
Energy_inv(pp)	0,015 (1,456)	-0,078* (0,039)	-0,068* (0,035)	-0,048* (0,022)	-,059* (0,031)	-0,073* (0,038)
CO_2 emissions	-0,034 (0,994)	-0,338 (0,155)	-0,772 (1,781)	-0,759 (1,342)	-0,534 (1,422)	-0,428 (1,228)
Urban_population	0,552* (0,221)	0,197* (0,089)	0,096* (0,049)	0,217* (0,104)	0,164* (0,086)	0,138* (0,068)
constant	1,069 (1,337)	1,431 (1,523)	0,961 (1,112)	1,195 (1,237)	1,536 (1,069)	1,459 (1,942)
N	354	354	306	306	262	245
F-test	704,11	689,75	831,42	715,1	914,4	588,3

Notes: Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors (Sharma, 2011). Also, *, **, and ***, respectively, indicate statistical significance at the 0.10, 0.05, and 0.01 levels.

Table 2.4 - Economic, Electric, Environmental Neighboring Effects

	Types of weights					
	Economic, No Electric and No Emissions	No economic, Electric and No Emissions	No economic, No Electric and Emissions	Economic, Electric and No Emissions	Economic, No electric and Emissions	Economic, Electric and Emissions
Model	(1)	(2)	(3)	(4)	(5)	(6)
λ lngdp	0,082*			0,247*	0,198*	0,175*
	(0,043)			(0,102)	(0,103)	(0,835)
μ lnelectric		0,731*		0,352*		0,309*
		(0,316)		(0,173)		(0,161)
ν lnemissions			0,112*		0,163*	0,077*
			(0,051)		(0,085)	(0,036)
GDP(pc)_2011 (economic)	0,041*			0,031*	0,723	
	(0,021)			(0,017)	(1,639)	
GDP(pc)_2011 (energy)		0,775*		0,642*		0,353*
		(0,310)		(0,340)		(0,162)
GDP(pc)_2011 (emissions)			0,539*		0,245*	0,205*
			(0,298)		(0,125)	(0,117)
Electric_consumption(pc)	0,167*	0,405*	0,388*	0,095*	0,069*	0,058*
	(0,085)	(1,760)	(0,210)	(0,045)	(0,037)	(0,034)
Energy_use	-0,058*	-0,135*	-0,109*	-0,108*	-0,082*	-0,049*
	(0.032)	(1,890)	(2,010)	(0,055)	(0,044)	(0.027)
FDI_out	0,009	0,003	0,216	0,788	1,002	1,329
	(1,553)	(1,045)	(0,996)	(1,741)	(1,172)	(1,859)
Energy_inv(pp)	2,442	-0,078*	-0,068*	-0,076*	-0,043*	-0,038*
	(2,004)	(0,039)	(0,035)	(0,035)	(0,024)	(0,018)
CO_2 emissions	-0,022	-0,338	-0,772	-1,442	-1,684	-1,003
	(0,741)	(0,155)	(1,781)	(0,995)	(1,935)	(1,641)
Urban_population	0,431*	0,197*	0,096*	0,055*	0,082*	0,074*
	(0,211)	(0,089)	(0,049)	(0,022)	(0,041)	(0,037)
constant	0,884	1,431	0,961	1,893	1,968	1,244
	(1,707)	(1,523)	(1,112)	(1,971)	(2.452)	(1,404)
N	354	354	306	306	262	245
F-test	502,75	689,75	831,42	654,2	743,2	495,4

Notes: Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors (Sharma, 2011). Also, *, **, and ***, respectively, indicate statistical significance at the 0.10, 0.05, and 0.01 level

Urban population boosts in all cases but especially when economic effect is only employed (0,431). As Table 2.3, Foreign Direct Investments and CO_2 emissions do not affect at all in all possible combinations of weights of Table 2.4. If we take a closer look in baseline estimations for the variable of energy use, it ranges from -0,235 to -0,881. However, when we use economic, electric and environmental effects, the contribution narrows from -0,049 to -0,135. Thus, we may conclude that energy use has a negative impact when using spatial, economic, electric and environmental effects as Table 2.3 and Table 2.4 show. Moreover, energy investments with private participation in Table 2.4 has the same behavior as Table 2.3.

Results with estimated spatial, economic and environmental weights are presented in Table *2.5* and Table *2.6*. Table *2.5* presents a potential comparison about the effects of different types of spillovers relative to the geographical clusters. In other words, it examines the changes in the sign and magnitude of our estimates should we do not define any a priori weights and allow their impact to vary along the distance. In this section, we present evidence that supports our hypothesis on the role of externalities across countries in the process of energy consumption by estimating the empirical counterpart presented above. We use energy consumption and a number of explanatory variables to capture the fundamental considerations of the models presented before. It should be stressed that when selecting the aforementioned conditioning variables with estimated weights, we do not allow observations to differ markedly across nearby countries, so that their inclusion can be considered as a test of robustness for our hypothesis on the role of externalities. This is so, because it could be argued that the estimated spatial lag of the energy consumption captures the effect of omitted factors within each region that are spatial and economically (or electric/environmental) correlated depending on the connectivity measure used. Spatial and economic (or

Table 2.5 - Economic, electric and environmental neighboring spillovers under estimated weights

	Types of weights		
	Economic, No Electric and No Emissions	No economic, Electric and No Emissions	No economic, No Electric and Emissions
Model	(1)	(2)	(3)
λ lngdp	0,167* (0,065)		
μ lnelectric		0,905* (0,464)	
ν lnemissions			0,238* (0,119)
GDP(pc)_2011 (economic)	0,014 (0,772)		
GDP(pc)_2011 (energy)		0,211 (0,907)	
GDP(pc)_2011 (emissions)			0,841 (0,683)
Electric_consumption(pc)	0,124* (0,061)	0,288* (1,610)	0,331* (0,154)
Energy_use	-0,039* (0.021)	-0,099* (0,045)	-0,075* (0,033)
FDI_out	0,018 (1,309)	0,027 (0,945)	0,438 (0,762)
Energy_inv(pp)	1,129 (1,441)	-0,065* (0,031)	-0,052* (0,031)
CO_2 emissions	-0,088 (0,921)	-0,751 (0,552)	-0,943 (1,332)
Urban_population	0,301* (0,161)	0,154* (0,071)	0,066* (0,032)
constant	1,632 (1,552)	1,889 (1,339)	1,512 (1,294)
N	354	354	306
F-test	781,02	702,41	994,52

Notes: Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors (Sharma, 2011). Also, *, **, and ***, respectively, indicate statistical significance at the 0.10, 0.05, and 0.01 levels.

Table 2.6 - Robustness under estimated weights

	Types of weights		
	Economic, Electric and No Emissions	Economic, No Electric and Emissions	No economic, Electric and Emissions
Model	(1)	(2)	(3)
λ lngdp	0,121*	0,241*	
	(0,058)	(0,119)	
μ lnelectric	0,621*		0,893*
	(0,295)		(0,502)
ν lnemissions		0,174*	0,089*
		(0,089)	(0,048)
GDP(pc)_2011 (economic)	0,014	0,019	0,026
	(0,772)	(0,821)	(0,642)
Electric_consumption(pc)	0,745	0,953	0,548
	(0,912)	(0,759)	(0,686)
Energy_use	-0,035*	-0,163*	-0,187*
	(0.022)	(0,084)	(0,095)
FDI_out	0,023	0,049	1,004
	(0,921)	(0,623)	(0,828)
Energy_inv(pp)	1,189	-0,045*	-0,076*
	(1,773)	(0,024)	(0,041)
CO_2 emissions	-0,318	-0,209	-0,592
	(0,828)	(0,954)	(1,001)
Urban_population	0,215*	0,178*	0,122*
	(0,108)	(0,079)	(0,061)
constant	1,907	1,383	1,952
	(1,721)	(0,995)	(1,047)
N	354	354	306
F-test	682,53	787,38	862,11

Notes: Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors (Sharma, 2011). Also, *, **, and ***, respectively, indicate statistical significance at the 0.10, 0.05, and 0.01 levels.

electric/environmental) level estimations allow us to study neighbouring effects and provide evidence in relation to the dynamics of each country separately (Deltas & Karkalakos, 2013). Finally, spatial econometric estimations include all countries and present combinations of neighbouring effects (Table *2.6*) to verify the robustness of our results.

Summarizing, growth is affected by the presence of similar electrical values, economic characteristics and environmental factors but there is no geographical aggregation. In Table 2.3, spatial proximity is positive but insignificant in all possible models, in contrast with economic proximity in Table 2.4 which is not only positive but also significant in all models. Electric and environmental proximities are significant and positive in both tables highlighting their contribution to growth. Table *2.5* and Table *2.6*, shed more light on the existing literature by introducing alternative definitions of neighboring criteria. Their results do consist key contribution of the current research area

2.5 Concluding Remarks

Energy consumption is a key challenge for building sustainable societies. Due to growing populations, increasing incomes and the industrialization of developing countries, the world primary energy consumption is expected to increase annually every year This scenario raises issues related to the increasing scarcity of natural resources, the accelerating pollution of the environment, and the looming threat of global climate change.

The efficiency of the supply systems and thus the amount of energy consumption is a critical topic to understand energy needs at relatively high spatial and economic resolution. An accurate prediction of energy demands could provide useful information to make decisions on energy generation and purchase. Furthermore, an accurate prediction would have a significant impact on preventing overloading and allowing an efficient energy storage. Many citizens may have a poor or incomplete understanding of the linkage between electricity infrastructure and the risk of power failures in their own region. Creating an awareness of the broader economic and environmental benefits associated with a tighter transmission grid also matters, as indicated by the strong and significant treatment effects for the sample at large (Cohen, et al., 2016). Hence, several computational works have started developing machine-learning models to predict the energy consumption of residential and commercial buildings using features such as weather and energy bills.

In the current paper, we explicitly address the effect of regional externalities of energy consumption pattern on the GDP growth. The reasoning behind such externalities is basically the consumption or production patterns between countries caused by energy consumption as well as emissions. Specifically, we target two different tasks of paramount importance: (i) estimating the average energy consumption using both spatial and economic neighboring relations, and (ii) examining the energy consumption related to growth and patterns of emissions.

Chapter 3

Spatial Hedonic Models for Environmental Hazards and Health Outcomes

3.1 Introduction

In a recent statement, Bill Gates commented that "So we can simulate Richter-10 earthquakes. We simulate 70-foot waves coming into these things. Very cool. We basically say no human should ever be required to do anything, because if you judge by Chernobyl and Fukushima, the human element is not on your side. We have, you know, total fail-safe… Any reactor that a human has to do something… that's a little scary. So, you've got to design something that humans just don't have to be involved in. I love nuclear. It does this radiation thing that's tricky (laughter). But they're good solutions. You know, it was interesting; recently, in Connecticut this natural gas plant blew up 11 guys. It just blew them up" (Gates, 2016). Therefore, there is environmental cost connected with the actual or potential deterioration of natural assets due to economic activities that can classified in two categories: a) costs caused associated with economic units actually or potentially causing environmental deterioration by their own activities and b) costs borne, incurred by economic units independently of whether they have actually caused the environmental impacts (United Nations, 1997). In this paper, we will discuss about radiation, that is described by Greek Atomic Energy Commission (EEAE) as the diffusion of energy within a space; either in the form of particles (electrons for example) or in the form of waves (radio waves for example). Radiation surround people by a vast volume of natural and artificial sources of radiation. Through human’s senses, people can understand a tiny area of the radiation spectrum: visible light through our eyes and infrared radiation through heat. Their existence has become more perceivable during the last century due to the development of technical means for their detection.

Natural radiation sources are the natural radioisotopes found in the soil, subsoil, air, water. The sun is also a natural source of radiation and so is the cosmic radiation emitted by celestial bodies. Artificial sources of radiation are the devices, which generate radiation, such as the equipment used in medical applications, lamps, radars, antennas, etc. Radiation is characterized by its wavelength or its frequency and the energy it bears. Depending on such energy and its impact to the matter, radiation is classified into two big categories: ionizing radiation and non-ionizing radiation.

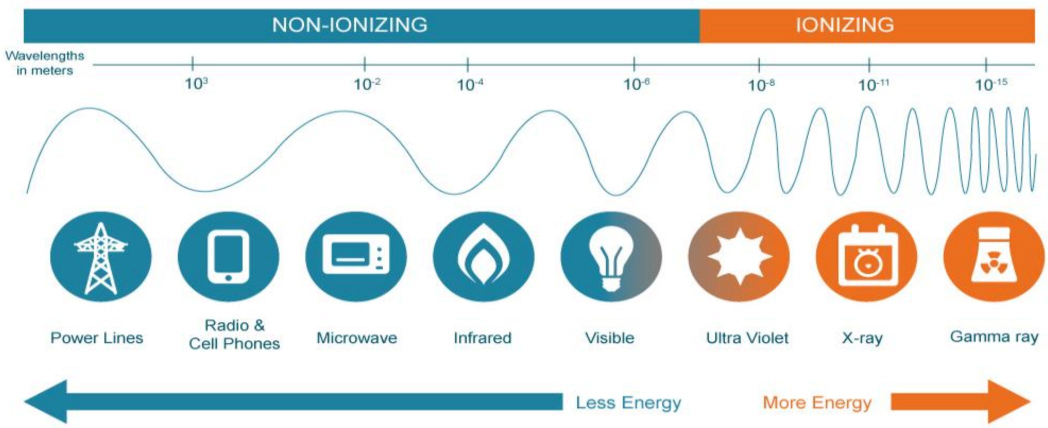

Figure 3.1 - The scale of electromagnetic radiation, broken down into categories of ionizing & non-ionizing radiation

Ionizing radiation is of high energy, capable to penetrate into the matter, to produce ionization of the atoms, to break chemical bonds and cause harm in living matter. The most known types of radiation are the X-rays, produced by the radiological equipment used in medicine, and the radiation α, β and γ, produced by the unstable nuclei of the atoms. The ionizing radiation is penetrating, depending on their type and energy. The energy transferred to the mass, per mass unit, is called absorbed dose. The probability of affecting the human health is directly related to the absorbed dose.

Non-ionizing radiation, known also an electromagnetic radiation, is not capable to cause ionization, but capable to affect the cells electrically, chemically and thermally. In this category are included: 1) the static electric and magnetic fields, 2) the low frequency electric and magnetic fields, 3) the radio waves and the microwave frequency fields, 4) mobile phones base stations, radar systems), 5) the infrared radiation, the optical radiation, 6) the ultraviolet (UV) radiation.

In 2017, according to Strengthening Capacity for Universal Coverage (SCUC) action, an effort has been made to build a country-wide medical equipment inventory including status and condition in Greece. They also rely on manufacturer's services for these technologies and the way the private sector operate depends on the individual companies. The data collected were compared amongst them in order to obtain the most reliable picture of the situation.

The term High Value Capital Equipment (HVCE) refers to high-tech medical devices that includes all equipment considered costly both in terms of initial investment and operation, requiring specially trained personnel for its use and needs regular quality control, preventive maintenance and management procedures, to function properly and safely. Most of these devices belong to the diagnostic and therapeutic radiation technology category, according to the Global Medical Device Nomenclature (GMDN). In this policy brief, the following groups are considered as Magnetic Resonance Imaging (MRI), Computed Tomography Imaging (CT), Positron Emission Tomography / CT (PET/CT), Single Photon Emission Computed Tomography (γ-Camera/SPECT), Radiotherapy Units (RT) and Mammography Units (MMUs).

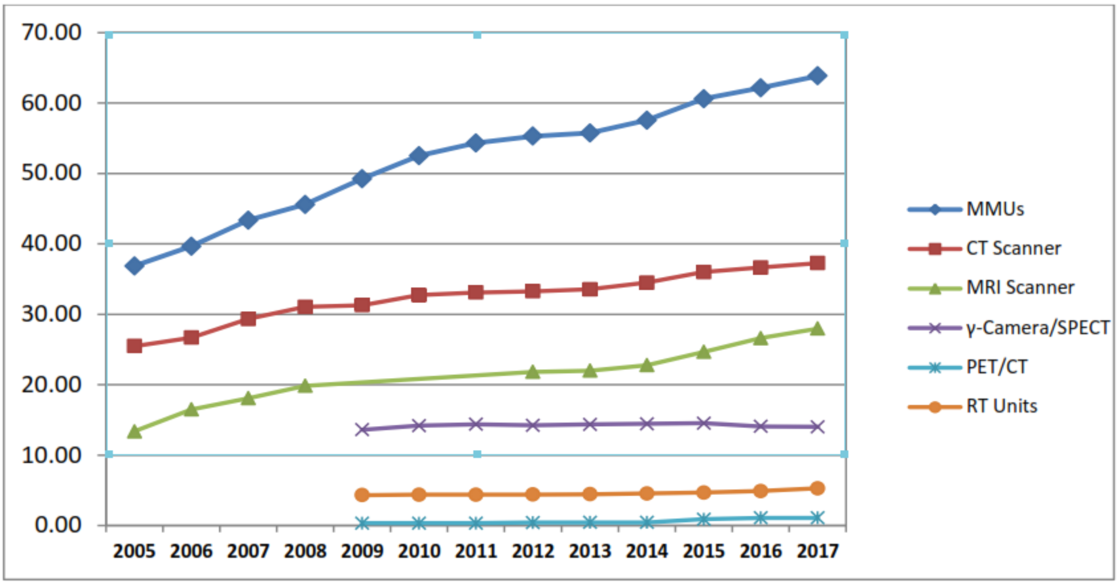

Figure 3.2 - Evolution of HVCE per million population in Greece from 2005 to 2017

As shown in Figure 3.2, the overall HVCE installed per million population in Greece, constantly increased from 2005 to 2017. All HVCE technologies followed this trend during the same time period, with the exception of γ-Cameras/SPECT that remained constant.

Our dataset refers to the number and type of radiation facilities, and systems[4] operating in Greece, EEAE's database show us with great detail what is registered and integrated in the licensing procedure. Regarding the facilities of non-ionizing radiation, EEAE inspection work concerns more than 10.000 mobile phone base stations, electric power transport lines and substations, TV and radio stations antennas, radar and satellite earth stations.

[4] Categories and number of radiation facilities in Greece by EEAE (2015): Radiology (1157), Nuclear medicine (176), Teletherapy (linear accelerators) (25), Teletherapy ^{60}Co (7), Brachytherapy (HDR/LDR and seeds ^{125}I) (16), Radiotherapy x-ray (1), Magnetic Resonance Imaging (MRI) (266), Research (192), Industrial units with radiation systems and sources (332), Blood irradiators (13), Isotopes production unit (1), Sterilization unit (1), Veterinary laboratories with x-ray systems (279), Dental laboratories with x-ray systems (7493). Special facilities: Research Nuclear Reactor (1), Tandem Accelerator (1), Interim storage of radioactive sources and waste facility (1)

Figure 3.3 - Contribution of EEAE to economy and society

The operation and the regulatory work of EEAE relates and contributes to a wide range of individuals, institutions and financial activities, as Figure 3.3 shows. Nevertheless, the real question is "Can this contribution be measurable?" and if yes "Which approach/technique will be used?". In such cases, the hedonic approach is applied. In the field or radioprotection, this approach became very widely known after the accident of Fukushima. Many authors addressed the problem of decreasing prices in the housing market around nuclear power plants in several countries. Although this approach is interesting, previous work has only been focused on the disastrous accident and limited to the impacts of it

3.2 Methodology

The hedonic approach to economic assessment can be used for evaluating the economic value of environmental goods that can be considered aggregates of different attributes, some of which, as they cannot be sold separately, do not have an individual price. The basic premise of the hedonic pricing method is that the price of a marketed good is related to its characteristics, or the services it provides, assuming that the price of a product reflects embodied characteristics valued by some implicit or shadow prices. The above approach attempts to estimate the economic value using implicit prices of single characteristics of a good based on market values of the whole good. It assumes that the economic value of each attribute influences the total value of the commodity and can thus be revealed as a difference in price, assuming all other characteristics to remain constant. If the market good is closely related to the use of a natural resource, then the hedonic approach is more suitable for the evaluation of the natural resource. Rosen's hedonic model (Rosen, 1974) contributed to the change of economist's view that the marginal willingness to pay (MWTP) for environmental public goods can be inferred by the explicit price of a property.

The hedonic pricing model has many advantages, including the ability to estimate values, based on concrete choices, particularly when applied to property markets with readily available, accurate data. The method is flexible enough to be adapted to relationships among other market goods and external factors.

At the same time, there are a number of limitations in the use of hedonic pricing method such as: information, measurement validity, market limitations, multicollinearity and price changes. Additionally, it does not always embody external factors or regulations such as taxes and interest rates, which could affect significantly market prices.

Several studies dealt with measuring the monetary value of man-sievert or the willingness to pay to reduce exposure to ionizing radiation. Schneider (Schneider, et al., 2000) revealed that the willingness to pay for a reduction of probability of developing a radiation-induced cancer for a member of the public should be between 2 and 6 times higher than that of a worker. The resulting monetary value of the man-sievert to be applied in optimization studies for the reduction of public exposures is ranged between 50k euros/man.Sv and 200k euros/man.Sv. Katona (Katona, et al.,

2003) supported that the monetary value of the unit averted collective dose at the reference individual dose is practically both for occupational and public exposures due to high uncertainty ranges. They also suggested that the difference between public and occupational situations seems to be not significant according to WTP method. Byoung-il concluded after a comparison of the internationally and domestically managed monetary values of man-mSv, that the most values by NPP operators are 2-10 times greater that the values used by the regulatory agencies in South Korea (Byoung-il, et al., 2012). Byoung-il also found that the age distribution of radiation workers in NPPs was composed mainly of 20–30 years old (83%) for 1990–1994 and 30–40 years old (75%) for 2003–2007 while most (77%) of the NPP radiation exposures from 1990 to 2007 occurred mostly during the refueling period in South Korea (Byoung-il, et al., 2010). Seong and Sun tried to reach an equilibrium balancing the costs and benefits of protection and concluded that under economic fluctuation, the real value should be equipped to reach optimization. Furthermore, step function models can provide with a fair equilibrium point for protection without loss of generality (Seong & Sun, 2009).

The structure of the paper is as follows. In Section 2, we summarize the theoretical and empirical literature on hedonic approach in several categories. Section 3 specifies our empirical model, presents the econometric methodology and data we use. The empirical findings are analyzed in Section 4, while in the last Section we outline the concluding remarks and policy implications.

3.3 Literature

The hedonic approach has been widely used in three strands: housing market, environmental pollution and health problems. Combining these categories allows us for a larger body of research. Below we will list each strand with specific literature in order to see the contribution in each category.

The literature about hedonic pricing focuses mainly in real estate issue and housing prices. Municipalities with higher rates of owner-occupied housing had higher shadow prices of housing because consumer MWTP was positively correlated with community measures of exclusion, while those considered to be more "pro-growth" by researchers in the 1990's had smaller estimated shadow prices of housing (Sunding & Swoboda, 2010). Nicodemo and Raya revealed the change in house prices in Spain is larger at both lower and higher percentiles during 2004-2007 and this difference is explained by coefficients (Nicodemo & Raya, 2012). Apartment complexes have height characteristics as well as length and width characteristics, which affect prices. Some of the characteristics to be price determining were the floor space area of the unit, the total land area of the building, the number of units in the building, the total number of stories in the building, the height of the sold unit, the age of the structure and the amount of excess land. (Diewert & Shimizu, 2016). According to Miura and Asami, housing price can be more sensitive to market reputation information than housing rent, and hence the present approach may contribute more to the improvement of estimation models for housing prices (Miura & Asami, 2011). Major factors that affect neighborhood reputation like school quality, crime, and job accessibility have impact on house prices for the Greater Boston Area and the MWTP will vary as the conditions of the housing market change (Zabel, 2015). D'Acci has shown how the quality of Turin can change the property value up to 143%, and how people expressed a willingness-to-pay of around 540€/year for an improvement of the quality of the area where they live (D'Acci, 2014). On the contrary, Grislain-Letrémy and Katossky find that housing prices and the MWTP for prevention strongly differs among hazardous industrial areas, even among one category of industries, and depends on the distance from these facilities in France (Grislain-Letrémy & Katossky, 2014).

Taking account environmental criteria to hedonic approach, MWTP for environment may differ with the level of income because income tends to influence MWTP positively and significantly in Sweden (Hokby & Söderqvist, 2003). Kuminoff et al suggested that large gains in accuracy can be realized by moving from the standard linear specifications for the price function to a more flexible framework that uses a combination of spatial fixed effects, quasi-experimental identification, and temporal controls for housing market adjustment (Kuminoff, et al., 2010). Chen applied a basic hedonic pricing model for 968 apartment transaction records during July-December 2013 in order to examine if river restoration could reverse negative externalities of polluted watercourses to positive externalities. Water quality improvement could increase apartment values by 0.9% and river restoration could increase property values by 4.61% (Chen, 2017). Bayer et al. used wage-hedonic model on the assumption that households move freely among locations and conclude that moving is costly and the variation in housing prices and wages may no longer reflect the value of differences in local amenities. Their model revealed also an estimated elasticity of willingness to pay with respect to air quality of 0.34–0.42 (Bayer, et al., 2009). Saphores and Li analyzed 20.660 transactions of single-family houses sold for 2003 and 2004 in Los Angeles and find that additional trees and grassy areas have different impacts on the value of houses and residents may want additional trees but they are unwilling to pay for them (Saphores & Li, 2012).

Besides, the literature of hedonic approach focuses also on the relationship between health and housing prices. As Portney suggested, it may be possible to draw inferences about individuals' valuations of risk by combining estimates of the effect of air pollution on both property values and human health risks (Portney, 1981). Smith and Huang illustrated the potential sensitivity of estimates to local conditions and the need to incorporate not simply differences in air pollution conditions in each location, but also economic variables important to the MWTPs transferred to individual cities (Smith & Huang, 1995). Davis measured the effect of health risk on housing values by exploiting an isolated county in Nevada where residents have experienced a severe increase in pediatric leukemia (Davis, 2004). The estimated MWTP to avoid pediatric leukemia risk is used to calculate the value of a statistical case of pediatric leukemia. Nau and Bishai applied hedonic pricing model for 371 MSAs from 1990 to 2010 and revealed that communities that invest their revenue from property taxes in public health infrastructure could benefit from a virtuous cycle of better health leading to higher property values while communities that don’t invest could widen geospatial health and wealth disparities (Nau & Bishai, 2018). Chay and Greenstone used the housing market via hedonic approach to estimate the economic benefits of air quality finding the elasticity of housing values with respect to particulates concentrations ranges from -0.20 to -0.35 (Chay & Greenstone, 2005). Hanna revealed that the estimates suggest that being a mile closer to a polluting manufacturing plant reduces house values by 1.9%, in the New England states (Hanna, 2007). While Davis examined housing values and rents for neighborhoods in the United States, where power plants were opened during the 1990’s and finds that neighborhoods within 2 miles of plants experienced 3% – 7% decreases in housing values and rents, with some evidence of larger decreases within 1 mile and for large-capacity plants (Davis, 2011). Currie et al. measured the housing market and health impacts of 1,600 openings and closings of industrial plants that emit toxic pollutants (Currie, et al., 2013). They found that housing values within one mile decrease by 1.5 percent when plants open, and increase by 1.5 percent when plants close. Greenstone and Gallagher developed estimates of the local welfare impacts of Superfund sponsored clean-ups of hazardous waste sites and they find that

Superfund clean-ups are associated with economically small and statistically indistinguishable from zero local changes in residential property values, property rental rates, housing supply, total population, and the types of individuals living near the sites (Greenstone & Gallagher, 2008). Tian et al. examined if transportation infrastructures have a positive influence on housing prices in Salt Lake despite its health risks, such as noise and air pollution that impact negatively. They find that the negative impacts are greater than the positive ones and residents are willing to pay in order to reduce environmental health risks (Tian, et al., 2017).

3.4 Empirical Framework

3.4.1 Data

Our sample includes 57.314 unique charges for services of Greek Atomic Energy Commission related with the radioprotection over the 2010-2016 period. The total cost of services is used as the dependent variable. This specific dataset, provided by the Information Technology Department of EEAE, contains detailed information about the type of institution, the region of the institution, the quantity of charged services, the department of the service, the exact year, the subtotal, the tax due and the total cost of each service of EEAE. Healthcare expenditure is taken into account because it quantifies the economic resources dedicated to health functions, excluding capital investment, which is a separate variable for our model. The data source is from Regio database for the period 2010-2016. Examinations of MRI refer to the total number of MRI exams in public and private sector from 2013 to 2016, according to National Organization for the Provision of Health Services (EOPPY). The number of Radiotherapy (RT) units, based on the data of EEAE, is the next variable that is taken account for our econometric model over the 2010-2016 period.

Table 3.1 - Variables in Hedonic Model

Name	Definition
Cost	Total cost of service
Healthcare expenditure	The economic resources dedicated to health functions
Medical Capital Investment	The economic resources dedicated to investment for medical equipment
Examinations MRI	Number of examinations with Magnetic Resonance Imaging (MRI)
RT units	Radiotherapy units in Greece
D_dos	Dummy variable equal to one when someone pays for services of Dosimeters
D_lic	Dummy variable equal to one when someone pays for services of License
D_rdl	Dummy variable equal to one when someone pays for services of Radiation Therapy & Radiology
D_cal	Dummy variable equal to one when someone pays for services of Calibration
D_ind	Dummy variable equal to one when someone pays for services of Industrial Applications
D_edu	Dummy variable equal to one when someone pays for services of Education and Research
D_mri	Dummy variable equal to one when someone pays for services of Magnetic Resonance Imaging (MRI)
D_trans	Dummy variable equal to one when someone pays for services of Radiopharmaceuticals' Transportation
D_rdt	Dummy variable equal to one when someone pays for services of Radiation
D_nion	Dummy variable equal to one when someone pays for services of Non-ionizing Radiation
D_dnuc	Dummy variable equal to one when someone pays for services of Dentist Clinic & Nuclear Medicine

Additional variables include the cost that one should pay separately for services of dosimeters, licenses, radiation therapy and radiology, calibration in ionizing facilities, industrial applications, education and research, magnetic resonance imaging, transportation of radioactive materials, radiation, non-ionizing radiation and for dentist clinic and nuclear medicine.

3.4.2 Econometric specification

Our standard hedonic model regresses the natural log of the total cost of services of Greek Atomic Energy Commission (Y) against a variety of characteristics (X's) which includes health expenditure, medical capital investment, examinations of magnetic resonance imaging (MRI) and Radiotherapy (RT) units. The standard model can be written as:

$$Y = X\beta + \varepsilon, \tag{3.1}$$

where ε is assumed to be normally distributed with zero mean and constant variance.

Our analysis of spatial effects addresses a major question. Are spatial effects or other effects present? In order to answer this question, we compare a model that includes spatial effects to one without spatial effects. Bowen found that one of the two models showed no substantial signs of spatial misspecification to the housing market of Cuyahoga Country in Ohio and the explicit modeling of space was not always justified (Bowen, et al., 2001). Anselin and Lozano-Garcia tested for the presence of spatial autocorrelation and estimated specifications that incorporate spatial dependence (Anselin & Lozano-Garcia, 2008). They distinguish between spatial dependence in the form of a spatially lagged dependent variable and a model with a spatially correlated error term. If evidence of spatial autocorrelation and/or spatial (autoregressive) dependence is found, the relationships between total cost of services and level of health characteristics will need to be modeled through the use of spatial statistics (e.g., see Cliff and Ord 1981). For example, spatial autocorrelation may exist when omitted unobservable characteristics, such as geomorphology and accessibility to institutions, are correlated across regions of Greece. Pace et al. underlined that local spatial errors (or spatially lagged variables as used with mixed regressive spatially autoregressive estimators) effectively proxy for omitted variables correlated with location (Pace, et al., 1998). In addition, because the total services cost of a particular region may depend on the total cost services and characteristics of nearby regions, we will need to incorporate and test for the significance of a spatially lagged dependent variable. Such a conceptualization corresponds with a standard description of how the total cost services of EEAE operates.

In light of evidence that spatial effects exist, some studies attempt to find the appropriate estimation model making a series of pairwise comparisons between different spatial models. The evidence of spatial autocorrelation leads to the decision if estimation must be based on either maximum likelihood or on a generalized moments approach (Kelejian & Prucha, 1999). The existence of spatial autocorrelation increases the possibility that the errors will not be the distributed normally. Maximum likelihood estimation of the spatial autocorrelation coefficient depends on the assumption of normality of the regression error terms, while the generalized moments approach does not (Anselin, 2001; Anselin & Bera, 1998).

Kissling and Carl had come to the conclusion that SAR models (spatial error = SARerr, lagged = SARlag and mixed = SARmix) depend on model specification (i.e. model type, neighborhood distance, coding styles of spatial weights matrices), and SAR model parameter estimates are not always more precise than those from OLS regressions (Kissling & Carl, 2008).[5] They do not therefore recommend them for real species distribution data where spatial autocorrelation is most likely to occur in model residuals, e.g. when important environmental variables have not been taken into account (Diniz-Filho, et al., 2003).

A general spatial econometric model can be written by incorporating a spatial error process as well as a spatially lagged dependent variable, modifying eq. (3.1) as follows:

$$Y = \rho WY + X\beta + \varepsilon, \qquad (3.2)$$

$$\varepsilon = \lambda W\varepsilon + \mu,$$

where μ is distributed normal with zero mean and constant variance and W is an N by N weight matrix (Kelejian & Prucha, 2007). The number of observations, N is equal to 57.314. In scalar notation, the weight that an individual charge for service (j) has on charge i's total cost for services is equal to

$w_{ij} = 1/d_{i,j}$, $\quad$ i,j=1,2,…,57.314

$\quad = 0,$ $\quad$ i=j,

where $d_{i,j}$ is the Euclidean distance between charge for service i and j. These weights are "row normalized" so that

$$\textstyle\sum_j w_{i,j} = 1, \text{ i,j=1,2…..,57.314}$$

When λ and ρ are equal to zero, what remains is the standard model of eq. (3.1) that we estimated by ordinary least squares.

5 Their results indicate that SARerr models are the most reliable SAR models in terms of precision of parameter estimates, reduction of spatial autocorrelation in model residuals and type I error control, independent of which kind of spatial autocorrelation is present in the data set. Other SAR models (SARlag, SARmix) and OLS regressions showed weak type I error control and/or unpredictable biases in parameter estimates when spatial autocorrelation was present in the errors.

To see if spatial effects are present, we first compare the model in eq. (3.1) with the following model:

$$Y = X\beta + \varepsilon, \qquad (3.3)$$

$$\varepsilon = \lambda W\varepsilon + \mu$$

where μ is an error term that is distributed normal with zero mean and constant variance, and W is as described above (Cohen & Coughlin, 2008).

Next, we proceed to test the significance of including the spatial autoregressive parameter ρ in this spatial error model. In other words, we test model (3.3) against model (3.2) as described above. We would expect the sign of the coefficient on the spatially lagged dependent variable (ρ) to be positive. This implies the presence of positive adjacency effects. Thus, another objective of this study is to test for the sign and magnitude of such adjacency effects through the spatial autoregressive parameter ρ.

3.5 Spatial Econometric Results

In this section, we present evidence of spatial autocorrelation for the cost of services in all the regions of Greece. Moreover, we use natural logs for variables to measure the elasticity to any of these variables. Nevertheless, such elasticities potentially do convey some useful information. It should be stressed that conditioning variables do not differ markedly across nearby region and it can be considered as a test of robustness for our hypothesis on the role of externalities.

In Tables 3.2 - 3.5, we use six estimation methods for the model in order to check the robustness and differences in sign or magnitude for each estimation method. Ordinary Least Squares (OLS) is the simplest estimation method and minimizes the sum of squares of errors. The Spatial Error Model (SEM) evaluates the extent to which the clustering of an outcome variable not explained by measured independent variables can be accounted for with reference to the clustering of error terms. The Spatial Autoregressive Model (SAR) is a generalization of the linear regression model to account for spatial autocorrelation and yields better classification and prediction accuracy for many spatial datasets. The General Spatial Model (GSM) is a combination of SAR and SEM models and it is appropriate when we cannot reject the hypothesis when the residuals are (still) spatially autocorrelated. The last two estimation methods are based on Generalized Moments (GM) and they are combined with spatial error model (SEM/GM) and general spatial model (GSM/GM).

3.5.1 Spatial (Baseline) Hedonic model

This section presents the Spatial Hedonic models estimates. Table 3.2 presents the outcome for the Spatial Baseline Hedonic model using neighboring criteria of various definitions. Initially, we study the impact of each variable or dummy on total service cost of EEAE.

The impact of Health Expenditure is significant, positive and substantial in magnitude across all estimation models for Greece’s regions. The estimated models explain over 58 percent of the variation in the log of total service cost (PriceLog). The total cost of services elasticity of one region with respect to the other regions is 0.27 which is the highest while the lowest is 0.18. The corresponding elasticity of this variable is 2.70 and therefore shows an important positive response of every region to neighboring ones choosing SEM/GSM methodology. The same pattern of responses appears for the remaining estimations. In 1993, 1997 and 2005 in USA, the top 20 percent of communities had public health agency spending levels more than 13 times higher than communities in the lowest quintile after adjusting for differences in demographics and service mix (Smith & Mays, 2009). The National Association of

State Budget Officers (NASBO) estimated that state governments' per-capita spending on public health activities varied by a factor of >30 in 2003, ranging from >$400 per person in Alaska and Hawaii to <$75 per person in Iowa, Arkansas, Idaho and Utah (National Association of State Budget Officers, 2005). Moreover, the impact of Medical Capital Investment on the total cost of the services is less strong than Health Expenditure but remains positive and significant. It varies in magnitude from around 0.03 (2.73) to around 0.7 (5.03). This finding comes in line with the report of Strengthening Capacity for Universal Coverage that underlines that high value capital equipment has increased in Greece from 2005 to 2017, with the exception of γ-Cameras/SPECT that remained constant. More specifically, the per million population number of MMUs, CT, MRI, PET and RT[6] by 30%, 19%, 28%, 175% and 19% respectively during 2009-2017 despite GDP and population declined from 21.529€ and 11,11 million to 17.386€ and 10,76 million respectively (World Health Organization, 2017; World Bank, 2017). In USA, from 2009 to 2014, the San Francisco area took in 25 percent of total venture capital (VC) funding and 23 percent of digital health funding—ranking first for both. But the five largest metro areas for digital health comprised just over half of all funding (54%), compared with 64% for total VC deals (Hathaway & Rothwell, 2015). The number of examinations MRI doesn't affect in all empirical results despite the fact that Greece has one of the highest numbers of MRI Units to population ratio compared to other EU countries. The last interdependent variable Radiotherapy units (RT units) does not have also any impact on the total cost of services, as indicated by the coefficients. A plausible explanation for the insignificant coefficient of the contemporaneous variable might be that 6 out of 13 regions (Central

6 γ- Camera/SPECT= Single Photon Emission Computed Tomography, MMU = Mammography Units, CT= Computed Tomography Units, MRI= Magnetic Resonance Imaging, PET= Positron Emission Tomography, RT=Radiotherapy Units

Greece, North Aegean, Peloponnese, South Aegean, West Macedonia and Ionian Islands) do not have any radiotherapy units according to Strengthening Capacity for Universal Coverage (World Health Organization, 2017). The radiotherapy units require expensive facilities, dedicated infrastructures and specialized human resources. Furthermore, services of Non-ionizing radiation (D_nion) is the only dummy variable that affects significantly. With respect to the specific estimates, which are all positive, SEM/GSM presents the highest estimation with 0.28 while SEM has the lowest estimation with 0.12. A reasonable explanation is that the number of cellular antennas is increasing every year due to the progression of technology and mobile phones, therefore telecommunication companies try to expand their network in every part of Greece. According to Hellenic Telecommunications & Post Commission (EETT), the contribution of telecommunication to GDP of Greece has increased to 177.735.000€ in 2017 from 174.199.000€ in 2016. The opposite pattern of responses, in terms of significance, appears for the remaining dummy variables Radiation (D_rdt) and Dentist Clinic and Nuclear Medicine (D_nuc).

Next, we examine the spatial impact of total cost accounting for neighboring costs. Interestingly, the estimator of neighboring value cost is significant and positive in all specifications and ranges from 0.89 to 0.28 based on estimates in Table 3.2. Moving to the next matrix, W* $\varepsilon(\lambda)$ declares if there is any unobserved variable missing in our econometric estimation model. The spatial autocorrelation parameter λ is positive in all estimation results but it is insignificant. The spatial error component indicates the absence of any relevant impact on the total cost services (Price Log). Since the generalized moments estimation of λ does not depend on the assumption of normally distributed error terms, it is not possible to conduct a t-test of the significance of this coefficient.

Table 3.2 - Estimation Results for Spatial Baseline Hedonic Model

Variable / Model	A	B	C	D	E	F
Constant	2.34	0.87*	0.75*	0.55*	0.63*	0.58*
	(1.16)	(1.99)	(2.32)	(2.89)	(3.07)	(3.71)
Healthcare expenditure	0.21*	0.18*	0.24*	0.19*	0.27*	0.25*
	(7.89)	(9.56)	(5.73)	(3.96)	(8.02)	(7.51)
Medical Capital Investment	0.08*	0.05*	0.07*	0.04*	0.05*	0.03*
	(4.56)	(6.09)	(5.03)	(3.16)	(4.45)	(2.73)
Examinations MRI	0.18	0.14	0.84	0.71	0.78	0.63
	(0.75)	(0.37)	(0.99)	(0.29)	(0.57)	(0.49)
RT units	0.03	0.02	0.05	0.04	0.03	0.06
	(0.14)	(0.01)	(0.11)	(0.19)	(0.04)	(0.08)
D_rdt	0.28	0.22	0.19	0.21	0.26	0.23
	(1.02)	(1.18)	(1.51)	(0.87)	(1.39)	(1.48)
D_nion	0.14*	0.12*	0.24*	0.17*	0.28*	0.25*
	(2.78)	(1.18)	(4.51)	(5.77)	(7.59)	(9.02)
D_dnuc	0.58	0.74	0.81	0.52	0.93	0.32
	(0.02)	(0.09)	(0.16)	(0.89)	(0.38)	(0.29)
W_Cost			0.89*	0.29*		0.28*
			(4.75)	(9.84)		(12.63)
W* ε(λ)		0.84		0.63	0.47	0.36
		(0.76)		(1.52)	n/a	n/a
R_2	0.62	0.58	0.69	0.71	0.62	0.68
GM σ_2					0.15	0.14
σ_2	0.18	0.18	0.18	0.18	0.18	0.18
Log-Lik	-174.01	58.92	45.41	377.55		

Notes: Dependent variable is Total Cost of Services (PriceLog). Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors (Sharma, 2011). * denotes significance at the 5% (two-tailed) level. Definitions of Models: A = OLS, B = SEM, C = SAR, D = GSM, E = SEM/GM, F = GSM/GM

The results for the spatial hedonic model are presented in Table 3.3, where we isolate the imprint of each dummy variable in order to measure the impact on the total cost of services. The dummy variables are all positive but not all significant at the 5 percent level and R_2 is at least 48 percent. The first dummy variable (D_dos) refers to the individual monitoring of the personnel (around 11.000 persons) occupationally exposed to ionizing radiation that uses dosimeters. The impact of dosimetry services (D_dos) is observed to be positive and slightly significant in all estimations. The impact of total cost of services in all regions varies in magnitude from around 0.07 to around 0.15. Therefore, dosimetry is an important equipment and profitable source of revenue for EEAE that applies in every region of Greece. The impact of ionizing radiation calibration on the total cost of services according to the selected estimation methodologies is found positive varying from 0.07 to 0.01. Therefore, we conclude that the calibration in ionizing radiation facilities in one region seems to influence slightly the total cost of services in the neighboring regions regardless of the estimation model. The transport of radioactive materials (D_trans) has mostly positive effect and therefore regional spillovers. The estimates of this variable present variations from 0.58 to 0.38. Radiation from natural or artificial radioisotopes (D_rdt) exhibits strong and positive externalities in all estimations presenting a maximum value of 0.83 and a lowest of 0.38. It indicates a noticeable impact of radiation services of one region on the total cost of services in neighboring regions. In addition, the variable of non-ionizing services (D_nion) enhances significantly the total service cost, confirming its importance exhibiting its maximum value of impact with 0.97 while the lowest with 0.78, verifying that non-ionizing radiation is the major cost driver. The latter finding refers to the variable of dentist clinic and the nuclear medicine (D_dnuc), which has significantly positive impact in all estimation methods. The significance varies from

Table 3.3 - Estimation Results for Spatial Hedonic Model

Variable \ Model	A	B	C	D	E	F
Constant	1.78*	1.65*	1.54*	1.72*	1.89*	0.95*
	(8.78)	(12.7)	(7.56)	(11.08)	(14.4)	(19.06)
D_dos	0.11*	0.07*	0.12*	0.15*	0.08*	0.09*
	(6.75)	(8.03)	(9.01)	(6.75)	(5.22)	(8.99)
D_lic	0.03	0.04	0.02	0.06	0.09	0.08
	(0.75)	(0.97)	(0.53)	(0.24)	(0.84)	(0.75)
D_rdl	0.14	0.16	0.11	0.12	0.15	0.19
	(1.02)	(1.28)	(0.95)	(1.17)	(1.45)	(1.32)
D_cal	0.01*	0.02*	0.05*	0.03*	0.06*	0.07*
	(5.15)	(7.08)	(6.24)	(9.78)	(8.94)	(7.35)
D_ind	0.03	0.02	0.04	0.01	0.02	0.11
	(0.17)	(0.29)	(0.17)	(0.56)	(0.48)	(0.71)
D_edu	0.26	0.31	0.49	0.16	0.29	0.45
	(0.11)	(0.05)	(0.08)	(0.01)	(0.35)	(0.23)
D_mri	0.16	0.25	0.29	0.59	0.41	0.48
	(0.29)	(0.17)	(0.51)	(0.83)	(0.91)	(0.84)
D_trans	0.15	0.28	0.45*	0.38*	0.58*	0.51*
	(0.98)	(1.32)	(2.89)	(4.56)	(6.72)	(7.32)
D_rdt	0.38*	0.42*	0.79*	0.68*	0.83*	0.79*
	(11.2)	(12.7)	(9.28)	(8.45)	(15.6)	(14.3)
D_nion	0.87*	0.95*	0.81*	0.97*	0.78*	0.85*
	(9.84)	(14.02)	(12.52)	(17.03)	(4.48)	(7.85)
D_dnuc	0.61*	0.53*	0.79*	0.85*	0.74*	0.91*
	(5.89)	(8.03)	(9.52)	(11.05)	(10.04)	(7.62)
W_Cost			0.42*	0.18*		0.73*
			(8.61)	(5.32)		(10.02)
W* ε(λ)		0.15*		0.12*	0.29	0.05
		(4.06)		(5.82)		
R^2	0.48	0.57	0.59	0.58	0.55	0.62
GM σ^2					0.18	0.19
σ^2	0.15	0.15	0.15	0.15	0.15	0.15
Log-Lik	-189.27	37.54	31.89	587.94		

Notes: Dependent variable is Total Cost of Services (PriceLog).Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors (Sharma, 2011). * denotes significance at the 5% (two-tailed) level. Definitions of Models: A = OLS, B = SEM, C = SAR, D = GSM, E = SEM/GM, F = GSM/GM

0.91 to 0.53. According to annual reports of EEAE, the number of licensed dentists has increased rapidly from 5.204 to 7.880 during the period of 2010-2017 while the nuclear medicine has a small decline from 180 to 168 (Greek Atomic Energy Commision, 2018; Greek Atomic Energy Commission, 2011). The global economic burden of dental diseases amounted to 442$ billion in 2010 while the direct treatment costs due to dental diseases worldwide were estimated at US $298 billion yearly, corresponding to an average of 4.6% of global health expenditure (Listl, et al., 2015). Regarding the remaining dummy variables for licenses (D_lic), radiation therapy and radiology (D_rdl), industrial applications (D_ind), education & research (D_edu) and magnetic resonance imaging (D_mri) on the basis of total cost of services are positive but have insignificant spillovers.

Finally, regarding the spatial parameters, the spatially lagged dependent variable is positive and significant in all estimation methods boosting total service cost in all cases (0.18-0.73). If the weighted average of any variable in region increases 1%, the total cost services in neighboring regions will increase from 0.18 to 0.73, depending on the chosen model. With regard to the spatial autocorrelation parameter λ, it is positive but not statistically significant in all estimation methods. In the contrary, λ is significant with the variation of maximum and lowest impact being so close (0.15 and 0.12 respectively), confirming the existence of missing unobservable variable(s) in our spatial hedonic model. This finding is true since due to dropping all the variables from the previous spatial baseline hedonic model in Table 3.2.

3.5.2 Economic and health personnel proximity

This section analyzes both structural models estimates across the same six estimation models incorporating economic in addition to health personnel proximity (Table 3.4 and Table 3.5). For the economic baseline hedonic model (Table 3.4), we define a form of economic weight as $W_{ij} = 1 - (GDP_i - GDP_j)/(GDP_i + GDP_j)$. Healthcare expenditure exerts a positive and significant effect on regions' GDP with the highest and lowest impact being 0.16 and 0.11 respectively. Studies have shown a direct relationship between health expenditures and GDP. If the income in OECD and developing countries is increased, this will lead to the increase of total healthcare expenditure (Baltagi & Moscone, 2010; Ke, et al., 2011). In some cases, GDP affects mainly healthcare expenditure due to income cyclical movements (Lago-Peñas, et al., 2013) or is the most significant determinant (Okunade, 2005; Murthy & Okunade, 2009) and in other cases their relationship's trend is predominantly bilateral (Amiri & Ventelou, 2012). Additionally, the impact of Medical Capital Investment ranges from 0.18 to 0.09. This result comes in line with the finding that an extra year of life expectancy is estimated to raise a country's per capita GDP by about 4 percent (Bloom, et al., 2004). Furthermore, Bloom et al. underlines that using full income in benefit-cost analyses of investments in health would markedly increase our estimates of net benefits or rates of return. National public health investments show an impact on overall health status and are associated with improved investment opportunities that contribute to growth. At the microeconomic level, clear causal relationships have been documented from health to earning potential and income (William & Maureen, 2009). Finally, non-ionizing radiation plays the most significant role as a determinant for regions' GDP presenting a lowest estimate of 0.11 and a maximum value of 0.27. As pointed out by the national legislation (FEK 1659/B/07.08.2015), a possible explanation has been offered to account for the observed positive and significant relationship. EEAE receives an annual fee of 220€ paid by each company for installation and operation of each antenna station. According to 2017 annual report of EEAE, there are about 9.500 antenna stations all over Greece (Greek Atomic Energy Commision, 2018).

Moving to spatial impact, W* $\varepsilon(\lambda)$ is positive in all estimation results but insignificant. On the contrary, neighboring cost (W_cost) is significant and positive in all three estimation models, denoting that if any variable increases by 1% in one region, then there will be an increase by 0,84% in total service cost of EEAE in the neighboring regions of it (GSM/GM).

Table 3.5 presents the estimation results for Health Personnel baseline Hedonic Model. The variables have the same patterns as Table 3.4 confirming contemporaneous spatial interactions for Greece's regions. For this table, we used a form for Health Personnel Weight defined as $HPij = 1–(HP_i–HP_j)/(HP_i+HP_j)$. The employment of labor in the health sector is the most significant variable in all estimations methods exhibiting the weakest impact with 0.34 while the strongest one with 0.39. This shows the important role health personnel plays as a service cost driver (Giannoni & Hitiris, 2002). The next significant variable is Medical Capital Investment, which with respect to the specific estimation results, it ranges from 0.17 to 0.09. One of the reasons behind this positive result might be associated with the fact that the effect of health investment on productivity is associated with human capital accumulation (Rivera & Currais, 2003). Finally, with regards to non-ionizing radiation, a positive and significant relation with health personnel is once more estimated in all methodologies. The impact of non-ionizing ranges varies from 0.16 to 0.29. According to Hellenic Telecommunications & Post Commission (EETT) "Annual Report 2017", telecommunication's contribution to GDP is related with the number of employees in telecommunication providers.

Table 3.4 - Estimation Results for Economic Baseline Hedonic Model

Variable / Model	A	B	C	D	E	F
Constant	1.12 (0.95)	0.87 (0.91)	0.54* (2.32)	0.29* (1.77)	0.48* (2.01)	0.41* (1.84)
Healthcare expenditure	0.14* (1.88)	0.11* (2.56)	0.15* (3.71)	0.12* (2.01)	0.16* (2.07)	0.11* (2.58)
Medical Capital Investment	0.11* (2.32)	0.09* (3.41)	0.13* (2.89)	0.14* (2.42)	0.12* (2.01)	0.18* (1.78)
Examinations MRI	0.05 (1.54)	0.02 (1.02)	0.01 (1.16)	0.07 (0.75)	0.09 (0.94)	0.08 (0.83)
RT units	0.01 (0.29)	0.06 (0.45)	0.07 (0.89)	0.05 (0.73)	0.08 (0.82)	0.05 (0.88)
D_rdt	0.73 (0.74)	0.64 (1.06)	0.58 (1.34)	0.73 (1.09)	0.98 (0.99)	0.65 (1.36)
D_nion	0.18* (1.93)	0.11* (2.18)	0.21* (2.51)	0.19* (1.77)	0.25* (2.59)	0.27* (2.62)
D_dnuc	0.89 (0.45)	0.92 (0.89)	0.66 (0.39)	0.71 (0.94)	0.91 (0.74)	0.57 (0.48)
W_Cost			0.73* (2.71)	0.16* (1.79)		0.84* (2.01)
W* ε(λ)		0.73 (0.71)		0.68 (1.05)	0.49 n/a	0.44 n/a
R_2	0.54	0.61	0.63	0.67	0.65	0.69
GM σ_2					0.17	0.16
σ_2	0.19	0.19	0.19	0.19	0.19	0.19
Log-Lik	-195.27	72.12	59.17	279.94		

Notes: Dependent variable is Total Cost of Services (PriceLog). Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors (Sharma, 2011). * denotes significance at the 5% (two-tailed) level. Definitions of Models: A = OLS, B = SEM, C = SAR, D = GSM, E = SEM/GM, F = GSM/GM

Table 3.5 - Estimation Results for Health Personnel Baseline Hedonic Model

Variable \ Model	A	B	C	D	E	F
Constant	4.72 (0.73)	1.54* (2.04)	1.89* (1.89)	1.65* (2.41)	1.92* (1.77)	1.74* (2.45)
Healthcare expenditure	0.36* (1.82)	0.38* (2.59)	0.34* (2.73)	0.38* (1.96)	0.37* (2.08)	0.39* (2.57)
Medical Capital Investment	0.12* (2.56)	0.09* (2.03)	0.17* (2.26)	0.14* (2.04)	0.12* (2.06)	0.17* (1.96)
Examinations MRI	0.02 (0.21)	0.01 (0.12)	0.05 (0.03)	0.09 (0.01)	0.03 (0.05)	0.06 (0.06)
RT units	0.02 (0.11)	0.01 (0.28)	0.01 (0.25)	0.07 (0.37)	0.08 (0.43)	0.09 (0.13)
D_rdt	0.72 (1.16)	0.22 (1.03)	0.19 (1.44)	0.21 (1.07)	0.26 (1.22)	0.23 (0.98)
D_nion	0.26* (1.73)	0.21* (1.76)	0.16* (2.04)	0.19* (1.95)	0.22* (1.68)	0.29* (2.71)
D_dnuc	0.89 (1.01)	0.95 (1.03)	0.98 (0.88)	0.73 (0.94)	0.84 (0.63)	0.54 (0.75)
W_Cost			0.95* (1.77)	0.15* (1.87)		0.12* (2.54)
W* ε(λ)		1.07 (1.16)		1.34 (1.07)	1.62 n/a	1.54 n/a
R^2	0.65	0.59	0.67	0.72	0.65	0.66
GM σ^2					0.12	0.11
σ^2	0.16	0.16	0.16	0.16	0.16	0.16
Log-Lik	-164.53	42.23	57.01	483.61		

Notes: Dependent variable is Total Cost of Services (PriceLog). Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors (Sharma, 2011). * denotes significance at the 5% (two-tailed) level. Definitions of Models: A = OLS, B = SEM, C = SAR, D = GSM, E = SEM/GM, F = GSM/GM

W* ε(λ) is positive in all estimation results but insignificant, denoting there isn't any missing unobserved variable in our econometric model. Finally, neighboring values of cost regions (W_cost) remains significant and positive implying that every change of any variable by 1%, it will increase the total service cost of EEAE from 0.12 to 0.95 depending on the model in neighboring regions.

3.5.3 Robustness

In this section, we examine the spatial and economic baseline hedonic model estimates in GSM/GM across regions of Greece in a unified sample (Table 3.6 and Table 3.7). We estimated our model with different methods for robustness purposes. Although we have also estimated our model with OLS estimation, we use generalized method of moments estimator. This estimator addresses the problem of autocorrelation of the residuals and deals with the fact that some of the control variables may be potentially endogenous (Bond, 2002).

The exclusion of geographical and economic neighboring effects defines each baseline model. In Table 3.6, we use only geographical proximity to identify its unique impact, while in Table 3.7 economic proximity in order to identify their distinctive influence and provide insight about their contribution to the total service cost. Using geographical proximity as the main criterion for neighboring values (Table 3.6), then controlling for healthcare expenditure at neighboring regions, shows that only non-ionizing variable does have an important role (0.19) and affects price changes. The remaining two cross-terms variables radiation, nuclear and dental clinic, denoting interactions with healthcare expenditure, indicate that there is no importance of geographical proximity for regional spillovers.

Table 3.6 - Robust Results for Spatial Baseline Hedonic Model

Variable \ Model	A	B	C
Constant	1.73* (2.91)	1.55* (2.42)	1.61* (2.38)
Healthcare expenditure	0.16* (2.42)	0.23* (1.96)	0.31* (2.04)
Medical Capital Investment	0.19* (1.84)	0.31* (2.01)	0.28* (1.96)
Examinations MRI	0.31 (1.03)	0.72 (1.62)	0.68 (1.52)
RT units	0.42 (1.31)	0.88 (1.27)	0.71 (1.11)
W_Healthexp* D_rdt	0.14 (1.35)		
W_Healthexp* D_nion		0.19* (1.76)	
W_Healthexp* D_dnuc			0.56 (0.07)
W_Cost	0.21* (2.11)	0.39* (2.31)	0.32* (2.23)
W* ε(λ)	1.71 n/a	1.85 n/a	1.42 n/a
R_2	0.61	0.64	0.61
GM σ_2	0.15	0.18	0.16
σ_2	0.21	0.34	0.23

Notes: Dependent variable is Total Cost of Services (PriceLog). Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors (Sharma, 2011). * denotes significance at the 5% (two-tailed) level. Definitions of Models: A = B = C= GSM/GM

In contrast to the Table 3.6, results in Table 3.7 verify that economic relationships are more important than spatial for cross-term interactions. More specifically, the interactions between healthcare expenditure, radiation services and non-ionizing services do affect the price variations (0.27 and 0.38 respectively) using a general spatial model. In other words, economic neighboring relationships across different regions do affect changes in total service cost from EEAE. The latter cross-term has insignificant contribution to the existing literature since it decomposes the impact of both neighboring and local effects through the explanatory variables of the model.

Furthermore, healthcare expenditure enhances total service cost when geographical and economic proximity are used (0.16-0.35). Accordingly, medical capital investment boosts price changes in all cases (0.19-0.42). Additionally, examinations with Magnetic Resonance Imaging and Radiotherapy units have insignificant impact on service cost variation in the whole sample. This means that the strong heterogeneity of the total cost service effects of both variables across regions makes it impossible to estimate these effects accurately for the whole sample. This shows the necessity for separate region estimations.

Finally, we have conducted estimations about the spatial parameters to provide more information about elasticities of the dependent variable to the explanatory variables and if there is any missing variable. The spatially lagged dependent variable (W_Cost) is important and positive in all cases ranging from 0.14 to 0.39, presenting the higher elasticities to Table 3.6. W* $\varepsilon(\lambda)$ indicates that there is not any missing variable in both baseline hedonic models, which is a satisfactory piece of information for our estimations.

Table 3.7 - Estimation Results for Economic Baseline Hedonic Model

Variable / Model	A	B	C
Constant	2.56* (2.24)	2.43* (1.87)	2.42* (1.79)
Healthcare expenditure	0.25* (2.23)	0.34* (1.72)	0.35* (2.17)
Medical Capital Investment	0.34* (1.95)	0.42* (2.52)	0.35* (2.07)
Examinations MRI	0.83 (0.65)	0.64 (0.34)	0.54 (1.21)
RT units	0.48 (1.39)	0.23 (0.73)	0.86 (0.55)
W_Healthexp *D_rdt	0.27* (2.11)		
W_Healthexp *D_nion		0.38* (1.95)	
W_Healthexp *D_dnuc			0.05 (0.01)
W_Cost	0.15* (1.82)	0.18* (1.75)	0.14* (1.73)
W* ε(λ)	1.43 n/a	1.16 n/a	1.07 n/a
R_2	0.67	0.69	0.66
GM σ_2	0.24	0.22	0.17
σ_2	0.19	0.18	0.12

Notes: Dependent variable is Total Cost of Services (PriceLog). Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors (Sharma, 2011). * denotes significance at the 5% (two-tailed) level. Definitions of Models: A = B = C= GSM/GM

Figure 3.3 to Figure 3.9 present the total cost of each service divided by region over the period 2010-2016 in Greece. The total cost of services is computed based on the charges of EEAE, using average values for the explanatory variables. The results reveal that region of Attica accumulates the highest proportion of the total service cost compared to all remaining regions together. This finding is absolutely awaited on the grounds that the population of Attica is nearly 35% of the total population in Greece. The next region with the next high total service cost in every figure is Central Macedonia, where Thessaloniki belongs and it is the second largest city in population. With regard to the results of the figures, we notice that the population of every region is a major factor that mainly affects the total service cost. The larger the population in each region, the higher the total service costs. Therefore, combining the results of the tables and figures above, if the population of a region increases, it will also increase the total service costs of the same region affecting also the same total service costs of the neighboring regions.

Our results come in line with the official stats of the latest annual economy report by the Hellenic Statistical Authority (ELSTAT). Attica has the highest gross domestic product in Greece with 83.872€ in 2016 while Thessaloniki has the second highest with 15.552€. Furthermore, Attica has the highest number in employment and Thessaloniki again the second highest with 1.556.112 and 654.387 persons respectively. An additional proof of ELSTAT that proves why Attica and Thessaloniki have the highest total service cost is that they have also the highest gross fixed capital formations in Greece.

3.6 Concluding remarks

Our analysis can be seen as a step-in revealing price changes spillovers play in the process of EEAE in regions of Greece. Our contribution lies, first in the estimation of two seminal models using separately geographical as well as economic neighborhood criteria, in order to test for the existence and magnitude of interregional spillovers. Second, we breakdown every providing service from EEAE in order to find out which are the ones that affect most the price variations.

The results robustly demonstrate that interregional externalities do matter for Greek regions, regardless of the way neighborliness is defined. Economic linkages imply strong cross-regional spillovers than geographical ones, which constitute the theoretical framework of our empirical analysis. Also, in both specifications, findings exhibit a fair strong positive pricing change influence of healthcare expenditure. Furthermore, regarding all models, medical capital investment enhances also price variations. The strongest determinant for pricing change is the non-ionizing radiation service, which plays the most significant role among the other providing ones by EEAE.

Two caveats should be mentioned when applying the hedonic model using the spatial econometric framework with aggregate values at the regional level. First, the clusters are found mostly in the central regions of Greece. A contributing factor to this phenomenon might be that the relatively small regions do not fit the spatial hedonic model better than the larger regions. Because the locations of specific regions are proxied by regional centroids in establishing the weight matrix in the spatially lagged model, the centroids of larger regions represent larger areas. The larger the area represented by the centroid, the wider and the larger the area represented by the optimal bandwidth, and the smaller the spatial heterogeneity inherent in the variables. Uneven region sizes may be a disadvantage of spatial analysis with regional-level data. Further analysis may compare differences between the regions with similar sizes. Second, the hedonic model is only able to capture those benefits from environmental improvements that are jointly consumed with other products or services. Environmental improvements captured at other places, may not be captured by health expenditures. In other words, the hedonic method only captures a portion of the environmental hazards resulting from services for non-ionizing radiation.

Limitations

Our research covers the fundamental area related to ionizing and non-ionizing radiation, but it may have three limitations. The first refers to the invoices of EEAE. We could only extract the total amount of invoices from the database and not the amount of received money for each invoice. We believe that it would contribute more accurate results about expecting profit or loss based on fluctuations of the variables not only in each region but also totally for Greece. The second is that the current literature includes very few studies from other national authorities in order to compare results. The majority of studies about hedonic models in radioprotection concerns the housing market after the disaster in Fukushima. The third concerns the existence of international data from other countries in order to compare it with our estimates. These limitations present the level of difficulty of collecting data on such sensitive areas from relevant national authorities.

Future research

This study has given rise to many questions in need of further examination. Empirical studies on the current topic are useful in order to explore similar research questions in other areas such as manufacture, research and development and telecommunications. Our results are encouraging and should also be validated by the real revenues and not only by nominal revenues presented at the issued invoices. On a wider level, it is also recommended to take into consideration how legislative and regulatory decisions, actions and initiatives may affect these results and to what extent.

We are confident that our research provides a solid basis for the upcoming studies about related topics.

Acknowledgements

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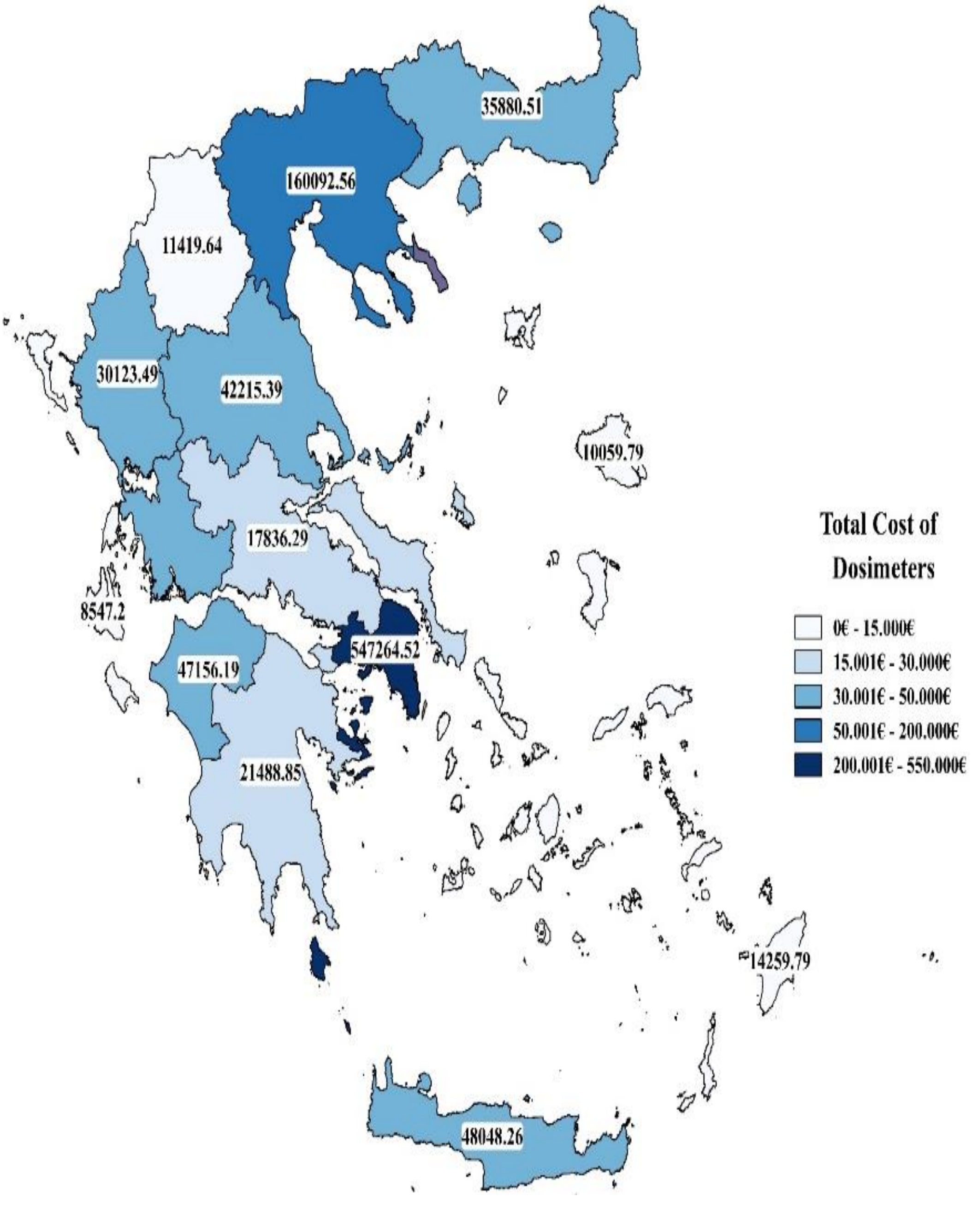

Figure 3.4 - Total Cost for Services of Dosimeters

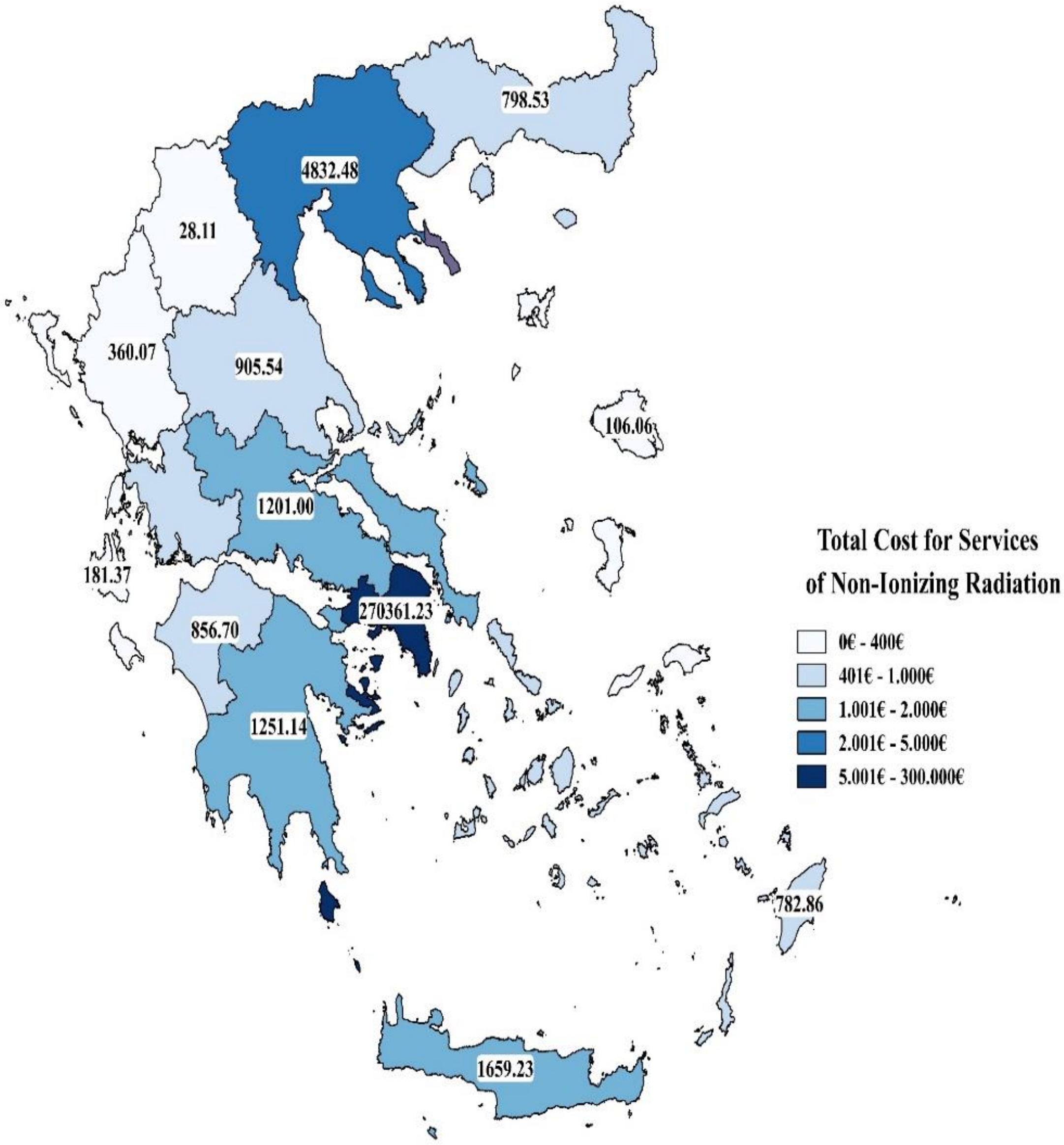

Figure 3.5 - Total Cost for Services of Non-Ionizing Radiation

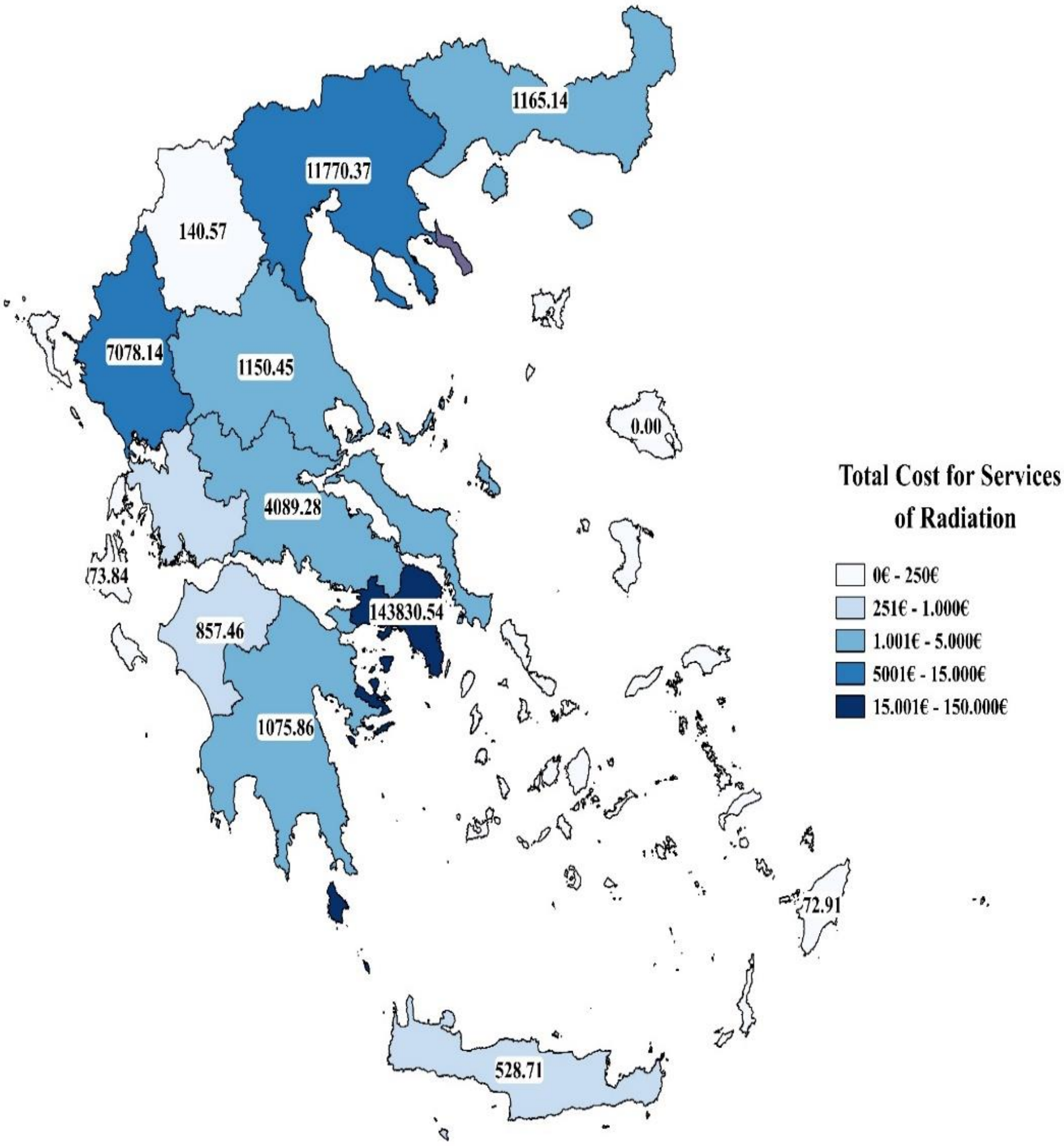

Figure 3.6 - Total Cost for Services of Radiation

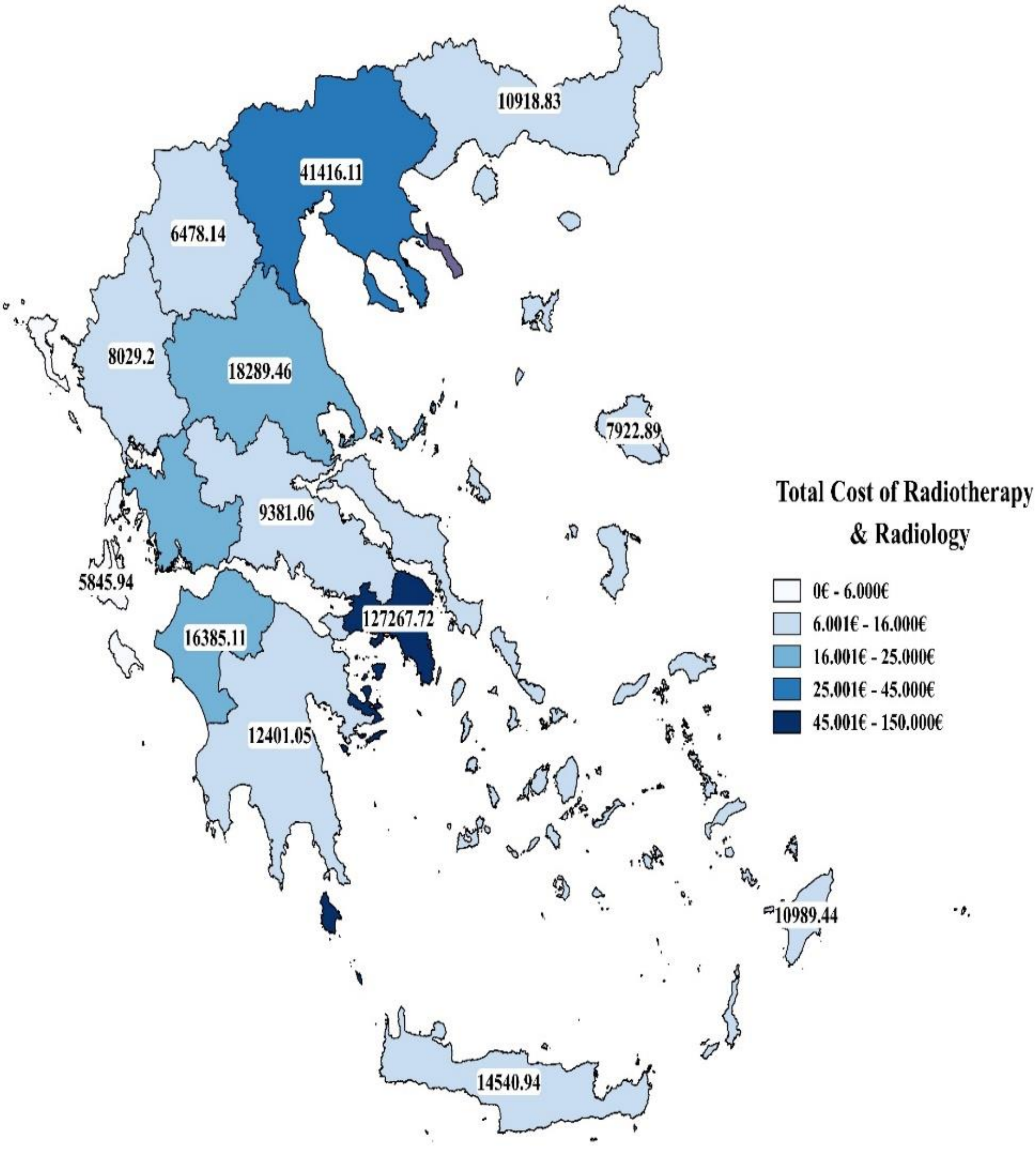

Figure 3.7 - Total Cost for Services of Radiotherapy & Radiology

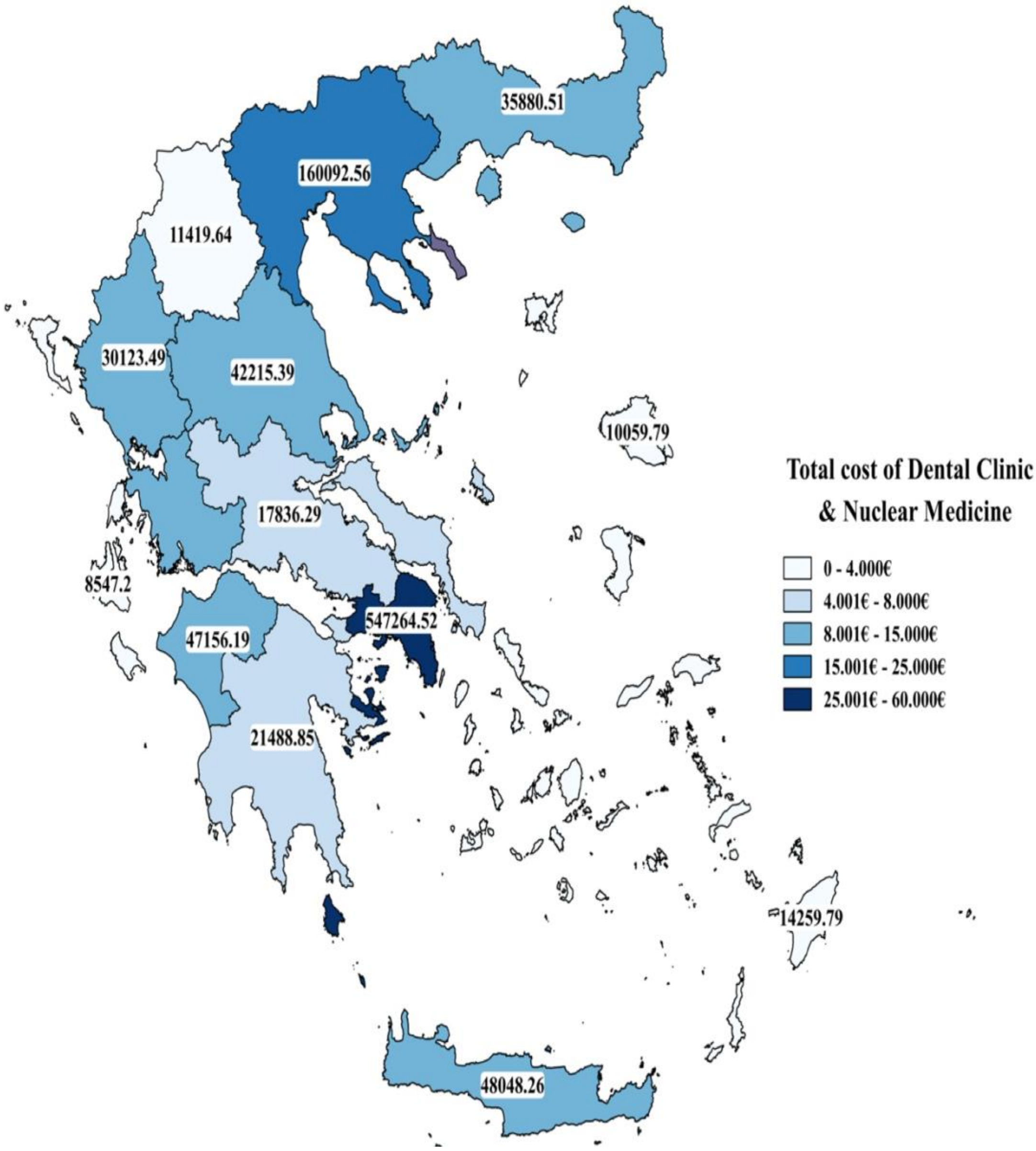

Figure 3.8 - Total Cost of Dental Clinic and Nuclear Medicine

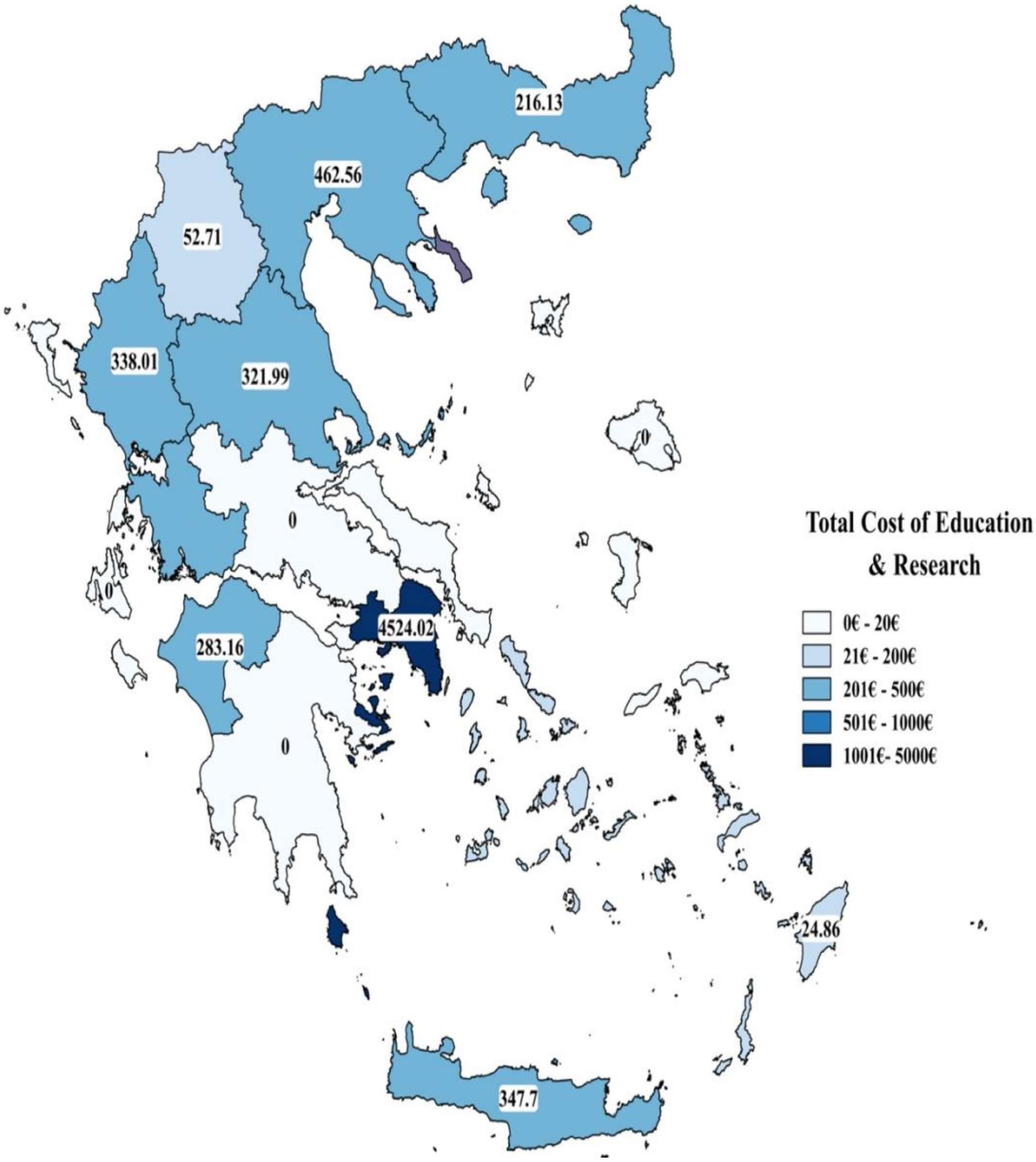

Figure 3.9 - Total Cost for services of Education & Research

Chapter 4

Financial and technological spillovers in space and time from the use of ionizing radiation

4.1 Introduction

In 2004 the famous Japanese economist and Governor of the Bank of Japan, Toshihiko Fukui, said in an opening speech that "The increased global linkages promote economic growth in the world through two key mechanisms: the division of labor and the international spillovers of knowledge".

Nowadays, it is very crucial that financial and technology spillovers must be appropriately quantified and used from a country to neighboring one in important sectors, like healthcare. Healthcare is not only defined as a public good or service in the society and economy but the most valuable one worldwide. It is indicated that after their systematic review from 2010 to 2013 in 19 electronic databases, they found a wide terminology used to describe spillover effects, a lack of standardization among spillovers measurement methods and poor reporting of spillovers effects in many studies for healthcare (Benjamin-Chung, et al., 2017). There were worthwhile efforts by programs ¨P4P¨ of OECD with positive spillovers in general strengthening of health sector governance through better data systems and feedback loops (Cashin, et al., 2014). In most cases of healthcare supply chain, similarities in technology and geographic proximity are two primary factors affecting the formation of IT alliances and investments in IT can be very costly (Shih, et al., 2009). A country surrounded by industrialized countries with relatively high per capita income and efficient healthcare systems benefits from the spatial spillovers with a high autocorrelation (Jeleskovic & Schwanebeck, 2012).

The technology spillovers in the healthcare system is vital among countries due to the knowledge externalities and the adoption of new technologies with positive productivity spillovers. In global healthcare system, the use of ionizing radiation is widespread known and applied in the radiological equipment such as mammographs, computed tomography, cabinet X-ray, medical accelerator, general and dental radiography. Therefore, the technological innovation is imperative not only for the medical equipment but also for the externalities to other countries.

The structure of the paper is as follows. In Section 2, we summarize the theoretical and empirical literature on financial and technological spillovers. Section 3 specifies our empirical model, presents the econometric methodology and data we use. The empirical findings are analyzed in Section 4, while in the last Section we outline the concluding remarks and policy implications.

4.2 Literature

In the empirical forefront, there is a wide body of literature that studies financial or/and technological spillovers from environmental effects. Due to vast literature, this section will be divided into three categories in order to refer adequately in each category.

4.2.1 Financial spillovers

This section includes some major determinants that are closely related to environmental issues such as Foreign Direct Investments (FDI), economic growth, agglomeration economies and not only. Financial spillovers are a crucial factor that can affect either positively or negatively the environment because the goal of every country/region aiming is economic growth.

Most notably, the relationship between FDI related and environmental effects is one of the latest trends in literature. It is supported that FDI significantly improves the host region's environmental outcome but it doesn't have direct measureable effects but it has indirect measurable effects to key macro variables such as investments (Huang, et al., 2017). It is also found that both FDI and domestic financial capital markets in an economy of 44 developing countries are likely to have positive impacts on the environment (Talukdar & Meisner, 2001). On the contrary, results indicate that the direct, undirect and total effects of FDI on pollutant emissions are all negative for 112 Chinese cities (Liu, et al., 2017). In accordance with the previous results, FDI induces negative environmental externalities in China for 287 cities and institutional development reduces the impacts of FDI across the board (Wang & Chen, 2014). Furthermore, findings supported that FDI tends to increase CO_2 supporting evidence of the pollution haven hypothesis (Baek, 2016) but also SO_2 emissions in Beijing-Tianjin-Hebei region (Zhu, et al., 2017). Concerning for FDI and energy demand, it is underlined the fact that FDI discourage non-renewable industrial energy consumption for 74 countries during 1985-2012 (Doytch & Narayan, 2016).

Another recent strand of research-studies is related with the economy growth as the main financial determinant. It is suggested that most air and water emissions rise with increases in economic growth at current income levels for 112 Chinese major cities during 2001-2004 (Cole, et al., 2011). In accordance with the previous result, economic growth along with population density, industrial structure and capital investment are driving forces of SO_2, COD and CO_2 emissions in China respectively (Li, et al., 2014) (Zhou & Wang, 2018). Moving to Malaysia, results showed that an increase in carbon dioxide emission will increase economic growth (Lau, et al., 2014). Immediate reduction of CO2 emissions and energy consumptions will severely hamper the poverty and unemployment alleviation but also the economic development process in China (Rauf, et al., 2018). Opposite results supported the existence of an inverted U relationship indicating economic growth has a restraining effect on environmental pollution, (Liang & Yang, 2019) . Regional differences presented a “U” shaped relationship existed in China's western region unlike the eastern and central ones. The economic growth reduced air pollutants in eastern region, whereas it promoted air pollutants in other regions (Xu, et al., 2019).

Agglomeration economies with environmental effects can be considered as a significant field of research related to our subject. Based on this theory, a research showed that specialization agglomeration of low-end technology industry has significant reduction effects on carbon emission of local and neighboring cities in most cases, while the diversification agglomeration has increased it. In mid-range technology industry, the carbon emissions of the local and neighboring cities have been increased. For high-end technology industry, there are significant carbon emission reduction effects in varying degrees for the local and neighboring cities (Han, et al., 2018). It is suggested also that it will be important to prevent agglomeration from becoming a source of congestion diseconomies by stretching “thin”, green institutional set-up (Cainelli, et al., 2012).

The literature is addressing more determinants except the above that combine financial sector with environmental effects. It is reported that only the indirect effect is significantly negative that overcomes the positive direct effect implying a negative and significant total effect (You & Lv, 2018). Talking about direct and indirect effects, findings confirmed the impact of Environmental Corporate Social Responsibility

(ECSR) on Corporate Financial Performance (CFP) indicating the direct impact of ESCR on CFP is negative (Lioui & Sharma, 2012). Replacing economic globalization with per capita GDP, result showed the direct effect of it on each pollutant emissions is entirely negative in China (Li, et al., 2018). In Sweden, there are significant positive economic spillovers at low income which turn negative at high income on both within and inter-municipality air emissions (Marbuah & Amuakwa-Mensah, 2017). An increase in renewable energy consumption, trade openness, and financial development decrease carbon emissions in 23 countries while increase in non-renewable energy consumption contribute to the level of emissions (Dogan & Seker, 2016).

4.2.2 Technological spillovers

In this section, we will refer to numerous studies about technological factors in relationship with environmental issues. Due to the continuing pollution of environment, new technology innovations are presented to the world. Many researchers are trying to investigate this relationship and its results.

Starting from a more theoretical point of view, some studies proposed guidelines or policies. The rate and direction of technological advance are influenced by market and regulatory incentives, and can be cost-effectively harnessed through the use of economic-incentive based policy. It is underlined the fact that in the presence of weak or non-existent environmental policies, investments in the development and diffusion of new environmentally beneficial technologies are very likely to be less than would be socially desirable. Positive knowledge and adoption spillovers and information problems can further weaken innovation incentives (Jaffe, et al., 2005). Innovation of new pollution abatement techniques requires a new market to develop. If policy is lax, few firms enter and are forced to charge a high mark-up in order to cover development costs. On the other hand, a stringent environmental policy induces higher demand and allows a lower mark-up (Greaker, 2006). Based on abatement technologies, it is indicated that strong public support for innovation is only justified if at least a moderate emissions policy is in place and spillover effects are significant. Technology policy is more effective with fuller emissions pricing and is better viewed as a complement to than a substitute for mitigation policy (Fischer, 2008). Applying Computable General Equilibrium (CGE), international technological spillovers can lead to small or even negative rates of carbon leakage, under standard assumptions of optimizing behavior of economic agents (Gerlagh & Kuik, 2007).

The trend of technology innovations is related with productivity, especially in ecological and environmentally friendly solutions. Findings revealed a positive relationship between firm investment in environmental practices and productivity improvement, also showing the presence of positive environmental spillovers in Spain in the agriculture sector (Galdeano-Gomez, et al., 2008). Consistent with the previous research, the improvement of the technological capabilities by R&D triggers environmental innovations, helps to reduce the information deficits to detect cost saving potentials that are also an important driving force of environmental innovation (Horbach, 2008). Spillovers between countries have a significant positive impact on further innovation in energy-efficient and environmentally friendly techniques (Verdolini & Galeotti, 2011). In 2005 in Italy, it is reported that interregional technological spillovers are more important than sector internal innovation for improving Environmental Performance (EP) for 20 regions (Costantini, et al., 2013). In China, a research supports that it depends on the location of region where the inter-provincial R&D direct technology spillover effects have a significant inhibitory effect on CO_2 emissions in eastern and central region while the indirect one is significant in central region (Jiao, et al., 2018). It is also reported that the productivity improvement, may also be related to the effect of labor productivity and the necessary better-qualified staff in the cooperatives, considering the existence of spillover effect in this environmental management (Galdeano-Gómez, 2011)

4.2.3 Economic and technological spillovers

Enriching our literature, apart from the individual specialization of each previous category, many researchers have combined them with imperative results because they can be interrelated due to the nature of them.

Research revealed that the trade-induced technological changes are GDP reducing and pollution increasing for 76 countries over the period 1963-2000 while the increased trade openness correlates to increased pollution (Managi & Kumar, 2009). In China, it is indicated that both indigenous R&D and import's technology spillover play a significant role in decreasing China's carbon intensity for 30 Chinese provincial-level regions during 2000-2014. The technology spillovers originating from FDI and export are also beneficial to the reduction of China's carbon intensity (Huang, et al., 2018). Findings presented China's current economic development level in total can trigger certain technology spillover effects. Especially in some rapidly economically developing areas, FDI inflows can exert a positive role in local economic and technological development (Song, et al., 2015). Furthermore, FDI can reduce industrial pollutant emissions both in general in specific industries, because the positive technological effect of FDI brought by introduction and expansion of technology is greater than the negative scale and structural effects (Bin & Yue, 2012). Adding population as a variable, the empirical results showed that high-tech industry, FDI and carbon emissions have spatial dependence and spatial agglomeration effects indicating the need for a low-carbon economy by increasing the proportion of high-tech industry through technological progress (Li, et al., 2019). In a recent research in China, an inverted N relationship exists between economic growth and environmental pollution, while FDI and R&D research have insignificant and significant influence on it respectively (Liu & Lin, 2019).

4.3 Empirical Framework

4.3.1 Data

The econometric estimations are based on pooled time-series cross-section yearly data for 15 European countries covering the period from 2000 to 2014. The sample consists of an updated yearly data set that allows us to carry out a thorough investigation of the growth rates for two variables GDP per capita (current $) and the Ionizing Radiation Therapy Equipment (IRTE). The data source is World Health Organization, Eurostat and from the corresponding ministry of Health of these countries. Our goal is to investigate the GDP and IRTE growth rates, compute the direct and spillover, point-in-time effects using model coefficients and a sequence of shocks.

4.3.2 Econometric specification and estimation methodology

The starting point for our exposition is the PVAR methodology in order to compare the results with the next referred methodology that is expanded to panel setups. PVAR methodology expands the basic VAR model, treats all the variables in the system as endogenous with the panel-data approach and allows for unobserved individual heterogeneity (Sims, 1980). The general form of the PVAR model can be presented as follows:

$$\mathrm{Y_{it}} = \mathrm{A_0} + \mathrm{A_1 Y_{it-1}} + \mathrm{A_2 Y_{it-2}} + \ldots + \mathrm{A_j Y_{it-j}} + \mathrm{BX_{it}} + \mu_\iota + \lambda_t + \varepsilon_{it} \qquad (4.1)$$

where Y_{it} is a vector of the endogenous variables, while the autoregressive structure allows all endogenous variables to enter the model with a number of j lags. X_{it} is a vector of the exogenous variables, μ_ι accounts for the unobservable country characteristics (country fixed-effects), λ_t express for any global shocks that may affect all countries in the same way (time fixed-effects) and ε_{it} is the error term (Antonakakis, et al., 2016).

The next point of our empirical framework, where spatial and GVAR models meet in terms of structure, is a cross-section of N units observed over T time periods. Applying the methodology of Elhost et al. we try to combine the spatial and global vector autoregressive classes of econometric models to the joint point of structure, interpretation and estimation methods (Elhorst, et al., 2018). The model structure representative for the spatial econometrics literature is the Dynamic Spatial Durbin Data Model (SDM) which reads, in vector form, as defined:

$$\mathrm{Y_t} = \tau \mathrm{Y_{t-1}} + \delta \mathrm{W} \mathrm{Y_t} + \eta \mathrm{W} \mathrm{Y_{t-1}} + \mathrm{X_t} \beta + \mathrm{W} \mathrm{X_t} \theta + \alpha + \lambda_t \iota_N + \varepsilon_t \qquad (4.2)$$

where Y_t is an N × 1 vector that involves one observation of the dependent variable for every unit i ($\mathrm{i} = 1, \ldots, \mathrm{N}$) at time t ($\mathrm{t} = 1, \ldots, \mathrm{T}$), X_t is an N × k matrix of exogenous explanatory variables and W an N × N non-negative matrix of known constants describing the relationships of the cross-section units. The terms τ, δ, and η denote the response parameters of, respectively, the time lagged dependent variable $Y_t - 1$, the spatially lagged dependent variable WY_t, and the spatially and time lagged dependent variable WY_{t-1}, while β and θ are k × 1 vectors of response parameters of the exogenous explanatory variables. The N × 1 vector $\alpha = (\alpha \mathrm{i}, \ldots, \alpha \mathrm{N})'$consists of unit specific effects a_i controlling for all unit-specific, time-invariant variables whose omission could bias the estimates in a typical cross-section application. Time-specific effects are captured by $\lambda_t(\mathrm{t} = 1, \ldots, \mathrm{T})$, where ι_N is an N × 1 vector of ones which controls for all time-specific, unit-invariant variables whose omission could bias the estimates in a typical time series application. The error term is represented by the N × 1 vector $\varepsilon_t = (\varepsilon_{1t}, \ldots, \varepsilon_{Nt})'$ of i.i.d. disturbance terms which have zero mean and finite variance σ^2.

Moving to the standard Global VAR (GVAR) model structure (Pesaran, et al., 2004) (Chudik & Pesaran, 2016) that stems from a local equation for each unit i which as adopts the subsequent form:

$$\mathrm{Y_{it}} = \varphi_\mathrm{i}\mathrm{Y_{i,t-1}} + \Lambda_{\mathrm{i0}}\mathrm{Y^*_{it}} + \Lambda_{\mathrm{i1}}\mathrm{Y^*_{i,t-1}} + a_\iota + \Gamma\omega_\mathrm{t} + \varepsilon_{\mathrm{it}} \tag{4.3}$$

Y_{it} is a vector whose elements consist of observations for k different variables $X_{it,j}$ (j=1,...,k) such that $\mathrm{Yit} = (\mathrm{Xit}, 1, \ldots, \mathrm{Xit}, \mathrm{k})'$, for every unit $\mathrm{i}\ (\mathrm{I} = 1, \ldots, \mathrm{N})$ at time $\mathrm{t}\ (\ \mathrm{t} = 1, \ldots, \mathrm{T}\ )$. Let $\mathrm{Xtj} = (\ \mathrm{X1t,j}, \ldots, \mathrm{XNt,j}\ )'$ be an N × 1 vector of all observations on the j-th X variable at time t. Then $X^*_{tj} = W^j X^{tj}$, where W^j is an N × N non-negative matrix of known constants describing the linkages of the units in the cross-section domain for this j-th X variable $(\mathrm{j} = 1, \ldots, \mathrm{k})$. Consequently, $Y^*_t = (\ W^1X^{t1}, \ldots, W^kX^{tk}\ )'$ is a k × N matrix of weighted foreign variables, and its i-th column Y^*_{it} a k × 1 vector of the foreign variable with respect to unit i and time t. The terms φ_i, Λ_{i0}, Λ_{i1} are k × k matrices of response parameters of the vectors of respectively, the time lagged dependent variables, the contemporaneous foreign (spatially lagged) variables and the time lagged foreign (spatially lagged) variables. The k × 1 vector a_ι contains the intercepts of each variable. ω_t and coefficient matrix Γ denote observed, exogenous common factors which are global from the perspective of all cross-section units. In principle, these variables could also be added to a spatial equation structure as the one in eq. (4.2). ε_{it} a k × 1 vector of idiosyncratic shocks (error terms) with mean zero and a nonsingular k × k covariance matrix Σ.

Considering their principal elements, linear spatial models and GVARs depend on an explicit modelling of cross-sectional links via connectivity (weight) matrices.

Nevertheless, the number of dimensions across these models is not similar, at least in their standard, conventional structures. Noticing the Table 4.1 that describes a complete synopsis about the discrepancies and the adjustments that can be formed such the two classes of models become equivalent in terms of framework.

Table 4.1 - Key distinguishing features of standard spatial and GVAR representations

Feature	**Spatial**	**GVAR**
Typical focus	Single equation, univariate dependent variable (k=1)	Simultaneous equation system, multivariate ($k \geq 1$)
Cross-section/time dimension	N large, T small ($N > T$)	N sufficiently large, T larger ($N < T$)
Slope coefficients	Homogenous across units for each explanatory variable	Heterogenous, unit-specific coefficients
Treatment of spatially lagged (“foreign”) variable (RHS)	Endogenous (WY_t)	Weakly exogenous ($Y_t^* = WY_t$)
Strictly exogenous variables	Included	Observed global common factors
Link (weight) matrix W	Usually location-based and exogenous, reflecting time-invariant neighbor structures and one matrix for all variables	Usually macro-financial empirical can be time variant and potentially different matrices for each variable
Cross-sectional dependence	Usually “weak”, i.e. related to a limited number of neighbors with relatively large weights (referred to as a sparse connectivity matrix W)	Usually “strong”, i.e. related to a large number of neighbors with rather evenly distributed weights (referred to as a dense connectivity matrix W)

The next step takes into account these interpreted versions modify, respectively, a univariate spatial autoregressive (SAR) panel model with unit-specific spatial fixed effects (α):

$$Y_t = \delta W Y_t + \alpha \, (+X_t \beta) + \varepsilon_t \tag{4.4}$$

along with a univariate GVAR model without time autoregressive lags of Y_t or additional lags of the foreign variable vector WY_t, reported in stacked pattern by connecting the equations of all cross-section items:

$$Y_t = \psi WY_t + a + \varepsilon_t \qquad (4.5)$$

where $\psi = diag(\delta_1, \ldots, \delta_N)$. To be more specific, the term $X_t\beta$ placed in eq.(4.4) in parentheses, indicates that this equation is possible to include an exogenous explanatory variable which in eq.(4.5) is endogenized as dependent variable. We underline the fact that both models include the variable of right hand-side WY_t as well as unit-specific intercepts. The main distinction is that the slope coefficients ψ are unit-specific in the GVAR model, whereas δ is a scalar in the spatial model. When these coefficients in the spatial model would be assigned to be heterogeneous across units, then both model frameworks would therefore end up equivalent.

Focusing on the next step which applies a two-step procedure to discriminate between weak and strong cross-sectional dependence and eventually model each type through either standard common factor or standard spatial models. To begin with their procedure, we expand it in order to contain the relevant estimation method and spillover measurement, establishing on the de-facto equilibrium between “augmented” spatial and GVAR models. This specific procedure (Bailey, et al., 2016a) is based in the CD-test established by Pesaran (Pesaran, 2004) (Pesaran, 2015) and the a-exponent estimator by Bailey et al. (Bailey, et al., 2016b). Let x_{it} indicate the individual observation of (one of) the dependent variable(s) of unit i at time $t (i = 1, \ldots, N; t = 1, \ldots, T)$. Then the CD test statistic is the following:

$$\mathrm{CD} = \sqrt{2\mathrm{T}/\mathrm{N}(\mathrm{N}-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \qquad (4.6)$$

where $\hat{\rho}_{ij}$ denotes the sample correlation coefficient between x_{it} and x_{jt} of two units i and j observed over time. The degree of cross-sectional dependence is proved by the test in terms of the rate at which the average (over all $N-1$ unit pairs) pair-wise correlation coefficient ranges with N as N goes infinity. Bailey et al. show that the average correlation coefficient has the order equity of

$$\bar{\rho}_{\mathrm{N}} = \frac{2}{\mathrm{N}(\mathrm{N}-1)} \sum_{\mathrm{i}=1}^{\mathrm{N}} \sum_{\mathrm{j}=\mathrm{i}+1}^{\mathrm{N}} \rho_{\mathrm{ij}} = \mathrm{O}(\mathrm{N}^{2\alpha-2}) \qquad (4.7)$$

where a is a parameter with acceptable values on the (0,1) interval (Bailey, et al., 2016a). For 0<α<1/2, $\bar{\rho}_N$ tends to go to zero rapidly, indicating weak dependence. If the result shows that $\alpha = 1$, $\bar{\rho}_N$ approaches to a non-zero value and strong dependence (common factors) needs to be taken into consideration. A noticeable observation to be accounted for is that α will maintain this value of unity if the number of ρ's tends to infinity at the same rate as N^2. Proceeding to the range $1/2 \leq \alpha < 3/4$, considers to represent moderate and $3/4 \leq \alpha < 1$ quite-strong strong-sectional dependence. Below in Table 4.2, all four distinct conditions are listed and will be related to the type of spatial weight/connectivity matrix (sparse or dense) and the appropriate estimation method. From eq. (4.4) it is denoted that the order of convergence of the average cross-section correlation coefficients is $N^{-1/2}$ consistent with estimation conditions with OLS, provided that α = 3/4.

Table 4.2 - Interplay between cross-section dependence, weight structure and estimation method

α	**Cross section dependence**	**Weight Structure**	**Estimation**
$0 < \alpha < 0{,}5$	weak	sparse: local, mutually dominant units	ML/IV/GMM
$0{,}5 < \alpha < 0{,}75$	moderate	still quite sparse	
$0{,}75 < \alpha < 1$	quite strong	Dense	OLS
$\alpha = 1$	strong	CS average or PC (no weights involved)	

According to Bailey et al. (2016b), a can be estimated by the following equation

$$a = 1 + \frac{\ln\sigma_{\bar{x}}^2}{2\ln N} - \frac{\ln u_v^2}{2\ln N} - \frac{c_N}{2N\ln N\sigma_{\bar{x}}^{2\prime}} \tag{4.8}$$

where $\sigma_{\bar{x}}^{2\prime}$ is defined as $\sigma_{\bar{x}}^{2\prime} = 1/T\sum_{t=1}^{T}(\bar{x}_t - \bar{x})^2$ and $\bar{x} = 1/T\sum_{t=1}^{T}\bar{x}_t$, which state the cross-section average and time average respectively. The terms u_v^2 and c_N are small bias-correction terms obtained by running separate regressions of x_{it} on a constant and $\bar{x}_t$ for each unit i in order that each regression is based in T on observations.

In GVARs or spatial systems, spillovers can be estimated through spatial indirect effects alike impulse responses from GVARs models. In order to represent externalities from GVARs model, it must be changed to a spatial system, a computation of responses to shocks in the error term and a more considerable focus on pairwise responses. The direct (marginal) effects of exogenous variables X on the dependent variable Y are expressed by the coefficient estimates of a standard linear regression equation while the coefficient estimates in a spatial econometric equation do not.

For this study, we examine a two-variable, two equation spatial system based on eq. (4.1) and (4.2). The two variables are Y = GDP and I = Ionizing Radiation therapy equipment.

$$\mathrm{Y_{it}} = \tau_{\mathrm{yi}}\mathrm{Y_{i,t-1}} + \delta_{\mathrm{yi}}\mathrm{W_{1i}Y_{it}} + \theta_{\mathrm{yi}}\mathrm{W_{2i}I_{jt}} + \varepsilon_{\mathrm{y,i,t}} \tag{4.9}$$

$$\mathrm{I_{jt}} = \tau_{\mathrm{ij}}\mathrm{I_{j,t-1}} + \delta_{\mathrm{ij}}\mathrm{W_{3j}Y_{jt}} + \theta_{\mathrm{ij}}\mathrm{W_{4j}I_{it}} + \varepsilon_{\mathrm{i,j,t}} \tag{4.10}$$

The separate cross-section item counters for GDP and Ionizing Radiation therapy equipment are $i = 1, \dots, N$ and $j = 1, \dots, M$ respectively and can be handled independently to allow the number and the order of items to be different. Furthermore, the weight matrices W_1 and W_3 are square and having zero diagonal elements while the matrices W_2 and W_4 may not be square (unless N=M) and are in general having non-zero diagonal elements.

The theory about spillovers that proposes Elhorst et al. contrasts what suggest Le Sage and Chih with a different computation (Le Sage & Chih, 2016). They proposed to measure the spill-in/out (indirect effects of a heterogeneous model) as the average over all off-diagonal elements in a row or column rather than their sum, because the latter have no economic interpretation as they increase with the number of units in cross-section. This approach is relevant to already existing literature to the forecast error variance in *y(i)* explained by *x(j)* (Diebold & Yilmaz, 2009). The spill-in effects are considered to present the sensitivity (vulnerability, response) of variable *Y* in unit *i* to changes in variable *I* in all other units. In the contrary, spill-out effects depict the impact (impulse) of the change in variable *I* in unit *i* on changes in variable *Y* in all other units.

4.4 Empirical Results

Based on the three model selection criteria (Andrews & Lu, 2001) and the over-all coefficient of determination, we choose first-order panel VAR since it has the smallest MBIC, MAIC and MQIC applying then GMM estimation. We use GMM-style instruments because we improve estimation (Holtz-Eakin, et al., 1988) replacing missing values in instrument lags with zeroes. This technique increases the estimation sample, which results to more efficient estimates. Our point of view is that the results in Table 4.3, being estimates do not convey so much information despite all variables are statistically significant. Instead, one should pay attention to the impulse response functions (IRF) because they describe the response of an endogenous variable over time to a shock in another variable in the system. Before computing the IRFs, we must estimate the confidence intervals with Monte Carlo simulations[7] because through this procedure it is generated a draw of coefficients of the PVAR (Love & Zicchino, 2006).

Table 4.3 - Baseline Estimation results of VAR using PVAR and GMM

Variables	**GDPpc**	**Ionizing Radiation Therapy Equipment (IRTE)**
GDPpc $_{t-1}$	0.9835***	0.0003**
IRTE$_{t-1}$	-42.3440*	.7670***

In terms of levels, the IRF plot in Figure 4.1 shows that a financial shock on Ionizing Radiation Therapy Equipment leads to a totally positive response while in the end shows a slight decrease in the sample. On the other side, a technological shock on GDP per capital shows a continuous backward bending in the same variable with negative magnitude. It is also noteworthy the current shock in GDP per capital have negative yet short-lived impacts on Ionizing Radiation Therapy Equipment while only in the end presents a stable condition. In the contrary, the effect of a financial shock illustrates a continuous decreasing trend on GDP per capital in the short and the long-run. Finally, similar to the previous result, a technological shock to IRTE proves also a declining trend in the short and the long-run with a negative coefficient at the end.

The first step for our methodology is to conduct the CD test and find the estimation of *a* for each variable separately. The estimation of CD test statistics is 35.6 for the first variable of GDP growth, with an average pairwise correlation of 0.29 while the a-estimate equals 0.75. Interpreting the results, we notice that CD test statistic presents to be significant while the a-estimate is exactly 0.75 and we choose the upper bound of the second level of a-estimations as usual in these cases. This estimate has

[7] This procedure is repeated 200 times to generate 5th and 95th percentiles of this distribution, which are then used as a confidence interval for the impulse-response.

quite sparse weight structure and moderate cross-section dependence with respect to GDP growth need to be accounted for. The last significant coefficient depicts the proper explanation of controlling common factors related with a still quite sparse weight matrix. It illustrates that a matrix will converge to infinity at a rate slower than N (Lee, 2004) and estimations of the coefficients of the common factors by IV shall be consistent. Moving to the next variable, IRTE presents analogous results as GDP growth. The estimate of CD-test statistic is equal with 31.2 with an average pairwise correlation coefficient of 0.29, while the a-estimate takes a value of 0.747. Taking into consideration both results, applying a GVAR first-order system in space and time with heterogeneous coefficients by IV is the appropriate estimation method.

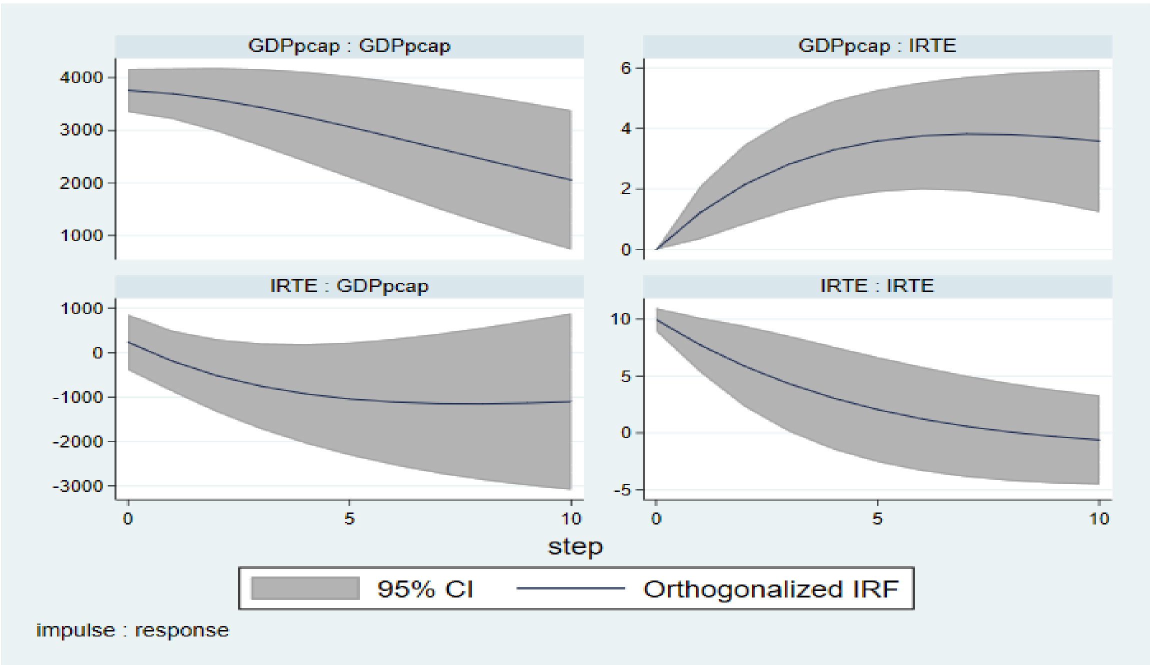

Figure 4.1 - Impulse Reponses Functions of PVAR model

We use four weight matrices in order to connect the two cross-sections, whose structure is presented in Table 4.4. There might be probability that GDP and Ionizing Radiation therapy equipment may affect each other mutually within country at time *t*, these terms have been considered separately unlike $X_t\beta$ in eq. (4.2). This structure is described as a two-way mutual and local dominant that indicates the relationship between ionizing radiation therapy equipment and GDP.

Table 4.4 - Connectivity (weight) matrices W that link GDP and Ionizing Radiation therapy equipment in exemplary spatial equation system

		RHS	
		GDP	**Ionizing Radiation therapy Equipment**
LHS	**GDP**	W11 =Transpose of health expenditure difference	W12 = Health Expenditure
	Ionizing Radiation therapy Equipment	W21= W12	W22 =Transpose of Medical High Technology Exports

The estimation results are illustrated for the GDP and Ionizing Radiation therapy equipment in Table 4.5 and *Table 4.6* respectively. After conducting likelihood ratio (LR) test, based on the log-likelihood function values of the heterogeneous and homogeneous models, we conclude that the system is strongly stable under both slope assumptions. Moving to the next test for remaining cross-sectional dependence residuals by implementing the CD-test on its residuals, it is illustrated for both equations (GDP and Ionizing Radiation Therapy Equipment) are insignificant.

Table 4.5 illustrates results about GDP growth equations. It is evident that the time-lagged variable Υ_{t-1} and especially the spatially lagged variable W11Υ_t are the two most relevant variables of GDP. Focusing on the spatially lagged variable W11Υ_t, the majority of countries appear to be strongly positive significant at 1% significance level and the rest 4 countries also positive from 10% to 5%. Talking about the magnitude, Austria presents the maximum value of 0.931 and Slovenia the minimum with 0.126. The time-lagged variable Υ_{t-1} is significant at 1% significance level in 3 countries and in 5 countries from 5% to 10% significance level. The remaining variables turn out to be significant for approximately one-third of the countries being considered.

Table 4.5 - Estimation results GDP growth equations

Country	Intercept	Y_{t-1}	$W11Y_t$	$W11Y_{t-1}$	Own I_t	$W12I_t$	Own I_{t-1}	$W12I_{t-1}$
AT	0.135*	-0.432*	0.931***	0.037	0.212	0.004	0.118	0.378
CZ	0.507***	-0.167	0.892***	0.361	0.226**	0.317	0.782	-0.372**
CY	-0.034	-0.112**	0.519***	0.478**	0.432*	-0.632*	0.487*	-0.033
DE	0.441**	0.017	0.643**	-0.119	0.718	-0.009	0.956**	-0.277**
HU	0.681*	0.413*	0.647***	0.226	0.116	-0.139	-0.021	-0.003
IS	-0.112	0.772***	0.287***	-0.118	-0.001	0.003	-0.067	-0.456
FR	0.931**	-0.227	0.789**	0.421	-0.117*	0.053	0.027	0.653*
GR	-0.217	0.118***	0.881*	-0.217	0.002	-0.013	0.108	0.003
IT	-0.438**	-0.354***	0.235***	0.433**	0.017	0.107*	-0.048**	-0.031
LU	0.317	-0.781**	0.195**	0.145	-0.104	0.025	0.471	-0.106
LV	-0.971***	0.008	0.732***	0.718***	-0.079	0.069	0.081*	-0.061
NL	-0.171**	-0.276	0.321***	0.197***	-0.658	0.424*	-0.501***	0.891**
PL	-0.002	0.002	0.287***	-0.469*	-0.822	0.549	0.714	-0.002
SI	-0.664	0.842**	0.126***	-0.018	0.029	0.151***	0.018	-0.123**
SK	0.732	0.611	0.771***	0.027	0.153	0.628***	0.374	0.009

Note: *** significant at 1%, ** significant at 5%, * significant at 10%.

Table 4.6 - Estimation results Ionizing Radiation Therapy Equipment (IRTE)

Country	Intercept	It−1	W22It	W22It−1	Own Y_t	W21Yt	Own Y_{t-1}	W21Yt−1
AT	-0.431	0.775**	0.371**	0.252	-0.003	0.104**	0.138*	-0.008
CZ	0.224	0.057	0.135	0.649	-0.969***	0.195**	-0.273	0.518**
CY	0.061	0.176***	0.372	0.429	0.731	0.346	0.741	0.491**
DE	-0.151	0.241	0.318	0.572	-0.631	0.472	0.139	-0.152
HU	0.781	0.542**	-0.661	0.432	0.007	0.218	0.162	-0.901
IS	0.316	-0.509	0.264**	-0.054	0.006	0.108	-0.003	-0.431
FR	0.209*	0.732***	-0.902	-0.436	-0.668	0.931	0.561	0.784
GR	-0.903	0.243**	0.539	-0.624	0.881**	-0.225**	0.117	-0.261**
IT	0.837	0.036	0.529	0.175	0.092	-0.455	0.197*	0.521
LU	-0.045	0.160***	0.595*	0.761*	0.801**	-0.471	0.254**	-0.336
LV	-0.022	-0.009	0.208	0.851	-0.037	0.354	0.004	0.003
NL	-0.023	0.811***	0.059	0.058	-0.006	-0.028	-0.021	0.481***
PL	0.528	0.471***	0.541**	-0.762	0.881**	-0.078	-0.034	-0.167
SI	-0.133	0.419***	0.102	0.617	-0.347	0.325	0.031	0.284
SK	0.561*	0.147*	0.321	0.147	-0.034	0.111	0.436	0.003

Note: *** significant at 1%, ** significant at 5%, * significant at 10%

Further, Table *4.6* displays analogous results regarding Ionizing Radiation therapy equipment equations. Nevertheless, the number of coefficients appears to be significant decreased to some extent. The time-lagged variable I_{t-1} is the most admissible variable of Ionizing Radiation therapy equipment revealing 10 significant results and more specifically 6 countries at 1% significance level. More specifically, Netherlands presents the highest value of 0.811 while Slovakia the minimum with 0.147. Observing carefully the coefficients of the spatially and time-lagged variable *W22*I_{t-1}, we notice that only one country has significant coefficient, implying that we could have removed it from the model equally well.

The next two tables (Table 4.7 and Table 4.8) demonstrate results for the short-term or point-in-time direct and spillover effects at h = 0 of a one standard deviation shock in each country's GDP and Ionizing Radiation equipment therapy respectively, based on the estimate $\hat{\sigma}$ for each country. In particular, Table 4.7 presents the direct or own country effect of this shock for GDP growth which ranges from 0.07 for Greece to 0.99 for France and is significant in all countries. The column "GDP spill-in" describes the spillover effect of such a shock on GDP growth in other countries. Each country may be affected by a shock in one of the other fourteen countries. In order to reduce the amount of output, the described spillover effect is calculated as the average over these fourteen outcomes. According to previous action, the spillover effect is smaller than the interrelated direct effect. The magnitude varies from 0.02 to 0.79 for Austria and Cyprus respectively. Only one country has insignificant spillover effect while the majority of countries (12 of 15) have significant and positive spillover effect at the 1% significance level. We must underline that although spill-in and spill-out effects are on average of the same order of magnitude, they are not the same, since they are on the same concept. For example, France is affected moderately to GDP growth spill-in effects and barely provides any GDP growth spill-out effects. On the contrary, Cyprus presents to be more vulnerable to these kinds of spill-in effects, while Denmark produces the strongest GDP spill-out effects.

The next column “Radiation spill-in” is described as the spillover effect of a GDP shock on radiation in the own or in another country. These spillovers are smaller about 0.70 (in absolute values) compared to the previous column because they reflect the vulnerableness of another variable than the variable that has been originally shocked (GDP). Furthermore, “GDP spill-in” effects appeared to be approximately a little more than one half of the direct effects. All countries produce GDP growth spill-out effects which are strongly statistically significant. On the contrary, only three countries, Cyprus, Greece and Luxembourg, produce IRTE growth spill-out effects with the latter two countries presenting a negative sign. We notice that only 3 or 4 of the radiation spill-in or spill-out effects present significance, denoting the increased difficulty of finding empirical evidence for significant spillover effects rather than significant direct effects. An obvious explanation is that there are many more parameters to affect spillover effects. Selecting horizon h = 0, we detect that direct effects from Table 4.7 depend on the parameters of WY_t from Table 4.5. Contradictory results appeared to the spillover effects that also depend on the parameters of WI_t of Table 4.5 and WY_t in Table *4.6*, which shows only 5 and 3 to be significant respectively. The interpretation of the previous results is when there are more insignificant parameters, then there is strong possibility that also spillover effects derived from them will be insignificant. Thus, the hypothesis, that a shock to one variable has effects on another on or the same variable in another unit is a strong one, is justified.

Table 4.7 - Short-term effects at h = 0 of a one standard deviation GDP growth shock in every country

Country	Direct effect	GDP spill-in	Radiation spill-in	GDP spill-out	Radiation spill-out
AT	0.852***	0.019***	-0.003	0.236***	0.011
CZ	0.712**	0.055***	-0.004	0.109***	0.621
CY	0.452***	0.791***	0.861	0.541***	0.107**
DE	0.824***	0.571***	-0.231	0.641***	-0.002
HU	0.107***	0.074***	-0.002	0.055**	0.018
IS	0.631**	0.104**	-0.161	0.592***	-0.021
FR	0.993***	0.331***	-0.002	0.029***	0.004
GR	0.069***	0.015***	-0.018***	0.032**	-0.121***
IT	0.551***	0.088*	-0.003	0.059***	0.003
LU	0.448***	0.051	-0.265***	0.322***	-0.478***
LV	0.571***	0.109***	-0.001	0.285***	-0.706
NL	0.562***	0.341***	-0.647	0.191***	-0.119
PL	0.622***	0.541***	-0.096*	0.346***	-0.218
SI	0.477***	0.171***	-0.005	0.242***	-0.009
SK	0.154***	0.051***	-0.021*	0.023***	-0.003

Note: *** significant at 1%, ** significant at 5%, * significant at 10%.

Table 4.8 - Short-term effects at h = 0 of a one standard deviation Ionizing Radiation therapy equipment shock in every country

Country	Direct effect	Radiation spill-in	GDP spill-in	Radiation spill-out	GDP spill-out
AT	0.901***	-0.027	0.081**	-0.112	0.082**
CZ	0.823***	-0.264***	0.016	-0.041**	0.122***
CY	0.642***	0.018	0.037	0.003	0.004
DE	0.831***	-0.789	0.015	-0.006	0.168**
HU	0.992***	0.021	-0.082	0.072	0.001
IS	0.461***	0.091	0.277***	0.519*	0.005
FR	0.981***	-0.203*	-0.013	-0.012	-0.001
GR	0.124***	0.178***	-0.009	0.018**	0.026
IT	0.421***	0.005	0.041	0.013	0.012
LU	0.726***	0.661***	0.006	0.017***	0.004
LV	0.4862**	-0.0052	0.023	-0.037	0.368**
NL	0.619***	-0.008	0.045	-0.005	0.032
PL	0.381***	0.053	0.228*	0.029**	-0.006
SI	0.732***	0.006	0.017	0.026	0.048
SK	0.521***	0.115***	0.003	0.027***	0.036*

Note: *** significant at 1%, ** significant at 5%, * significant at 10%

Moving to Table 4.8, results present the direct and spillover effects at h = 0 of a one standard deviation shock in each country's ionizing radiation therapy equipment growth. The first column illustrates the direct or own country effect of this shock for IRTE growth that varies from 0.12 for Greece to 0.98 for France and is strongly significant in all countries. A matching point with the same column in Table 4.7 is that strong direct effects at h=0 depend also only on the parameters of the spatially lagged variable. The IRTE spill-in effects depict the spillover effect of such a shock on IRTE growth in other countries. Only five countries present significant results with different signs with the Luxembourg presenting the maximum value with 0.66 and Czech Republic the minimum one with -0.26. Looking carefully the spill-out effects across variables, we notice that there are more significant ones than Table 4.7, of ionizing radiation therapy equipment growth shocks in Austria, Czech Republic, Denmark, Latvia and Slovakia on GDP growth in other countries. The estimates display a productive discrimination between spill-in and spill-out effects due to the insignificant spill-in effects of these countries, except for Austria. Furthermore, a noticeable remark is that Slovakia presents to be barely sensitive to IRTE growth spill-in effects and also hardly produces any IRTE growth spill-out effects. On the opposite hand, Luxembourg appears to be the most sensitive country to these kinds of spill-in effects, while Czech Republic produces the most spill-out effects in an absolute value relatively with the other fourteen European countries.

4.5 Concluding Remarks

The paper sought to analyze the GDP per capital and Ionizing Radiation Therapy Equipment (IRTE) growth in a multivariate equation model for 15 European countries for the period 2000 - 2014. The empirical strategy adopted was a convergence of spatial and global vector autoregressive (GVAR) to the joint point which allows a broad and measurable concept of spillovers and more specifically on indirect effects from the spatial literature and impulse responses from the GVAR literature.

The estimated results of impulse response analysis from a baseline panel VAR model indicate that responses of IRTE and GDP per capital appear to have different signs from financial and technological shocks respectively. More specifically, technological shock from IRTE seems have a continuous negative impact to GDP per capital in the short run and the trend stabilizes in the long-run. In the contrary, financial shock illustrates a steady positive response on IRTE with an upwards trend in the short run and a slight downward trend at the end of long-run but the total response remains positive.

Our results from our spatial and GVAR model show that direct spillovers are all strongly significant and persistent, exerting considerable impact on GDP per capita and IRTE growth depending only on the parameters of the spatially lagged variable. By all means, direct effects are much stronger than the indirect effects, but also a financial shock is stronger than a technological one if we notice the coefficients of the GDP growth spill-in and IRTE growth spill-in effects in both shocks respectively.

Looking forward to indirect effects from a financial shock, most countries are moderate vulnerable to GDP growth spill-in effects and only four countries appear to have significant IRTE growth spill-in effects but with a negative sign. On the other side, the results of indirect effects from a technological shock presented mixed sign in the apparently fewer countries with significant impact to sensitivity to IRTE spill-in effects and produce spill-out effects. Moreover, we underline the noteworthy evidence that there are more significant spill-out effects across variables of IRTE growth shock in other countries than from a GDP growth shock. Since not all resembling countries present in both cases of spillover effects significance, these findings depict the noticeable difference between spill-in and spill-out effects.

To sum up, the results robustly demonstrate that financial spillovers do matter for the European countries more than technological ones from ionizing use based on indirect effects, even for direct effects being significant to all countries. Financial linkages imply strong externalities, which constitute the theoretical framework of our empirical analysis.

Chapter 5

Conclusion

The present thesis investigates the relationship between the economic development, radiation and the energy imprint, and to effectively tackle this issue, it is organized into five chapters.

The second chapter investigates the relationship among the economic growth and the electric power consumption seeking for uncovering any geographical and economic effect in a worldwide level. Any presence of these effects will validate the existence of motifs of localization of CO_2 emissions. It addresses questions that thus far have not been approached in the literature: (i) is there any externality under combination of spatial or economic, electric and environmental neighboring effects framework? and (ii) the reasoning of the presence of these externalities. We clarify these questions, using data from World Bank's database and including 89 countries from the period 1990 to 2014, employed with their natural logarithms form to reduce heteroscedasticity. Economic as well as geographical spillovers are allowed to rely on the similarity of their economic characteristics regarding GDP per capita, which the GDP connectivity matrix varies depending on any distance. Using several estimation methods to check robustness and the magnitude of each variable, we exceptionally refer the impact of regional spillovers of energy consumption motifs on the GDP growth. A plausible interpretation for such spillovers is mainly the consumption or production patterns between countries created by energy utilization in conjunction with emissions. In a particular economy, the economic growth can be influenced by energy consumption, emissions rates in bordering countries or economies regarding geographic or economic factors. The spillovers satisfiy the flows of reducing revenues to scale to capital growth inside each particular economy. Two divergent functions of primary interest are particularly highlighted: (i) predicting the average energy consumption utilizing both spatial and economic bordering connections, and (ii) investigating the energy consumption linked with growth and patterns of emissions. Nowadays, it is possible due to the evolution and progress of data science and technology to implement machine-learning models and algorithms not only to predict but also improve the estimations regarding the energy consumption depending on the data availability. Therefore, a better information network will be constructed for awareness of extensive economic and environmental assets within a stricter transmission framework.

The aim of the third chapter sheds new light on the linkage between economic growth and energy, from a different type of energy, the radiation. The research evaluates not only the economic impact via the total cost of services for radioprotection but also different type of spillovers between regions of Greece. For this purpose, a set of variables is employed such as economic, environmental, health, technological, using a hedonic model. The majority of papers, using this specific model, concentrated only on the real estate market. After the Fukushima accident, the hedonic approach became widely known in the radioprotection sector measuring and underlining the effect of decreasing housing market values around nuclear power plants in several countries. Therefore, previous work has only been focused on this disastrous accident and limited to the impacts of it. This chapter explores the current knowledge of radioprotection using the specific approach from another aspect. Our research is based on a dataset that includes 57.314 unique charges for services of Greek Atomic Energy Commission related with the radioprotection over the 2010-2016 period along with variables such as healthcare expenditure, medical capital investment and examinations MRI. Within the framework of these criteria, we try to broaden current knowledge of radioprotection and hedonic models in an innovative structure. For this purpose, spatial analysis is employed in a hedonic price framework to examine the impact of total service cost in Nuts 1 level in Greece. We include geographical, economic and health personnel impacts in order to confirm the existence and magnitude of interregional spillovers. The research focuses on the possible price fluctuation externalities by EEAE to the regions of Greece. The results strongly reveal that interregional spillovers affect regions of economic connections meaning robust cross-regional externalities in contrast with geographical ones. Moreover, we separate the effect of each single service for radioprotection, provided by EEAE, in order to discover the magnitude of each service in the total cost services. The findings demonstrate that non-ionizing radiation services present the strongest effect. Generally, it is considered extremely difficult to collect similar datasets from other national authorities on such sensitive area in order to compare the results in a larger level. The chapter also underlines the fact that it must be conducted a similar research based on the nominal revenues, which is a limitation, taking into consideration the magnitude of the effect of possible legislative and regulatory decisions, actions and initiatives.

The fourth chapter investigates the externalities after a sequence of shocks to the GDP per capita and Ionizing Radiation Therapy Equipment (IRTE) growth respectively of 15 European countries for the period 2000 – 2014. Healthcare innovations and patents are a vital part for a country's economy and health system as well as the quick adoption of them. The transfer of this diffusion of knowledge in other countries is imperative in order to improve the overall level of health systems. In this chapter, it was conducted an interesting research to reveal the existence and magnitude of spillovers after a series of shock between countries. The deployed methodology is a combination of spatial and global vector autoregressive till the common point of providing an extensive and quantitative approach of spillovers. Before applying this specific methodology, we derive that IRTE and GDP per capital depict different signs from financial and technological shocks respectively via impulse response functions from PVAR model for short, middle and long term concerning only the behavior of variables. Focusing on the main methodology, the direct effects exert major effect on the growth of these two variables depending on the parameters of the spatially lagged variable. Applying a financial shock, the majority of countries not only display a moderate exposure to GDP growth spill-in effects but also a negative sign. On the other hand, there are more significant spill-out effects across variables of IRTE growth shock in other countries than from a GDP growth shock with both trends, positive and negative. The results strongly present that financial externalities affect significantly the European countries more than technological ones from ionizing use depending on indirect effects. The same findings apply even for direct effects being significant to all countries. Financial connections indicate robust spillovers, which constitute the theoretical structure of our empirical analysis. A noticeable fact is that several of the strongest economies of European countries do not provide details about their medical equipment in order to be conducted a more detailed research.

In summary, the empirical analysis of the relationship between economic development, radiation and the energy imprint, through three different frameworks, in the present thesis, proposes valuable and helpful findings to paramount policy issues based mainly on spillovers between countries on European, worldwide level but also on regional in Greece. The energy imprint presents different results depending not only on the geographical level of research but also on the economic growth as a common variable along with the rest variables in the previous chapters. Further, by examining different types of spillovers such as spatial, economic, electric, technological, it is generally concluded that the economic ones are the most significant compared to the other types. Therefore, relevant policies and suggestions can be proposed into that directions based on the results.

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