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Residential building resource consumption: A comparison of Portuguese municipalities' performance

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ABSTRACT

The purpose of this paper is to develop a robust methodology to assess municipalities' performance concerning the consumption of resources in residential buildings. The assessment is carried out at a municipal level to inform decision makers about the relative position of their municipalities compared to others. In addition, the factors associated to better levels of municipal performance are identified, and the extent of their effects is quantified. The study uses an enhanced stochastic frontier panel model based on data of energy, water and materials consumption in Lisbon municipalities during the period 2003–2009. The study reveals that the municipalities' performance has remained stable over the years, although there are considerable differences in performance among municipalities. In addition, it is concluded that municipal performance tends to improve with the environmental policy expenditure and scale size, and decline with buildings' age, population density and the proportion of buildings with private ownership.

1. Introduction

The performance assessment of municipalities has gained momentum in recent years due to the implementation of decentralized policies at local scales. Decentralization enables to deliver public services more oriented to local communities' preferences, although it may lead to increased complexity in decision making and higher expenditures. The development of robust methodologies for the assessment of local government performance is vital in order to support local authorities to curb costs while providing good levels of services.

The literature on municipal performance assessment can be divided into two main research streams (see Doumpos & Cohen, 2014; Kalb, Geys, & Heinemann, 2012 for literature reviews). The first research line includes studies that evaluate the efficiency of local governments in the provision of several services under their responsibility (see Afonso & Fernandes, 2008; Cruz & Marques, 2014 for literature reviews). Typical services under local government's responsibility include transportation, road maintenance, health care, sewerage or water services. Examples of this type of studies include the evaluation of local government performance in Australia (Marques, Kortt, & Dollery, 2015a; Worthington & Dollery, 2000), Belgium (Borger & Kerstens, 1996), Brazil (Sousa & Stoi, 2005), Korea (Sung, 2007), Portugal (Afonso & Fernandes, 2008), Spain (Balaguer-Coll, Prior, & Tortosa-Ausina, 2007; Benito, Bastida, & Garcia, 2010), Canada (Pollanen, 2005), United States (Grossman, Mavros, & Wassmer, 1999), or Norway (Borge, Falch, & Tovmo, 2008).

The second research line encompasses studies that focus on the assessment of the performance of particular areas under local government's responsibility. Examples of these studies include the assessment of the efficiency in waste management (Rogge & De Jaeger, 2012; Simões & Marques, 2012), fire services (Bouckaert, 1992), transportation (Marques, Simões, & Carvalho, 2015b), road maintenance (Kalb et al., 2012), water services (Pinto, Cruz, & Marques, 2015), or health care (Kirigia, Emrouznejad, Cassoma, Asbu, & Barry, 2008).

None of the previous studies addressed the evaluation of the buildings sector, which represents a major concern of local governments. The life cycle of buildings is large (around 50 years) and includes various phases that may have a severe impact on the environment (e.g., production or extraction of materials, design, construction, operation and maintenance). According to EuroACE (2012), 210 million buildings across Europe are responsible for 40% of Europe's total energy consumption and 36% of CO_2 emissions. In addition, the construction of buildings requires approximately 50% of total raw material consumption and 40% of total materials' waste.

The purpose of this research is to develop a methodology to assess residential buildings' performance in terms of the consumption of natural resources (energy, water and materials). The assessment is carried out at a municipal level, informing policy makers on the position of their municipalities compared to others, as well as the evolution of

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performance over time. In addition, this study aims to identify the factors associated with better levels of municipal performance and quantify the extent of their effects.

From a methodological perspective, this research uses the Stochastic Frontier Analysis (SFA) technique to evaluate municipal performance. SFA enables the estimation of an overall measure of performance for each municipality in a given year by comparing its features with a set of peers. In this context, a high performance score indicates that the municipality is able to consume fewer resources per building than its peers. The inputs included in the SFA model concern the major resources used in residential buildings in each municipality and year (i.e., the consumption of energy, water, and materials for rehabilitation). The output of the SFA model is the number of residential buildings in each municipality and year. The model also includes exogenous factors, all measured at a municipal level, to control for contextual conditions, enabling an adequate evaluation of municipalities in terms of buildings' resource consumption. The exogenous variables relate to buildings' average age, environmental policy expenditure per inhabitant, population density, purchasing power per capita, municipality turnover per km^2, size of the municipality in relation to the total area of the Lisbon region, and proportion of privately owned dwellings in relation to the total number of new dwellings.

The performance assessment illustrated in this paper uses data from Lisbon region (Lisbon city and 17 surrounding municipalities) covering the time period 2003–2009. This paper is to the best of our knowledge the first to evaluate residential buildings' efficiency in terms of energy, water and materials consumption using frontier methods.

The main reasons that motivated this research concern: i) the enhancement of the level of analysis of previous studies that mostly dealt with sustainability issues at the building level, by proposing a new methodology to evaluate residential buildings' resource consumption at a municipal level, ii) the development of a methodology that allows benchmarking municipalities concerning residential buildings' resource consumption, which is crucial in order to monitor and improve municipal performance on a continuous basis, and iii) the application of the methodology proposed in a real world context, attempting to gain insights concerning municipal best practices.

The remainder of this paper is organized as follows. Section 2 provides an overview of the literature on the assessment of environmental sustainability in construction. Section 3 describes the methodology, which includes the SFA model used, the variables and the sample studied. Section 4 discusses the results obtained and suggests how municipalities can use the benchmarking results for urban planning. The last section concludes and suggests topics for future research.

2. Environmental sustainability in construction

As mentioned by Vatalis, Manoliadis, and Charalampides (2011), sustainable construction relies on four main pillars: environmental, social, economic, and technical dimensions. The environmental dimension concerns ecosystems' protection, which involves the efficient use of resources. Social sustainability concerns the quality of human life and the human living environment in terms of safety, comfort and health. Economic sustainability is related to the financial return of the project, taking into account the perspectives of all stakeholders involved in the process, such as clients, construction players or government. Technical sustainability is related to building components and construction technologies in terms of durability, quality and usability.

The assessment of environmental sustainability in construction has attracted particular attention in recent years (see Forsberg & Malmborg, 2004; Ding, 2008 for literature reviews). The research conducted up to date on environmental sustainability mostly focuses on the evaluation of buildings.

The environmental evaluation of buildings was first based on a single criterion, such as energy, water or materials usage. For instance, Mwasha, Williams, and Iwaro (2011) investigated the most appropriate energy indicators for modeling the performance of the residential building envelope. Kavousian and Rajagopal (2014) and Grosche (2009) focused on the evaluation of the energy efficiency of residential buildings, whereas Onut and Soner (2006) estimated the energy efficiency of hotels. Ilha, Oliveira, and Goncalves (2009) reviewed the main issues in terms of water conservation to be considered on environmental evaluations of buildings. Other studies focused on the environmental impact of specific building materials, such as marble (Traverso, Rizzo, & Finkbeiner, 2010), facade materials (Kim, 2011; Tatari & Kucukvar, 2012), structural materials (Bakhoum & Brown, 2012), floor coverings (Lippiatt, 1999), or clay bricks (Koroneos & Dompros, 2007). However, monitoring buildings performance merely based on a single criteria results in a limited assessment, which cannot cover appropriately the multiple dimensions of sustainability.

More recently, comprehensive building assessment models appeared in the literature. These models typically cover a broad set of environmental criteria using several key performance indicators. They can be aggregated to provide an overall measure of performance for each building using a weighted average. However, the models specified often differ in terms of the environmental criteria, performance indicators, rating scales, and weighting schemes used. The scope of the analysis usually covers various phases of the building life cycle (e.g., design, construction or operation phase), and different types of buildings (e.g., residential, commercial, or industrial buildings). The models are frequently used to support building environmental certification, which is currently carried out on a voluntary basis. As the environmental building certification may become mandatory in the near future, the attention devoted to this issue is growing in the literature. For a comprehensive comparison of these models please refer to the study by Suzer (2015).

Concerning the historical evolution of these models, the first building assessment model was launched in 1990, in the United Kingdom, and is called the BRE Environmental Assessment Method (BREEAM). The BREEAM system includes the assessment of new and existing buildings of any type (offices, supermarkets, houses, light and heavy industrial buildings). The BREEAM initiative has served as inspiration for the development of many other building assessment systems in different countries, such as Canada, Australia or Hong Kong. A few other models to assess building environmental performance appeared later. For instance, the Leadership in Energy and Environmental Design Green Building Rating System (LEED) was developed in 2002 in the United States, the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) was developed in 2004 in Japan, and the Sustainable Building Tool (SBTool) was developed in 1995 as an international tool for building assessment. More recently, the literature on environmental assessment in the CI includes evaluations at an urban scale. This is a consequence of today's urbanization context, which requires adequate infrastructures, buildings and utilities leading to enhanced standards of living, urban governance and environmental quality. The most well known tools developed to assess CI in an urban context are extensions of the building environmental assessment models (BREEAM Communities, LEED for Neighborhood Development, CASBEE for Urban Development, and SBTool Generic).

In addition to the aforementioned models, there are some studies in the literature that focused on the development of specific models based on advanced quantitative techniques, including analytical hierarchical process or life cycle assessment. Different types of buildings were studied, including industrial buildings (San-Jose, Losada, Cuadrado, & Garrucho, 2007), apartment buildings (Kim, Yang, Yeo, & Kim, 2005), office buildings (Korkmaz, Riley, & Horman, 2010; Love, Niedzweicki, Bullen, & Edwards, 2012), or intelligent buildings (ALwaer & Clements-Croome, 2010). The need of creating models to support urban evaluations has been also highlighted in the literature (e.g., Conte & Monno, 2012; Huang & Hsu, 2011; Jones, Patterson, & Lannon, 2007). However, as mentioned by Haapio (2012), this topic