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Energy productivity convergence within the Australian construction industry: A panel data study

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ABSTRACT

Energy productivity reflecting the volume of goods and services with one-unit consumption of energy has become an important indicator of production and competitiveness within the construction industry. In order to understand the long-run growth patterns of energy productivity in the Australian construction industry, this study investigates the convergence of the construction energy productivity across a sample of seven Australian regions, from 1987 to 2014, and identifies regional clubs for future effective-energy-consumption strategy of production. Using a panel data approach, the study presents a picture of the impacts of the influential components on the equilibrium and growth patterns of construction energy productivity across the studied regions. The findings provide a better understanding of the impact of booms and busts on the Australian construction energy productivity, at the state level. This adds to the body of knowledge on construction productivity by adapting a panel data approach of the convergence study into construction energy productivity.

1. Introduction

The reduction of total energy consumed in the construction and operation phases of the construction industry has become an active field of research (Hong et al., 2016; Baynes et al., 2018). That is, due to the rapidly increasing energy prices and public awareness of climate change, energy consumption plays a vital role in defining productivity in the construction industry (Xue et al., 2015; Hu and Liu, 2016). This has led to the emergence of the concept of energy productivity (Hu and Liu, 2015) which can be defined by the volume of goods and services produced by per unit of energy within a given time period. As an effective measurement tool of energy consumption, energy productivity is linked to environmental issues (Pullen, 2000), energy conservation, as well as more broadly to economic and industrial development and competitiveness (Dimitropoulos, 2007).

Research into construction energy productivity, as recently emerged, is analogous to the analysis of labour productivity depicting the temporal trends of energy productivity. The data envelope analysis (DEA) method is employed through a longitudinal (panel data) approach, with the purpose of calculating periodical energy productivity indices (Hu and Liu, 2015). Recent research studies have used the DEA method to estimate the Malmquist indices reflecting the temporal changing trends of construction energy productivity across different observed regions (Hu and Liu, 2015; Xue et al., 2015; Hu and Liu, 2016). While, DEA-based research provides valuable contemporary references for both policy makers and practitioners, this non-parametric method nevertheless does not provide theoretical explanations. The convergence research of productivity proposes a fully specified competitive equilibrium, which is assumed to be determined by three components, being the external technology level, input ratios, and the technology utilisation efficiency (Romer, 1986; Kumar and Russell, 2002). Analogous to convergence theory of productivity, recent studies have

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explored the convergence status of energy productivity across industries, over many countries (Jakob et al., 2012; Wan et al., 2015; Apergis and Christou, 2016). Even so, research on the convergence of construction energy productivity remains scarce (Hong et al., 2016).

The present study intends to address this knowledge gap by presenting an empirical study of the convergence in construction energy productivity across seven Australian states and territories. This is deemed essential, in view of recent calls from investigators for further research into convergence in disaggregated energy, across specific sectors and in various countries (cf. Mishra and Smyth, 2014, 2017). According to a comprehensive review study by Smyth and Narayan (2015, p. 353): *"Future research could examine convergence in energy consumption at the sector level within specific countries."*

With the references to endogenous convergence, the equilibrium of the energy productivity is arguably determined by the external technology level, capital-energy ratio, labour-energy ratio, and technology utilisation efficiency. A panel data approach is used to explore the equilibrium and dynamic patterns of the construction energy productivity, along with the four factors. The remainder of this paper is organised as follows. The next section reviews the previous literature into convergence research in the field of energy productivity. The following section outlines the theoretical models for the energy productivity convergence. Then there is an introduction into the macro data on Australian construction activities, including the energy consumption across regions. Finally, the results of the model estimations and validations are illustrated, ending with concluding remarks.

2. Convergence research of energy productivity

Convergence research has been widely conducted to address the equilibrium and dynamic patterns of productivity across the broader economy, and specific industries. These are mainly developed from the theories of exogenous and endogenous growth (Solow, 1956; Romer, 1986). The exogenous growth theory argues that the long-run growth of labour productivity is dominated by improvement in exogenous factors, such as changes in technology. As such, national productivity converges to a steady-state value if there are no changes in technology (Barro and Sala-i-Martin, 1992). The endogenous dynamic model proposes a fully specified competitive equilibrium, where the accumulation of knowledge primarily drives the long-run productivity growth, as well as changes in technology (Romer, 1986). Accordingly, the equilibrium states of productivity should be different across countries and regions due to their initial levels and different economic structures (Galor, 1996). Kumar and Russell (2002) presented an empirical study to assess the cross-country endogenous convergence of productivity, using a deterministic method. Their findings reveal that the convergence of productivity is mainly determined by changes in technology, while the growth and divergence of productivity are driven by capital deepening.

As a key indicator of the energy consumption, energy productivity is seen by economists as a mechanism for the productive use of energy (Patterson, 1996). Particular attention has been paid to the strategic optimisation of energy within the built environment across many countries (Kellett and Pullen, 2012; Ali Al-Arja and Awadallah, 2016). Prior studies have investigated the relationship between energy consumption and GDP to simulate the contribution of energy consumption in different sectors of the economy (Berndt, 1978; Stern, 1993). While confirming the significant contribution energy consumption makes to economic and sectoral growths, previous studies have also presented empirical evidence attesting to the differences of energy-productivity development across various countries and regions (Lee, 2005; Ball et al., 2015). Dimitropoulos (2007) reviewed the literature on energy productivity improvement and confirmed the cross-country diversity of relationships between energy productivity and the economy. This has been attributed to discrepancies of technology, policy, capital and labour inputs, which accordingly leads to the issue of productivity convergence.

The long-run relationship of energy productivity in the fields of broad-economics and other individual industries has been addressed by convergence research. For example, the energy productivity convergence clubs in the manufacturing sectors were similarly examined across countries, where the results revealed that the cross-country differences in energy productivity were persistent (Miketa and Mulder, 2005). Markandya et al. (2006) applied an econometrical regression method to the energy consumptions and GDPs of 16 EU countries. Their findings confirmed the conditional convergence of energy productivity and revealed that convergence clubs were mainly caused by the cross-country gaps and growths in the energy productivity. In their cross-country study, Mulder and De Groot (2007) investigated the energy productivity convergence from different sectors of aggregation and showed that the energy productivity levels converged to different steady states as per the different structures of each examined country.

Jakob et al. (2012) investigated the convergence patterns of energy productivity along with the broad economies of 51 countries, using panel data estimation. They presented strong evidence for the conditional convergence of energy productivity, which were associated with the economic progress of the studied countries. With reference to broad economic development, an empirical study by Wan et al. explored the spatial effects on energy productivity convergence across EU countries (Wan et al., 2015). A spatial econometrical model was applied to the trading activities to specify geographic proximity. Another study used a panel regression model to investigate the convergence clubs of energy productivity across 31 countries over 40 years (Apergis and Christou, 2016). The empirical results rejected the proposition that energy productivity converged to a common point for all the observed countries, but rather to several convergence clubs. Although the conditional convergence status in energy productivity has been evidenced in many sectors, insight into construction energy productivity have yet to be explored within the extant literature. Apergis et al. (2017) investigated energy convergence across sectors in Australia, using an adapted unit test framework. The findings, when adjusted for transportation effect, revealed that per capita energy consumption was indeed convergent across sectors.

3. Theoretical model of energy productivity convergence

The convergence research of energy productivity is analogous to the research approach of labour and capital productivity at the economic and sectoral levels. Following the framework of Cobb-Douglas production function, which takes factor inputs capital (K) and labour (L) to produce the output (Y), energy (E) is incorporated as an additional input (Saunders, 2008). A common expression of the production function that treats energy productivity as an integral part of economic productivity, is presented as Eq. (1):

$$Y_{it} = A_i K_{it}^{\alpha} L_{it}^{\beta} E_{it}^{\gamma} \quad (1)$$

In Eq. (1), Y_{it} indicates the economic or sectoral output, and K_{it}, L_{it}, and E_{it} represent the amounts of capital, labour and energy that are used to produce the output respectively; and the subscripts i and t denote a region and a certain period respectively. The item A_i is a regional specific coefficient, indicating the average level of the technology in the corresponding region i. The elasticity α, β, and γ indicate the marginal return of the inputs capital, labour and energy respectively, where $\alpha + \beta + \gamma = 1$ under the constant returns to scale. Accordingly, the function of the energy productivity (EP) can be derived from divided Eq. (1) by E_{it} as illustrated in Eq. (2).

$$EP_{it} \equiv \frac{Y_{it}}{E_{it}} = A_i \left(\frac{K_{it}}{E_{it}}\right)^{\alpha} \left(\frac{L_{it}}{E_{it}}\right)^{\beta} = A_i * {KE_{it}}^{\alpha} * {LE_{it}}^{\beta} \quad (2)$$