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# Short-run and the long-run effects of electricity price on electricity intensity across regions ☆

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## HIGHLIGHTS

- Short-run and the long-run effects of electricity price on electricity intensity.
- Effects of electricity price on electricity intensity across regions.
- Increases in electricity price improve electricity intensity in the long run.
- Substitutability of electricity-consuming equipment between short and long runs.
- Electricity-price management as a policy tool to improve electricity-use efficiency.

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## ABSTRACT

Global electricity consumption has increased rapidly in recent years. Improving the efficiency of electricity use as an alternative and/or complement to the construction of new power plants has received recent attention because of the potential environmental harm and high cost of constructing new power facilities. The objective of our research is to determine the effects of electricity price on electricity intensity in the manufacturing sector with particular focus on how this relationship changes over space and time. As a case study, we developed a simultaneous-equations system for a three-input production function using 108 months of panel data (January 2004 – December 2012) over 16 regions in South Korea. We found that increases in electricity price improved electricity intensity in South Korea's manufacturing sector in the long run, but not in the short run. The effects of electricity-price increases on electricity intensity varied over time and space. The differences may have resulted from different degrees of (1) substitutability of electricity-consuming equipment between the short and long runs, (2) price impact on electricity demand and manufacturing output in the regions' manufacturing sectors, and (3) technology improvement in manufacturing that allows substituting or replacing electricity-consuming equipment with high efficiency and less power consumption. Our findings imply that electricity-price management can be a potential policy tool to improve electricity intensity in the manufacturing sectors of countries with government-controlled electricity prices, with the following caveats. First, electricity price increases are likely to be effective as a long-term tool, but may not be as effective in the short run with some regional exceptions. Second, electricity price increases may hinder electricity-use efficiency in regions characterized by manufacturing sectors where price increases reduce manufacturing output more than they reduce electricity demand.



## 1. Introduction

### 1.1. Background and objective

Global electricity consumption has increased rapidly in recent years. Worldwide electricity consumption increased by 40% between 2000 and 2013, and electricity consumption in Asia

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increased by more than 200% during the same period [1]. With these increases, excess electricity demand has become a global problem. For example, due to unusually hot weather, a major blackout imposed disruptions (i.e., traffic signals, elevators, and machines) on the daily lives of South Koreans in September 2011 [2]. The northeastern United States and India also experienced unparalleled blackouts during the summer peaks for electricity demand in 2003 and 2012, respectively [3,4].

Building new power plants and technology and material improvement is the ultimate solution to the problems caused by excess electricity demand. However, because of the potential high cost of new plants and innovations [5], improving the efficiency of electricity use as an alternative and/or complement to the ultimate solution has received recent attention. For example, the U.S. Federal budget for energy-efficiency projects more than tripled from $2 billion in 2006 to $6.7 billion in 2011 (i.e., $5.5 billion focusing on electricity efficiency and $1.2 billion focusing on natural gas efficiency) [6]. Another example is the Japanese government's investment of $450 million in 2013 to improve energy efficiency, including developing a feedback mechanism to save energy by using a monitoring program [7,8].

Electricity intensity, which is defined as the amount of electricity consumed per unit of output, has been commonly used to measure the efficiency of electricity use (e.g., [9–11]). Managing electricity prices is a low-cost tool to improve electricity efficiency for countries where governments control electricity prices (e.g., China, South Korea, and South Africa). Such a tool has been implemented under the hypothesis that higher prices improve electricity intensity because they encourage electricity users to consume less electricity to produce the same levels of output or service (e.g., to use more energy-efficient machinery).

Despite the policy interest in improving electricity efficiency by managing electricity prices, limited focus has been given to assessing the following hypothesis: Electricity price increases improve electricity intensity. One of the few examples in the literature found that electricity intensity in 14 Organization for Economic Co-operation and Development (OECD) countries increased when the end-use electricity price decreased [10]. Similar research in China concluded that the energy intensity of electricity-intensive industries (e.g., cement and steel industries) improved with increases in the electricity price [12,13]. These findings suggest a positive role as a policy tool for price adjustments to improve electricity efficiency as measured by electricity intensity. These studies contribute to the literature by providing assessments that help policymakers choose sources of energy for a sustainable electricity future based on quantified relationships among electricity demand, energy-intensity innovations, and economic wealth. Notwithstanding their clear contributions, they did not address three key issues associated with the aforementioned hypothesis that relate to the relationships among electricity price, electricity demand, and production output: (1) causal relationships between electricity demand and production output, (2) spatial dependences in electricity demand and production output, and (3) short-run versus long-run effects of electricity price on electricity demand (see Section 1.2 for details).

Our research attempts to fill these gaps in knowledge by analyzing the effects of electricity price on electricity intensity in the manufacturing sector, focusing particularly on how this relationship changes over space and time. To achieve the objective, we test the hypothesis that increases in the electricity price have different effects on electricity-use efficiency, reflected in electricity intensity, over space and in the short and long runs. To test the hypothesis, we developed a simultaneous-equations system for a three-input production function, given the assumption that the effect of electricity price on electricity intensity depends on the relationship between electricity consumption and production output and their spatial dependences across time under stable economic conditions. We then used the predicted quantities of electricity demanded and manufacturing output from the simultaneous-equations system to calculate short-run and long-run electricity intensities. We implemented the empirical model using 108 months of panel data (January 2004 – December 2012) over 16 regions in South Korea as a case study.

### 1.2. Literature review and our contributions

The majority of the literature dealing with the three key issues mentioned above assumed that electricity consumption is demand driven under stable economic conditions and not supply driven. However, economic dynamics under unstable circumstances (e.g., war and disaster) require exceptional consideration [14]. For example, the Japanese government's mandatory rationing of electricity to large industry after the Tohoku Earthquake temporarily switched electricity consumption from demand driven to supply driven [15]. As exceptions to the unstable circumstance rule, some countries with transition economies, such as Turkey, have had supply driven electricity consumption [16]. In our case study of South Korea during the 2004–2012 period, demand driven electricity consumption was the rule. In fact, the Korean Power Exchange, which mediates wholesale trading of power between generators and retail suppliers, has been determining electricity consumption by real-time electricity demand on an hourly basis since 2001 [17]. Accordingly, our empirical model assumes electricity consumption is demand driven. Below we summarize the relevant literature dealing with the three key issues mentioned above assuming demand driven electricity consumption. We also describe how our research contributes to each branch of literature.

In dealing with key issue (1), previous research often attempted to investigate the causal relationship between electricity demand and production output [18–24] and the effect of electricity price on electricity demand and the subsequent impact of electricity demand on production output, mainly focusing on the manufacturing sector [19,20,24,25]. Despite its abundance, the literature dealing with the effect of electricity price on electricity intensity has neglected the causality among electricity price, electricity demand, and manufacturing output (e.g., [10,12,13]). We simulated in a single modeling framework the effect of electricity price on electricity intensity by estimating the effect of electricity price on electricity demand and the subsequent effect of electricity demand on manufacturing output. Our *ex-ante* simulations can help policy makers evaluate the potential role of price adjustment as a policy tool for improving electricity efficiency.

In relation to issue (2), past research identified spatial heterogeneity in price elasticities of electricity demand (e.g., [26–28]), variation in price elasticities of electricity demand across industries with different electricity intensities [29], different cost efficiencies between regionally-varying and regionally-uniform electricity pricing policies [30,31], and spatial dependences in electricity demand and production output [32–36]. Despite the abundant literature dealing with spatial dependences in electricity demand and production output, the literature dealing with the effect of electricity price on electricity intensity has not accounted for spatial dependencies. The regional differences in the effects of electricity price on electricity intensity found through our spatial modeling framework will help policy makers anticipate the consequences of electricity price policy on electricity-use efficiency at the regional level.

Concerning issue (3), short-run and long-run price elasticities of electricity demand have been analyzed using a partial adjustment model [28,37–39], cointegration analysis for industrial electricity demand [40], and nonstationary panel estimation techniques to explore the short-run and long-run dynamics of electricity demand