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## The moderating effects of urbanization on carbon dioxide emissions: A latent class modeling approach

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## ABSTRACT

This study proposes an alternative conceptual and analytical framework to identify the environmental impacts of urbanization, where urbanization is treated as a background/contextual factor. This study especially focuses on the issue of “in what conditions of urbanization, human activities can be more environmentally efficient” rather than “whether urbanization has a positive or negative impact on the environment,” an issue that has been explored in a number of existing studies. To capture such so-called moderating effects of urbanization, the latent class STIRPAT model is developed, which can produce urbanization-dependent elasticities. Empirical analysis is conducted to confirm the impacts of urbanization on the strength of the links between human activities and carbon dioxide (CO<sub>2</sub>) emissions. Scenario analyses based on the developed model are also carried out under the different urbanization scenarios, taking into account different development stages. The main empirical findings include: (1) the progress of urbanization could make countries more environmentally friendly when the country's GDP per capita and the percentage share of service industries in GDP are sufficiently high; and (2) it might be better to reach a certain level of urbanization before the high GDP growth associated with the increase of the share of tertiary industry.

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### 1. Introduction

The environmental impacts of urbanization have been identified extensively in a number of studies, and the results have emphasized the importance of dealing with urbanization issues in discussions of environmental matters [1–10]. However, the term “urbanization” can have different meanings depending on the context, and researchers have used it in

different ways. In a broad sense, urbanization can be defined as an interrelated process of economic, demographic, political, cultural, technological, environmental and social changes, which involves the concentration of population and economic activities in urban areas along with land use change [11]. On the other hand, urbanization can also be narrowly defined as the physical growth of cities, i.e., the expansion of population size and of urbanized territories [12]. The former (broadly defined) urbanization provides a more comprehensive view on the impacts of urbanization on the environment because it takes into account the interrelated processes between the physical growth of cities and human activities (increases in production and consumption, the rising use of motor vehicle, etc.). Some of these processes may be coincidental occurrences of human activities associated with physical changes in cities (e.g., land use and land cover change), and some of them may have some cause–effect relationships, which could involve both static and dynamic aspects of urbanization (e.g., the level

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and speed of urbanization). Although identifying the real processes of urbanization is quite complicated, basically, the direct factors causing environmental damage are changes in human activities rather than physical changes in cities. Thus, as Madlener and Sunak [13] emphasized, analyzing the process and mechanism of urbanization is crucially important for a comprehensive understanding of the impacts of urbanization on the environment. Although the interaction between human activities and physical changes in cities (i.e., narrowly defined urbanization) has been discussed in a number of studies and this has been one of the main research issues in the field of urban sociology [14], most of the empirical evidence on the environmental impacts of urbanization has been derived without taking into account the interaction. In other words, the assumption regarding the cause–effect relationship may be too simple to shed light on the process or mechanism of urbanization. The primary purpose of this study is to fill this gap by describing broadly defined urbanization as the interaction between narrowly defined urbanization and human activities in the context of determining the environmental impacts of urbanization. Hereinafter, to avoid confusion, the term urbanization is used in a restricted sense, which is described by physical changes in cities (population size and urbanized territories).

In reality, urbanization may have complex impacts on the environment through changes in human activity patterns, resulting from thousands of independent decisions about where to live, work and shop [1,15]. Existing studies have shown different consequences of urbanization on the environment, with plausible explanations of both positive and negative consequences. Taking transportation activities as an example, a positive interpretation of urbanization is that it increases the efficiency of the use of public transportation, resulting in a decreased environmental burden. On the other hand, a negative interpretation of urbanization is that it can increase the demand for freight transportation because the average distance between producing and consuming regions may increase, resulting in an increased environmental burden. Such *plausible* explanations could be given in a number of ways. The problem here is that the analytical framework used in most existing empirical studies on the environmental impacts of urbanization cannot provide evidence of these effects because human activities and urbanization are assumed not to interact with each other, though the interaction between human activities and urbanization itself have been widely discussed [14]. In other words, to explain the environmental consequences of urbanization with empirical data, it is necessary to develop an alternative framework that can explore how urbanization influences human activities and their environmental efficiency. Understanding such interactions can be very crucial to answer, for example, the following policy relevant questions: (1) does environmental burden depend on the order of occurrences of urbanization and economic development? and (2) which combination of development stage (such as industry structure and economic condition) and urbanization level would produce the smaller amount of CO<sub>2</sub> emissions?

Considering the abovementioned issues, this study first develops a conceptual and theoretical framework that deals with the interactions between urbanization and human activities. In the framework, we employ a moderator approach in which urbanization is assumed to be a third variable that

modifies the impacts of human activities on the environment. Then, the proposed framework is represented by using a latent class model for an empirical analysis. Following the empirical analysis, by taking carbon dioxide (CO<sub>2</sub>) emissions as an example of environmental burdens, we calculate the urbanization-dependent elasticities of CO<sub>2</sub> emissions with respect to human activities, and conduct several scenario analyses, especially focusing on the process of urbanization and its interaction with human activities. Finally, we summarize the contributions of this study and future tasks.

## 2. Literature review and conceptual framework

In this section, we first review the results of existing studies analyzing the impacts of urbanization on the environment, focusing on empirical findings. Then, following the conceptualization of cause–effect relationships between urbanization and human activities, we describe several hypotheses to be examined through empirical analysis.

### 2.1. Existing studies on urbanization impacts

An examination of the empirical findings on urbanization impacts indicates that opposing results have been reported for national-level analysis and city-level analysis [16]. In particular, the majority of the previous studies at the national level have shown that urbanization has a negative impact on the environment. For example, [1] showed that urbanization increases energy use per capita, noting three identifiable mechanisms behind it: energy conversion from one form to another, indirect energy consumption in goods-producing and transportation activities, and direct energy consumption in final uses such as transportation. [3] empirically showed that urbanization increases both CO<sub>2</sub> emissions and the energy footprint, mentioning that the findings are opposite to the inference from modernization theories [17–20]. Cole and Neumayer [21] also found a tendency similar to that found by York, Rosa and Dietz [3], suggesting particular concerns for developing countries that are in the process of rapid urbanization. On the other hand, Poumanyong and Kaneko [7] hypothesized that the urbanization impacts on CO<sub>2</sub> emissions depend on the developing stages, and empirically confirmed the different impacts of urbanization on energy use and CO<sub>2</sub> emissions, noting that their results supported the ecological modernization theory. Martínez-zarzoso and Maruotti [22] confirmed the different impacts of urbanization among different counties, by applying a finite mixture model where countries are endogenously grouped into homogeneous groups. They also concluded that the results support the modernization theory, but not for all countries. Although the details are different, all of the abovementioned studies have indicated that urbanization has negative impacts on the environment, especially in less developed countries. In contrast, existing studies on city-level analysis showed that urban density contributed to reductions in residential and road energy use, ultimately resulting in a reduction in CO<sub>2</sub> emissions. In particular, a number of studies have reported that urban density contributes to reductions in road energy use and natural gas and electricity consumption per capita [23–27]. Dodman [28] also found that urban density contributes to reductions in greenhouse gas

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