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# A spatial panel data approach to estimating U.S. state-level energy emissions

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A B S T R A C T

We take advantage of a long panel data set to estimate the relationship between U.S. state-level carbon dioxide ($CO_2$) emissions, economic activity, and other factors. We specify a reduced-form energy demand model to account for energy consumption activities that drive energy-related emissions. We contribute to the literature by exploring several spatial panel data models to account for spatial dependence between states. Estimation results and rigorous diagnostic analysis suggest that: (1) economic distance plays a role in intra- and inter-state $CO_2$ emissions; and (2) there are statistically significant, positive economic spillovers and negative price spillovers to state-level emissions.



## 1. Introduction

Economists, ecologists, private industries and government decision-makers have long been interested in the relationship between energy consumption, economic growth, and environmental quality. These relationships are often the subject of intense public policy debates such as the discussions surrounding the recent U.N. climate change conference in Durban, South Africa. In the U.S. many opponents to climate change related legislation claim that carbon pollution abatement policies may hinder economic growth. Supporters, on the other hand, claim that such policies are absolutely necessary to prevent irreversible global warming caused by anthropogenic emissions of greenhouse gases.

In order to determine whether abatement policies would be harmful to economic growth, policy makers must first determine whether carbon emissions are indeed related to economic activity. It may seem apparent that emissions and economic activity are inextricably linked yet modern day economists, still as of yet, have not been able to consistently determine a causal relationship between the two. Moreover, there is still no consensus on the drivers of carbon emissions. We do know that anthropogenic carbon emissions are largely caused by the combustion of fossil fuels. Therefore, an economic model of energy demand would seem to be a good approach to better understand the relationship between emissions and growth. Past studies often examined this relationship across a panel of different countries. Although important for policy implications, empirical analysis at such an aggregated level is unable to capture the complexity of different economies, histories, and environmental policies that are unique to each individual country. In this study we further disaggregate country-level data by exploring a panel of U.S. state-level data of emissions, income, and other covariates.

Two past studies have recognized the importance of analyzing the state-level relationship between emissions and income: Aldy (2005) and Auffhammer and Steinhauser (2007). Aldy (2005) tests the environmental Kuznets curve hypothesis between state-level $CO_2$ emissions and income. Auffhammer and Steinhauser (2007) further the study of Aldy (2005) by using a spatial econometrics model to forecast state-level COV emissions. Aldy (2005) offers a model to explain emissions but fails to explicitly control for spatial interactions between states; Auffhammer and Steinhauser (2007) control for spatial interactions but do not explore differing data generating processes for spatial dependence, nor do they offer a rigorous interpretation of the spatial impacts. These small deficiencies present a gap in the literature. This paper, therefore, contributes to the literature by extending these previous

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two studies. The main focus of this paper is to determine how spatial dependence affects the drivers of state-level carbon dioxide emissions. Four unique contributions of this paper are: (1) more explicitly considering and testing for the types of spatial dependence within the relationship; (2) using recently developed, spatial panel data models and diagnostics to determine the most appropriate spatial econometric model; (3) offering a more rigorous interpretation of both the direct and indirect (spillovers) spatial impacts; and (4) extending the data set to include the years 2001–2009, which is important for capturing recent developments in state-level energy consumption and economic growth.

Looking ahead, our estimation results suggest five conclusions about the relationship between state-level $CO_2$ emissions and economic growth. One, economic distance between states has a positive and statistically significant affect on own and neighboring $CO_2$ emissions. “Economic distance” is a concept that suggests the closer the two regions (states) are in geographic distance to one another, the more likely the economic activity within each region will be affected by one another (Conley and Ligon, 2002). This concept specifically recognizes that economic growth across regions (states) is not independent of the economies of others. Two, economic activity (consistent with the definition of economic distance) in one state has a positive, short-run direct impact on its own $CO_2$ emissions and a positive, short-run indirect impact on neighboring emissions. Three, increasing electricity and oil prices in one state has a negative, short-run direct impact on its own emissions and a negative, short-run indirect impact on neighboring emissions. Four, additional heating degree days have a positive, short-run direct impact on own emissions and a positive, short run indirect impact on neighboring emissions. Five, estimated elasticities are larger (in absolute terms) for the models with spatial dependence (over the models without spatial interactions) because the elasticities capture interaction effects between neighboring states.

The rest of this paper is structured as follows. Section 2 will offer a conceptual framework to motivate the basic model setup and consider how spatial interactions may affect state-level emissions. In Section 3 we will extend the model to include the spatial interactions in the data generating process and discuss diagnostic tests. Section 4 will provide a description of the data. In Section 5 we will present the empirical model and estimation results. Finally, in Section 6 we will discuss implications, limitations, and suggestions for future research.

## 2. Conceptual framework

In this paper we analyze the relationship between energy consumption, economic activity, and pollution emissions while controlling for potential spatial effects within the data. The pollution variable, carbon dioxide ($CO_2$), examined in this paper is estimated by the Department of Energy (DOE) based upon the conversion of fossil fuels to their final energy use; e.g., the conversion of coal into electrical energy in a power plant generates emission gases as a byproduct of the combustion process. In other words, $CO_2$ emissions are estimated based upon a state's observed energy use. Therefore, $CO_2$ emissions are not to be confused with actual $CO_2$ pollution that is emitted from the end of a smokestack or tailpipe.[3] As the $CO_2$ data in this paper do not constitute actual $CO_2$ emissions we will in general refer to this variable as *energy emissions* to avoid any confusion — a more thorough explanation of the emissions data, including how it is estimated, is provided in the Data description section.

As emissions are estimated from state-level energy use, our analysis is implicitly based upon the relationship between energy consumption (i.e., consumption leads to emissions) and economic activity. Hence, we use a reduced-form energy demand model to explain the difference in state-level energy consumption. According to Ryan and Ploure (2009), a reduced-form energy demand model is specified as follows

$$\ln E = \beta_1 + \beta_2 \cdot \ln P + \beta_3 \cdot \ln Y + e, \tag{2.1}$$

where $E$ denotes energy consumption; $P$ denotes energy price(s); $Y$ denotes a measure of income or aggregate economic activity; and $e$ denotes a stochastic error term.[4] All variables are expressed in natural logs to account for growth rates and allow for the estimated coefficients to be interpreted as elasticities. Since emissions are based upon energy consumption we can substitute energy emissions for energy consumption in Eq. (2.1). We will further extend this model by explicitly considering spatial dependence, state-level heterogeneous effects, and time-period effects.

We examine emissions on a per capita basis to control for population growth within each state. A justification for examining per-capita $CO_2$ emissions is outlined in a recent report by the US Energy Information Administration (2012). According to this report: “It is difficult to compare total carbon dioxide emissions across States because of variation in their sizes. One way to normalize emissions across States is to divide them by State population and examine them on a per capita basis.”

Aldy (2005) used a similar data set as this paper and found mixed evidence for the environmental Kuznets curve hypothesis with $CO_2$ emissions at the state-level in the contiguous U.S. Aldy made an important distinction between consumption-based emissions and production-based emissions. He argued that through interstate trade, a state's emission intensity from production may differ from its intensity from consumption. To account for this distinction he modified the data for states that are net exporters of electricity by deducting the state's average electricity carbon intensity (as a proxy for exported electricity) from its total emissions for a given year. Carson (2010) points out that this distinction is important because it helps control for net electricity importing states that consume energy without experiencing externalities associated with their production.

Consistent with the insight of linkages between state emissions through commerce (Aldy, 2005; Carson, 2010), we explicitly incorporate a term for spatial dependence to account for linkages between states that may affect intra-state and inter-state $CO_2$ emissions. In other words, we argue that there is potential spatial dependence between state-level economic activities and state-level energy consumption which in turn creates carbon dioxide emissions.

The idea of spatial dependence in this relationship has been captured by two recent studies: Auffhammer and Steinhauser (2007) and Auffhammer and Carson (2008). These studies use spatial econometric models to forecast $CO_2$ emissions based upon the relationship between energy consumption, economic growth, and pollution emissions — which the authors claim to exhibit spatial dependence. For example, Auffhammer and Steinhauser (2007) use the same dataset of $CO_2$ emissions as this study to estimate a variety of short-run forecasts of emissions in the U.S. to compare forecasts of state-level data versus nationally aggregated data. By using the state-level data and controlling for spatial effects, the authors find significant improvement in forecasting performance.

Auffhammer and Carson (2008) use a similar model specification and spatial econometric procedure as Auffhammer and Steinhauser (2007) to forecast province-level $CO_2$ emissions in China. They find that model selection criteria favor a class of dynamic models with spatial dependence over the static, non-spatial model.

There are in principal three types of spatial dependence that may manifest itself in the relationship between emissions, energy consumption, and economic activity. The first type is a spatial lag model, in which the dependent variable, energy emissions, in state $i$ is affected by the emissions in state $j$.[5] Loosely speaking, this specification captures spatial spillovers; in other words, the emissions in one place predict an increased likelihood of similar events in neighboring places. From an air pollution perspective this is arguably the most intuitive spatial process

[3] The $CO^2$data should not be confused either with atmospheric $CO^2$ pollution, which following emission enters the upper atmosphere and is more global in scope.

[4] To make our empirical estimates comparable with the results of Aldy (2005) we can extend Eq. (2.1) to express a quadratic polynomial of income.

[5] This is the model specification assumed by Auffhammer and Steinhauser (2007) and Auffhammer and Carson (2008), but there are other types of spatial autocorrelation (or dependence) models.