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The convergence of U.S. state-level energy intensity

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ABSTRACT

This study extends a neoclassical growth model to include the accumulation of physical capital and energy consumption within a panel of fifty states (plus the District of Columbia) in the U.S. The theoretical model allows us to examine the implications for convergence in economic growth and energy intensity. From the theoretical model, we formulate an empirical approach using a dynamic panel model that is estimated using a general method of moments framework to test the conditional rates of convergence. The empirical results indicate convergence in energy intensity, and our estimates accurately predict both the growth in and convergence of energy intensity across our entire sample. Consistent with other findings in the literature, our results imply that energy use, over the past four decades, plays a small and positive role in state-level, per capita economic growth and convergence. Based on these results, we discuss policy implications for state-level income growth and energy consumption.

1. Introduction

The economic literature is replete with studies that have explored the relationship between energy consumption and economic growth, and after four decades of empirical research there is still no consensus on the causal link between energy consumption and real income (Payne, 2010; Ozturk, 2010). The relationship between energy and growth gained the attention of scholars, and the public alike, after the two global oil crises in the 1970s. Interest in the topic re-emerged in the 2000s in conjunction with the run-up in oil prices, which peaked at nearly $150 per barrel in 2008 (compared to an average global price of $25 per barrel in the 1990s) (Energy Information Administration, 2016). The fundamental problem within the literature is in identifying a causal link, if any exists, between energy and growth.

Two recent studies, offered by Csereklyei and Stern (2015) and Rühl et al. (2012), observe that global energy consumption has been on the rise for the past few decades, but energy intensity is declining for developed countries such as the U.S. and the U.K. These observations motivated Csereklyei and Stern (2015) to question whether economic growth has less of an effect on the growth in energy use in richer countries, which they describe as a "decoupling of energy and growth." The authors test a weak and strong version of the decoupling hypothesis. The strong hypothesis is that economic growth has less of an effect on energy use as income grows through time; while the weak hypothesis is that energy use is declining in developed countries through time. Similar to Csereklyei and Stern (2015), we find strong evidence of convergence in energy intensity and weak decoupling, but no evidence of strong decoupling.

In this paper, we derive a theoretical model strongly grounded in macroeconomic growth theory. In our case, however, we treat energy resources as an input (factor of production) into an economy's income formation through time. Thus, our extension of the model allows for a closer examination of the energy-growth relationship and constructs its empirical counterpart using disaggregated U.S. state-level data between 1970 and 2013.[3] Specifically, our framework offers two testable hypotheses regarding the energy-growth

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[3] For the sake clarity, our exposition regarding the energy-growth relationship does not explicitly relate economic "growth" to energy consumption, but rather the effect of energy consumption on the level of state-level income. However, our derived convergence model specifications have direct implications for the economic growth path through time, so we will use the term "growth," in a general sense, throughout the remainder of the manuscript.

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relationship that closely mirror Csereklyei and Stern's (2015) definitions of strong and weak decoupling. The first hypothesis differs slightly from the strong decoupling definition as we do not directly test the effect of economic growth on energy. Instead, we test whether energy is a determinant of economic growth. Our second hypothesis tests the co-evolution of an economy's growth and energy intensity through time, where energy intensity is defined as consumption per unit of gross domestic product (GDP).

The two concepts are interrelated in that if the first hypothesis (energy is necessary for economic growth) is rejected, but an examination of the second hypothesis (the convergence of energy intensity) results in a failure of rejection, then it would suggest that energy resources need not be a constraint for future economic growth. In other words, energy resource consumption would not necessarily constitute a constraint because the economy is consuming its energy resources more efficiently — as evidenced by the economy's decreasing trends in energy intensity through time. Fig. 1 demonstrates the trends in energy intensity among U.S. states over the past four decades. For ease of exposition, we have averaged the state-level intensities across Census regions. The figure clearly suggests convergence in intensity across states, as demonstrated by the clustering in the series near the last periods of observation.

In order to empirically test our two hypotheses regarding the energy-growth relationship, we estimate the models using a two-step system GMM framework on U.S. state-level data from 1970–2013. Our examination of disaggregate national data is consistent with the insights of Barro and Sala-i-Martin (1991), who posited that convergence in income is more likely to occur *among* regions within a country than *across* different countries. Figs. 2 and 3 further illustrate the point that within the U.S., states are converging (exemplified by the negative slope of the trend line within each graph) in terms of per capita income and per capita energy expenditures.

We offer three unique contributions to the energy-growth literature. One, we offer a simple extension of the Solow growth model, based on seminal past works within the growth literature (Solow, 1956; Mankiw et al., 1992; Islam, 1995; Caselli et al., 1996; Bond et al., 2001), that includes energy resources as a factor of production (Stern, 1993, 2000; Stern and Kander, 2012). Based on the extended model, our second contribution consists of deriving the theoretical rate of convergence and then developing an empirical estimation model based directly on the derivation. Third, we estimate the empirical model using a GMM approach, which is consistent and asymptotically efficient.

This study differs from related research, such as Stern and Kander (2012), who develop a theoretical model to analyze the relationship between energy and economic growth and test the model's hypotheses using empirical specifications that correspond to the theoretical model. In contrast, our main focus is to examine the implications of economic and energy growth *convergence* within a set of advanced economies. We find strong evidence that state-level energy intensities are converging and energy consumption plays a significant role in explaining the energy-intensity convergence process. At the same time, we find that energy consumption plays a small (positive) and significant role in economic growth and convergence, which is similar to the results of Csereklyei and Stern (2015), who did not find of evidence of the aforementioned strong decoupling hypothesis.

The current study is organized as follows. In the next section we establish the theoretical growth model, which is extended to include energy resources as a factor of production in state-level income, and we motivate the empirical specification that directly corresponds to the theoretical model. In section three we describe the data, and in section four we briefly develop the GMM framework used to empirically verify the predictions of the theoretical model. In section five and six we discuss the empirical findings and the potential policy implications.

2. Adding energy resource accumulation to the Solow growth model

2.1. Adding energy resource accumulation to the Solow model

As outlined in Mankiw et al. (1992), the Solow growth model can easily be extended to three factors:

$$Y(t) = K(t)^{\alpha} \cdot E(t)^{\beta} \cdot (A(t) \cdot L(t))^{1-\alpha-\beta} \quad 0 < \alpha, \beta < 1, \tag{2.1}$$

where where Y denotes output, K is physical capital, L is labor, A is a labor-augmenting level of technology, and E denotes energy resources (both non-renewable and renewable energy). (For the readers not familiar with the Solow growth model, we have provided a brief outline of the model and underlying assumptions in the Appendix.) The same assumptions for the production function specified within the original Solow (1956) model, provided in the Appendix, hold here.

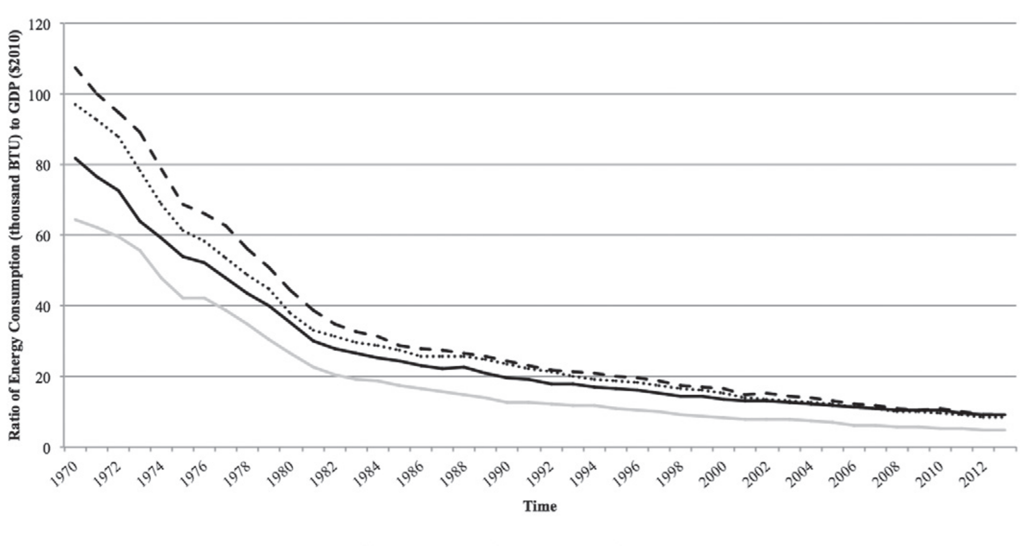

Fig. 1. U.S. Regional Energy Intensity (Energy use per unit of GDP), 1970–2013.