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Disentangling temporal patterns in elasticities: A functional coefficient panel analysis of electricity demand☆

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ABSTRACT

We introduce a panel model with a nonparametric functional coefficient of multiple arguments. The coefficient is a function both of time, allowing temporal changes in an otherwise linear model, and of the regressor itself, allowing nonlinearity. In contrast to a time series model, the effects of the two arguments can be identified using a panel model. We apply the model to the relationship between real GDP and electricity consumption. Our results suggest that the corresponding elasticities have decreased over time in developed countries, but that this decrease cannot be entirely explained by changes in GDP itself or by sectoral shifts.

1. Introduction

A diverse literature addresses methods for handling structural change in the coefficients of econometric models, usually by allowing the coefficients to vary over time. Many of these approaches neglect one or both of two important aspects of structural change. First, such models do not typically allow changes in the specification of the functional form itself. Such misspecification may invalidate the economic interpretations of the coefficients when these interpretations are derived from partial derivatives, as is the case with elasticities. Second, few models of coefficient change aim to identify the underlying drivers of that change.

A functional coefficient with multiple arguments, consisting of the regressor itself and each potential driver of parameter change, remedies both of these deficiencies. Specifying the coefficient as an unknown function of the regressor explicitly allows for nonlinearity in the conditional mean of the regressand. The additional arguments further elucidate the underlying causes of the coefficient changes. However, a functional coefficient with more than one argument cannot be effectively estimated — especially when the arguments are highly correlated or share trends.

In order to operationalize such a model and remedy the deficiencies mentioned above, the main novelty of this research is to couple a panel data approach to a nonparametric functional coefficient model. From an econometric point of view, our functional coefficient approach with a nonstationary panel builds on the functional coefficient models of Cai and Li (2008) for stationary panels and Cai et al. (2009) for nonstationary time series. This approach provides several advantages in this context.

First, the addition of the cross-sectional dimension of the data allows effective estimation of an unknown function of two variables. We consolidate the additional arguments into a single time trend to represent structural change. Thus, once the model is estimated, we

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may fix time and examine nonlinearity in the conditional mean. For a fixed regressor or a constant function of the regressor, on the other hand, the model reduces to a more standard model of temporal coefficient change. Such flexibility is not possible using only a time series model.

Second, the allowance of the coefficient to vary over *both* the regressor and time enabled by a panel allows dynamic misspecification, because the nonlinear function itself may evolve over time. Third, a panel provides a much larger number of observations to counter the well-known drawback of the slower rate of convergence of nonparametric estimators.

Once a temporal pattern in the coefficient is established and any nonlinearity is identified, further analysis may unlock distinct components of that pattern. These components could be of interest in their own right. For example, a policy maker considering a stimulus package to a particular economic sector might be interested in the effect on overall electricity consumption — especially in a country with a limited power grid that cannot import electricity, such as Korea or Taiwan, or in which the constituents have substantial concerns about increasing pollution from fossil fuel consumption.

We apply our econometric approach to a panel of observations on electricity consumption across countries with disparate GDP levels. A stylized fact of developed economies is change over time of energy intensity, measured as the ratio of energy consumption to real GDP. Many of these countries have seen a decrease in energy intensity, often referred to as an autonomous energy efficiency increase (AEEI). Such changes have occurred not only with respect to overall energy consumption, but also with respect to consumption of individual energy sources, such as electricity. For example, over the period 1995–2010, our data suggest that this ratio (*electricity* intensity) has decreased by 14–17 % for the US, UK, and Denmark, and decreased by 1–4 % for Japan, Germany, and Belgium, but increased by 46% for Korea.

A common specification for modeling the relationship between electricity and GDP is a fixed coefficient regression of the log of electricity consumption per capita on the log of real GDP per capita and covariates.[1,2] Holding the covariates constant, this specification assumes that the relationship is linear and stable.

Galli (1998), Judson et al. (1999), and Medlock and Soligo (2001) document an inverted U shape in the relationship between log GDP and log energy consumption, which they attribute to changing patterns in electricity consumption as countries develop and especially to shifts in the compositions of national economies from more energy-intensive to less energy-intensive sectors. In other words, the relationship is changing over time.

In similar applications, Galli (1998), Medlock and Soligo (2001), and Richmond and Kaufmann (2006a,b) use panel data with a quadratic term for nonlinearity, while Judson et al. (1999), Luzzati and Orsini (2009), and Nguyen-Van (2010) use more flexible semiparametric panel data approaches to allow for nonlinearity.

To the best of our knowledge, ours is the first study of AEEI that utilizes a panel data model with functional coefficients that allow both for nonlinearity like the models in the studies just mentioned *and* for a coefficient that varies smoothly over time.

Even for a single economic sector, the relationship between log electricity consumption and log income, proxied by log GDP in the household sector, or log electricity consumption and log output, proxied by log GDP in the firm sector, may be linear but with unstable coefficients or may not be linear at all. The often assumed log-linearity of the aggregate household demand function or the aggregate firm conditional factor demand function results from multiplicative indirect utility or production functions.[3] However, changes in utility, technology, policy, or other factors may shift or change these functions over time, inducing time-varying coefficients and even functional misspecification.

While an ideal specification might allow the coefficient on log GDP to be a function of GDP itself, utility, technology, energy policy, sectoral shares, and perhaps other factors, estimating such a model and identifying each of these components would be very difficult given the available data. Instead, we use the panel nonparametric approach to create counterfactuals at fixed levels of development and time periods.

Our model generates a very clear empirical result and one that is expected from the discussion of AEEI's: income elasticities have been declining over time for developed countries.[4] Our counterfactual analysis with time fixed and varying GDP suggests that economic development does not fully explain the declining elasticities in developed countries. The right-hand tail of the inverted U shape is almost flat and has become flatter over time — i.e., there is a threshold beyond which GDP (per capita and relative to other countries) barely affects the elasticity, and both the threshold and the decreasing effect have decreased over time.

Similarly, we construct counterfactuals in which GDP is fixed and time varies and find that the decreasing temporal pattern remains. Reliable sectoral data on electricity consumption for a subset of our panel that includes developed countries over a relatively recent time period allows further analysis of this decrease. We isolate the component of the time-varying elasticities for this subsample that cannot be explained by sectoral reallocations over time, and we find that the decreasing trend in elasticities of these developed countries still remains.

Having accounted for nonlinearity in GDP, as modeled by the Galli (1998) *inter alia*, and for sectoral shifts discussed by Medlock and Soligo (2001) as possible explanations for the evident decreasing pattern in elasticities, we conclude that the salient decrease has been driven by one or more residual influences: utility, technology, policy, or something else proxied by time. It would indeed be difficult to further isolate the effects from these possible drivers given the inherent difficulty in measuring these influences, and we leave this task to future research.

The remainder of the paper is organized as follows. Section 2 provides a short and general motivation of the panel nonparametric approach to modeling economic elasticities. In Section 3, we detail the construction and sources of our electricity panel. We present a basic benchmark model of electricity demand, discuss possible sources of coefficient instability in such a model, and introduce a functional coefficient panel model to better identify these sources. Our empirical results are collected in Section 4, and we conclude with Section 5. Appendix A lists countries used to obtain our empirical results, Appendix B presents the econometric methodology, Appendix C discusses some additional technical details of the methodology and some ancillary empirical results, and Appendix D contains our data and code.

[1] Initiated by Kraft and Kraft (1978), Granger causality is a major focus of the literature on this relationship. However, Granger causality is not a focus of the present analysis.

[2] For brevity, all further references to electricity consumption or GDP should be interpreted to mean electricity consumption per capita or real GDP per capita, unless otherwise specified.

[3] A large number of studies on household demand, including Halvorsen (1975), Maddala et al. (1997), and Silk and Joutz (1997), *inter alia*, have estimated a fixed coefficient on log income (income elasticity of demand), for which log GDP may be considered a proxy. In the firm sector, GDP may be a proxy for either output or income. Halvorsen (1978) included measures of both output and income in his model of commercial demand, while Berndt and Wood (1975) and Halvorsen (1978) used measures of output in industrial demand.

[4] We will refer to the partial derivative as the *income elasticity*, or simply the *elasticity*, even though it reflects both an income elasticity and an output elasticity in sectorally aggregated data.