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Hidden regimes and the demand for carbon dioxide from motor-gasoline

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ABSTRACT

Perhaps the most tactile source of anthropogenic carbon dioxide (CO_2) emissions stem from vehicle-use. Because consumers are well aware of their price and quantity decisions it is likely that consumer demand for CO_2 emissions from motor-gasoline are quite responsive to the overall state of the economy. Using a structurally identified Markov-switching demand model I find that CO_2 emissions respond asymmetrically to changes in income and the price of gasoline in expansionary and contracting states of the economy. The findings of this paper indicate that flexible policy instruments have the potential to mitigate undue burden on consumers and producers compared to their static counterparts.

1. Introduction

Since the oil embargo of 1973 the manner in which consumers demand gasoline in the United States has evolved to accommodate technological and societal progress. Consumers, firms, and policy-makers alike have confronted issues of energy scarcity and abundance, the introduction of new plant-based fuels, and growing concern for the environmental impact of emissions that are a natural byproduct of the combustion process. Concerns over anthropogenic climate change have resurfaced and brought the issues of energy production and consumption to the forefront of debates at both the national and international level. For instance, the Intergovernmental Panel on Climate Change (IPCC) recently established that it "is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century" (IPCC, 2013). Within the same report the IPCC also stated that, "[g]reenhouse gases contributed a global mean surface warming likely to be in the range of 0.5 °C to 1.3 °C over the period 1951–2010" (IPCC, 2013). Carbon dioxide emissions, which are a major greenhouse gas and at present are largely due to energy use, have naturally evolved alongside changes in the structure of energy production and consumption. The rigorous study of carbon emissions from energy-use over time, then, is crucial for shaping future carbon dioxide policy domestically. Moreover, insights gained by a case study on the United States' history of carbon dioxide emissions from energy use (CO_2) are widely applicable to the developing world and emerging market economies as they continue to consume more energy.

Carbon dioxide emissions have traditionally been studied at their aggregate level instead of by the constituent pollutants that contribute to overall emissions. This study goes beyond the typical analysis of CO_2 emissions as an aggregate and instead focuses at a more 'micro' level on one of the largest sources of CO_2 emissions from energy-use for the United States, motor-gasoline. In 2014 motor-gasoline emissions accounted for 20.2% of all energy-related emissions. For comparison the dirtiest burning fossil-fuel and largest contributor to emissions from energy-use, coal, contributed only 11% more (EIA, 2015). This focus on motor-gasoline is an important departure from the literature because one-size-fits-all policy measures may not be appropriate for each fuel source. Studying a single, but major, source of pollution can lead to more nuanced proposals that have the potential to alleviate undue burden on consumers.

Motor-gasoline is perhaps the most tactile source of CO_2 emissions from an individual-use perspective. Consumers make purchasing decisions frequently and are immediately faced with the price of the fuel when purchasing a gallon of gas; unlike coal and natural gas which are commonly used to meet electricity demand, but are paid for in aggregated monthly increments. Because motor-gasoline consumers are well aware of their purchasing decisions, it is likely that they are more responsive to changes in the state of the economy and may not have time-invariant demand parameters. The vast majority of research on the nexus of economic growth and CO_2 demand has assumed that emissions respond the same to changes in income during expansionary

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periods as contractionary periods. This study relaxes that assumption and explores the possibility of multiple states, or hidden regimes, through the use of a structurally founded Markov regime-switching model and a large sample of monthly observations on emissions from motor-gasoline covering the time period 1973–2013. I find that allowing for time-varying parameters is very important in characterizing emissions demand. Specifically, I find that motor-gasoline emissions demand is characterized by having two states, and that one state corresponds with periods of aggregate economic turmoil while the other aligns with periods of economic growth.

Recognizing that CO_2 emissions respond differently to price shocks or changes in income depending on the state of the economy has vital implications for policies aimed at limiting these emissions. Policy instruments must have some degree of pliability to reflect the changing nature of demand when the economy is in a downturn or gasoline prices are at unordinary highs or lows so that undue burden is not faced by consumers. For example, when gasoline prices are very high there will naturally be a decrease in overall quantity demanded, even if it is by small amount due to the inelastic nature of gasoline demand. In this scenario a static carbon tax could be unnecessarily high and cause more of a market distortion than necessary. The converse could hold, too, if prices were very low and consumers were driving more often due to the decrease in price. This would be a situation in which the carbon tax was inefficiently low. The prior scenarios are only exacerbated when changes in aggregate economic activity are included — it seems natural that high gasoline prices would have a different effect in the middle of a recession than during an expansion. This, in essence, is the lesson learned from the Lucas critique — macroeconomic policy should not be based on regression coefficients in econometric models that do not account for structural change or differing attitudes of consumers across different states of the economy because the coefficients are not regime-invariant (Lucas, 1976).

The balance of this paper continues as follows: section two briefly discusses prior literature; section three tests for and discusses the intrinsic deterministic components of CO_2 from motor-gasoline and the relationship of CO_2 emissions with the other non-stationary variables used in the demand analysis; section four estimates a non-regime-switching structural supply and demand model of CO_2 emissions from motor-gasoline; section five estimates the structurally founded Markov regime-switching CO_2 demand model; section six concludes with a policy discussion.

2. Prior literature

The relationship among gasoline consumption, gasoline prices, and macroeconomic growth is well studied in the economic literature, though research on these variables and emissions from motor-gasoline is severely limited. For that reason, the majority of focus in this literature review will be placed on major developments in modeling gasoline consumption at the aggregate level (Ryan and Ploure, 2009). Gasoline consumption naturally leads to new emissions, so this body of work on the nexus between economic activity and gasoline demand has substantially influenced the way motor-gasoline emissions are modeled here.

Hamilton (1983) is an excellent analysis and survey of the bond between gasoline and economic growth in the post-war period. Rotemberg and Woodford (1996) also comment on the intricate relationship of gasoline prices, demand, and macroeconomic conditions and their effect on markups in particular. Further microeconomic evidence on the relation between aggregate economic shocks and gasoline consumption in Bresnahan and Ramey (1993) indicates that aggregate shocks affect the mix of demand for automobiles. More recently, the dynamic effects of oil-price changes have been analyzed (Lee and Ni, 2002). Specifically, great strides have been made in modeling the oil-macroeconomy relationship as a non-linear relationship (Hamilton, 1996, 2003, 2013; Kilian and Vigfusson, 2011; Kilian and Vigfusson, 2013). In fact, Hamilton (2003) notes that when "allocative disturbances are indeed the mechanism whereby oil shocks affect economic activity, then there is no reason to expect a linear relation between oil prices and GDP." Kilian (2008) provides an overview of recent literature on the interconnection between energy prices and macroeconomic activity, and describes how vector autoregression (VAR) modeling allows for the endogeneity of energy prices and macroeconomic growth to be accounted for. He notes that when using high frequency (monthly) data, it is reasonable to assume a recursive structural definition in which macroeconomic activity can only affect energy prices in future months, not contemporaneously.

Markov switching (MS) models are certainly not new to the field of econometrics, and have been used since the primal work of Goldfeld and Quandt (1973), though they became widely popular after the work of Hamilton (1989) which describes how growth rates of real GNP are "subject to autocorrelated discrete shifts" and that these shifts between growth and recessionary states are better characterized using this method than by positive coefficients at low lags in autoregressive models. Since then there have been relatively few applications that study gasoline demand in an MS model. Moreover, previous studies have not focused on pollution and instead have primarily been concerned with the effect of energy price shocks on macroeconomic aggregates (Cologni and Manera, 2009; Hamilton, 1996, 2003) or retail gasoline price dynamics in the industrial organization literature (Noel, 2007, 2009, 2011).

There are a few studies with which the present analysis may be compared to and considered among. Soytas, et al. (2007) study the relationship between emissions from energy and income in the United States while paying particular attention to the time-series properties of emissions by using a five variable VAR model. Roach (2013) proxies for vehicle emissions in a structural VAR by estimating the impact of income shocks on the amount of miles driven by vehicles. Galeotti, et al. (2006) offers a "robustness exercise" in that they use a non-parametric functional form to study the income–CO_2 relationship. Doda (2014) finds that the cyclical component of emissions is positively correlated with the cyclical component of GDP. Ajmi, et al. (2015) uncover how important time-variation is in detecting Granger causality between economic activity, energy use, and CO_2 emissions for a number of developed countries. These are among the many available references available that discuss the relationship between economic growth and CO_2 emissions, not including the explosion of research on the environmental Kuznets curve that links economic growth with the amount of emissions (Dinda, 2004). The literature referenced here is mostly meant to represent how influences from the abundant energy and economic growth literature have begun to influence new work on emissions, for instance in the more prevalent use of VAR models.

The only prior work that uses a Markov switching framework to describe CO_2 emissions and economic growth is Park and Hong's (2013) analysis of South Korea. In a somewhat related study, Chevallier (2011a, 2011b) studies the futures price for the European Union Allowance, a carbon price of sorts, in a two-state Markov switching model to capture the varying demand in high-growth and low-growth regimes. The present study may be seen as a complement to Chevallier's work on carbon prices for two reasons. First, carbon allowance prices are naturally linked to the quantity of carbon demanded in a society. Second, because there is not a Federal-level policy for limiting CO_2 emissions in the United States this study allows for a better understanding of the underlying determinants should a federal tax or permit system be implemented like that of the European Union.

A final body of literature is worth mentioning because it is related to the policy-implications of this research. "Environmental Macroeconomics" is a recent subfield in environmental economics in which agent-based Dynamic Stochastic General Equilibrium (DSGE) models are used to evaluate environmental policy (Heutel and Fischer, 2013). A common finding within this literature is that a carbon tax should be dynamic in nature and allowed to fluctuate according to the business cycle