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Flexible-fuel automobiles and CO_2 emissions in Brazil: Parametric and semiparametric analysis using panel data

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ABSTRACT

The replacement of fossil fuels by clean energy sources has emerged as a focus for those concerned with the creation of a less polluted urban environment. In this context, Brazil's use of ethanol as a vehicle fuel is unique, especially considering the country's successful adoption of flex-fuel technology first introduced in 2003. Currently, most of the fleet of vehicles circulating in Brazilian cities can use ethanol. The effect of this alternative fuel on the Brazilian urban environment is the focus of this study. In our study, the relationship between Brazil's fleet of flex-fuel vehicles and local CO_2 equivalent emissions was investigated using parametric and semiparametric analysis based on modified Environmental Kuznets Curve (EKC) equations. The analyses employed an annual set of state-level panel data for the period from 1998 through 2013. Both analyses show that the Brazilian introduction of flex-fuel vehicles in 2003 contributed to a marginal reduction of passenger car CO_2 emissions by 2013. Moreover, results also indicate that (1) there is evidence that flex-fuel vehicles can be a component in the generation of an EKC; and (2) there is a negative relationship between the area under sugarcane cultivation and CO_2 emissions due to carbon sequestration. These results indicate that the substitution of ethanol for gasoline through the use of flex-fuel technology leads to fewer total greenhouse gas emissions, considering that greenhouse gas emissions from ethanol combustion and ethanol processing are outweighed by their sequestration during sugarcane growth in rural areas.

1. Introduction

Environmentalists leading global efforts to transition to a low-carbon economy often note Brazil's long and unique experience in the large-scale production of ethanol fuel as an alternative to gasoline. Researchers focused on the impacts of this transition on urban areas use the Brazilian case as the basis for analysis. Brazil's experiment with the use of ethanol as a vehicle fuel began in the 1930s when the government mandated that gasoline be mixed with anhydrous ethanol. Later, Brazilian ethanol production increased significantly with the creation of the National Program for Ethanol (Proálcool) in 1975.

This program provided government assistance to sugarcane growers and distillery operators. As ethanol supplies increased, the government in conjunction with the country's automobile industry pushed for the development of a fleet of 100 percent hydrous ethanol-powered automobiles (Moraes & Zilberman, 2014).[1] The first of the cars designed to run on ethanol, designated E100, entered the Brazilian market in 1979 and represented 23 percent of the country's light vehicle fleet in 1980; however, by the beginning of the new millennium these mono-fueled ethanol cars had fallen out of favor.

Ethanol-fueled vehicles in Brazil were once again an interesting option for the Brazilian consumer at the end of 2003, driven by the market introduction of flex-fuel vehicles capable of running on any arbitrary combination of gasoline and hydrous ethanol. In 2014, flex-fuel light vehicles comprised over 50% of the national vehicle fleet, were responsible for more than 90% of passenger car sales, and ethanol was offered in practically all Brazilian cities (Anfavea, 2015).[2] By 2013, Brazil's had the world's largest fleet of flex-fueled transportation vehicles and had the highest percentage of these vehicles in its fleet.

Several published studies have analyzed the potential effect of

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[1] Brazil produces two types of fuel ethanol: anhydrous ethanol, which is mixed with gasoline; and hydrous ethanol, which can be used in flex-fuel automobiles and in automobiles that run exclusively on fuel ethanol.

[2] Unlike other countries, Brazilian legislation only allows the production of gasoline, ethanol or flex-fuel passenger cars. Diesel-powered vehicles are restricted to the commercial vehicle and cargo transportation (*Portaria DNC N° 16, 29/06/93*).

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replacing gasoline with ethanol on vehicle emissions, especially greenhouse gas emissions (GHG). Macedo (2005) estimated that the use of sugarcane-derived ethanol as an alternative to gasoline can contribute to an approximate 13% reduction in the entire energy sector's GHG emissions when gases reabsorbed through carbon sequestration by the next season's sugarcane crop are taken into consideration. Studies have found that the use of ethanol in place of gasoline (or blended fuel) has the potential to mitigate the release of toxic lead, carbon monoxide, and sulfur pollutants (Goldemberg, Coelho, & Guardabassi, 2008; Macedo, 2005).

Brazil is a predominantly urban country with more than 80% of the country's population living in urban areas and the concentration of vehicular carbon emissions is greatest in urban areas (IBGE, 2010; Carvalho, 2011). Since vehicular emissions are one of the main sources of urban pollutants, urban and regional pollutant emissions policies often focus on their reduction (Dou et al., 2016).

Urban planning interventions in regard to vehicle emissions are generally more effective over the long run as the reduction of vehicle emissions depends on replacing one type of vehicle for a less polluting type and improving transport infrastructure. However, other social demands can further delay the implementation of emissions reduction policy, especially in developing countries, when taking into account the cost of replacing transportation options and the need for investments in urban transport infrastructure (Dulal, Brodnig, & Onoriose, 2011; Dulal & Akbar, 2013).

In this context, flex-fuel technology that facilitates the use of cleaner burning vehicle fuels, such as ethanol, has emerged as a greenhouse gas (GHG) reduction policy option. Moraes and Zilberman (2014) and Gilio and Moraes (2016) have highlighted that the use of ethanol in large quantities can contribute to the reduction of GHG emissions, especially in large urban areas, while at the same time stimulating economic development in rural areas.

To date, there are no studies that evaluate the actual long-term effect (more than a decade) of a change of vehicle fuels on vehicle emissions in Brazilian urban areas, a fact favored by the introduction and acceptance of flex-fuel vehicles. Our study intends to remedy this by analyzing empirically the effect of the use of flex-fuel vehicles on CO_2 emissions (in CO_2 equivalent emissions) in Brazil since this technology's introduction more than a decade ago and determine if the use of flex-fuel vehicles does contribute to decreasing CO_2 emissions. The information provided in this paper should be of use to those designing policies directed toward the reduction of carbon emissions from the urban transportation sector.

The investigation initially consisted of parametric analysis based on the well-known empirical hypothesis underlying the Environmental Kuznets Curve (EKC) using a Brazilian state level panel data set covering the years 1998 through 2013. However, some econometric studies have concluded that this type of empirical work does not provide much guidance regarding the choice of the functional form for estimation purposes (Schmalensee & Stoker, 1999; Yatchew, 2003) and that most empirical economic research seems to ignore the benefits of semiparametric methodology (Henderson & Parmeter, 2015). For this reason, our study added the novelty of a semiparametric analysis specifically designed for panel data to determine if there is any link between flex-fuel vehicles and CO2 emissions.

To the best of our knowledge, economic studies investigating the relationship between flex-fuel vehicles and GHG emissions are scarce. Our study aims to fill this gap, at least regarding CO2 emissions, by analyzing the relationship between the Brazilian fleet of flex-fuel-powered noncommercial passenger vehicles and CO2 emissions in the country using a well-behaved panel data set for 1998–2013 period. In respect to ethanol's impact on rural areas, our study also considered the effect of increased sugarcane cultivation and ethanol production on the rural environment arising from growing urban ethanol demand. The study will supplement other international literature on energy efficiency and CO2 emissions in the urban environment, especially works addressing the relationship between urbanization and CO2 emissions by Zhu, You, and Zeng (2012), Zhang and Lin (2012) and Dulal and Akbar (2013).

2. Review of literature: emissions, EKC, and flex-fuel vehicles

Given the growing importance of environmental policies related to the possible impacts and causes of global warming, the issue of CO_2 emissions and their main determinants has been widely discussed. The major determinants cover a wide set of economic subjects, which include gross domestic products (GDPs), trade liberalization, energy consumption, population growth and urbanization, number of vehicles and the distances driven, vehicle technologies, and alternative energy sources (Ang, 2007; Bertinelli & Strobl, 2005; Azomahou , Laisney, & Van, 2006; Chang, 2010; Jalil & Mahmud, 2009; Kang, Zhao, & Yang, 2016; Lee & Mukherjee, 2014; Martínez-Zarzoso, Bengochea-Morancho, & Morales-Lage, 2007).

The environmental Kuznets curve (EKC) is often noted in economics literature focused on the determinants of greenhouse gas emissions (GHG). The curve arose from Kuznets' hypothesis that economic growth has an impact on environmental quality. It offers a projection of mankind's impact on the environment by showing that there is an inverted-U shaped relationship between environmental degradation indicators and per capita income (Dinda, 2004). According to Stern (1998), the EKC suggests that economic growth can mitigate negative environmental impacts driven by an initial period of economic development; and after this initial period, economic growth leads to technological advances and more stringent regulation that lessen environmental degradation in countries that have traditionally been major polluters.

The first empirical analysis of the EKC hypothesis was the 1991 study of SO_2 (sulfur dioxide) emissions and GDP per capita in various countries conducted by Grossmann and Krueger and first published in 1993 (Dinda, 2004; Stern, 1998). They found that there was an inverted-U relationship between SO_2 and per-capita GDP. There have been several other recent studies that confirm the EKC for various environmental degradation factors, but the results are mixed when CO_2 emissions are considered separately (Ahmed & Long, 2012; Apergis and Payne 2007; Farhani & Ozturk, 2015; Fodha & Zaghdoud, 2010; Friedl & Getzner, 2003; Galeotti & Lanza, 1999; Harbaugh, Levinson, & Wilson, 2002; Iwata, Okada, & Samreth, 2011; Jalil & Mahmud, 2009; Kang et al., 2016; Lantz & Feng, 2006; Taskin and Zaim, 2000). The literature shows that this group of nongeneralizable results was derived from a diverse collection of methodological approaches.

Bertinelli and Strobl (2005) using a semiparametric estimation and panel data from various countries over the 1950–1990 period found a positive relationship between CO_2 emissions and GDP per capita and were, therefore, unable to corroborate the EKC hypothesis. Zhu et al. (2012) used a dynamic semiparametric model to examine the relationship between urbanization and CO_2 emissions in 20 emerging countries and found that there is little evidence to support an inverted-U curve relationship. Kang et al. (2016), using a spatial model of panel data for Chinese cities from 1997 to 2012, identified a relationship in the form of N-inverted, again, not validating the EKC's traditional inverted-U curve. The authors noted that as the level of urbanization increases, CO_2 emissions increase due to the massive burning of coal in China They also point out that trade liberalization tends to reduce the emission of polluting gases, probably due to weaker environmental regulations in some countries.

Ang (2007) evaluated the relationship between CO_2 and energy consumption and corroborated the EKC hypothesis for France with a time-series analysis and error correction models using data from 1960 to 2000. Also, using an error correction model applied to panel data from Central American countries between 1971 and 2004, Apergis and Payne (2007) found that long-run equilibrium energy consumption has a positive and statistically significant impact on CO_2 emissions and that real CO_2 output exhibits the inverted-U shape pattern associated with the EKC.