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A dynamic general equilibrium model of driving, gasoline use and vehicle fuel efficiency

Chao Wei

Department of Economics, George Washington University, 2115 G Street NW, Washington, DC 20052, United States

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ABSTRACT

The paper constructs a dynamic general equilibrium model to study the endogenous determination of gasoline use, driving and vehicle fuel efficiency. Before vehicles are produced, their fuel efficiency can be chosen optimally. Once produced, their fuel efficiency cannot be changed. The model generates endogenously different short-run and long-run price elasticities of gasoline use, with their magnitudes well within the region of plausible estimates in the empirical literature. The paper shows that although raising gasoline taxes and tightening the CAFE standard both reduce gasoline use in the long run, they are different in terms of the transmission mechanism, magnitudes of responses and dynamic paths of key endogenous variables.

Gasoline consumption accounts for 44% of the U.S. demand for crude oil. Reducing gasoline consumption has become part of the strategic efforts to protect the nation from the serious economic and strategic risks associated with the reliance on foreign oil and the possible destabilizing effects of a changing climate. There has been heated discussion on policy options to discourage gasoline consumption, including increasing the gasoline taxes and tightening Corporate Average Fuel Economy (CAFE) standards. In order to evaluate the merits of these policy options, we need a structural framework to understand how people decide on how much to drive and what types of vehicles to own.

Key to this evaluation is the fact that the decisions on how much to drive and what types of vehicles to own are dynamic in nature. Vehicles are important durable goods with embodied technological characteristics. The durable nature of vehicles implies that people are forward-looking in making decisions regarding vehicle choice and utilization. The embodiment of technological characteristics also implies that the characteristics of existing vehicles may have significant impact on the transition dynamics after any exogenous shocks. Despite the dynamic nature of the issue, static models of consumer and producer behavior are widely used in this literature.[1]

In this paper we construct a dynamic general equilibrium model to study the endogenous determination of gasoline use, driving and vehicle fuel efficiency by a representative household which takes utility in vehicle miles of travel. The model captures the putty-clay nature of the way transportation capital (vehicles) and gasoline are combined to "produce" vehicle miles of travel. Before vehicles are produced, their fuel efficiency can be chosen optimally in anticipation of future gasoline prices and economic conditions. Once the vehicles are produced, their fuel efficiency cannot be changed *ex post*. Decisions

E-mail address: cdwei@gwu.edu.

[1] For example, Parry and Small (2005), Bento et al. (2009), Jacobsen (2007), and etc., as discussed later in the introduction.

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can be made on whether or not, or how often to utilize a vehicle, but if the vehicle is utilized, the gasoline use required for a given mileage is determined by its fuel efficiency.

Under the putty-clay specification, gasoline price shocks affect gasoline use through two main channels. The first channel is the endogenous capacity utilization of pre-existing vehicles. Since the quantity and fuel efficiency of existing vehicles are pre-determined, the representative household can only alter its driving behavior in the short run. As gasoline prices increase, vehicles are driven less due to higher gasoline cost, thus creating immediate gasoline savings. The second channel is the substitution of more fuel efficient vehicles as new generations of vehicles are produced. This channel leads to continuing gasoline savings as fuel-inefficient vehicles are phased out gradually. The impact of a permanent change in gasoline prices is fully realized after all the pre-existing vehicles are replaced.

The putty-clay specification allows the model to capture different short-run and long-run price elasticities of gasoline demand. These elasticities are obtained from endogenous dynamic responses of key variables to gasoline price shocks as a result of households' optimal decisions. The magnitudes of those elasticities, generated by the model calibrated to U.S. fuel consumption and vehicle usage data, are well within the range of plausible estimates in the empirical literature.

We use this model to compare two policy options: gasoline taxes and CAFE standard. Gasoline taxes have a long history in the United States. The CAFE regulation was enacted after the 1973 oil embargo. It imposes a limit on the average fuel economy of new vehicles sold by a particular firm, with fines applied to violations of the standard. In a representative-agent model like ours, the impact of an increase in gasoline taxes on the model dynamic is the same as that of a corresponding increase in gasoline prices under the assumption of a lump-sum tax rebate. As a result, the short- and long-run price elasticities of gasoline use can also be used to characterize the effect of gasoline taxes.

Although there has been conjecture that the minimum CAFE standard may have contributed to reduced gasoline use, it has been difficult to conduct a "comprehensive assessment of what would have happened had fuel economy standards not been in effect" (NRC 2002). The structural model developed in this paper, however, allows us to quantify the effect on gasoline savings achieved through the minimum CAFE standard. In contrast to gasoline taxes, a tightening of the CAFE standard achieves the gasoline savings by raising the fuel efficiency of new vehicles, with little effect on miles driven by pre-existing vehicles. We find that in order to achieve the same amount of permanent gasoline savings as a one-percent permanent increase in gasoline prices, the CAFE standard has to increase by 0.68 percent from its initial level which is assumed to be binding to start with.[2] We also find that the presence of the minimum CAFE standard alone avoids around 60 percent of the increase in gasoline consumption, which would have occurred absent such a standard at the time of permanent price decreases.

Existing studies in this literature have typically adopted a static approach. Parry and Small (2005) adopt a structural approach to study the optimal gasoline tax. In their model the representative agent decides on its optimal driving and gasoline use in a one-period utility-maximizing framework, where vehicle miles of travel is related to gasoline consumption in a reduced form and vehicle fuel efficiency is not a choice variable. This approach does not examine the dynamic responses of driving and vehicle choice in a multi-period setting. Bento et al. (2009) estimate the distributional and efficiency impacts of increased U.S. gasoline taxes using a large sample of household data. Jacobsen (2007) incorporates the producer's decision problem into Bento et al. (2009) framework to study the equilibrium effects of an increase in the U.S. CAFE standards. However, both papers impose a specific indirect utility function for households and use Roy's identity to derive household decisions on vehicle choices. While in this paper, the representative households make optimal decisions on driving and vehicle ownership based on the direct utility function.[3]

In contrast with nearly all prior work, this study adopts the dynamic general equilibrium modeling approach. The advantages of this approach are threefold. First, the structural framework makes transparent the transmission mechanism from exogenous shocks to optimal decision-making on driving and vehicle fuel efficiency and makes it possible to analyze the roles played by deep structural parameters. Second, the model is internally consistent. Third, it is a dynamic model which is not only forward-looking, but also captures the dynamic paths of key economic variables over time. To our knowledge, this is the first paper that employs a dynamic general equilibrium approach to examine the determination of gasoline use, driving and vehicle fuel efficiency.

This paper is related to the literature on the relationship between energy price shocks and the macroeconomy. Wei (2003) utilizes a putty-clay model to study the impact of energy price shocks on the stock market. In that paper, the adverse impact of an oil price shock is limited by the small share of oil costs as a fraction of the total production costs in the aggregate economy. The present study focuses on the effect of gasoline price shocks on transportation. The importance of gasoline to transportation makes it possible to capture the significance of oil to the aggregate economy through the transportation sector. This paper also relates to Bresnahan and Ramey (1993) and Ramey and Vine (2010), which use industry data to examine the segment shifts and capacity utilization in the U.S. automobile industry. The household's optimal

[2] Austin and Dinan (2005) estimate that a 3.8 miles per gallon increase in the standard reduces long-run gasoline consumption by 10%. According to our model calculations, it takes a 20-percent increase in the after-tax gasoline price or a 13.6-percent increase in the minimum CAFE standard to reduce gasoline consumption by 10%. The latter is equivalent to a 3.4 miles per gallon increase in the CAFE standard, a magnitude within the ballpark of the estimation by Austin and Dinan (2005).

[3] The models in Bento et al. (2009) and Jacobsen (2007) are solved period by period, different from a dynamic general equilibrium model with rational expectations, where current and future variables are jointly determined and future expectations of variables are consistent with one another. The agents are considered fully forward-looking in the latter setting.