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A sequential input–output framework to analyze the economic and environmental implications of energy policies: Gas taxes and fuel subsidies

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HIGHLIGHTS

- Novel framework integrates monetary and physical changes in sequential input–output analysis.
- Estimate economy-wide environmental changes as a result of combined energy policies.
- Life cycle resource consumption and emission data for the U.S. economic sectors are adopted.
- Ecosystem impacts could increase as a consequence of combined gasoline tax and bio-subsidy.

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ABSTRACT

A novel generic sequential input–output framework is developed to model the economy-wide changes in resource consumption and environmental emissions as a result of combined applied energy policies, e.g. taxes for non-renewables and subsidies for renewables. Many input–output analyses are based on a single period analysis. However, in the case of analyzing the effects of multiple policy interventions over time, the input–output table reflecting the state of the economy before the energy policy was introduced cannot be used for analyzing the economic effects of another policy intervention in the next time period since the monetary and physical transaction of commodities have already been affected. To show the efficacy of the proposed method, a case study is developed that introduced a gasoline tax and earmarks the revenues to subsidize biofuel production in the subsequent time period in the United States. In order to assess the change of environmental indicators after sequential policy interventions, Ecologically-based Life Cycle Analysis (ECO-LCA) inventories which include data on resource consumption, emissions, ecosystem goods and services related to the U.S. economic sectors are adopted. The environmentally extended input–output framework is ideally suited to model the interlinkages between a range for environmental indicators and detailed structural economic information at the sector level for the analysis of energy policies. The proposed framework can be utilized as a tool for leveraging the energy and environmental policy trade-off decisions which consider the impacts to resource consumption and environmental emissions. Our results show that, if a share of the gasoline tax revenue is reinvested to subsidize biofuel production, economy wide resource consumptions and emissions from the fossil fuel related supply chains will decrease. However, ecosystem goods and services such as soil erosion, water consumption for agricultural and livestock, cropland, nitrogen deposition along with the emissions such as nitrous oxide and ammonia will increase in short term as a consequence of the price drop and the increased demand for biofuels. This emphasizes the importance of focusing on a wide range of environmental outcomes and unintended side effects when introducing a specific environmental policy.

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1. Introduction

Imposing a specific monetary charge to a commodity has long been viewed as a theoretically attractive tool to discourage environmental harm, conserve energy, and for certain countries to reduce dependence on imported oil. Placing a tax on fossil fuels may make alternative fuels more attractive, and creates an incentive for manufacturers and consumers to choose more fuel-efficient products and processes. A number of policy studies consider the change of commodity prices through an energy tax or subsidy merely as an additional social cost directly caused by certain energy policies (i.e. gasoline tax, bio-subsidies, etc.). Doing so fails to capture system-wide effects, i.e. the cost accrued throughout the entire supply chain through consumption of resources and factors whose prices are also affected by the policies indirectly. In this paper, we model the environmental effects and trade-offs arising from the introduction of a gasoline tax coupled with subsidies for biofuels based on the earmarked tax revenues for the US. We do by developing a novel generic sequential input–output framework to assess the direct and indirect economic and environmental impacts of energy policies by considering both monetary and physical changes of economic goods and services.

There are three major contributions of this work. First, the proposed methodology adjusts the baseline input–output table by updating the effect of a policy. The amended input–output table is then used to assess the economic and environmental impacts after reallocating the portion of the fuel tax revenue to subsidize the biofuel production. Therefore, the advantage of the proposed methodology come into play when a modeler assesses the sequential policies. This analysis differs with the case of applying combined fuel tax and bio subsidy at a single period where the availability of funding for subsidies are automatically assumed. Secondly, this study utilizes partially available information about price elasticities of demand to model consumer behavior in the short-run in the input–output analysis context. Thirdly, the proposed framework will be able to model the changes in resource consumption, environmental emissions, ecosystem goods and services upon various combined policy interventions. Life cycle resource consumption and emission data for the U.S. economic sectors are adopted from the ECO-LCA [1]. ECO-LCA is taking into account not only resource consumption and emissions but also ecosystem services like soil erosion, pollination, flood prevention and cropland coupled with the economic sectors in the United States [2–4]. Ecosystem services in the tool is classified into four areas: Supporting services (soil, pollination, sunlight, hydro, geothermal, wind, etc.), regulating services (flood protection, disease regulation, carbon sequestration, etc.), provisioning services (fuels, ores, water, timber, cropland, etc.), and cultural services (spiritual and recreational benefits, etc.) [5,6]. It provides a coarse estimation of how different products might compare to one another and provide broader environmental implications of economic products. Since all the economic activities are correlated, these environmental loads are changing directly and indirectly based on different policies. In this paper, we illustrate the changes in resource consumption, ecosystem goods and services, and emissions. Comprehensive data can be found from the ECO-LCA.

2. Background

In the US, the first gasoline tax was created in 1919 in Oregon with the other 47 states adding a gasoline tax by the end of 1929. In 1932, the U.S. Federal Government implemented the first federal gasoline tax at $0.01/gallon. This tax has risen periodically until 1997, since when it has remained at $0.184/gal [7]. Incorporating state gasoline taxes, the US national fuel tax is $0.403/gal on average. [8]. According to the U.S. Energy Information Administration (EIA), U.S. motor gasoline and diesel fuel usage in 2014 was responsible for 28% of energy related CO_2 emissions. Each gallon of gasoline consumed emits roughly 19.6 lb of CO_2 and the EIA estimates that 1075 million metric tons of CO_2 were emitted in 2014 as a result of gasoline consumption [9]. Recognizing the benefits of decreased CO_2 emissions to mitigate climate change, it seems advantageous to increase fossil fuel taxes further to incentivize consumers to choose other propellant sources (i.e. electric, biofuel, hydrogen fuel cell, compressed natural gas, etc.). There are numerous factors to consider in the economics of increasing fuel taxes. For example, there are competing economic interests at stake when considering raising the fuel tax versus maintaining or reducing the fuel tax [10]. In addition, there is a distributional effect. Recognizing that the United States is in the bottom third of OECD countries for population density and how this impacts private vehicle ownership will be a factor in accounting for the impacts of raising fuel taxes on different sectors and households. A number of studies explored whether pursuing increased taxes on vehicles would be equally effective in reducing CO_2 emissions as increasing fuel taxes. However, they found that pursuing taxes on vehicles is less effective at reducing long-term fuel consumption than increasing fuel excise taxes to change consumer behavior [11]. Similarly, a study focusing on the CO_2 emissions of urban transportation found that increasing fuel taxes by $0.11/gallon over a ten year period would result in a 13.2% reduction in the number of vehicles operated in an urban area when compared against a baseline growth model [12], and that increasing the fuel tax was more effective at reducing fuel consumption, and thus CO_2 emissions, than making public transportation free or improving support for motorcycles. The degree to which fuel taxes should be increased to result in significant changes in long run fuel consumption requires some guidance for policy makers [13].

In addition to the impacts of increased fuel taxes, there is growing concern about the impacts of increased reliance on alternative transportation fuels. Searchinger et al. [14] suggest that far from reducing carbon emissions, bioethanol that results from crop switching could represent a 52 year payback and an increase in CO_2 emissions by 50% over 30 years. This is in part due to utilizing commodities that were previously for food consumption and now have switched to fuel, resulting in increased food costs, and also in part due to land use changes that occur from farmers changing from crop or timber production to biofuels. Delucchi [15] found through life cycle analysis that the production of corn ethanol did not result in GHG emissions significantly lower than that of gasoline, whereas in the case of cellulose ethanol, the GHG emissions were 50% of the emissions of gasoline. Fully accounting for the life cycle costs of a commodity is necessary for the market to accurately price goods and concerns about biofuel production expansion should be heeded lest they aggravate climate change further. Some studies show that even when the highly debated land use change GHG emissions are included, switching to biofuels helps to significantly increase the reductions in energy use and GHG emissions [16,17]. The additional revenue that can be reaped from an increased fuel tax can partly be earmarked to increase research into new strains of transportation fuels to minimize the need to expand land use. For example, with further research aquatic microbial oxygenic photoautotrophs (AMOPs) present the opportunity of higher efficiency solar collection, to use less or no land, and can provide secondary uses that are not otherwise possible with fossil fuels [18]. While biofuels present great promise, a measured approach is warranted to reasonably account for the indirect consequences.

Input–output analysis is a macro-economic tool utilized for assessing the overall economy-wide impacts of producer and consumer activities. Input–output analysis has been widely used for