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Decomposing the drivers of aviation fuel demand using simultaneous equation models

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ABSTRACT

Decomposition analysis is a widely used technique in energy analysis, whereby the growth in energy demand is attributed to different components. In this paper the decomposition analysis is extended in a system econometric modelling framework in order to understand the drivers of each of the components in the decomposition analysis. The growth in aviation fuel demand is decomposed into five components: population, passenger per capita, distances per passenger, load factor and fuel efficiency, and then seemingly unrelated regression methods is applied in order to model each of these. Results show that the fuel demand in the US air transport sector most closely follows the trend of passenger per capita. The growth in fuel demand is slowed by improvements in fuel efficiency and usage efficiency (load factor). Increases in income affects both passengers per capita and distances per passenger. However, increases in travel costs have opposite effects on passenger per capita (decreases) and distance per passenger (increases). Increases in jet fuel prices improves both the load factor and fuel efficiency.

1. Introduction

Aviation is responsible for a modest 2% of all anthropogenic carbon emissions and around 5% of global radiative forcing [26]. Yet demand for global passenger and cargo transport by air and subsequent demand for aviation fuel and carbon emissions have been growing at a higher rate compared to other economic sectors. Even in as mature a market as the US, which accounts for almost 40% of global aviation carbon emissions, carbon emissions are set to quadruple in absolute terms by 2050 [24]. However, due to a lack of alternate energy carriers to power aircrafts, liquid fuel remains the only viable aviation fuel and the carbon mitigation options often boil down to reduction in fossil fuel use through technological means or replacement of fossil fuels by renewable biofuels [24]. For both of these options, demand for aviation fuel is an important metric for mitigation planning and policy making. At the same time, fuel costs constitute a major share of airlines' operational costs (one-quarter in 2012 [6]), and as such fuel consumption is an important planning and forecasting metric for the aviation industry as well. Therefore, understanding and modelling fuel demand for air transport is an important area of applied research.

In the aviation sector, fuel demand is often modelled using hybrid econometric-engineering models. Aggregate econometric methods are used to model or forecast demand, which may or may not be divided among different travel segments (e.g. business vs. leisure, short haul vs. long haul etc.). Projected aggregate demand in passenger or passenger-mile is then allocated to different aircraft types or sizes to determine aircraft-miles and number of aircrafts. An engineering-economic fleet turnover model along with technologies available (or projected) is then used to determine the fleet fuel efficiency and overall fuel consumption. Details vary, but models used for UK [16], USA [17] or global [26] aviation fuel demand and carbon emissions all follow the same hybrid modelling approach. These models are quite data intensive, and are particularly useful to *simulate* the effects of new technologies on aggregate fuel consumption or carbon emissions, yet the feedback loop from technology to demand is often absent, making them less useful to understand the effects of some of the demand drivers or policy initiatives.

On the other hand, decomposition analysis is a retrospective modelling approach: the method decomposes energy consumption in an economy into various component elements and seeks to explain the co-evolution of energy demand and these components on a temporal scale. In aviation, Andreoni and Galmarini [2] have recently applied the method directly to analyze the evolution of air transport fuel use in the European Union, while Schafer et al. [29]

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also implicitly follow the decomposition framework to explain historical determinants of aviation fuel use. The advantage of the decomposition method is that it reveals the relative effect of the components on aviation fuel demand. These components often include items like energy intensity of the sector, contribution of the sector to overall economy, economic growth, etc. However, traditional decomposition analysis stops at explaining energy demand at the component level and any understanding of the drivers of these individual components are often qualitative in nature. For example, a decomposition analysis will be able to allocate the growth in aviation fuel demand due to a growth in activity (travel), but it cannot explain the factors that leads to the growth in activity. On the other hand, policy tools generally address the drivers instead of the components directly. For example, policies cannot directly target the number of passengers flying (unless by rationing), but would rather use taxes or duties to affect the demand and thus energy consumption. Therefore it is important to understand the quantitative impacts of the drivers of these components which gives a more comprehensive picture of the underlying factors affecting aviation energy consumption.

In this work, the traditional decomposition analysis is extended to quantitatively understand the drivers of the individual decomposition components. In order to achieve this objective, each of the decomposition components is modelled using econometric techniques within a simultaneous equation framework. To the author's knowledge, such an approach has not been applied in the area of energy decomposition or aviation fuel demand before. Also, unlike the previous decomposition components, the novel components suggested here are able to link aviation energy consumption to air travel demand and energy efficiency metrics. The paper is laid out as follows: section 2 describes the decomposition techniques, applies it to aviation fuel consumption in the US and presents the findings of decomposition analysis. Section 3 presents the simultaneous equation modelling approach to each of the decomposed components of section 2, presents the econometric detail and results. Section 4 links the decomposition analysis with the econometric model while section 5 concludes.

2. Decomposition analysis

2.1. Brief literature review

IDA (Index Decomposition Analysis) is a widely used technique to separate out the impacts of structural change (changes in the mix of economic sectors, modes of transport etc.) and energy intensity/efficiency change in an economy. The technique, in various formats, is applied in national energy efficiency monitoring in several countries such as the US, the UK and New Zealand. Although primarily used for understanding the aggregate energy consumption or carbon emissions of an economy, the method has been applied to individual sectors or subsectors of the economy as well. For example the technique was applied to industrial energy demand in Canada [5], and to residential energy demand in China [25]. In the transportation sector decomposition method was used for analyzing the entire transport energy use in 12 countries in Asia [31], or for analyzing the energy used in road freight in Denmark [22].

The indices used for IDA can be divided into two major types - Divisia and Laspeyer - with several variations possible under each type. Laspeyer-type indices have an easier interpretation as they are based on simple per cent changes. The impact of a specific component is determined by changing that component, while keeping others constant. On the other hand, Divisia indices, first introduced by Boyd et al. [9], are based on logarithmic changes and offer some theoretical advantages over Laspeyer indices. These include a complete decomposition with no residuals and the symmetry of the indices [3]. Therefore Divisia indices are used more in recent literature. Among the different Divisia indices Ang [3] recommends the use of LMDI-I (Log Mean Divisia Index – type I). A description of different indices used IDA and there advantages and disadvantages are available in Ang [3].

Although there are a number of techniques for IDA, in the transportation sector or at the individual transportation mode level, the decomposition often gets simplified because only one sector or mode is analyzed. This simplified approach is a multiplicative Divisia method in essence but is often known in other popular names such as the Kaya method [37] or ASIF method [38]. The multiplicative Divisia approach dominates the decomposition analysis in transport energy or transport carbon emissions, although additive decomposition methods can be found occasionally too (e.g. [31] for carbon analysis).

So far, the only study that explicitly apply the IDA technique for energy or carbon emissions in aviation is [2], who conduct the analysis for several European Union countries (and the European Union as a whole) for the period 2001–2008. That analysis was carried out using the Laspeyer type index, and it is not clear why such a choice was made, given the superiority of Divisia type indices and their dominance in recent literature. The time period used is also quite small and misses the growth in aviation demand and thus aviation carbon emissions pre-2001, or the reduction during the recession post-2008.

2.2. Decomposition of aviation fuel demand

The first stage of any decomposition analysis is to select the decomposition components and the identity structure. There is no precise scientific rule governing the choice of the components and often policy relevance, research questions and data availability dictates this choice. A larger number of components generally allow a better understanding of the evolution of fuel demand, however too many components can lead to a difficulty in interpretation. The only previous work [2] on decomposing aviation fuel consumption used three components: total GDP in a country, contribution of aviation to total GDP and energy intensity of aviation industry output (expressed in MJ/€). However, the primary interest of this work is a more disaggregated and detailed understanding of the components and their drivers - especially drivers that can be addressed by policy tools (such as income or price) to influence energy demand. Thus, aviation's fuel consumption has been decomposed into the following five components:

$$Fuel = Population \times Pass.per\ capita \times Miles\ per\ pass. \div Load\ factor \times Efficiency \quad (1)$$

Each of the five components on the right hand side is directly measurable or computable and has a physical meaning. The first three items together generates the traditional measure of demand in aviation: RPM (revenue passenger miles). However, decomposing the revenue passenger miles into three components allows us to understand the impact of each of these three components on demand for passenger air transport. The two right-most components together represent a metric for fuel efficiency: fuel used per revenue passenger mile. This fuel efficiency is a combination of usage efficiency and technical efficiency. Usage efficiency is expressed as load factor: ratio of revenue passenger miles to available seat miles, whereas technical efficiency is expressed as fuel required per available seat mile. The advantage of these five components over a traditional GDP based decomposition [2] is that these have useful meanings in transport literature as well. Especially, the chosen components are able to link travel and energy consumption together, which was missing in a GDP based