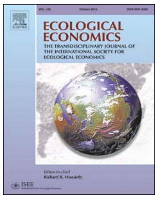
Ecological Economics 146 (2018) 136–147

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon



Analysis

Can Private Vehicle-augmenting Technical Progress Reduce Household and Total Fuel Use?

Gioele Figus[a,b,*], J.Kim Swales[b], Karen Turner[a]

[a] Centre for Energy Policy, International Public Policy Institute, University of Strathclyde, United Kingdom
[b] Fraser of Allander Institute, Department of Economics, University of Strathclyde, United Kingdom

ARTICLE INFO

JEL Codes:
C68
D58
Q43
Q48

Keywords:
Technical progress
Energy efficiency
Private transport
Energy service

ABSTRACT

This paper demonstrates the importance of modelling energy-intensive household services in general, and private transportation in particular, as combinations of energy and other inputs. Initially a partial equilibrium approach is used to analyse private transport consumption as a self-produced commodity formed by household vehicle and fuel use. We particularly focus on the impact of private vehicle-augmenting technical progress in this framework. We show that household fuel use will fall if it is easier to substitute between vehicles and fuel in the household production of private transport services than it is to substitute between private transport and the composite of all other goods in overall household consumption. The analysis is then extended, through Computable General Equilibrium simulation, to investigate the wider implications of similar efficiency improvements when intermediate demand, prices and nominal income are endogenous. The subsequent reduction in the price of private transport service (not observable in market prices) allows the wage measured relative to the CPI to rise whilst the wage relative to the price of foreign goods falls. This simultaneously increases UK international competitiveness, encouraging increased exports and reduced import penetration whilst allowing employment to rise. This provides an additional supply-side stimulus to production, employment and household income.

1. Introduction

This paper has three main aims. The first is to model the use of energy-intensive consumer services in a more appropriate manner than in the existing literature. In particular, we operationalise the approach suggested in Gillingham et al. (2016) by explicitly incorporating both energy and non-energy inputs to both the supply of energy-intensive services and the determination of their price. We take, as an example, the household production of private transport services using inputs of refined fuel and motor vehicles.

The second aim is to analyse the impact of technical change in the household provision of this energy-intensive service, focussing on improvements in vehicle efficiency. To be clear, we have in mind efficiency improvements in the use of these inputs in the act of consumption, not in the production of the vehicles that are consumed.[1] Adapting a general result derived in Holden and Swales (1993) to this particular setting, we identify the condition under which such an efficiency increase reduces the household fuel use in a partial equilibrium analysis. This occurs where the elasticity of substitution between fuel and vehicles in the household production of private transport is greater than the elasticity of substitution between private transport and the composite of all other goods in household consumption.

The third aim is to extend the analysis through simulation using the UK-ENVI Computable General Equilibrium model. These simulations investigate the wider implications of household vehicle-augmenting efficiency improvements where prices, real and nominal incomes are endogenous. This captures the impact on the system-wide change in fuel use, including its use as an intermediate in production. The subsequent reduction in the price of private transport services (not observable in market prices) allows the real wage, measured against the adjusted consumer price index (CPI^{r}), to rise, enabling employment to increase. However, simultaneously the nominal wage, measured against foreign prices, can fall, stimulating UK international competitiveness, increasing exports and reducing import penetration. The increase in household vehicle efficiency thereby provides an additional combined demand- and supply-side stimulus to production, employment and household income. In general, the CGE work supports and extends the partial equilibrium findings.

---

* Corresponding author at: Centre for Energy Policy, International Public Policy Institute, University of Strathclyde, United Kingdom.
E-mail address: gioele.figus@strath.ac.uk (G. Figus).

[1] However, a neutral efficiency increase in the production of only those vehicles destined for household use would have the same impact.

http://dx.doi.org/10.1016/j.ecolecon.2017.10.005
Received 31 May 2017; Received in revised form 29 August 2017; Accepted 2 October 2017

2. Background

Many studies have analysed the impact of energy-saving technical improvements in consumption so as to assess the potential impact on final energy use (see, for example, Chitnis and Sorrell, 2015; Duarte et al., 2016; Druckman et al., 2011; Frondel et al., 2008; Frondel et al., 2012; Lecca et al., 2014; Schwarz and Taylor, 1995; West, 2004).[2] These technical improvements simply mean that the same amount of fuel services can be delivered with less physical fuel (and no change in the consumption of any other commodity). However, households typically use energy as one element in the technology that delivers energy-intensive consumption services (Becker, 1965). Examples of such services include domestic space heating, air-conditioning, lighting and cooking.[3] In the present paper we treat these consumption services as though they are produced by the household using the appropriate inputs. Therefore in this case we assume households produce private transport using inputs of fuel and vehicles.[4]

A small number of papers do attempt to model domestic energy use explicitly in the context of the generation of energy-intensive services (Haas et al., 2008; Hunt and Ryan, 2015; Walker and Wirl, 1993). However, the technology implicitly used in these papers is extremely rudimentary. Output is a linear (fixed-coefficient) function of energy use, so that technical improvements simply reduce that coefficient. Therefore, for example, in Walker and Wirl (1993) private transport is obtained by combining fuel and technology. This technology converts fuel use into miles travelled. In this approach, the price of private transport is calculated as the price of fuel divided by the fuel efficiency of vehicles. The cost of the vehicle, its role in determining the price of private transport and the possible substitution between expenditure on the vehicle and fuel is not discussed.

Wirl (1997) makes the case for explicitly treating household energy use as a derived demand, as one element of the inputs to domestically produced consumer services and Gillingham et al. (2016) similarly argues that producing vehicles using a lighter material would improve fuel efficiency of motoring services and increase the number of miles travelled per unit of fuel. This approach implies that the price of the energy-intensive service depends on the price of energy and all the other inputs that combine to deliver the service. Although it does not discuss specifically how this should be modelled and is mostly interested in the implications of energy efficiency for the calculation of the rebound effect, Gillingham et al. (2016) offers an interesting starting point. In the present paper we operationalise this approach, beginning with a partial equilibrium analysis and them moving to a Computable General Equilibrium simulation.

3. Modelling Household Production of Motoring Services

3.1. The Basic Model

In this model households produce private transport, measured here as miles travelled, m, over a given time period, by combining vehicles, v, and fuel, f. Consumption demand for fuel is therefore a derived demand stemming from the household requirement for private transport. It is important to stress that this is essentially an illustrative example and it has been chosen primarily because of data availability in the general equilibrium modelling.

We use a conventional, well-behaved production function to determine the relationship between the inputs of vehicles and fuel and the miles travelled. This is a standard approach in economics, but we detail some of its key features for two main reasons. First, the notion of a production function is being applied here in an unusual setting. Second, given the way in which the relationship is characterised we adopt particular definitions of improvements in fuel and vehicle efficiency. These may differ from the definitions used in other disciplines.

It is convenient to express the inputs in terms of efficiency units, indicated by an e superscript. The household production function for private transport is therefore given as:

$$m = m(f^e, v^e) \tag{1}$$

There are a number of general features of a well-behaved production function that are of interest here. First it is linear homogeneous and therefore exhibits constant returns to scale. If all inputs are doubled, output is doubled. This implies that the household private-transport technology can be studied by focussing on the unit-isoquant, the set of techniques that could be used to produce one unit, say 100 miles travelled per week. Given our formulation, more expensive vehicles are less fuel intensive.[5] The consumer chooses the combination of vehicles and fuel that maximises the amount of miles travelled, m, given her budget constraint. This involves a trade-off between the increased vehicle cost and the lower fuel cost per mile.

Suppose that the production of private transport becomes more efficient due to technical progress.[6] To investigate the implications we employ a graphical analysis in which refined fuel and motor vehicles are represented in efficiency units. If the household allocates expenditure y to private transport we specify the relation between natural and efficiency units in the household utility maximisation problem as follows:

$$\max \quad m = m(f^e, v^e) \text{ subject to } p_f^n f^n + p_v^n v^n - y \leq 0 \tag{2}$$

where $z^e = \varepsilon_z z^n$ and $p_z^e = \frac{p_z^n}{\varepsilon_z}$ for $z = f, v$.

In Eq. (2), p indicates a price, ε is an efficiency parameter and n is a superscript for natural units. In the base period $\varepsilon_z = 1 \ \forall_z$ so that initially natural and efficiency units are the same for both inputs.[7] To increase the efficiency of a particular input z, we increase the value of ε_z.

From the first order conditions we have that:

$$\frac{\partial m}{\partial z^n} = p_z^n = \frac{\partial m}{\partial z^e}\varepsilon_z \text{ and } \frac{\partial m}{\partial z^e} = p_z^e = \frac{p_z^n}{\varepsilon_z} \tag{3}$$

Expression (3) implies that for any input whose efficiency is increased, technical progress is reflected in a change in its price, expressed in efficiency units. Technical changes can therefore be represented through adjustments in the budget constraint, specified in efficiency units.

The impact of the reduction in the price of vehicles on the consumption of fuel depends on the elasticity of substitution, $\sigma_{v,f}$, between the two inputs:

$$\sigma_{v,f} = \frac{\%\Delta(v^e/f^e)}{\%\Delta(p_f^e/p_v^e)} \tag{4}$$

---

[2] These studies primarily attempt to identify rebound from the endogenous price and redirected expenditure effects of efficiency changes in consumption.

[3] In investigating rebound, Chitnis et al. (2015), Mizobuchi (2008) and Sorrell (2008) relate energy efficiency improvements to linked capital costs but fail to explore the relationship between the physical energy and the capital appliances used in the production of the energy-intensive consumer services.

[4] We assume that the efficiency improvement is limited to household private transport, although it would be likely that these would also apply to at least some transport use as an intermediate in production.

[5] This is a simplification and more expensive vehicles are likely to offer other characteristics such as comfort or security. We plan to investigate this aspect in future research.

[6] There are three primary benchmark cases. In these vehicles and fuel either individually become more efficient or both become equally more efficient. Hybrid cases are where the efficiency of both inputs increases at different rates. If the elasticity of substitution between fuel and vehicles equals unity, so that the function takes a Cobb-Douglas form, there is no difference in the qualitative operation of an increased in efficiency in either of the inputs.

[7] For the aggregate US economy, Hassler et al. (2012) identify the efficiency units of capital and energy used in production using Maximum Likelihood Estimation.