ABATEMENT TECHNOLOGIES AND THEIR SOCIAL COSTS IN A GENERAL EQUILIBRIUM FRAMEWORK: A HYBRID CGE MODEL ENRICHED BY A FLOW-STOCK MODEL AND CONSUMERS CHOICE

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Overview

We present a novel methodology to integrate heterogeneous micro-founded preferences into a computable general equilibrium (CGE) model with high technological detail to quantify the social costs of an endogenous, demand-driven abatement technology (electric vehicles). A hybrid model is developed that directly integrates consumers' decisions on conventional and emission-reducing technologies derived from a discrete choice (DC) model into a fully dynamic CGE model. Demand for vehicles determines the vehicle fleet through an embedded stock-flow vehicle accounting model, affecting the use of fuel and electricity, service and maintenance. Endogenously determined demand for electricity is satisfied by production optimised in a bottom-up electricity model to supply it by least-cost combination of fuels and power technologies. Emissions stemming from vehicle use, electricity generation, and economic production provide an input to quantify external environmental effects associated with the technological change. Impacts on the economy, power sector, and external costs are quantified.

Methods

The model is a fully dynamic CGE model implemented in MCP/GAMS, see Rutherford (1995), and based on the structure of Böhringer and Rutherford (2008). On the production side, we distinguish 21 different cost-competitive sectors with three inputs: labor, capital and intermediate goods. While our model is intentionally kept as simple as possible on the production side, we elaborateon consumption to focus on the endogenous, demand driven nature of electric vehicles as a newtechnology increasingly penetrating the vehicle market starting from low initial levels. In particular, to accountfor the different preference structures constituting vehicle demand, we distinguish nine types ofconsumer households by three levels of education (low, medium, high) and three degrees of urbanisation (rural, suburban, urban). Household consumption decisions are modelled through a standard nested CES function. In the modal split decision branch, each consumer has the possibility to substitute between public (PT) and individual transport (IT). The expenditures on IT include purchases of new vehicles, and expenditures connected to the use of the vehicle stock (fuels incl. taxes, service and maintenance). Consumer choose among four vehicle technologies – conventional (CV), hybrid (HEV), plug-in hybrid (PHEV) and battery electric (BEV) vehicles.

Vehicle purchases by consumers are determined in the integrated dicrete choice model by their preferences, as well as by the purchase price of vehicletechnologies and their technological characteristics (for instance driving range or engine power). Any rise in vehicle purchases that exceeds the number of depreciating vehicles will lead to an increase in the vehicle stock. In this way, the purchase decisions also determine the development of the vehicle stock, with some inertia. In order to depict these developments correctly, we include a detailed vehicle fleet accounting module.

The electricity sector is represented by a bottom-up cost optimisation energy model directly integrated into the CGE model. It is divided into multiple technologies generating electricity, including coal, gas, oil, nuclear power, hydro, wind, biomass, solar photovoltaic, and other (mostly from processed gas such as LPG). All technologies produce electricity subject to different input structures, production costs, and resource constraints. The aggregate supply of electricity delivered by the bottom-up electricity model meets the aggregated demand for electricity in the CGE model. Similarly, demand for energy goods, which is derived from the CGE model equals to their use by electricity generating technologies.

Quantification of externalities covering the impacts on premature mortality, morbidity, building materials, crops, and ecosystems (Ščasný et al., 2015) attributable to both direct and indirect emissions stemming from domestic economic production, imports, fuel use, and electricity production, based on the ExternE’s Impact Pathway Analysis (Bickel and Rainer, 2005), completes our impact assessment to achieve a measure of the total social costs of electromobility as an abatement technology.

Results

Results fo two policy scenarios (MODEST and EM+) are compared to the business-as-usual (BAU) scenario, which is based on a benchmark scenario where the economy follows a steady-state growth path. Scenarios include investments into the charging station infrastructure, shift of household preferences towards greener technologies and tax policy measures incentivizing electromobility (new registration tax and mineral oil tax). The model covers the period 2008 to 2030.

Even though the infrastructure investments have some positive effects on domestic GDP, overall, both scenarios lead to small GDP loss. Since PHEVs and BEVs have a higher average purchase price, the price for the IT bundle rises in the model shifting part of household demand for transport services to PT and reducing household transport demand by a small amount.

In MODEST, the mild invest-ments in charging infrastructure together with the shift in consumer preferences influence thepenetration of EVs (PHEVs and BEVs) only after 2025 when their share in vehicle stock increases steadily to 16 % in 2030, reducing the share of CVs to less than 74 %. The overall change of the vehicle fleet size fluctuates around 1 % over the model horizon. In EM+, The share of EVs on the vehicle fleet increases swiftly after 2020 due to tax rises and more prominent charging infrastructure investments reaching almost 28 % in 2030. In 2030, CVs account for lesst han 60 %. The share of EVs on new registrations reaches almost 50 % in MODEST and even 68 % of all new registrations in EM+. Thenumber of newly registered cars declines over time with respect to BAU due to a shift in consumer preferences away from IT to PT.

The benchmark output growth induces an increase in the vehicle stock and consequently a ris ein fuel use by 16 % in MODEST, and by 9 % in EM+ from 2008 to 2030. For the same reason, aggregate electricity demand grows by 27 % and 29 % over the model horizon in MODEST and EM+, respectively. Despite the fuel used by the rising fleet of HEVs and PHEVs in both scenarios,the diminishing share of CVs in new registrations results in lowering fuel used by CVs by 26 % by 2030 even in MODEST and by 41 % in 2030 in EM+ with respect to BAU. On the other hand, due to increase in demand for electricity to charge batteries in EVs, the electricity supply increases by 2 TWh in EM+ in 2030.

Considering all abatement channels activated in our hybrid model, EM+ reduces total air quality pollutant emissions (abatement in Austria as well as abroad). In each year in the model, the positive effect of fuel use reduction exceeds the negative effect of increased electricity demand on the total net environmental benefits.

Conclusions

The core aim of this paper was to develop a novel simulation tool to estimate the total social costsand benefits of the introduction of electric vehicles as an endogenous, demand-driven abatementtechnology. Extending previous literature, the costing methodology relies on an integrated hybridCGE-DC framework and on an established impact pathway analysis to quantify environmentaland health externalities. We demonstrate that the social costs and benefits of using EVs tomitigate emissions are related to consumer preferences that determine the change in demand forEVs as a reaction to a given policy incentive or preference shifts. At the same time, we considervehicle technology developments and associated purchase price and fuel efficiency changes, aswell as the energy system with a bottom-up focus on the electricity sector, which altogetherdetermine the amount of emissions by individual transportation. Our modelling approach was able to capture even small external effects due to the increased uptake of alternative fuel vehicles, and as such, it can be applied to other national economies with different energy systems relying more on non-renewable resources. Extending our frame-work could provide insight on the extent to which the net social costs of a policy-guided uptakeof electric vehicles differ between countries, different energy systems and sets of policy measures.

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