**Spatial Spillovers in Forecasting Market Diffusion of Electric Mobility**

Reinhold Kosfeld, University of Kassel

According to a study of the Global Carbon Project (GCP), the emissions of environmental damaging greenhouse gas carbon dioxide (CO2) will further rise even though less markedly than in the previous two years. The slowed down growth of a good half per cent occurs against the background of a call of a reduction in greenhouse gas of about 7.5 per cent of the UN Environment Programme (UNEP) to limit the global warming to at most two degrees centigrade. As an interim target the „Green Deal“ of the European Union strives a reduction of greenhouse gas emissions by 65 per cent below the 1990 levels by 2030. Germany has undertaken to decrease emissions in non-TTS sectors by 38 per cent against 2005 until 2030. While a wider diffusion of electromobility is observed during the corona crisis, the suspension of the environmental bonus at the end of 2023 exerted a temporary negative effect on the climate protection goals.

The transition from combustion engines to electromobility is one of the core elements in achieving these objectives. In cooperation with European countries and regions and public private partnerships the European Commission has set up various projects to promote and advance electric mobility. The German climate protection programme 2030 provides a bundle of measures to reduce greenhouse gas emissions by about 40 per cent to below 100 million tons in the transport sector. Especially in the area of individual motorized transport, the expansion of the infrastructure of charging stations and promotion of the transition to electric cars plays an important role.

A high-profile support measure targeting electric mobility is the environmental bonus introduced by the German government in 2016. For three years, buyers were eligible for a subsidy of 4,000 € for purely electric cars and 3,000 € for plug-in hybrid cars. The funding by the Government and the automotive industry in equal parts had been limited to an amount of 1.2 billion €. In 2019 the bonus scheme has been extended until 2025 with higher purchase premiums up to 50 per cent. Additional funding is provided for expanding the charging infrastructure, public procurement programme for the purchase of electric vehicles by public authorities and tax breaks. On the basis of the National Mobility Act (2015) national support measures are complemented by regional strategies at the state and local level. Cities and municipalities, for example, have the right to grant special privileges for electric vehicles on the road such as allocating them special parking spaces, lowering or waiving parking fees and exempting them from certain access restrictions.

In order to schedule the type and extent of support measures and assessing their contribution to achieving the climate targets, projections on the likely development in the different fields of climate protection policy are indispensible. As far as electric mobility is concerned, the progress in market penetration of electric cars is at the center of interest. In 2011, the National Platform for Electric Mobility (NPE) rationalized the government projection of one million electric vehicles on German roads by 2020 (NPE 2011). Based on plausible assumptions at that time, a trend curve („market ramp-up curve“) of the annual evolution of the stock of electric cars has been published. In view of an attained value of 83,175 by the end of 2018, the projection of one million e-cars has been postponed to 2022 (NPE 2018). With a stock of about 2.2 million electric cars, NPE expert forecasts of 2 to 3 million registered electric vehicles by 2025 are met at least at the lower end of the range. With currently about 800,000 installations, the target number of 2.4 to 3.5 million private charging points, is however, clearly missed. While the government plans to have between 7 and 10 million electric vehicles in Germany by 2030, the market growth forecast of the NPE considers an order of magnitude between 4.2 and 7 million realistic (NPE 2018).

While the role of regions for climate change policy is highlighted by a number of institutions and researchers (Gallastegui and Galarraga 2010; Galaragga, Gonzalez-Eguino and Markandya 2011; Gadani, Galarraga, de Murieta 2019; Zeigermann, Kammerer, Böcher, 2023, Kastelein 2024), up to now, regional forecasting models for electric mobility are missing. Space-time models can capture the dynamics of varying degrees of electric motorization across regions that can occur due to different conditions and initiatives. Prospective regional analysis on electric motorization can provide a grounded foundation to fine tune or realign planning measures in the field of electric mobility.

Regional data at the state and district level on registered electric vehicles is now provided by the Federal Motor Transport Authority (Kraftfahrt-Bundesamt) for a time period of ten years. Using additional information of Statistical offices of the Federal States, panel data at the state level can be constructed for the period 2013 – 2025. The short panel poses a challenge from the econometric point of view. As regions may interact with proximate areas in market penetration of electric cars, spatial effects have to be allowed for in the dynamic modeling framework. While in other research fields sometimes long panels are available (see Baltagi and Li 2004, 2006; Angulo and Trivez 2010; Schanne, Wapler and Weyh 2010; Angulo, Mur and Trivez 2014; Mayor and Patuelli 2015), short panel are by no means the exception in regional economics (see Kholodilin, Siliverstovs and Kooths 2008; Baltagi, Bresson and Pirotte 2012; Baltagi, Fingleton and Pirotte 2014; Zhao and Burnett 2014; Baltagi, Fingleton and Pirotte 2019; Billé, Tomelleri and Ravazzolo 2023). Short panels can be used, for example, to avoid structural breaks. In the transition from internal combustion engine vehicles to electric vehicles driven by the climate goals, the time dimension of spatial panels is naturally limited.

To account for spatial and temporal effects in market diffusion of electric mobility, we utilize dynamic spatial panel data models. Regional characteristics (X-variables) are involved as control variables. Additionally, the effect of the environmental bonus on newly registered electric cars (BEV) is tested. In the dynamic spatial framework, effects of temporal and spatial lags of electric vehicles on market penetration can be estimated in the spirit of Arellano and Bond (1991) by a spatialized dynamic generalized method of moments (GMM) approach. In particular Kapoor, Kelejian and Prucha (2007) derived a GMM estimator (KKP estimator) for dynamic spatial panel models with spatially autoregressive disturbances where an endogenous lagge dependent variable has to be instrumented. From a forecasting perspective, temporal and spatial lags of the endogenous variable are preferable (cf. Korniotis 2010). The inclusion of regions‘ own and proximate regions‘ electric motorization levels attained in the previous period as explanatory model variables reflects a partial spatial adjustment mechanism in the diffusion process. The dynamic panel data model can be extended by spatial lags of the exogenous control variables.

Initial estimation results show the importance of autoregressive processes in the dissemination of electric vehicles. Spatial effects are present both at the regional scale of districts and states. However, the inclusion of spatial spillovers is expected to improve the forecasting performance more at the district level than at the state level. The environmental bonus seems to exert a relevant but limited influence on the electric car expansion. A preliminary assessment of out-of-sample forecasts reveals that prediction errors on the basis of dynamic panel data models for electric mobility are well-behaved and increase with growing time horizon. By aggregating regional predictions, regional forecasting errors are partially balanced out in the prediction of the electric vehicle fleet at the national scale.