**Quantifying and Comparing Economy-wide Rebound Effects in Europe**

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## Overview

”Green growth” is nowadays considered the panacea to combine economic development and environmental sustainability. The essence of green growth strategies is to uphold economic development and growth, while simultaneously ensuring social equity and environmental protection. Therefore, economic growth has to be decoupled from emissions and material consumption via technological innovation. Empirically, a decrease in environmental intensity per unit of economic output is indeed observed due to gains in efficiency and technological advances. However, the environmental impact declines only relative to GDP and not absolutely.

Rebound effects challenge the idea of green growth as they address the issue that efficiency gains might paradoxically lead to an increase in resource use. The effect occurs whenever consumption does not decrease as much as what is expected from an engineering perspective. These effects are commonly explained by economic and behavioural responses (e.g. saved income, reduced costs, increased demand) to the use of a more efficient technology (Sorrell & Dimitropoulos, 2008). Rebound effects have been studied empirically on the microeconomic level in great detail (Sorrell, Dimitropoulos & Sommerville, 2009). However, these studies ignore the impact of an increased demand for complementary energy services or the effect of reduced energy prices. Thus, an economy-wide quantification of the rebound effect is essential for evidence-based policy making.

## Methods

The quantification of the economy-wide effect is challenging due to the complexity of differentiating the rebound effects versus effects attributable to consequences of structural change or those occasioned by economic growth (Gillingham, Rapson & Wagner, 2016). Due to that, results of previous studies trying to quantify the effect size vary extremely. Predominantly, the rebound effect is estimated via computable general equilibrium models (Turner, 2013; Koesler, 2013) or partial equilibrium econometric estimates (Orea, Llorca & Filippini, 2015; Saunders, 2013). The former depend on many a priori assumptions and adopted parameter values, and the latter do not include all economic mechanisms that might increase or reduce the rebound effect.

We define energy efficiency improvements as those that save energy due to the adoption of more efficient cost-reducing technology and in consequence define the rebound effect as the resulting behavioral responses of economic agents that cause the actual energy savings to differ from the potential energy savings. We estimate the economy-wide rebound effect by means of a structural vector autoregression (SVAR) with an empirically identified contemporaneous causal structure (Gouriéroux, Monfort & Renne, 2017). This approach is data-driven and relies on a minimum of a priori assumptions. The multivariate time series model allows us to identify the evolution of economic output, energy prices and energy use in response to exogenous energy efficiency shocks and thereby the size of the rebound effect can be approximated.

## Results

We apply the model to a number of European countries and the US to compare the dynamics following energy efficiency shocks. Preliminary results indicate high rebound effects (between 60-100 %) for the analyzed countries after a time period of 6 months.

The results of the SVAR models seem to deliver a great deal of useful structural information, especially considering the simple modelling structure. However, the sparse set of specific time series commonly included in the approach may potentially lead to omitted-variable biases. Unfortunately, the inclusion of additional variables is limited due to degrees-of-freedom constraints. For the European countries this is crucial, as the data available consists of relatively short time series.

We try to overcome these difficulties and condition the data analysis on a richer information set by augmenting the SVAR with factors estimated from a large, monthly frequency, macroeconomic data set. This approach, frequently called factor-augmented vector autoregressive (FAVAR) model, was first proposed by Bernanke et al. (2005). The latent factors are extracted via a principal component analysis from a large panel of time series describing the economy. For this purpose, we use the Main Economic Indicator (MEI) database which is developed and maintained by the OECD. It presents comparative statistics that provide an overview of recent international economic developments for the European countries we analyzed, covering information on the labour market, national accounts, retail sales, production, construction, prices, finance, international trade and balance of payments (OECD, 2018). Augmenting the previously described SVAR model with one or two factors provides a way to check the model robustness and control for the influence of omitted variables.

## Conclusions

The results are congruent with previous research (e.g. van Benthem, 2015; Freire-González, 2017) that hints that the economy-wide rebound effect could be large. In general, the high rebound effects imply that most of the energy efficiency measures and policies trying to encourage cost-reducing energy efficiency innovations do not seem to reduce energy use. This implies that policies to encourage costless energy efficiency innovation are not likely to significantly reduce energy use, which has important implications for climate mitigation policies. Further analysis is warranted in order to better understand the variation in estimated rebound effects across countries.

## References

*Bernanke, B. S., Boivin, J. & Eliasz, P. (2005). Measuring the effects of monetary policy: A factor-augmented vector autoregressive (FAVAR) approach. Quarterly Journal of Economics, 120 (1): 387–422.*

*Gillingham, K., Rapson, D., and Wagner, G. (2016). The Rebound Effect and Energy Efficiency Policy. Review of Environmental Economics and Policy, 10(1): 68–88.*

*Gouriéroux, C., Monfort, A. & Renne, J.-P. (2017). Statistical inference for independent component analysis: Application to structural VAR models. Journal of Econometrics, 196 (1): 111–126.*

*Freire-González, J. (2017). Evidence of direct and indirect rebound effect in households in EU-27 countries. Energy Policy, 102, 270–276.*

*Koesler, S. (2013). Catching the rebound: economy-wide implications of an efficiency shock in the provision of transport services by households. ZEW discussion papers.*

*McCracken, M. and S. Ng (2015) FRED-MD: A Monthly Database for Macroeconomic Research, Federal Reserve Bank of St. Louis Working Paper 2015-012B.*

*Orea, L., Llorca, M. & Filippini, M. (2015). A new approach to measuring the rebound effect associated to energy efficiency improvements: An application to the US residential energy demand. Energy Economics, 49: 599–609.*

*Saunders, H. D. (2013). Historical evidence for energy efficiency rebound in 30 US sectors and a toolkit for rebound analysts. Technological Forecasting and Social Change (7): 1317–1330.*

*Sorrell, S. & Dimitropoulos, J. (2008). The rebound effect: Microeconomic definitions, limitations and extensions. Ecological Economics, 65 (3): 636–649.*

*Sorrell, S., Dimitropoulos, J. & Sommerville, M. (2009). Empirical estimates of the direct rebound effect: A review. Energy Policy, 37 (4): 1356–1371.*

*Turner, K. (2013). ”Rebound” effects from increased energy efficiency: A time to pause and reflect. Energy Journal , 34 (4): 25–42.*

*van Benthem, Arthur A. (2015) Energy Leapfrogging. Journal of the Association of Environmental and Resource Economists 2(1): 93–132.*