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1. Introduction

Carlos de Miguel (Vigo), Massimo Filippini (ETH), Xavier Labandeira (Vigo) and Andreas Löschel (Münster)

2. Climate policies under climate model uncertainty: max-min and min-max regret

Armon Rezai (Vienna) and Frederick van der Ploeg (Oxford)

Temperature responses and optimal climate policies depend crucially on the choice of a particular climate model. To illustrate, the temperature responses to given emission reduction paths implied by the climate modules of the well-known integrated assessments models DICE, FUND and PAGE are described and compared. A dummy temperature module based on the climate denialists' view is added. Using a simple welfare-maximising growth model of the global economy, the sensitivity of the optimal carbon price, renewable energy subsidy and energy transition to each of these climate models is discussed. The paper then derives max-min, max-max and min-max regret policies to deal with this particular form of climate (model) uncertainty and with climate scepticism. The max-min or min-max regret climate policies rely on a non-sceptic view of global warming and lead to a substantial and moderate amount of caution, respectively. The max-max leads to no climate policies in line with the view of climate sceptics.

3. Induced Technological Change and Energy Efficiency Improvements

Jan Witajewski-Baltvilks (FEEM), Elena Verdolini (FEEM) and Massimo Tavoni (FEEM)

We present a theoretical and empirical model which (1) shows that the demand for energy is shifted down by innovations in energy intensive sectors and (2) highlights the drivers of innovative activity in these sectors. The theoretical model and the empirical analysis of patent and energy data indicates that the level of innovative activity is determined by energy expenditure as well as international and inter-temporal spillovers. The solution of the theoretical model along the balanced growth path suggests that in general equilibrium the level of innovative activity depends on the growth rate of energy generation cost. The model predicts also that a level increase in the cost of energy does not alter the long-run energy share of income. Finally, we show that our results can be used to calibrate Integrated Assessment Models to project energy efficiency growth.

4. Free riding and rebates for residential energy efficiency upgrades: A multi-country contingent valuation experiment

Mark Olsthoorn (Grenoble), Joachim Schleich (Grenoble), Xavier Gassmann (Grenoble) and

Corinne Faure (Grenoble)

The cost-effectiveness of energy technology upgrade programs critically depends on free riding. This paper assesses ex ante the effects of free riding on the cost-effectiveness of a rebate program that promotes the adoption of energy-efficient heating systems, relying on contingent valuation choice experiments carried out through identical representative surveys in eight EU Members States. The analysis distinguishes between strong and weak free riders: strong free riders already plan to adopt a new heating system in the next five years; weak free riders decide to purchase once propositioned with an attractive technology package (and therefore do not require a rebate to adopt). The reservation rebates for incentivized adopters (those who decide to adopt because of a rebate) differ substantially across countries. On average, they amount to approximately 40% of the heating system's purchasing price, suggesting generally high opportunity costs for premature upgrades. The reservation rebate and weak free-ridership vary with income, risk and time preferences, and environmental identity. At a rebate level that corresponds to half the purchase price of the offered heating system, the estimated share of free riders exceeded 50% for most countries, with a typically higher share of weak free riders than strong free riders. Specific rebate cost estimates (in €/tCO_2) differ considerably across countries, suggesting that cooperation can yield budgetary benefits.

5. Using Production Incentives to Avoid Emissions Leakage

Dallas Burtraw (RFF), Anthony Paul (RFF), Karen Palmer (RFF) and Hang Yin (RFF)

Policies to reduce greenhouse gas emissions and set the world on a path toward meeting long-run emissions reductions targets are being implemented in a decentralized and heterogeneous fashion both across and within nations. This patchwork approach raises concerns about emissions leakage from uncapped sources that may or may not face other forms of regulation. The potential for such leakage may be particularly keen within the electricity sector where market and political boundaries are not perfectly aligned or when emissions regulations differ by fuel source or by vintage of the electricity generator. In this paper we use simulation modeling to explore options for using emissions allowance value as a production incentive to reduce leakage to uncapped generators due to vintage differentiated regulation within the context of US EPA's Clean Power Plan. We show that updating allocation based on electricity production to covered emitting generators can reduce emissions leakage by 70%.

6. Using Output-based Allocations to Manage Volatility and leakage in Pollution Markets

Guy Meunier (INRA), Juan-Pablo Montero (PUC) and Jean-Pierre Ponssard (CREST)

Output-based allocations (OBAs) are typically used in emission trading systems (ETS) to mitigate leakage in sectors at risk. Recent work has shown they may also be welfare enhancing in markets subject to supply and demand shocks by introducing some flexibility in the total cap, resulting in a carbon price closer to marginal damage. We extend previous work to simultaneously include both leakage and volatility. We study how OBA permits can be implemented under an overall cap that may change with the level of production in contrast with a design that deducts OBA permits from the overall permit allocation as is the current practice in the EU-ETS and California. We show that introducing OBA permits while keeping the

overall cap fixed would only increase price fluctuations and induce severe welfare losses to non-OBA sectors.

7. Elasticities of transport fuels at times of Economic Crisis: An Empirical analysis for Spain

Mohcine Bakhat (UNED), Xavier Labandeira (Vigo and FSR), José M. Labeaga (UNED) and Xiral López-Otero (Vigo)

This paper provides an updated calculation of the price and income responsiveness of Spanish consumers of transport fuels, with an explicit exploration of the effects of the recent economic crisis. We examine separate gasoline and diesel demand models using a set of estimators on a panel of 16 Spanish regions over the period 1999-2015. The paper confirms the persistence of low own-price elasticities both for diesel and gasoline in the short and long runs. It also shows that the crisis of 2008-2013 slightly increased the price elasticity of demand for transport fuels, with a higher effect on diesel than on gasoline. By contrary, the crisis slightly reduced the income elasticity of transport fuel demand. Given the intensity and length of the economic recession in Spain, the results of this paper may be useful to anticipate the effects of domestic public policies that impact transport fuel prices as well as to advance some of the potential consequences of crises elsewhere.

8. The Impact of Energy Prices on Product Innovation: Evidence from the UK Refrigerator Market

François Cohen (Geneve), Matthieu Glachant (Paris) and Magnus Söderberg (Gothenburg)

This paper uses product-level data from the UK refrigerator market to evaluate the impact of electricity prices on product innovation. Our best estimate is that a 10% increase in the electricity price reduces the average energy consumption of commercialized refrigerator models by 2%. A large share of this reduction is explained by a reduction of freezing space. We also show that the exit of energy-inefficient products contributes more to energy reduction than the launch of new energy-efficient models. These findings suggest that innovation– the development of better technologies embodied in new products – does not respond strongly to energy price variations.

9. Explaining electricity demand and the role of energy and investment literacy on end-use efficiency of Swiss households

Julia Blasch (Amsterdam and ETH), Nina Boogen (ETH), Massimo Filippini (ETH and USI) and Nilkanth Kumary (ETH)

This paper estimates the level of transient and persistent efficiency in the use of electricity in Swiss households using the newly developed generalized true random effects model (GTREM). An unbalanced panel dataset of 1,994 Swiss households from 2010 to 2014 collected via a household survey is used to estimate an electricity demand frontier function. We further investigate whether energy and investment literacy have an influence on the household electricity consumption. The results show significant inefficiencies in the use of electricity among Swiss households, both transient (11%) and persistent (22%). We note that the high persistent inefficiency is indicative of structural problems faced by households and

systematic behavioral shortcomings in residential electricity consumption. These results indicate a considerable potential for electricity savings and thus reaching the reduction targets defined by the Swiss federal council as part of the *Energy Strategy 2050*, wherein end-use efficiency improvement is one of the main pillars. The results support a positive role of energy and, in particular, investment literacy in reducing household electricity consumption. Policies targeting an improvement of these attributes could help to improve efficiency in the use of energy within households.

10. Climate Change: Behavioral Responses from Extreme Events and Delayed Damages
Riccardo Ghidoni (Tilburg), Giacomo Calzolari (Bologna) and Marco Casari (Bologna)

Understanding how to sustain cooperation in the climate change global dilemma is crucial to mitigate its harmful consequences. Damages from climate change typically occur after long delays and can take the form of more frequent realizations of extreme and random events. These features generate a decoupling between emissions and their damages, which we study through a laboratory experiment. We find that some decision-makers respond to global emissions, as expected, while others respond to realized damages also when emissions are observable. On balance, the presence of delayed/stochastic consequences did not impair cooperation. However, we observed a worrisome increasing trend of emissions when damages hit with delay.

11. Environmental protection, innovation and price-setting behavior in Spanish manufacturing firms
Carlos de Miguel (Vigo) and Consuelo Pazó (Vigo)

In this paper, we analyze the effects of environmental protection regulation on process and product innovation decisions and their impact on price-setting behavior in Spanish manufacturing firms throughout 2009-2014. To this end, we estimate several discrete choice probit models using firm-level data. Our results show a positive relationship between the existence of environmental regulations (environmental expenditures as a proxy) and innovation. However, the magnitude of the effects and their significance depend on the type of innovation and the size of the firms: environmental regulation positively impacts process innovation only in large firms (more than 200 workers) while it positively impacts product innovation exclusively in small firms (up to 200 workers). Taking into account innovation activities, we additionally explore the behavior of product prices. We obtain that process innovation increases the probability of reducing prices for both small and large firms; while product innovation only raises the likelihood of increasing prices for the former. Finally, we look into the determinants of investment in environmental protection and find a positive impact of environmental regulation.

12. US Climate Policy: A Critical Assessment of Intensity Standards
Christoph Böhringer (Oldenburg), Xaquin Garcia-Muros (BC3), Mikel Gonzalez-Eguino (BC3) and Luis Rey (Sevilla)

Intensity standards have gained substantial momentum as a regulatory instrument in US climate policy.

Based on numerical simulations with a large-scale computable general equilibrium model we show that intensity standards may rather increase than decrease counterproductive carbon leakage. Moreover, standards can lead to considerable welfare losses compared to emission pricing via carbon taxation or an emissions trading system. The tradability of standards across industries is a mechanism that can reduce these negative effects.

13. Deep Transformations of the Energy Sector: A Model of Technology Investment Choice
Florian Landis (ETH) and Sebastian Rausch (ETH)

Economy-energy equilibrium models have emerged as a dominant tool to investigate future pathways taking into account technological aspects, economic behavior, markets, and policy. A challenge for any model is to represent situations that involve large departures from a benchmark mix of energy technologies that would be associated with "deep" transformations of the energy sector (e.g., energy mix with a high penetration of renewables or near-complete decarbonization). This paper proposes a model which differentiates technologies at the level of investments and which is capable of representing large shifts in the market shares of competing technologies that produce a homogeneous energy good (e.g., electricity). We compare the partial equilibrium properties of the proposed technology investment choice model with the standard approach for modeling technology competition based on product differentiation. We also embed both approaches in a numerical general equilibrium multi-sector Ramsey growth framework. We find that the technology investment choice model overcomes some important limitations of the standard approach and is more suited to accommodate large changes in market shares of energy technologies in response to highly stringent energy and climate policy.

14. The Effect of Globalisation on Energy Footprints: Disentangling the Links of Global Value Chains
Oliver Kaltenegger (Münster), Andreas Löschel (Münster) and Frank Pothen (Hannover)

This paper investigates the impact of global value chains on energy footprints. Energy footprints are consumption-based indicators which record the energy used to produce a country's final demand. In order to disentangle key characteristics of global value chains and their effects on the global energy footprint, we employ structural decomposition analyses (SDA). Furthermore, the analysis combines a retrospective with a prospective SDA approach. After an analysis of the global energy footprint for the period between 1995 and 2009, we discuss three scenarios of international integration and their implications for energy footprints for the period from 2009 to 2030. Our results show that the global energy footprint has increased by 29.4% from 1995 to 2009, and the scenarios indicate that it will increase by another 23.5% until 2030. Economic activity is the most important driver for the increase in energy footprints. Rising final demand alone would have increased the global energy footprint by 47.0% between 1995 and 2009. The composition of countries from where consumption and investment goods come adds another 12.6%. Sectoral energy intensity reductions are the most important decelerator of energy use (-27.8%). There is a substantial contribution of changing global value chains on the rise in the global energy footprint (7.5%): Stronger backward linkages in global value chains increased the global energy footprint by 5.5% between 1995 and 2009. Changes in the regional composition of intermediate inputs raised it by another 1.8%. The

shift of the world economy towards East Asia alone would have increased the global energy footprint by 3.0%. The sectoral composition of global value chains, on the other hand, had a negligible effect on energy footprints.