Green is Good—The Impact of Information Nudges on the Selection of Voluntary Green-Power Plans

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Prompted by legislative enthusiasm and regulatory reform, combined with an increase in demand for "green" power, a recent trend has been a move toward greater reliance on renewable energy infrastructure. One sector embodying these changes is residential electricity, where customers have been increasingly offered the option to participate in voluntary green-power programs, where at least part of the power generation is from renewable sources (e.g., wind and solar). Given the increased availability of green plans and the public policy driven expectations of green electricity use, it is important to think about possible mechanisms to increase take-up of such plans. Such insights can be valuable for renewable-energy policy as more stringent emissions standards increase the focus toward green power, as well as for the operational strategies of electric-utility providers in response to renewable electricity generation becoming more cost effective.

Using a choice experiment, this paper examines how providing informational "nudges" regarding the efficiency, cost, and environmental impacts of different power-generating sources impact consumers' stated preferences for selecting voluntary green-power plans. Based on 21,000 plan choices from two different samples totaling over 1,800 respondents, our results indicate that informational nudges significantly impact respondents' choice of plan. Promoting the advantages of the green plan *or* the disadvantages of the "gray" plan increase green plan selection. The magnitudes of these estimated effects are economically significant, as they are roughly equivalent to the estimated change in green plan selection resulting from a change in the monthly premium of $4/month; moreover, the effects persist as respondents progress through the choice sets. We also find that promoting the advantages of the green plan is more effective when the green plan premium is relatively small, while highlighting the drawbacks of the gray plan is more effective when the green plan premium is relatively large.

From a green-power marketing standpoint, utility companies have the ability to advertise different factors associated with their green plans, including information about the potential benefits and merits of the plan. A natural and important question arises as to whether, and the extent to which, different information marketing approaches and/or "eco-labeling" of such plans are effective at stimulating demand. In our study, we directly manipulate the information respondents receive in a randomized manner, which provides some plausible causal inference about the efficacy of information provision in altering plan choices. Our results suggest that information nudges have the potential to be a plausible, economical, and effective mechanism to increase adoption of voluntary green-power plans.

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How Sensitive are Optimal Fully Renewable Power Systems to Technology Cost Uncertainty?

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Many studies have shown the feasibility of fully renewable power systems, in various countries. Yet little is known about the robustness of the results to uncertainty over the weather-year(s) chosen for the optimisation and over the future cost of key technologies. Most studies focus on one or a few weather-years, and sensitivity analyses on technologies costs vary each component separately, keeping the remaining parameters fixed. To overcome these limitations we have developed EOLES, a model optimising investment and dispatch of renewable energy and storage technologies, meeting hourly demand in France for 18 weather-years.

We show that optimising the energy mix on a randomly chosen weather-year may yield a very different mix than the one resulting from an optimisation over the 18 weather-years simultaneously. Then we perform a sensitivity analysis with 315 cost scenarios, by varying simultaneously the cost of PV (from –50% to +50%), wind (–25% to +25%), batteries (–50% to +50%) and power-to-gas (–50% to +50%).

We find that the system levelized cost of electricity, including generation and storage, ranges from €36.5 to €65.5/MWh_e, depending on the cost scenario, with an average value of €50/MWh_e. This average value is based on the assumption that the energy mix is optimized after the arrival of information on technology costs. If instead we assume that all investment must take place before knowing the true cost scenario, the average system-wide cost is only 4% (€2/MWh_e) higher and it is less than 9% higher in 95% of the scenarios. Hence the 'regret' is limited when the optimization is based on cost assumptions which do not materialize.

The main takeout message is thus that even though the technologies involved in a fully renewable power system are very different, they are by and large substitutable. For instance, if batteries are more expensive than expected, the optimal mix includes fewer batteries and less PV, but this is compensated for by additional windpower, with a very limited impact on the system-wide cost.

In addition, we show that the optimal power mix is highly sensitive to the chosen weather-year and to the cost assumptions. Finally, the cost of storage should not be overestimated: in our reference cost scenario, storage (batteries, pumped-hydro and methanation) accounts for only 14.5% of the system cost, vs. 85.5% for electricity generation.

The Impact of the Early Capacity Market Auctions on Wholesale Electricity Prices and Revenues

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The context for this work is the recent growth of subsidised renewable generation with zero marginal cost of production. These have raised concerns that wholesale revenues from the

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sale of energy may become inadequate in ensuring the presence of conventional generation plant on the system when needed during the transition to a zero carbon energy system, and thereby present a threat to secure supplies. To address this risk, many European countries have considered the introduction of 'Capacity Market' auctions, with auctions held years in advance of delivery, to pay generators that make capacity available during delivery years.

A key factor influencing appraised net benefit for the consumer of capacity market introduction links to the extent to which wholesale market costs are reduced by a downward effect on energy prices during peak periods. Although the wholesale price in future may be lower, offsetting part of the cost borne by consumers, it is quite hard to persuade them that the costs are not as high as the apparent cost of the auction,

The size of the sums involved combined with the uncertainty over how and whether practice will play out according to theory therefore emphasise the importance of research in in this area.

The objective of this analysis is to shed light on the impact – in terms of energy price and net cost to the consumer – of the introduction of the 'Early Auction' Capacity Market for winter 2017/18. It uses forward prices before and after the 'surprise' announcement of Capacity Market introduction for delivery year 2017/18 to assess the wholesale price impact using 'difference-in-differences' method.

Results suggest that the announcement of introduction of the Early Auction reduced the spread between peak and base prices by about £0.85/MWh. This may equate to a wholesale revenue reduction of about £170-£210 million. This suggests the net injection of funds for generators – paid for by consumers – resulting from introduction of the Early Auction could be around half of the £380 million paid to generators. In theory this additional payment purchases a higher level of security.

In terms of importance for government policy and more widely, the analysis provides ex post evidence of the transfer of value from wholesale market to Capacity Market, an interaction set out in many Capacity Market ex ante impact assessments. In particular, it suggests theory does to some extent materialise in practice, but that policy-makers may exercise caution in the size of the transfer effect they 'bank'.

Optimal Nuclear Liability Insurance

Alexis Louaas[a] and Pierre Picard[b]

Despite their low probability of occurrence, nuclear catastrophes are very tangible threats. The Fukushima-Daiichi disaster that occurred in March 2011 for instance, led the Japanese authorities to evacuate 150 000 people up to 20 kilometers around the damaged power plant. Solely for the purpose of decontamination, indemnification and decommissioning, the Japanese government now expects a cost of 177 billion euros, three times higher than its 2013 estimate, and some believe that this is still a too conservative assessment. Confronted with such potential damages, States are liable to organize the prevention, protection and indemnification of citizens. Adequate indemnification is achieved by setting liability rules that determine how potential victims are compensated, and who bears the costs of these compensations. Taking as given the prevention and protection behaviors of the States, we focus attention on the design of an optimal liability scheme, from risk sharing perspective. On the one hand, a high level of liability reduces the risk of potentially dramatic and un-insured losses, hence mitigating the adverse consequences of a catastrophe for risk averse citizens. On the other hand, low probability—high severity risks, such as large-scale nuclear accidents, are

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systemic and therefore they cannot be covered through usual insurance mechanisms. Designing a liability scheme for those risks therefore entails the use of innovative risk transfer mechanisms such as cat bonds, in addition to the more traditional issuance of sovereign debt. These instruments may be efficient to handle risks such as nuclear accidents, but their cost is bound to be passed-on, at least partially, to the final energy consumers and/or to taxpayers. In this context, we show that the optimal mechanism provides the same deductible insurance contract to all individuals, whatever their distance from the source of risk. Our model also allows us to characterize the optimal apportionment of the total liability between the State and the nuclear operator, which entails two tiers of liability. A first tier is born by the operator, while a second tier is supported (almost fully) by the State, in accordance with the prescriptions of nuclear international, such as the Paris and Vienna conventions. A numerical calibration of the model allows us to study the optimal liability level for nuclear risk in France, a country that produces over 70 % of its electricity through nuclear power plants. Using Probabilistic Safety Assessments of a nuclear reactor and considering various loss scenarios, we characterize the risk exposure of French citizens. Thanks to a new cat bond market database, as well as a simple modelling of the cost of sovereign debt, we assess the cost of setting up such an optimal liability scheme. Considering the most likely accident scenarios, we find that the French liability law could be significantly improved, by providing higher level of risk coverage.

Seasonal Flexibility in the European Natural Gas Market

Iegor Riepin[a] and Felix Müsgens[b]

Seasonality of gas demand is a central characteristic of the European gas market. European countries balance the seasonal demand swing (i.e. differences in gas consumption across seasons) with a mix of flexibility options such as varying domestic gas production, varying pipeline or liquified natural gas (LNG) imports, and operating of underground gas storage facilities.

The years leading up to 2018 saw a relative abundance of flexible capacity in the gas market. It was reflected by low seasonal gas price spreads on gas hubs and low utilization of regasification terminals. However, this abundance of seasonal flexibility is not permanent. In the future, several factors will put significant downward pressure on the oversupply of flexibility options. They include (i) closures of existing seasonal flexibility options and (ii) decreasing volumes (and associated flexibility) of European domestic gas production. On the other hand, there are factors that work in the opposite direction. They include continuous integration of European gas markets (completion of new transmission and storage infrastructure), as well as optimized utilization of existing assets. Taken together, the future need for seasonal flexibility (and implied scarcity) remains unclear.

The paper analyzes flexibility options covering European seasonal gas demand swing. Previous studies either discussed seasonal flexibility using other methodological approaches or they maintained a narrow focus, mostly on security of supply issues. Furthermore, a systematic understanding of how to measure the importance of a particular supply source contributing to a seasonal demand swing is still lacking.

Hence, we contribute to the ongoing discussion of this topic (i) focusing our analysis on seasonal flexibility and (ii) addressing the problem using a bottom-up market optimization model to simulate the operation of the gas market over a long period. This allows us to explore structural trends in market development, which are driven by changing supply and demand fundamentals.

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Furthermore, we contribute to the methodological question of how to measure the contributions of different flexibility options by proposing a new metric. We also publish the source code and associated data for the entire research project.

Our results provide several insights about the development of gas supply sources' utilization. In particular, we illustrate that (i) European domestic production is facing a significant decrease in production volumes; (ii) LNG has a growing share in the European import mix; (iii) Europe most likely continues to rely heavily on pipeline imports from Russia; (iv) storage utilization at peak demand levels is forecasted to remain high on both the national and European level.

We show that our methodologically enhanced metric—the scaled coefficient of variation—allows for a better understanding of how market dynamics affect seasonal flexibility. The scaled coefficient of variation captures the effects caused by, e.g. the drop of Dutch domestic production volume and flexibility, the closure of Rough storage facility in the UK, and the completion of new transmission infrastructure projects (e.g. Nord Stream 2). We find no evidence that gas storage facilities will be displaced by pipeline or LNG imports from its role as the key seasonal flexibility provider in the long term.

On Bond Returns in a Time of Climate Change

Alessandro Ravina[a]

The impact of a particular market-based instrument, the EU-ETS, upon financial values has already been addressed by the literature; nevertheless, efforts pertain primarily to stocks, leaving the bonds field out of the picture. The objective of this paper is to assess the impact of low-carbon policy—the 2003/87/CE directive which generated EU-ETS— upon the bond returns of European firms.

In order to accomplish this objective, a Fama and French (1993) framework is employed for the first time. Alongside the two bond market factors proposed by Fama and French (1993), *TERM* and *DEF*, an EU-ETS participation factor is added, *GMC*. *GMC* (Green minus Carbon) is meant to mimic the risk factor in bond returns related to low-carbon policy, the 2003/87/CE directive in this case. It has been found that augmenting the Fama and French (1993) model for bonds with the *GMC* factor improves the effectiveness of the model, at least with regard to Europe between 2008 and 2018. This holds true in the 2008–2018 time-span and in the 2008–2012 (Phase II) and 2013–2018 (Phase III) sub-periods.

The sensitivity of bond portfolio returns to the *GMC* factor has been found to be positive in the case of Green portfolios and negative in the case of Carbon portfolios. Most importantly, slopes on *GMC* are statistically highly significant. Ultimately, the average value of *GMC* itself is positive: a positive *GMC* means that in Europe, in the 2008–2018 time-span, there is no carbon premium as some of the literature asserts, but rather a green premium. The presence of a green premium in the European bond market in the years 2008–2018 is a useful asset management insight for financial practitioners. In other words, low-carbon investments can no longer be understood solely from the point of view of taking an ethical stand: nowadays, as the green premium shows, investing in low-carbon firms is a profitable exercise.

Recently, the literature has proposed stress testing, a technique developed for testing the stability of an entity, as an evaluation framework for climate change risks. The carbon stress test put

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forward, which leverages the *GMC* factor, is able to indicate the impact of an EU-ETS average price increase upon bond returns: results show the effects of a plausible but more severe EU-ETS average price on bond portfolios and on individual bonds. The low-carbon transition risk stress test provides useful insights to legislators in terms of the financing of the low-carbon transition, i.e. increasing capital inflows towards green firms and capital outflows from carbon firms. The low-shock scenario, for example, would provide an additional boost to the low-carbon transition, without harming excessively high-carbon firms.

Understanding Hourly Electricity Demand: Implications for Load, Welfare and Emissions

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In this study, using sub-hourly appliance-level data from a representative sample of Swedish households on standard tariffs, we investigate the welfare and emission implications of moving to a mandatory dynamic pricing scheme. Our analysis views the substantial variability in the hourly demand for electricity explicitly as being driven by the demand for the underlying, heterogeneous, demand for services provided by it. A related aspect is the fact that the welfare implications of prices differ across appliances and hours, i.e., that a given price has different welfare implications across different hours. The framework we use explicitly accounts for both aspects by constructing household-specific price indices, exploiting the variation in composition of expenditure within hours. In addition, we explicitly allow for unobserved heterogeneity, whose importance has been stressed in the modern demand estimation literature but has thus far not been accommodated in studies on dynamic electricity pricing

Our contribution to the literature is thus two-fold: first, we provide a consistent framework for understanding the effect of the characteristics of residential electricity demand upon hourly retail pricing, allowing us to evaluate welfare and carbon emission implications of different price profiles. Secondly, the use of more detailed consumption data than hitherto available enables us to use household-specific hourly information to drive the hourly demand model.

Our study uncovers interesting changes in hourly demand patterns consequent to hourly retail pricing: households are likely to reduce peak demand and increase off-peak demand, with a maximum peak reduction of three percent and a maximum off-peak increase of two percent. Overall, changes in load at the daily level are rather small, with only a small amount of substitution across hours (at least on average). A similar finding has been reported in some of the literature using household daily or hourly data. In any case, our findings (of relatively low substitution across hours) call into question (at least for the Swedish context) the commonly made assumption in the literature outlining the benefits of RTP, that households are willing to significantly substitute electricity consumption across hours. Another interesting finding is that welfare, measured by the cost of living (for a constant utility), is reduced for most households, with some heterogeneity (some households experience reduced cost of living). This finding suggests that it is unlikely that many households will voluntarily switch to hourly price contracts. Finally, we find negligible effects on

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emissions, with a very small overall reduction (less than one percent over the day) for both hourly pricing scenarios.

To summarize, our findings suggest that the scope for hourly pricing in Sweden in the short-run is limited. The effects on load are small, most households face a reduction in welfare, and emission effects are negligible.

High Taxes on Cloudy Days: Dynamic State-Induced Price Components in Power Markets

Leonard Göke[a] and Reinhard Madlener[b]

Compliance with European climate policy objectives necessitates a major expansion of variable renewable energy (VRE) sources like wind and solar. The power generation costs of these technologies have dropped substantially in recent years but, due to the fluctuating nature of VRE, its large-scale integration into the power system continues to be a challenge. To achieve a better match between demand and generation of VRE, one measure frequently proposed is that of passing on wholesale price signals to consumers, a policy that is also referred to as “real-time pricing (RTP)”. Taking the idea of RTP one step further, we analyze how charging state-induced price components—which often constitute the major share of electricity prices—at time-variant rates can foster the integration of VRE and thus support decarbonization in the power sector.

Specifically, we focus on an energy-based subsidy scheme for renewables which is financed by a levy on the consumption of electricity, and we analyze how charging this levy proportionally to wholesale prices affects the costs of integrating VRE and of avoiding greenhouse gas (GHG) emissions. For this purpose, we apply a detailed power market model that puts particular emphasis on electricity demand and its price sensitivity. For a quantitative case study, the model is parametrized to represent a hypothetical electricity market situation in Germany with an 85% share of renewables.

Based on our study we find a decrease in integration costs of VRE from price dynamization of up to 4%. Findings on decarbonization, however, are ambiguous. If specific emissions of mid-load power plants exceed those of peak-load plants, we observe an overall increase in CO_2 mitigation costs. If this is not the case, CO_2 mitigation cost reductions of up to 5 €/tCO_2 can be observed. The reason for this is that dynamization in general causes demand to increase and to shift from peak-load towards mid-load power plants. Accordingly, positive impacts of dynamization are found to arise if the gap between marginal costs of mid-load and peak-load power plants widens and also if the own-price elasticity of demand increases. Furthermore, strong distributional effects can be observed: Those consumers who are able to shift their demand to low-price hours profit from doing so at the expense of less flexible consumers.

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Comparing the Risk Spillover from Oil and Gas to Investment Grade and High-yield Bonds through Optimal Copulas

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While a significant share of energy companies' funding comes in the form of bank loans, the recent trend reveals that energy firms have gradually shifted from bank-led financing to capital market-based financing. Deepened political and economic instability following the 2008 global financial crisis could cause such transformation. Although the global bond market is twice as big as the global stock market, investigating the effect of energy prices on the bond markets did not receive considerable attention in the literature. We compare and contrast the risk propagation from energy markets (oil and gas) to investment grade and high-yield bonds. The novelty lies in the comparison of risk spillover as the nature and dynamics of investment grade and high-yield bonds differ. While most of the previous work relate (theoretically and empirically) oil and stock markets, little is known about the relationship between oil and bond markets. Specifically, there is no prior evidence disaggregating the impact of oil price changes on investment grade and high-yield bonds. Employing the novel time-varying optimal copula approach, we find that the bond returns are more sensitive to risk shocks in the oil market compared to gas market. Additionally, we document market state specific asymmetric tail dependence between bond and energy pairs and that the association becomes robust during the oil-crunch period.

Our results have important implications for devising portfolio strategies, setting financial market stabilizing policy and developing overall energy landscape. An extreme downward and upward co-movement between the bond and energy markets indicates that the bond market is not immune to global energy shocks. A time-varying dependence structure also indicates that investors can rotate their investment in the bond market based on their forecasting of states of the energy market. Policymakers should be aware of the global oil price risk when designing bond market schemes. The nature of dependence between these two markets must be incorporated in deriving energy policy because of its potential impact on stability of the bond market. It is also worth mentioning that policymakers should take into account the asymmetric risk spillover between the markets in different conditions, which should improve the policy response to shocks in the markets.

The Household Appliance Stock, Income, and Electricity Demand Elasticity

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Many energy policies specifically target low-income households for assistance. Even though policies, such as the Low Income Home Energy Assistance Program (LIHEAP) and the

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Percentage of Income Payment Plan (PIPP) program, are implemented with concern for low-income households, often such policies fail to consider the impact that income changes have on a household's electricity consumption as well as a household's appliance stock. Given that the residential sector accounts for over one-fifth of the total primary energy consumption in the U.S., understanding the factors that impact consumption can help inform energy policy. The literature on residential electricity consumption provides a variety of income and price elasticity estimates at the household level; however, several studies find that appliance ownership and usage explain more variation in electricity consumption than socio-demographic variables such as price and income

This paper contributes to the literature on electricity demand in three important ways. First, we demonstrate that low income households are more price responsive than high income households. Second, basic summary statistics show that low-income households use less electricity than high-income households, illustrating that the differences in price elasticity estimates are likely due to differences in overall electricity use. Finally, we show that appliance ownership is a useful metric to generate differences in overall kWh electricity reduction through price changes.

Based on various appliance characteristics, we estimate the electricity reduction from a 1% price increase. As price increases, households relying on electricity for cooking, heating, and/or water heating are much more responsive than their non-electric counterparts. A non-electric household responds to a 1% price increase by reducing electricity between 31–37 kWh, on average. In comparison, an all-electric household responds to a 1% price increase by reducing electricity between 142–164 kWh, on average. These all-electric households tend to be lower income households. Using the same analysis, we consider the appliance stock through televisions, AC ownership, and fridges, and observe a greater inelasticity among "high stock" households, which tend to be high-income households. Our results show that the mechanism through which low-income households adapt to price changes differs from high-income households because of heterogeneity in their appliance stock.

The results can aid policymakers concerned about electricity demand, rising electricity rates, and the impact on low-income households. The results can also inform the design of demand response and demand side management programs. Current policies aimed at reducing electricity consumption, such as information- based marketing, home energy audits, energy efficiency rebates, dynamic pricing, and technical consumption feedback are more likely to be utilized by high-income household because of the greater perceived benefits. These programs will cause greater disparities between low- and high-income households and their behavior in the marketplace, unless designed specifically to address these divergences.

Investment Allocation with Capital Constraints. Comparison of Fiscal Regimes

Petter Osmundsen,[a] Kjell Løvås,[b] and Magne Emhjellen[c]

The dramatic fall in oil prices after 2014 has led to more extensive capital rationing in international oil companies, and subsequent fierce competition between resource extraction countries to attract scarce investment. This situation is not adequately addressed by the large general litera-

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ture on international taxation and multinational companies, since it fails to take account of capital rationing in its assumption that companies sanction all projects with a positive net present after-tax value. The paper examines the effect of tax design on international capital allocation when companies ration capital. We analyse capital allocation and government take for four equal oil projects in three different fiscal regimes: the US GoM, UK upstream and Norway offshore. Implications for optimal tax design are discussed.

The analysis examines the portfolio investment decision when applying a formal portfolio model and when using industry metrics. Our analysis seems to confirm textbook warnings against using internal rate of return (IRR) as decision criteria; we find that the IRR metric yields the lowest portfolio net present value (NPV). In our analysis the net present value index method (NPVI) yields the same choices as the portfolio maximization approach. We also find that the breakeven price method (BEP) corresponds to the NPVI method when investments are calculated on an after-tax basis.

The paper also casts light on current petroleum tax systems. Starting off with a mathematical portfolio optimisation model, we find that no Norwegian projects are developed with the tightest capital constraint (USD 40 billion), while three in the UK and two in the USA will be. With a less stringent capital constraint of USD 70 billion, the same two projects in the USA are developed, all four in the UK, and only the large project in Norway.

So, what are the implications of our research for petroleum tax design? Our analysis has some immediate implications for tax levels. We find that strict capital rationing by oil companies leave profitable fields undeveloped. The suboptimal investment level is likely to instigate tax reduction which may develop into tax competition between resource rich countries. On the basis of our analysis, one might in particular question the competitiveness of the Norwegian fiscal regime. This concurs with recent observations; the majors are reducing their presence on the Norwegian shelf. The US authorities, on the other hand, should worry about cream-skimming, since projects perceived to be marginal by capital-rationing oil companies—and which therefore fail to be sanctioned—may be profitable for society.