Economic Impacts of Renewable Energy Promotion in Germany

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ABSTRACT

Over the last decade Germany has boosted renewable energy in power production by means of massive subsidies. The flip side are very high electricity prices which raise concerns that the transition cost towards a renewable energy system will be mainly borne by poor households. In this paper, we combine computable general equilibrium and microsimulation analyses to investigate the economic impacts of Germany's renewable energy promotion. We find that the regressive effects of renewable energy promotion could be attenuated by alternative subsidy financing mechanisms.

Keywords: Renewable energy policy, feed-in tariffs, computable general equilibrium, microsimulation

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1. INTRODUCTION

Germany has been a forerunner in the promotion of renewable energy over the last decade with the outspoken objective to achieve a share of renewable energy in gross power production of 35% by 2020 and of 80% by 2050. The central legislation in Germany's renewable energy policy is the Renewable Energy Sources Act—the so-called Erneuerbare-Energien-Gesetz (EEG; see BMWi, 2014). The core element of the EEG are technology-specific feed-in tariffs (FITs) that guarantee purchases of green power at fixed prices over longer periods. The FITs are combined with the system operators' obligation to provide connection to the electricity grid and to give feed-in priority to electricity from renewable energy sources over electricity from conventional energy sources. The difference between FITs and the (lower) electricity market price is borne by the electricity consumers via the EEG reallocation charge (RAC). For reasons of international competitiveness, electricity-intensive industries are paying a reduced RAC.

Over the last ten years the share of renewable energy in Germany's gross power production has increased from around 11% in 2006 to ca. 32% in 2015—with rapid expansions especially in wind power, photovoltaic, and biomass. The flip side of the massive expansion of renewable power is the drastic increase of subsidy payments. From 2006 to 2014, the total subsidies almost quadrupled from 5.8 to roughly 21.4 billion euros. As a consequence, the EEG surcharge on households' electricity bills meanwhile exceeds 6 euro cent/kWh, which is roughly a quarter of the average household electricity price in Germany (Bundesnetzagentur, 2015). The high cost burden has provoked an intense public debate on the economic impacts of Germany's renewable energy policy. One key issue is whether the subsidy scheme could be changed to achieve the same share of

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renewable power production at lower cost. Another pressing question is how costs are spread across different households. In this paper we provide quantitative evidence to both issues.

We investigate how the overall macroeconomic cost of renewable energy promotion change by switching to uniform as compared to differentiated FITs. Regarding cost incidence, we examine how the abolition of exemptions for electricity-intensive industries or a more fundamental shift towards value-added financing of green subsidies affect the burden across households. Clearly, in a broader economic perspective the efficiency and incidence of policy design are intertwined and potentially subject to trade-offs. For our quantitative assessment we use a numerical framework which combines a computable general equilibrium (CGE) model with a microsimulation (MS) model. The advantage of the CGE–MS combination is that we can analyse the overall macroeconomic cost of policy reforms while at the same time provide a very detailed perspective on households' cost incidence. The integrated modelling framework does not only feature a rich representation of household heterogeneity but accounts for important inter-sectoral linkages and price-dependent market feedbacks across the whole economy. Another special feature of our modelling framework—owing to the requirements of technology-specific policy regulations in the electricity sector—is the bottom-up representation of discrete power generation technologies within the top-down CGE model following the seminal contributions by Böhringer (1998) and Böhringer and Rutherford (2008).

We find that phasing out the exemptions from the RAC for electricity-intensive sectors lower the macroeconomic cost of the EEG. Replacing the RAC by increasing the value-added tax (VAT) uniformly across all consumption goods would lower cost even further. The VAT financing would also attenuate the adverse incidence on the poorest households which are particularly hurt under the current policy design. Making FIT uniform across subsidised renewable technologies neither improves on the total economic adjustment cost nor on the regressive impacts of renewable energy promotion as long as the distortive RAC is in place.

So far, economic analyses of Germany's renewable energy promotion largely focused on the implications of the EEG in the context of EU-wide climate policies. Taking CO_2 emission reduction as the major objective of renewable energy promotion, the EEG has been particularly criticised on the grounds of missing climate effectiveness. As a matter of fact, CO_2 emissions from the power sector as well as other energy-intensive industries in Germany and the rest of the EU are capped through an EU-wide emissions trading system—the so-called EU ETS. Massive subsidies to renewable power production will simply reallocate emissions across these EU ETS sectors while the overall compliance cost to the EU-wide emission cap will rise due to costly CO_2 emission abatement from excessive expansion of renewable energies and too little abatement from other (cheaper) mitigation opportunities such as fuel switching from coal to gas or energy efficiency improvements (Böhringer et al., 2009; Frondel et al., 2010). Beyond inducing excess cost in climate policy, the EEG generates potentially undesired shifts in cost incidence across regions, industries, and technologies. The EEG lowers the demand pressure on the supply of emission certificates, which depresses the price for CO_2 emission allowances. Cross-region and cross-industry carbon 'leakage' then benefits countries that are importers of emission certificates (industries that purchase emission allowances) and hurts regions that are exporters of emission certificates (industries that sell emission allowances); likewise the most CO_2-intensive power technologies such as lignite-fired power plants gain a cost advantage at the expense of non-renewable technologies with lower CO_2 intensity such as gas power plants (Böhringer and Rosendahl, 2010).

A more narrow cost perspective on the EEG—which is also adopted in the current paper—does not question renewable energy targets against the background of overlapping counterproductive regulation with the EU ETS. The major point for discussion is rather the redesign of renewable promotion policy to make compliance with exogenous renewable targets less costly. In the absence of technology-specific market failures such as differential knowledge spillover or adoption externalities, economic efficiency suggests expansion of renewable power in a manner that marginal costs of green production across technologies are equalised. In practice, however, FITs as stipulated in the EEG vary depending on the technology. For instance, electricity generated from solar power gets remunerated with a much higher price than electricity generated from wind power. As a result, too much solar power is being produced and the expansion target for renewable energy is not implemented at least cost. Reform concepts by various expert commissions (Statistisches Bundesamt, 2011; Monopolkommission, 2013) propose to select renewable power plants eligible for funding through a tendering procedure; an alternative mechanism would be to switch to tradable green certificates, i.e., a market-based regulatory system that is already in place in various other EU countries such as Belgium, Sweden, and Poland.

Due to the sharp increase in the RAC over the last decade, the distributional impacts of the EEG have gained more and more attention. According to a survey by the German Network Agency, German private consumers rank third in Europe in terms of electricity prices (Bundesnetzagentur and Bundeskartellamt, 2014). Average electricity prices for a three-person household have risen from 18.01 cent/kWh in 2006 by more than 50% to 29.16 cent/kWh in 2015 with the subsidies to renewable energy as the main cost driver. Since demand for electricity is very inelastic, one would assume that low-income households are burdened to a higher degree than high-income households, yielding regressive effects of the German transition towards renewable energy.[1] The regressive effects on the expenditure side may be further strengthened when accounting who is likely to gain from the renewable energy subsidies on the income side: payments emerging from the EEG's provisions accrue to owners of rooftop photovoltaic installations or shareholders in wind parks—these beneficiaries tend to belong to a more affluent segment of society.

Neuhoff et al. (2013) use household micro data to explore the distributional implications of the EEG. Their analysis confirms that poorer households are more heavily affected and propose three options for alleviation: lump-sum transfers, a reduction of electricity taxes, or additional subsidies to improve energy efficiency. Grösche and Schröder (2013) show that the redistributive effects of the German FIT system persist for alternative inequality indices. Existing literature on the distributional effects of renewable promotion policies focuses largely on the expenditure (spending) side, i.e., how consumers are affected by policy-induced price changes given the way they spend their income. These studies tend to base the incidence analysis on exogenous price changes or use simple input–output models to gauge the direct and indirect impacts of policy intervention. Such analyses remain, however, an incomplete attempt with respect to assessing the full distributional impacts as they (i) suppress behavioural responses of consumers, (ii) assume away the role for price-dependent market interactions, and (iii) do not take into account how (various components of) consumer income may be affected. To our best knowledge of the existing literature, our paper is the first that combines an economy-wide impact assessment with a detailed incidence analysis of the German EEG. A comprehensive and coherent impact assessment is warranted through the combination of computable general equilibrium analysis with microsimulation analysis.

The remainder of this paper is organised as follows. In Section 2, we describe the numerical framework underlying our quantitative analysis. In Section 3, we lay out the policy scenarios. In Section 4, we present and discuss our simulation results. In Section 5, we conclude.

1. The fact that electricity-intensive manufacturing companies have to pay only a reduced EEG RAC so as to remain competitive leads to an even greater cost burden for residual electricity consumers.

2. NUMERICAL FRAMEWORK

To assess the economic impacts of Germany's renewable promotion strategy, we couple a CGE model calibrated to German national input–output (IO) accounts with a MS model of German household income and expenditure. Our combined CGE–MS model system is static and provides insights into the long-run allocative impacts of changes in policy regulations. We do not capture economic adjustment along the transition path which would call for a dynamic (intertemporal) time treatment. In the following, we describe the CGE and MS components of our modelling framework separately and also lay out the specific data requirements.

2.1 Computable general equilibrium (CGE) model

2.1.1 Model summary

Our CGE model features a standard small-open economy representation of the German economy. The CGE approach accommodates counterfactual ex-ante comparisons, assessing the outcomes of changes in policy regulation against a business-as-usual reference without regulatory changes. CGE models are rooted in general equilibrium theory combining assumptions on the optimising behaviour of economic agents with the analysis of equilibrium conditions: producers employ primary factors and intermediate inputs at least cost subject to technological constraints; consumers with given preferences maximise their well-being subject to budget constraints. The CGE approach provides a comprehensive microeconomic representation of price-responsive market interactions and income-expenditure circles. CGE analysis quantifies the changes in key macroeconomic indicators (e.g. gross domestic product) as well as sector-specific economic activities (e.g. output, export, import) as compared to a business-as-usual situation. CGE analysis does not only deliver positive information on policy-induced changes in key economic indicators at the macroeconomic level, at the sector level and at the household level; CGE analysis also allows for normative rankings of alternative policy options to achieve some given policy target such as the promotion of renewable energy.

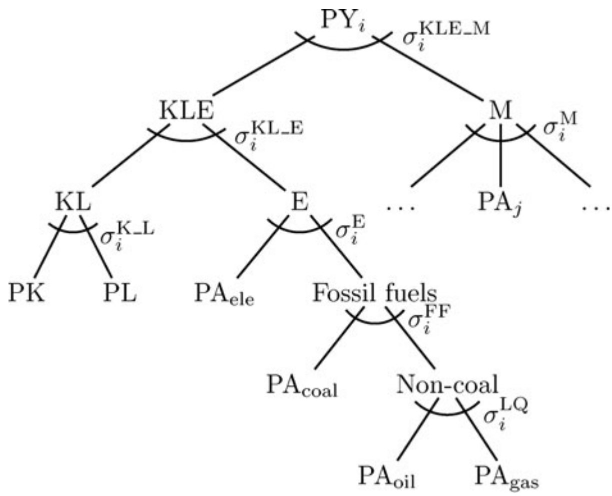
Below we provide a non-technical description of key model features. A detailed algebraic exposition of the generic economic logic is provided in Böhringer et al. (2005).

Production technologies and firm behaviour. Industries produce gross output (Y) using primary inputs labour (L) and capital (K) as well as intermediate inputs of energy (E) and materials (M). Intermediate inputs are composed of a domestically produced variety and an imported variety.

We employ separable nested constant-elasticity-of-substitution (CES) cost functions to characterise price-responsive trade-offs across inputs in production. Figure 1 provides a diagrammatic representation of the nesting structure where we refer to inputs with their input prices.[2] The elasticities of substitution that govern how easy one input can be replaced by another in the production process are denoted with σ. In the bottom-level nest, labour and capital are combined in a value-added (VA) nest. VA is then combined with energy in a CES nest that represents a VA–energy composite. In the top-level nest, a composite of intermediate material inputs trades off against the VA–energy composite at a CES. The composites of energy and material in itself are again CES aggregates of various energy or material inputs. All industries except for fuel resource extraction and electricity generation are characterised by constant-returns-to-scale production functions.

2. For example, the Armington price for intermediate input i is denoted PA_i.

Figure 1: Cost function in production



In the production of fossil fuels, all inputs, except for the sector-specific fossil fuel resource, are aggregated in fixed proportions. This aggregate trades off with the sector-specific fossil fuel resource at a constant elasticity of substitution.

Given the paramount importance of the electricity sector with respect to the promotion of renewable power generation we distinguish discrete generation technologies that produce electricity by combining technology-specific capital with inputs of labour, fuel, and materials. Electricity output from different technologies is treated as a homogeneous good. For each technology, power generation takes place with decreasing returns to scale and responds to changes in electricity prices according to technology-specific supply elasticities (see Rutherford, 2002, for details on the calibration technique). In addition, lower and upper bounds on production capacities can provide explicit limits to the decline and the expansion of technologies. While our activity analysis approach provides policy-relevant details on individual power generation technologies (compared to the conventional aggregate top-down characterisation of production), it must be seen as crude approximation of real-world power production.[3]

Fossil fuel resources and generation capacity to power technologies are treated as specific capital in fixed supply, whereas capital otherwise is assumed to be perfectly mobile across sectors; likewise labour can move freely across sectors. Firms operate in perfectly competitive markets and maximise their profits by selling their products at a price equal to marginal cost.

Preferences and household behaviour. Final consumption demand is determined by a representative agent who maximises welfare subject to a budget constraint with fixed savings which determines investment demand. The representative household receives income from net factor earnings and government transfers. The disposable income is then spent across consumption categories at given prices subject to CES preferences where the different consumption categories are traded off at a constant elasticity of substitution. Each consumption category consists of goods produced by industrial sectors.

3. For instance, our approach cannot reflect that a renewable technology such as solar may be a substitute for gas at low solar production levels, while the two become complements at higher levels of solar power generation.

Government. The government collects taxes to finance transfers and the provision of a public good. The public good is produced with commodities purchased at market prices. Across all policy simulations the level of public good provision is kept constant in order to assure a meaningful cross-comparison analysis without the need to trade off private consumption and government (public) consumption. By default, the equal-yield public good provision is warranted through lump-sum transfers between the government and households.

International trade. In international trade, Germany is treated as small relative to the world market. That is, we assume that changes in German import and export volumes have no effect on its terms of trade.[4] Domestic and foreign products are distinguished by the Armington assumption of product heterogeneity (Armington, 1969). On the import side, domestic goods and imported goods of the same variety are combined to a so-called Armington composite that enters intermediate and final demands. On the export side, goods destined for domestic and international markets are treated as imperfect substitutes, produced subject to a constant elasticity of transformation. We impose a constant trade balance with respect to the rest of the world, accounting for an exogenously specified net trade surplus which is warranted through an endogenous real exchange rate.

2.1.2 Data

As is customary in applied general equilibrium analysis, benchmark quantities and prices—together with exogenous elasticities—are used to calibrate the model. They determine the free parameters of the functional forms that capture production technologies and consumer preferences.

We use the input–output table of the German federal statistical office for the year 2006 as the central data source for model calibration. The choice of 2006 as the base-year for model calibration is motivated by the fact that renewable energy subsidies under the EEG started to become quite substantial from 2006 onward. The first quadrant of the input–output table reports intermediate inputs for each sector. The second quadrant provides information on final demand components: private and public consumption, investment, inventory changes, and exports. Factor payments to labour and capital (combined with profits in the row 'operating surplus') are included in the third quadrant which also reports the inflows of foreign goods and services to each production sector. Output by production sector is linked to consumption by private households in terms of consumption expenditure categories through the Z-matrix (the so-called 'Konsumverflechtungstabelle'). The electricity sector is decomposed into discrete power generation technologies according to technology-specific production shares provided by AG Energiebilanzen e.V. (2016) and input cost shares provided by Wissel et al. (2008).

Elasticities of substitution for the input structure sketched in Figure 1 are chosen in accordance to empirical estimates by Koesler and Schymura (2012) and Steinbuks and Narayanan (2015). The elasticities of substitution in fossil fuel sectors are calibrated to match exogenous estimates of fossil fuel supply elasticities (Graham et al., 1999; Krichene, 2002). The price elasticities of electricity supply by technologies are calibrated to match the changes in power generation shares across technologies following the massive subsidies to renewables over the period between 2006 and 2014 (see scenario *DIFFRACX* in Section 3).

4. Our small-open-economy assumption neglects the potential scope of those German industries that are large global players to pass on a fraction of domestic regulatory cost via higher export prices.

Table 1: Overview of sectors, consumption categories, and power generation technologies

Sectors	
Primary and secondary energy	Crude oil (cru)†, Coal mining (coa)‡, Natural gas (gas)*
	Electricity supply (ele), Coke and mineral oil products (oil)*,
Electricity-intensive and trade-exposed	Food production (fod), Textiles (tex), Leather (lea),
	Timber (tim), Paper (pap), Paper products (ppp),
	Chemicals (chm), Rubber (rub), Plastics (syn),
	Glass (gla), Stoneware (sto),
	Iron and wrought material from iron (cir),
	Non-iron metals and wrought material from such metals (nim),
	Foundry products (fnd), Metal products (mpr),
	Research and development (red),
Remaining industries	Not electricity-intensive and trade-exposed (NEITE),
	Electricity-intensive and not trade-exposed (EINTE),
	Not electricity-intensive and not trade-exposed (NEINTE),
Consumption categories	Food, Housing, Electricity, Heating, Transport,
	Education and leisure, Other non-durable goods and services,
	Durables
Electricity generation technologies	Coal, Nuclear, Gas, Hydro, Solar, Wind, Biomass

† *cru* is electricity-intensive and trade-exposed.
‡ *coa* is grouped with EINTE in the results section.
* *gas* and *oil* are grouped with NEINTE in the results section.

Table 1 provides an overview of sectors, consumption categories and power generation technologies that are explicitly represented in our CGE model. As to sectors, we include all primary (coal, crude oil, gas) and secondary (refined oil, electricity) energy carriers that are present in the German IO table. The distinction of energy carriers is relevant for capturing inter-fuel substitution possibilities in production and consumption. As we want to highlight the effects of RAC exemptions on electricity-intensive and trade-exposed sectors, we refrain from aggregating sectors from the IO table that display above-average electricity-intensity (electricity expenditures per sales revenue) and trade-exposure (value share of exports in total sales). The remainder is aggregated in three composite sectors: electricity-intensive and not trade-exposed (EINTE), not electricity-intensive and trade-exposed (NEITE), not electricity-intensive and not trade-exposed (NEINTE).

As to consumption categories, we follow Nichèle and Robin (1995) for the representation of expenditure groups in the demand system where energy-intensive goods such as electricity, heating, and transport are singled out. Our specification avoids multiple zeros in the reported categories which would require more complex estimation methods. For power technologies, the model distinguishes between four types of renewable power that receive different feed-in tariffs: hydro power, wind power, photovoltaics, and biomass. The model also considers coal, gas, and nuclear as major conventional power generation technologies.

2.2 Microsimulation (MS) model

The core of the microsimulation model is the AIDS established by Deaton and Muellbauer (1980). Data from income and expenditure surveys is used to estimate the AIDS which then drives demand responses of households in the MS model. As is the case for the representative household in the CGE model, each household in the MS model is represented by its factor endowments from which it receives income, its savings decision, and its spending of disposable income across consumption categories.

2.2.1 Model summary

The AIDS assumes an expenditure function $e(\vec{p},u)$ which is homogeneous of degree one in prices.[5] Applying Shephard's lemma yields the following system of budget shares:

$$\theta_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i \log \frac{m}{P}, \tag{1}$$

where θ_i, p_i, m denote expenditure shares for commodities i, commodity prices and total expenditures. P is a price index given by

$$\log P = \alpha_0 + \sum_i \alpha_i \log p_i + \frac{1}{2} \sum_i \sum_j \gamma_{i,j} \log p_i \log p_j, \tag{2}$$

Our econometric estimation is based on data for 128,245 households. In order to capture heterogeneity in consumption behaviour, the parameters γ_{ij} and β_i are allowed to differ across seven household groups (see Blundell et al., 1993). These groups, which account for household size and age of the head of household, are as follows: single $+65$ (above 65 years), single no children, single with children, 2 adults $+65$ no children, 2 adults no children, 2 adults one child, 2 adults two children.

The system is then estimated employing the Seemingly Unrelated Regression (Zellner, 1962). The estimated parameters related to price and income changes are statistical significant (see Table 9 in Appendix 6.1).[6] Changes in commodity prices and income simulated by the CGE model are passed to the AIDS system through the terms p_i and m. The equilibrium prices are used to estimate P as defined in equation (2). These values are then used to compute our welfare metric of equivalent variation (EV) which following Creedy and Sleeman (2006), is derived as follows:

$$\frac{EV}{\bar{m}} = \left(\frac{\bar{P}}{\bar{m}}\right) \exp\left[\prod_i \left(\frac{\bar{p}_i}{p_i}\right)^{\beta_i} \log\left(\frac{m}{P}\right)\right] - 1, \tag{3}$$

where $\bar{p}_i$ and $\bar{m}$ are the reference price levels and total expenditure. Moreover, we use Atkinson's index (Atkinson, 1970) to quantify the trade-off between efficiency and equity (e.g., mean equivalent income and its distribution across households), which is defined as follows:

$$\text{Social Welfare} = \underbrace{\frac{\sum_h (Y_{\text{no-policy},h} + EV_h)\sqrt{\text{hsize}_h}}{\sum_h \text{hsize}_h}}_{\text{Mean equivalent income (MEI)}} \times (1 - A\epsilon), \tag{4}$$

5. The estimated parameters follow the standard constraints for homogeneity $\sum_i \alpha_i = 1$ and $\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = \sum_i \beta_i = 0$.

6. For the econometric estimation, we follow standard practice by approximating the price index P using the Stone index (Deaton and Muellbauer, 1980).

where $Y_{\text{no-policy}}$ is total household expenditure in the no-policy situation (in our case the base-year equilibrium), hsize is household size, and $A\epsilon$ is Atkinson's inequality index at a given level of the inequality aversion parameter ϵ (see e.g. King, 1983).

2.2.2 Data

The AIDS is based on the German income and expenditure survey (the so-called Einkommens- und Verbrauchsstichprobe—EVS), which provides information on expenditure across different commodities, income, and other socioeconomic variables. The survey is carried out every five years. We use the waves 1993, 1998, 2003, 2008 and 2013 for the econometric estimation and only the wave 2008 (closest to 2006, the year the input–output table for the CGE model refers to) for the microsimulation exercise. Thus, the econometric estimation is based on 128 245 observations and the MS model includes 34 506 households. Regarding prices, we use Lewbel's (1989) methodology to obtain household-specific prices by combining the micro data and prices reported by the German Statistical Office. Table 8 in the Appendix provides mean and standard deviation of the variables used in the estimation.

2.3 Linkage of CGE and MS models

The coupling approach follows the decomposition method by Rutherford and Tarr (2008). It uses the CGE model which represents households by one single representative household in order to evaluate impacts of given policies on market prices for consumer goods and production factors. The MS model then takes these prices as given and calculates first household income and then household consumption at the given prices. The representative household in the CGE model is then recalibrated such that it reproduces aggregate consumption according to the MS model at present prices. This creates new imbalances in the markets for the consumption goods. By repeatedly resolving the top-down model and re-evaluating the MS model at new market prices the two models converge towards an overall consistent solution of the integrated CGE–MS model system. Thus, the coupled model produces the same results as would a stand-alone CGE model with all the households now included in the MS model. The combined CGE–MS approach has the advantage that the two parts of the model remain numerically tractable for large numbers of households and thereby also makes the numerical solution process less time-consuming.

In order to achieve a tight link between the CGE model and the MS model, we need the aggregate incomes and consumption demands of households in the MS model to match the corresponding numbers in the CGE model. The survey data used in the MS model comes with statistical weights, which indicate how many of Germany's actual households are represented by one household in the survey. The aggregate consumption and income from the survey data in general, however, does not coincide with national accounts in the Z-matrix. We scale up households' total expenditure from the survey to match total household expenditure according to national accounts. For implementing the AIDS, it is imperative that we leave expenditure shares as they are in the survey. Thus, differences in national household expenditure on a commodity basis must be adjusted for in the CGE model. We do so by shifting the residual demands to government consumption. Thus, for consumption categories where a positive amount of consumption is transferred to the government,[7] overall market demand is less responsive to price changes than in a situation where all of con-

7. Education and leisure, Transport, Other non-durable goods and services, Durables

Table 2: Scenario overview

	differentiated RAC	uniform RAC	VA tax
uniform FIT	*UNIRACX*	*UNIRAC*	*UNIVAT*
differentiated FIT	*DIFFRACX*	*DIFFRAC*	*DIFFVAT*

sumption according to the IO table was subject to household's demand response. For consumption categories, where the government has to supply consumption categories for household demand that is beyond what is supplied according to the IO table,[8] demand is more responsive.

On the income side, we scale capital and labour income in the MS model uniformly across all households. Lacking information about savings from the survey, we distribute saving decisions among households in proportion to their capital income. The residual between expenditure, savings, and factor income is allocated to government transfers.

3. SCENARIOS

The reference scenario for our economic impact assessment is established by the design of Germany's renewable promotion policy as mandated under the EEG: (i) there are FITs that vary substantially across renewable technologies, and (ii) the difference between the electricity market price and the technology-specific FITs is financed by a RAC across electricity consumers with electricity-intensive industries paying only a fraction of the nominal RAC. In our simulation analysis we investigate how the cost magnitude and cost distribution of renewable promotion policy change as we change the EEG prescriptions along two dimensions. The first dimension refers to the cost-effectiveness of renewable subsidies. Instead of differentiated FITs,[9] one could grant uniform subsidies in order to equalise marginal cost of renewable expansion across technologies. The second dimension reflects concerns on distributional impacts of the RAC: to avoid discrimination across electricity consumers, one would at least postulate electricity-intensive sectors to pay the full RAC; alternatively, one might abolish the RAC and switch to a financing of the renewable energy subsidies by increasing value-added taxes.

We distinguish renewable promotion policy scenarios with respect to tariff design [differentiated (labelled DIFF-) versus uniform (labelled UNI-)] and the financing of subsidy payments (RAC with exemptions (labelled -RACX), RAC without exemptions (labelled -RAC), or VA tax (labelled -VAT)). In total, we obtain six scenarios with acronyms as provided in Table 2. Note that scenario *DIFFRACX* most closely reflects the current design of the EEG and represents the reference against which we try to find improvements. Given that Germany cannot unwind its EEG policy in the past, our analysis of alternative policy options is retrospective. However, our insights into the magnitude and distribution of economic adjustment cost for alternative regulatory designs may spur the German discussion on future reforms regarding the future design of FITs and the payments for subsidies.[10]

8. Food, Electricity, Heating, Housing

9. In 2014 the average FITs amounted to roughly 34 euro cents per kWh for photovoltaics, 20 euro cents per kWh for biofuels, and 13 euro cents per kWh for wind power.

10. Complementary analysis would involve an explicit dynamic perspective assessing different unwinding scenarios with FITs and subsidy payments being shifted over time from *DIFFRACX* to the alternative schemes listed in Table 2.

Across all renewable promotion scenarios, we keep the electricity generation from renewable energy sources at the level of scenario *DIFFRACX* to accommodate a coherent cost-effectiveness analysis of alternative policy designs. The economic impacts of renewable promotion are measured against a no-policy scenario which we take as the 2006 base-year equilibrium before the massive penetration of renewable energy into the power system started.

In our scenario analysis, we abstain from any other policy regulations—such as the EU ETS—but focus solely on the impacts of renewable energy promotion.

4. RESULTS

We start the discussion of simulation results with electricity market effects. Changes in electricity prices induced by alternative designs of renewable power promotion constitute a key driver of economic impacts at the sector level, in particular for electricity-intensive industries. We then assess the aggregate macroeconomic cost of policy reforms from the perspective of a representative agent neglecting any details and concerns on cost distribution. Finally, we discuss the incidence of renewable energy promotion policies across different households.

If not mentioned otherwise, all results are reported in percentage change from the no-policy benchmark.

4.1 Electricity market effects

Table 3 shows the impacts across our policy scenarios on electricity generation, electricity prices, and the policy instruments to finance renewable power. Overall power generation changes little across the different scenarios that finance the FIT with a RAC. Only if the FIT is financed by a value-added tax, does electricity generation increase due to a demand-side effect from lower consumer prices. Consumer prices of electricity vary considerably in scenarios in which RAC has exemptions (*UNIRACX* and *DIFFRACX*). The average RAC rate that different electricity consumers pay are given in the fourth section of Table 3. The total volume of RAC payments necessary for reaching the targeted renewable energy sources (RES) generation in electricity generation is given in the fifth section and increases somewhat for scenarios in which the FIT is uniform.[11] Without preferential treatment of electricity-intensive industries (scenarios *DIFFRAC* and *UNIRAC*), all consumer groups face a uniform RAC rate. The RAC is applied to total electricity consumption and finances the difference between FIT payments and the (lower) market value of RES electricity generation. With differentiated RAC rates (scenarios *DIFFRACX* and *UNIRACX*), electricity-intensive industries pay a lower rate.[12] We use base-year statistics to determine for each industry in our dataset what fraction of electricity demand applies for the reduced rate which then yields the effective adjustment factor to the nominal RAC rate.[13] The nominal RAC rate (which applies for household consumption and industries that do not qualify for exemptions) then must increase to make up for lower effective RAC rates of industries with exemptions. The increase in the value-added tax that is necessary for financing the FIT again is higher in scenario *UNIVAT* (1.99 per-

11. Fischer (2010) shows that promotion of renewable energy sources in electricity generation can have ambiguous effects on electricity prices depending on the price elasticities of supply across technologies.

12. The EEG allows firms that use more than 1 GWh of electric power per annum and spend more on electricity than 14% of their value-added to apply for reduced rates. Annual electricity demand beyond 1 GWh is then charged a lower RAC with further reductions for demand beyond 10 GWh and 100 GWh.

13. See Appendix 6.2 for details.

Table 3: Impacts on power generation, prices, and subsidy-financing instruments

	DIFFRACX	*UNIRACX*	*DIFFRAC*	*UNIRAC*	*DIFFVAT*	*UNIVAT*
Producer price of electricity [EUR per MWh]						
Market rate	41.9	41.4	42.2	41.7	50.7	50.6
FIT wind	128.0	214.3	128.0	214.3	133.3	223.8
FIT biomass	201.0	214.3	201.0	214.3	209.3	223.8
FIT PV	336.0	214.3	336.0	214.3	349.9	223.8
Generation [TWh]						
Conventional	498.4	494.8	499.1	495.6	553.7	553.1
Wind	56.5	61.9	56.5	61.9	56.5	61.9
Biomass	42.7	43.8	42.7	43.8	42.7	43.8
PV	35.5	29.1	35.5	29.1	35.5	29.1
Other RES	23.3	23.2	23.3	23.3	24.0	23.9
Consumer price of electricity [EUR per MWh]						
EITE_lowrac†	117.1	117.9	154.3	158.1	106.2	106.1
EITE_medrac†	142.1	145.2	154.3	158.1	106.2	106.1
EITE_highrac†	150.4	154.1	154.3	158.1	106.2	106.1
EINTE	149.7	153.3	154.3	158.1	106.2	106.1
NEITE	156.4	160.6	154.3	158.1	106.2	106.1
NEINTE	155.7	159.9	154.3	158.1	106.2	106.1
Households	172.8	178.5	154.3	158.1	106.2	106.1
Average RAC [EUR per MWh]						
EITE_lowrac†	26.7	28.8	60.7	65.3		
EITE_medrac†	48.7	52.7	60.7	65.3		
EITE_highrac†	57.1	61.8	60.7	65.3		
EINTE	56.7	61.4	60.7	65.3		
NEITE	63.1	68.3	60.7	65.3		
NEINTE	62.7	67.8	60.7	65.3		
Households	79.6	86.1	60.7	65.3		
Renewable subsidy (FIT−Market rate) payments [billion EUR]						
National	22.1	23.3	22.1	23.3	22.08	23.34
VAT rate increase [percentage points]						
National					1.89	1.99

† EITE_lowrac consists of the six electricity-intensive and trade-exposed (EITE) sectors with the lowest effective RAC: tex, pap, gla, sto, cir, and nim. EITE_medrac consists of five EITE sectors with medium effective RAC: fod, tim, chm, rub, and fnd. EITE_highrac consists of the six EITE sectors with the highest effective RAC: cru, lea, ppp, syn, mpr, and red.

centage points) than in scenario *DIFFVAT* (1.89 percentage points) reflecting the higher volume of FIT payments needed under uniform FIT rates (see fifth part of Table 3).

4.2 Industry-specific effects

Exemptions to the RAC have been granted in order to preserve international competitiveness of electricity-intensive industries. Our results indicate that abolishing the exemptions would indeed hurt those industries (see Table 4): They produce less and export less under scenarios *DIFFRAC* and *UNIRAC* than under scenarios *DIFFRACX* and *UNIRACX*. But it is the scenarios that finance the FIT through an increase in value-added taxes that would constitute the most favourable outcome for the electricity-intensive industries. Their output in these scenarios shrinks only by little,

Table 4: Impacts on industries (% change from no-policy).

	DIFFRACX	*UNIRACX*	*DIFFRAC*	*UNIRAC*	*DIFFVAT*	*UNIVAT*
Output at baseline prices						
Electricity	−0.42	−1.10	−0.21	−0.87	10.65	10.54
EITE_lowrac†	−1.17	−1.43	−18.85	−19.90	1.75	1.80
EITE_medrac†	−4.99	−5.34	−7.45	−7.90	0.13	0.16
EITE_highrac†	−2.61	−2.81	−2.79	−3.00	−0.05	−0.05
EINTE	−0.53	−0.53	−1.23	−1.26	−0.32	−0.29
NEITE	−0.37	−0.36	1.87	1.99	−0.48	−0.49
NEINTE	−0.04	−0.03	−0.10	−0.10	−0.02	−0.01
Imports at baseline prices						
Electricity	−56.07	−58.60	−55.03	−57.49	−3.37	−3.97
EITE_lowrac†	−1.45	−1.66	−10.32	−10.82	0.72	0.75
EITE_medrac†	−1.72	−1.81	−3.90	−4.07	−0.14	−0.10
EITE_highrac†	−0.95	−1.15	−1.44	−1.66	1.42	1.38
EINTE	−1.63	−1.68	−2.78	−2.87	−0.66	−0.64
NEITE	−0.14	−0.16	−0.45	−0.48	0.05	0.06
NEINTE	−1.42	−1.54	−2.52	−2.69	0.20	0.23
Exports at baseline prices						
Electricity	71.63	75.57	69.92	73.63	22.34	22.69
EITE_lowrac†	−1.11	−1.42	−28.50	−30.01	2.74	2.82
EITE_medrac†	−8.01	−8.60	−11.37	−12.09	0.44	0.47
EITE_highrac†	−4.56	−4.91	−5.29	−5.68	0.02	0.03
EINTE	−0.95	−0.97	−1.13	−1.15	−0.31	−0.28
NEITE	−0.43	−0.42	2.47	2.63	−0.61	−0.63
NEINTE	0.18	0.19	0.86	0.90	0.09	0.08
Electricity intensity of output						
EITE_lowrac†	−0.06	−0.08	−16.60	−17.63	1.48	1.54
EITE_medrac†	−10.85	−11.67	−13.95	−14.82	1.19	1.23
EITE_highrac†	−10.91	−11.67	−11.60	−12.32	0.96	0.99
EINTE	−28.46	−30.30	−29.65	−31.38	2.48	2.58
NEITE	−14.23	−15.20	−13.77	−14.65	1.15	1.19
NEINTE	−16.35	−17.44	−15.69	−16.67	1.21	1.27

† EITE_lowrac consists of the six electricity-intensive and trade-exposed (EITE) sectors with the lowest effective RAC: tex, pap, gla, sto, cir, and nim. EITE_medrac consists of five EITE sectors with medium effective RAC: fod, tim, chm, rub, and fnd. EITE_highrac consists of the six EITE sectors with the highest effective RAC: cru, lea, ppp, syn, mpr, and red.

if at all, and their exports even increase compared to the no-policy scenario. Sectors react to changes in electricity prices by adjusting their electricity intensity[14] (see fourth part of Table 4). This results in lower electricity intensities in those scenarios that finance the FIT through a RAC. If the FIT is financed through a value-added tax, electricity intensities tend to increase compared to the no-policy case.

Our simulation analysis indicates a drop in industrial production and exports compared to a no-policy baseline. Clearly, we do not claim that this has been happening in the real world between the introduction of the EEG and 2015. By assumption, we keep world prices constant in our simulation analysis, while electricity prices and thus market prices for electricity intensive goods have experienced upward pressure in several places across the EU. Also, our model does not keep

14. Electricity intensity is the electricity consumption per € of output.

Table 5: Impacts on consumer and factor prices (% change from no-policy)

	DIFFRACX	*UNIRACX*	*DIFFRAC*	*UNIRAC*	*DIFFVAT*	*UNIVAT*
Consumption goods						
Food	0.24	0.26	0.18	0.20	1.93	2.04
Education and leisure	0.03	0.02	−0.15	−0.16	1.94	2.05
Electricity	58.48	63.63	41.51	44.97	−0.76	−0.75
Heating	−1.07	−1.11	−1.13	−1.16	1.75	1.87
Housing	−0.24	−0.26	−0.51	−0.54	1.94	2.06
Transport	−0.11	−0.12	−0.31	−0.32	1.94	2.05
Other goods and services	−0.16	−0.17	−0.38	−0.40	1.94	2.05
Durables	0.08	0.09	−0.08	−0.08	1.95	2.06
Income factors						
Wages	−0.68	−0.76	−0.83	−0.91	0.23	0.22
Rents on						
capital	−0.44	−0.45	−0.86	−0.89	−0.15	−0.13
resources	−13.73	−14.40	−16.79	−17.59	−1.75	−1.69
technologies	70.87	81.48	71.66	82.33	105.42	118.25
average	0.59	0.75	0.17	0.30	1.50	1.72

track of which power utilities own which assets and thus is not able to capture the financial distress that particular German power companies have gone through over the last decade.

4.3 Macroeconomic cost

At the macroeconomic level, policy reforms affect earnings through changes in wage and capital rates (reflecting policy-induced shift in the marginal productivity of primary factors) and expenditure through price changes for consumption goods. Table 5 provides an overview of impacts on consumer prices and factor remuneration. If the FIT is financed by a RAC, consumer prices for electricity go up considerably while other prices only change little. If the FIT is financed by a uniform value-added tax, consumer prices increase almost uniformly, while the FIT depresses consumer electricity prices somewhat compared to the no-policy case. On the income side, average rents on capital resources and technology-specific factors increase (especially so for scenarios where the FIT is financed through a VAT) while wages decrease for scenarios with a RAC and increase (but less so) for scenarios that finance the FIT through a value-added tax.

The overall effect on the representative German households in terms of equivalent income (EI)[15] is reported in the fourth column of Table 6. This measure indicates that the German population bears the lowest cost of renewable energy promotion for the case that a uniform FIT is financed through a value-added tax—thus scenario *UNIVAT* turns out to be the most cost-effective design across our policy variants for promoting renewable energy in power production. As expected, abolishing exemptions in the current RAC decreases the macroeconomic cost. But making FIT uniform across promoted technologies surprisingly increases macroeconomic cost as long as tariffs are financed by a RAC. While promoting RES for electricity generation with FIT is most efficient if the tariffs are uniform across technologies, it also entails a decrease in the market rate for electricity generation and an increase in the volume of FIT payments (see first and last rows in Table 3)

15. Equivalent income denotes the amount of money that households would need to afford a scenario's utility level of consumption at prices of the no-policy scenario.

Table 6: Inequality and social welfare changes

	AI†	Δ AI (%)	MEI‡	Δ EI (%)	SW*	Δ SW (%)
DIFFRACX	0.109	1.252	1229.426	−1.784	1095.557	−1.932
UNIRACX	0.109	1.465	1228.601	−1.850	1094.541	−2.023
DIFFRAC	0.109	1.035	1233.392	−1.467	1099.379	−1.590
UNIRAC	0.109	1.231	1232.927	−1.504	1098.705	−1.650
DIFFVAT	0.107	−0.395	1246.326	−0.434	1112.825	−0.386
UNIVAT	0.107	−0.294	1247.050	−0.376	1113.336	−0.341

† Atkinson Index, ‡ Mean equivalent income (€/month), * Social Welfare estimated with expression (4) and the inequality aversion parameter $\epsilon = 1.2$.

compared to the differentiated FIT. Because the FIT is financed using a distortionary mark-up on consumer prices of electricity, this entails additional efficiency cost.

Our macroeconomic cost assessment so far is based on a mean EI metric for the representative household taking a Benthamite perspective which neglects the distribution of cost across household types with different income levels. Modifying mean EI by the Atkinson index yields a social welfare function that values gains in EI by poor households higher than it does gains in EI of rich households depending on the assumed degree of inequality aversion. The first column of Table 6 gives the Atkinson index for an inequality aversion parameter $\epsilon = 1.2$[16] and column six displays the resulting change in social welfare (SW) vis-à-vis the no-policy scenario. Note that social welfare and MEI have similar relative changes (see columns four and six of Table 6) and their ranking among the investigated scenarios is more or less the same. This is due to the fact that the Atkinson index only changes by small amounts between the scenarios that use a RAC for financing the promotion of RES. If the FIT is financed through a VAT, the Atkinson index actually improves against the no-policy scenario, which makes the scenario *UNIVAT* not only superior in overall economic adjustment cost but also most desirable from a distributional perspective.

4.4 Cost incidence across households

Our combined CGE–MS model permits welfare calculation for each household included in the MS model. Thus we can not only evaluate the Atkinson index to account for inequality aversion, but we can analyse how different household types are affected by alternative policy options. The first part of Table 7 displays the estimated mean EV relative to total expenditure across expenditure quartiles. Comparison of the first and fourth quartile indicates that when the FIT is financed through a RAC, poor households suffer disproportionately more. For scenarios that finance the FIT through an increase in VAT, the situation for the poorest quartile actually improves compared to the no-policy scenario, which is in line with the decrease in the Atkinson index discussed before.

In order to assess how different policy scenarios affect vulnerable households with different income sources, the second part of Table 7 shows average EV for households where the household head does not have a job[17] (first row) or is a blue-collar worker (second row). The fact that wage income fares worse than capital and resource rents under the policy scenarios causes employed

16. Creedy and Sleeman (2006) use $\epsilon = 0.2$ and $\epsilon = 1.2$. Our choice of ϵ seems to be a reasonable upper bound for the inequality aversion parameter, even though Pirttilä and Uusitalo (2010) suggest that under certain circumstances, even higher values of ϵ may apply.

17. This includes disabled, retired, and unemployed householders.

Table 7: Policy impacts across quartiles and vulnerable households

	DIFFRACX	*UNIRACX*	*DIFFRAC*	*UNIRAC*	*DIFFVAT*	*UNIVAT*
Equivalent variation estimates in % of total expenditure						
1st quartile	−2.07	−2.19	−1.68	−1.77	0.01	0.04
2nd quartile	−1.98	−2.06	−1.62	−1.68	−0.44	−0.39
3rd quartile	−1.71	−1.75	−1.41	−1.43	−0.64	−0.57
4th quartile	−1.36	−1.37	−1.11	−1.09	−0.43	−0.34
Monthly equivalent variation for vulnerable households (€)						
Jobless	−23.20	−23.96	−18.76	−19.16	15.59	17.52
Blue-collar workers	−43.08	−46.00	−35.21	−37.49	−17.86	−18.46
Tenants	−33.84	−35.99	−27.52	−29.15	−18.05	−18.56
Occupants of old dwellings	−27.95	−26.79	−23.47	−21.73	−21.19	−18.32

working age households to lose the highest share in income. On the expenditure side, tenants and occupants of old dwellings may be more vulnerable to increases in energy cost because the buildings they occupy tend to be less energy efficient (see e.g. Rehdanz, 2007). But the fact that the decrease in electricity prices in scenarios *DIFFVAT* and *UNIVAT* brings less relief to these two types than to other households suggests that income effects are at least as important for them as are expenditure effects.

5. CONCLUSIONS

We couple a MS model that employs the AIDS for representing household demand with a CGE model to investigate the economic impacts of renewable energy promotion policies in Germany.

Our simulation analysis indicates substantial scope for policy reforms to reduce macroeconomic adjustment cost while achieving the same level of renewable power production (as under the current regulation). The phase-out of exemptions from the reallocation charge (RAC) would reduce the economy-wide cost of the German EEG by around 5%. The replacement of the RAC by increased value-added taxes would cut the EEG's cost even by more than two thirds. Making the FIT uniform across promoted technologies, surprisingly, does not yield efficiency gains as long as the RAC is not replaced by a different financing mechanism. This is due to a rise in distortionary RAC rates under such scenarios. From a distributional perspective, replacing the RAC by higher value-added taxes turns out to be attractive as the poorest households benefit. The Atkinson index (a measure of social welfare that accounts for inequality aversion) also points to the VAT-based financing of green subsidies as the most favourable policy design among those investigated in this paper.

Our analysis looks at the macroeconomic cost for Germany of meeting a given target for electricity generation from RES. We cannot judge, however, if it is worthwhile to have a renewable energy target in power generation in the first place. The economic compliance cost to such targets must be balanced against potential economic benefits arising from increased energy security or spillover effects from technology innovation.

6. APPENDIX

6.1 Supplementary statistics

Table 8: Summary statistics, rounded

Individualized consumer prices	**Mean**	**Std. Dev.**
Food	82.900	19.074
Housing	76.579	27.04
Electricity	75.697	19.67
Heating	24.513	10.424
Transport	52.318	17.991
Education	79.516	17.819
Others	68.452	13.281
Durables	50.066	17.188
Household economic variables		
Budget share for food	0.18	0.07
Budget share for housing	0.27	0.09
Budget share for electricity	0.03	0.01
Budget share for heating	0.04	0.03
Budget share for transport	0.06	0.03
Budget share for education	0.08	0.07
Budget share for others	0.25	0.09
Budget share for durables	0.10	0.11
Total expenditure	9627.25	5002.45
Dwelling and households characteristics		
Central heating (dummy)	0.73	0.44
District heating (dummy)	0.17	0.38
Built before 1948 (dummy)	0.18	0.39
Building date 1949–1990 (dummy)	0.53	0.50
Living space in m^2	99.52	40.64
Tenant (dummy)	0.49	0.50
Below 20k inhabitants (dummy)	0.11	0.32
k-100k inhabitants (dummy)	0.20	0.40
Jobless households (dummy)	0.29	0.46
Workers (dummy)	0.13	0.33
Heating degree days	258.89	130.51
Number of observations	128,254	

Table 9: Almost Ideal Demand System as specified in Equation (1), estimated as a seemingly unrelated regression, estimates rounded to 3 digits.

	Dependent variable: budget share for . . .						
	food	housing	electricity	heating	transport	education	durables
log(p_food)	0.028	−0.030	−0.002	−0.009	−0.006	−0.026	0.015
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
log(p_housing)	−0.030	0.031	−0.004	−0.002	−0.012	−0.000	0.006
	(0.001)	(0.002)	(0.000)	(0.001)	(0.001)	(0.002)	(0.001)
log(p_electricity)	−0.002	−0.004	0.015	−0.003	−0.004	−0.006	−0.000
	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)
log(p_heating)	−0.009	−0.002	−0.003	0.010	−0.004	−0.001	0.003
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
log(p_transport)	−0.006	−0.012	−0.004	−0.004	0.025	0.001	−0.007
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
log(p_education)	−0.026	−0.000	−0.006	−0.001	0.001	0.044	−0.017
	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
log(p_durables)	0.015	0.006	−0.000	0.003	−0.007	−0.017	0.003
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.002)
log(M/P)	−0.025	−0.107	−0.009	−0.013	−0.012	0.002	0.113
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Central heating	−0.018	0.009	−0.005	0.009	−0.002	0.010	−0.007
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
District heating	−0.016	0.007	−0.007	0.012	−0.006	0.011	−0.006
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Building: 1948	−0.006	−0.053	0.002	0.006	0.002	−0.017	0.049
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Building:1949-1990	−0.010	−0.037	0.001	0.004	0.001	−0.020	0.044
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Dwelling size	−0.000	0.001	0.000	0.000	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Tenant	0.007	−0.011	−0.002	−0.002	0.000*	0.004	−0.001
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Below 20k inh	−0.013	−0.019	−0.002	−0.004	0.000	0.020	0.006
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
k-100k inh	−0.015	−0.012	−0.002	−0.006	−0.003	0.028	0.002
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Jobless	0.018	0.013	0.003	0.005	−0.010	−0.006	0.000
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Workers	0.018	0.005	0.002	0.003	0.002	−0.009	0.011
HDD	0.000	0.000	0.000	−0.000	−0.000	−0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
constant	0.367	0.652	0.070	0.106	0.136	0.078	−0.405
	(0.002)	(0.003)	(0.001)	(0.001)	(0.001)	(0.003)	(0.004)
R-squared	0.275	0.443	0.222	0.139	0.137	0.171	0.214
N				128,254			

Household specific parameters for prices and expenditure are available upon request.

6.2 Derivation of RAC rates

We assume $sel = 0.2$ for the share of electricity demand getting exemptions from RAC and $sracx = 0.015$ for the share of RAC payed for exempted electricity demand.[18] We compute *rracx* to be

$$rracx := \frac{\text{All breaks from RAC}}{\text{nominal RAC rate} \cdot \text{German electricity demand}} = sel \cdot \left(1 - \frac{sracx}{sel}\,\frac{1-sel}{1-sracx}\right).$$

We define eva_i as sector i's ratio between electricity demand $d_{\mathrm{ele},i}$ and value-added and argue that

$$sre_i = \frac{\mathrm{erf}\left(\frac{eva_i - 0.14}{0.10}\right) \cdot d_{\mathrm{ele},i}}{\sum_j \mathrm{erf}\left(\frac{eva_j - 0.14}{0.10}\right) \cdot d_{\mathrm{ele},j}}$$

is a useful assumption about the share of national RAC exemptions going to sector i. μ_i^{RAC}, the difference between the nominal RAC rate and the average effective RAC rate for sector i, is then computed as

$$\begin{aligned}
\mu_i^{RAC} &:= \frac{\text{Effective RAC rate for sector } i}{\text{Nominal RAC rate}} \\
&= 1 - \frac{\text{Exempt electricity demand of sector } i}{\text{Total electricity demand of sector } i} \\
&= 1 - \frac{sre_i \cdot rracx \cdot \sum_g d_{\mathrm{ele},g}}{d_{\mathrm{ele},i}},
\end{aligned}$$

if index g covers all economic agents that demand electricity in Germany.

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