ECONOMY-WIDE ANALYSIS OF SWEDISH NUCLEAR POWER AND ELECTRICITY CERTIFICATES

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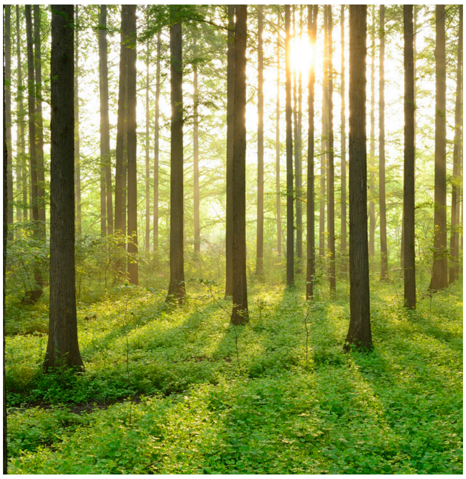

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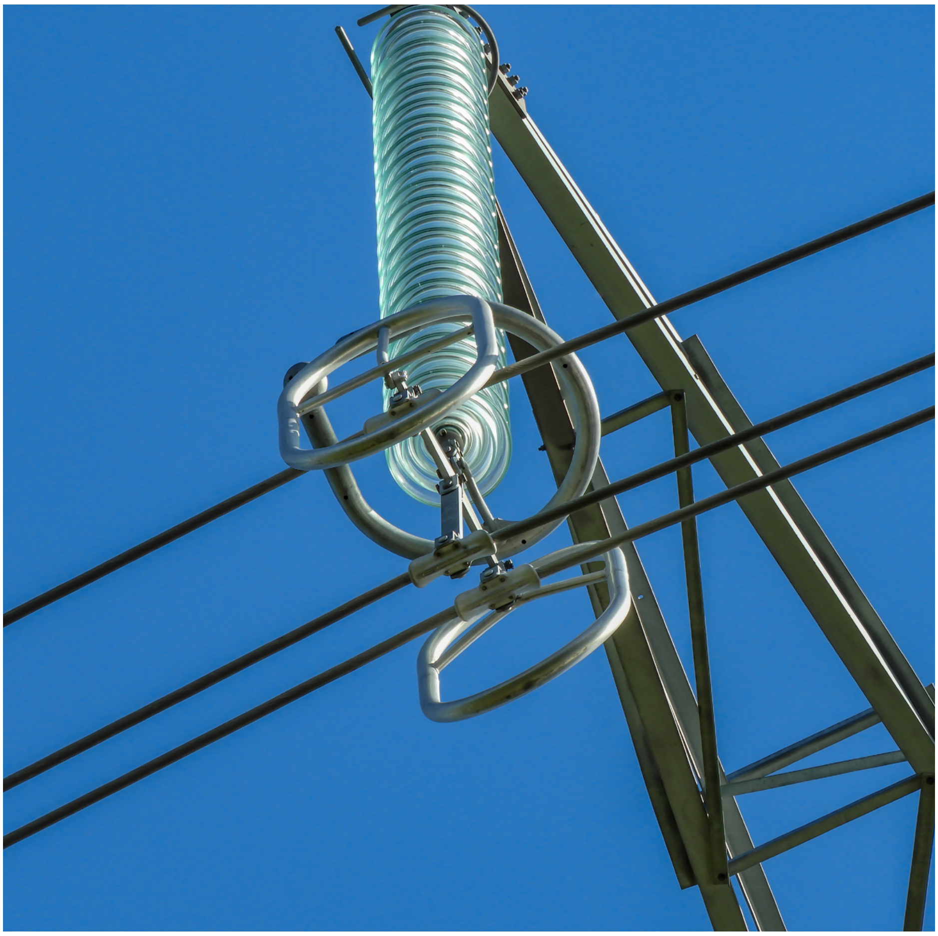

Energiforsk

Economy-wide analysis of Swedish nuclear power and electricity certificates

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Foreword

EFORIS, Function and role of the electricity market in society, is a research program on electricity market design. The program was initiated by Energiforsk and involves dozens of highly reputable Swedish and international researchers.

This project has been carried out by:

- Bengt Kriström, Institutionen för skogsekonomi, Sveriges lantbruksuniversitet, Umeå and CERE, Centre for environmental and resource economics, SLU och Umeå University
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Sammanfattning

Denna rapport beskriver de analyser som gjorts inom projektet ”Energy taxation in Sweden- a general equilibrium assessment with a focus on electricity taxation”. Utgångspunkten är att förändringar på energipolitikens områden ger samhällsekonomiska konsekvenser utöver de vi kan observera på energimarknaderna. Projektet har sålunda syftat till att analysera energipolitik i ett brett samhällsekonomiskt perspektiv. Vi har använt två olika angreppssätt, beräkningsbara allmänjämviktsmodeller (CGE, Computable General Equilibrium models) och en metod som bygger på modern teori kring samhällsekonomisk lönsamhetsbedömning, här kallad CBA (Cost-Benefit Analysis). Utöver att lägga ett helhetsperspektiv på den samhällsekonomiska analysen, har vi även försökt arbeta in fördelningsfrågor.

Vår CGE-modell, som finns i två versioner, använder nationalräkenskapsdata för 140 länder; i en version adderar vi mikrodata över de svenska hushållens konsumtionsmönster för att på så sätt sprida ljus över ”vinnare” och ”förlorare”. Arbetet utgår ifrån databasen GTAP, som samlar nationalräkenskaper för nästan alla länder i världen. Data innehåller handelsflöden, energibärare och koldioxidutsläpp. Med hjälp av den första versionen av modellen, CGE-CERE 1.0, beräknar vi konsekvenser av olika nedskalningar av kärnkraftskapaciteten till 2030. Kostnaden, eller ”prislappen”, är i storleksordningen 1 procent av realinkomst, eller storleksordningen tiotals miljarder per år (hundratals miljarder som nuvärde, beroende på valet av ränta). Vi visar hur vi kan ”fylla igen” kärnkraftstappet med import, besparingar och alternativa energislag. En uppdaterad version av modellen, CGE-CERE 2.0 används till att studera klimatpolitik, där vi inkluderar policyval även för EU och resten av världen inklusive möjligheter för svensk industri att vältra inhemska kostnadsökningar framåt. Kostnaden för svensk klimatpolitik är inte oberoende av den klimatpolitik som förs i andra delar av världen. Den beror också på hur stor del av kostnaden som kan vältras över på världsmarknaden. Klimatpolitikens kostnader fördelas dessutom inte jämnt över hushållen. Den traditionella uppfattningen är att klimatpolitik inte sällan har regressiva effekter. Vi visar att fördelningskonsekvenserna av ett höjt koldioxidpris kan mildras väsentligt via transfereringar. Generellt finner vi att energiintensiv verksamhet påverkas negativt, eftersom priset på el/klimatutsläpp stiger i simuleringarna.

CBA-ansatsen har fokuserat elcertifikaten, där huvudsyftet har varit att göra en beräkning av de samhällsekonomiska kostnaderna och intäkterna av att skrota systemet. Ansatsen är långt mindre data-krävande jämfört med CGE-ansatsen. Intäkter och kostnader är beräknade med hänsyn tagit till att ekonomins <u>alla</u> marknader, i princip, anpassar sig till förändringar av t.ex. energipolitiken; i beräkningarna ingår även de effekter certifikaten kan ha på offentlig budget (via direkta och indirekta moms- och energiskatte-effekter). De centrala ekonomiska konsekvenserna av att ”skrota” systemet är en transferering från certifikatägare till hushåll; överlag finner vi en samhällsekonomisk nettovinst, med traditionella antaganden kring hur ”vinnare” och ”förlorare” hanteras i dessa kalkyler. Metodiken är generell och har även tillämpats utanför projektet för att studera

innovativa sätt att göra den svenska klimatpolitiken mer kostnadseffektiv, genom att bättre nyttja de flexibilitetsmekanismer som finns tillgängliga inom EU-samarbetet.

Vi har kompletterat CGE och CBA ansatserna genom att samla in detaljerade longitudinella data på hushållens konsumtionsmönster, i syfte att skärskåda fördelningseffekter av förändrade elpriser. Överlag bekräftas ett väl känt resultat i litteraturen; energipolitiken tenderar att ha regressiva effekter givet hushållets inkomst. Som nämnts ovan, kan fördelningseffekterna dock mildras via transfereringar.

Projektet har givit spridningseffekter i form av nya forskningssamarbeten, där de verktyg som utvecklats används i nya projekt. CGE-modellen har integrerats i en del av nytt större samarbetsprojekt, som leds av professor Sonja Peterson, Kiel, och professor Chris Boehringer, Oldenburg, inom *Energy Modelling Forum,* Stanford University. (Projekttitel *"EMF round on "Carbon Pricing after Paris"*). Tanken är där att ett antal olika CGE-modeller, utvecklade i olika modellerargrupper, används för att studera ett givet problemområde, i detta fall europeisk klimat- och energipolitik. Europeiska Investeringsbanken (EIB) har givit finansiellt stöd åt ett projekt som syftar till att gifta ihop de två huvudansatserna vi använt. Här utgör vår teoretiska ansats utgångspunkten för projektet "*Improving the measurement of the indirect effects of investment projects: specifying and calibrating EIA methods to maximise compatibility with CBA*", Projektledare är professor Juan Luis Martin, ULPGC, Las Palmas.

VETENSKAPLIGA PUBLIKATIONER

Carlén, B., och B Kriström. 2019. "Are climate policies in the Nordic countries cost-effective". I *Nordic Economic Policy Review 2019: Climate Policies in the Nordics*. Nordic Economic Policy Review, 2019:12. Nordiska Rådet. (använder teori utvecklad i projektet, men ingår också i separat projekt)

Johansson, Per-Olov, och B Kriström. 2019. "Welfare Evaluation of Subsidies to Renewable Energy in General Equilibrium: Theory and Application". *Energy Economics*, juli. https://doi.org/10.1016/j.eneco.2019.06.024.

——— 2019. "Elcertifikat: En gratislunch för kapitalägare?" Briefing Paper 24. Stockholm: Timbro.

——— 2018a. *Cost-Benefit Analysis*. Cambridge Elements 1. Cambridge, UK: Cambridge University Press. (använder teori och empiri från projektet i denna lärobok)

———. 2018b. "Economics and Social Costs of Hydroelectric Power". Working Paper, Umeå: SLU. http://dx.doi.org/10.2139/ssrn.3266466.

———. 2018c. "Partial equilibrium versus general equilibrium of small versus large projects". I *Teaching Cost-Benefit Analysis Ch*. Cheltenham, UK: Edward Elgar. (använder teori utvecklad i projektet)

Johansson, P-O, och G. de Rus. 2018. "Evaluating Large Projects when there are Substitutes: Looking for Possible Shortcuts". Working Paper, CERE och FEDEA, Las Palmas, Spanien: ULPGC. (använder teori utvecklad i projektet men ingår också i annat projekt)

———. 2019. "On the Treatment of Foreigners and Foreign-owned Firms in the Cost-benefit Analysis of Transport Projects." *Journal of Transport Economics and*

Policy, nr Volume 53, Part 3 (juli): 1–13. (använder teori utvecklad I projektet, men ingår också i separat projekt).

Kriström, B. 2016. ”A General Equilibrium Cost-benefit Rule for Green Certificates”. CERE Working Paper. Umeå. http://www.cere.se/se/forskning/working-papers/812-a-general-equilibrium-cost-benefit-rule-for-green-certificates.html.

DEBATT

Johansson, P-O, och B Kriström. 2019. ”Certifikaten har knappast påverkat mängden grön el”. *Ny Teknik*, 30 augusti 2019.

———. ”Elcertifikat – ytterst kostsamt för Sverige”, *Ny Teknik*, 9 juni 2016.

MEDIA

Lundin, K. 2019. ”Forskare sågar systemet – kunderna blir blåsta på över 100 miljarder”. *Dagens Industri*, 27 augusti 2019

Summary

This report contains a description of work carried out within the EFORIS-project "Energy taxation in Sweden- a general equilibrium assessment with a focus on electricity taxation". The focal point is assessment of energy policy in a broader perspective, using general equilibrium, or economy-wide, models. Our point of departure is a study of energy/climate policy in a small open economy with important energy-intensive production sectors. To this end, we have developed and implemented two approaches to measurement, one based on CGE-models (Computable General Equilibrium), the other on general equilibrium cost-benefit analysis; we call this approach CBA in the sequel. In addition, we have gathered longitudinal data on household expenditures, in order to study distributional impacts of changing electricity prices.

The CGE-model, which exists in two versions, is based on a global database that includes detailed sectoral data from almost all countries, coupled with data on trade flows, energy carriers and carbon emissions. Swedish electricity generation is modelled such that we can study a scaling down of nuclear capacity (according to current plans, 4 reactors out of 9 in use will be taken out of production by 2020). We detail how a scaling down of nuclear capacity may affect the Swedish economy using a version of the model called CGE-CERE 1.0. I a second main analysis, using the extended and revised model CGE-CERE 2.0, we study carbon policy, with different assumptions about how EU and other countries pursue their climate policy and the extent to which higher costs in Sweden can be passed on to the world-market.

Overall, the considered scenarios imply higher electricity/carbon prices relative to a business-as-usual scenario. This will tend to hurt energy-intensive industry; phasing out nuclear to 2030 roughly costs the economy about a percentage point of GDP per year. While energy policy tends to be regressive, our results show that this depends importantly on how tax revenues are returned.

We use the CBA approach to study a close down of the certificate system, also general equilibrium in nature, yet it is much less data-intensive. We develop a way to assess the benefits and costs of closing the electricity certificate system. A Monte-Carlo analysis suggests that our main result is robust; it is profitable for society to close the system down, using the conventional way to treat distributional effects in cost-benefit analysis. Indeed, the main part of the economic effects is a transfer from owners of certificates to households; on net there is a welfare gain, even when taking into account emission increases. Our CBA-methodology is general and we have used it elsewhere to shed some light on how to make Swedish climate policy more effective, given flexibility options that exists in EU.

Finally, we have collected longitudinal data on household expenditures for Sweden. This analysis buttress the conventional finding that energy policy tends to be regressive in a partial perspective. Using CGE-CERE 2.0 we show that there exist transfer policies that can alleviate distributional effects.

The project has led to a number of knock-on effects. Our CGE-model is now part of a working group in EMF (*Energy Modelling Forum*, Stanford University) This

project is led by Sonja Peterson, Kiel and Chris Boehringer, Oldenburg (awarded by the Germany ministry, project title: "*EMF round on "Carbon Pricing after Paris*"). The European Investment Bank (EIB) has supported a project which aims at tying together CBA and CGE methodology (EIBURS call: "*Improving the measurement of the indirect effects of investment projects: specifying and calibrating EIA methods to maximise compatibility with CBA*"). Project leader: professor Juan Luis Martin, ULPGC, Las Palmas.

SCIENTIFIC OUTPUTS

Carlén, B., and B Kriström. 2019. ”Are climate policies in the Nordic countries cost-effective”. I *Nordic Economic Policy Review 2019: Climate Policies in the Nordics*. Nordic Economic Policy Review, 2019:12. Nordiska Rådet. (tools developed in the project, but is also a part of another project.)

Johansson, Per-Olov, and B Kriström. 2019. ”Welfare Evaluation of Subsidies to Renewable Energy in General Equilibrium: Theory and Application”. *Energy Economics*, july. https://doi.org/10.1016/j.eneco.2019.06.024.

——— 2019. ”Elcertifikat: En gratislunch för kapitalägare?” Briefing Paper 24. Stockholm: Timbro.

——— 2018a. *Cost-Benefit Analysis*. Cambridge Elements 1. Cambridge, UK: Cambridge University Press. (uses tools developed in the project for this textbook)

———. 2018b. ”Economics and Social Costs of Hydroelectric Power”. Working Paper, Umeå: SLU. http://dx.doi.org/10.2139/ssrn.3266466.

———. 2018c. ”Partial equilibrium versus general equilibrium of small versus large projects”. I *Teaching Cost-Benefit Analysis Ch*. Cheltenham, UK: Edward Elgar. (uses tools developed in the project)

Johansson, P-O, och G. de Rus. 2018. ”Evaluating Large Projects when there are Substitutes: Looking for Possible Shortcuts”. Working Paper, CERE and FEDEA, Las Palmas, Spain: ULPGC. (tools developed in the project, but is a part of another project)

———. 2019. ”On the Treatment of Foreigners and Foreign-owned Firms in the Cost-benefit Analysis of Transport Projects.” *Journal of Transport Economics and Policy*, nr Volume 53, Part 3 (juli): 1–13. (tools developed in the project, but is a part of another project).

Kriström, B. 2016. ”A General Equilibrium Cost-benefit Rule for Green Certificates”. CERE Working Paper. Umeå. http://www.cere.se/se/forskning/working-papers/812-a-general-equilibrium-cost-benefit-rule-for-green-certificates.html.

OP-EDS (IN SWEDISH)

Johansson, P-O, och B Kriström. 2019. ”Certifikaten har knappast påverkat mängden grön el”. *Ny Teknik*, 30 augusti 2019.

———. ”Elcertifikat – ytterst kostsamt för Sverige”, *Ny Teknik*, 9 juni 2016.

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1 Computable General Equilibrium Modelling

1.1 ECONOMIC IMPACTS OF SWEDISH NUCLEAR PHASE-OUT USING CGE-CERE 1.0.

Nuclear power has been controversial in Sweden for long. Less than a decade after the first nuclear power plant has been built in 1972 a national referendum in 1980 pledged for the phase-out of nuclear power by 2010. The referendum had been triggered by safety concerns after the nuclear accident of Three Mile Island at Harrisburg in 1979. Severe concerns on large-scale accidents revived with the nuclear catastrophes in Chernobyl 1987 and Fukushima 2011. Furthermore, proponents of a nuclear phase-out stress that the problem of how and where to store nuclear waste is still unsolved. On the other hand, there are arguments in favor of nuclear power: First, nuclear power is perceived as a low-cost energy source which helps to foster the competitiveness of Swedish energy-intensive and export-oriented industries. Second, nuclear power contributes to energy security by cutting import demand for fossil fuels. And third, nuclear power seems to be attractive from a climate policy perspective helping Sweden to achieve ambitious CO2 emission reduction commitments. These arguments may explain why nuclear phase-out plans are yet to materialize with nuclear power contributing on average more than 40% to domestic electricity generation over the last 10 years.

The dismantling of Swedish nuclear power has already begun, propelled by decreasing electricity prices, new safety regulations, environmental concerns and the fact that the reactors are reaching the end of their economic life. Barsebäck's reactors B1 (1975-1999) and B2 (1975-2005) were the first in a string of reactor closings. Oskarshamn reactors O1 (1970- 2017) and O2 (1975-2015) have now ceased operation, following a decision in 2015; the remaining reactor O3 is planned to be in operation until 2045. Ringhals was destined to close R1 and R2 2019-2020, cutting short the initial plan to run them to 2025. According to current plans, R3 and R4 continue to operate until the beginning of the 2040s. The remaining plant, Forsmark, will, it seems, keep its 3 reactors running. Exactly how all this will pan out is difficult to say; for example, R2 was to be closed beginning of 2019 (according to a Board decision in 2015) but is still running. The uncertainty about the future of Sweden's nuclear capacity is one reason why we consider different scenarios regarding Sweden's nuclear capacity in 2030.

Several papers have studied the economic impacts of nuclear phase-out policies in Sweden (Bergman 1981, Mill 1990, Nordhaus 1995, Andersson and Hådén 1997, and Nyström and Wene 1999). All these – rather dated – studies investigate the effects of a nuclear phase-out until 2010 and largely conclude that the economic cost of a phase-out can be substantial. However, key propositions of past studies may no longer hold: First, the Swedish electricity system (along with other energy-intensive industries) forms part of the EU emission trading system since 2005 which accommodates imports of CO2 emission rights at rather low cost to compensate for emissions from increased use of gas and coal power. Second, the massive global expansion of renewable power from wind and solar over the last 10 years led to a strong cost decrease for these environmentally compatible power supply options. Third, the Swedish power system became more and more integrated into the Nordic electricity market raising prospects for potentially low-cost electricity imports.

1.1.1 Analysis

Against this background, we investigate the economic impacts of a nuclear phase-out in Sweden by 2030 which constitutes a reasonable time horizon for such a massive re-organization of the Swedish electricity system. Our analysis thereby takes into account most recent EU climate policy legislation up to 2030 as well as the cost developments in renewable power technologies and the Nordic electricity market integration. Given the intense debate on the competitiveness impacts of a nuclear phase-out for Sweden's energy-intensive and export-oriented industries we go beyond a narrow energy-system analysis and adopt a more comprehensive view using a multi-sector open-economy computable general equilibrium (CGE) model of the Swedish economy. To capture the technological options for power generation appropriately, we integrate a bottom-up activity analysis representation with discrete power technologies (see Böhringer and Rutherford 2008 for the fundamental concept). The latter replaces the composite representation of electricity generation based on smooth constant-elasticity-of-substitution production functions in standard CGE models.

We find that the phase-out of nuclear power in 2030 causes non-negligible direct economic cost predicated on the business-as-usual assumption that nuclear power constitutes a low-cost large-scale power generation technology. The direct cost simply reflect the loss in producer surplus from a partial equilibrium perspective as more expensive supply technologies kick in to substitute for nuclear. We furthermore show that the general equilibrium cost of a phase-out can be substantially higher depending on the cost-potential of renewable energy supply, political restrictions on the expansion of fossil-fuel based power generation, and last but not least, on the scope of additional electricity imports from the Nordic electricity market. For pessimistic settings along these three dimensions, electricity prices in Sweden will increase markedly which will not only hurt energy-intensive and export-oriented industries but result in costly electricity demand adjustment and an economy-wide reallocation of production factors to less efficient uses. At the other extreme, a phase-out can be achieved at rather low cost if nuclear power is taken as less profitable in the business-as-usual and there are low-cost substitutes in alternative power generation or electricity imports. In the latter case, electricity prices may hardly increase and negative indirect spillover effects to the rest of the economy remain quite limited – the general equilibrium cost then come close to the partial equilibrium calculus of the producer surplus loss. Beyond the Swedish case, our insights on the drivers of direct and indirect cost induced by technology and energy market regulations contribute to the broader debate on the potential economic impacts of a nuclear phase-out in other countries.

1.1.2 Background data

To understand the role of nuclear in Sweden relative to the rest of EU, it is useful to portray the generation mix and how electricity prices in Sweden for industrial users line up against the rest of Europe, see Figure 1 and Figure 2. Figure 3 shows how the Swedish electricity generation mix has changed over time.

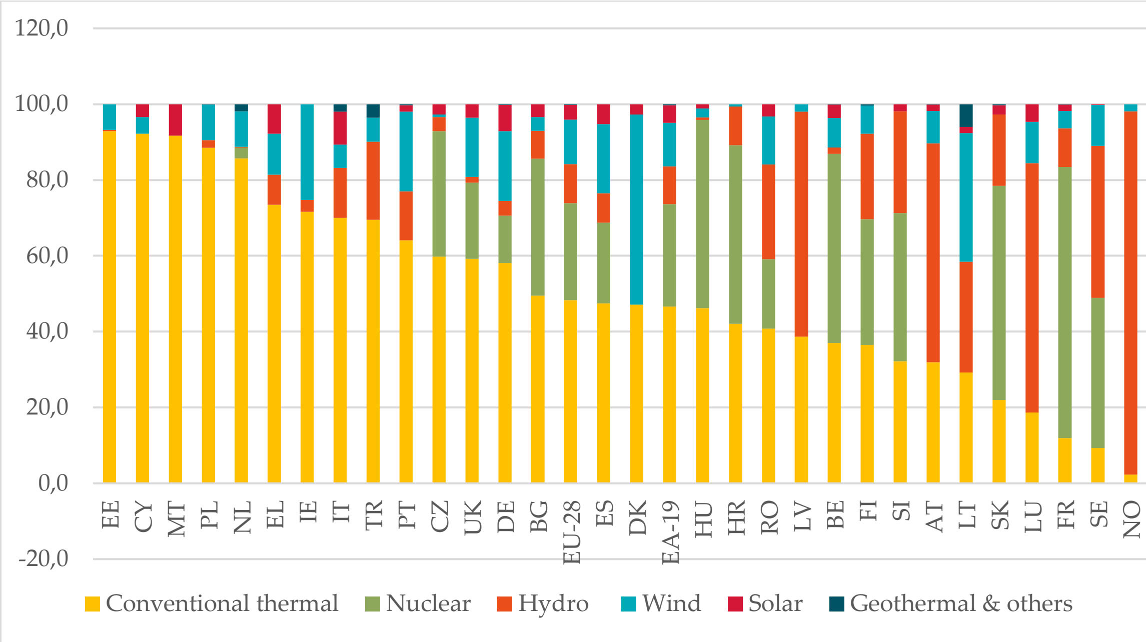


Figure 1 Electricity generation mix 2017. Source: Eurostat (online data code: nrg_105m)

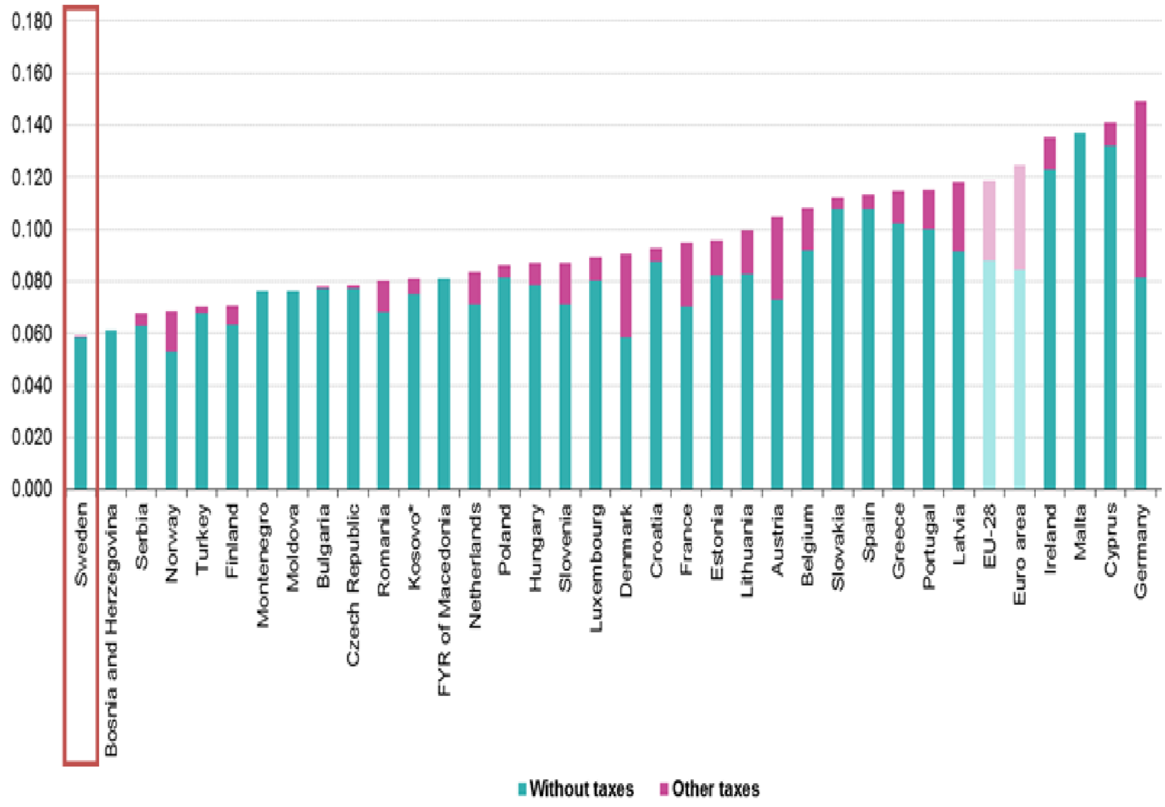


Figure 2 Industrial electricity prices in the EU 2015. Source: Eurostat (online data code: nrg_pc_205)

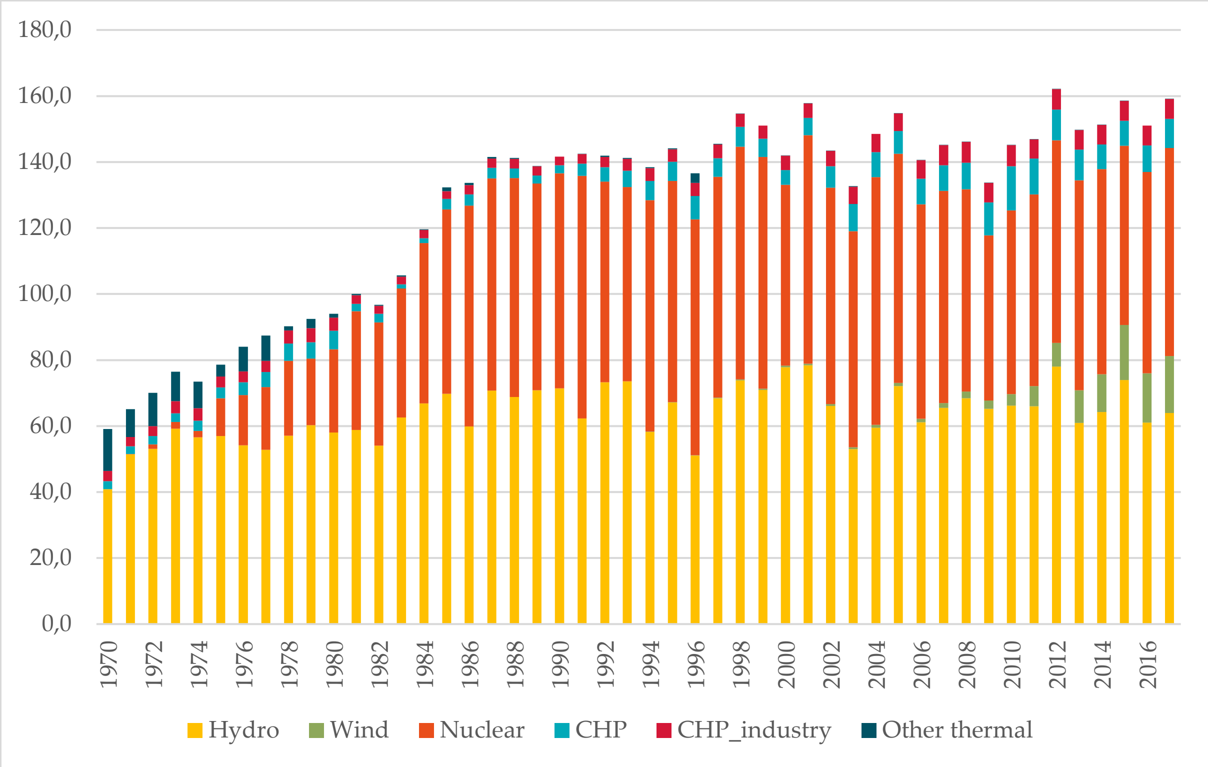


Figure 3 The development of Swedish electricity generation 1970 – 2018. Source: https://www.ekonomifakta.se/Fakta/Energi/Energibalans-i-Sverige/Elproduktion/

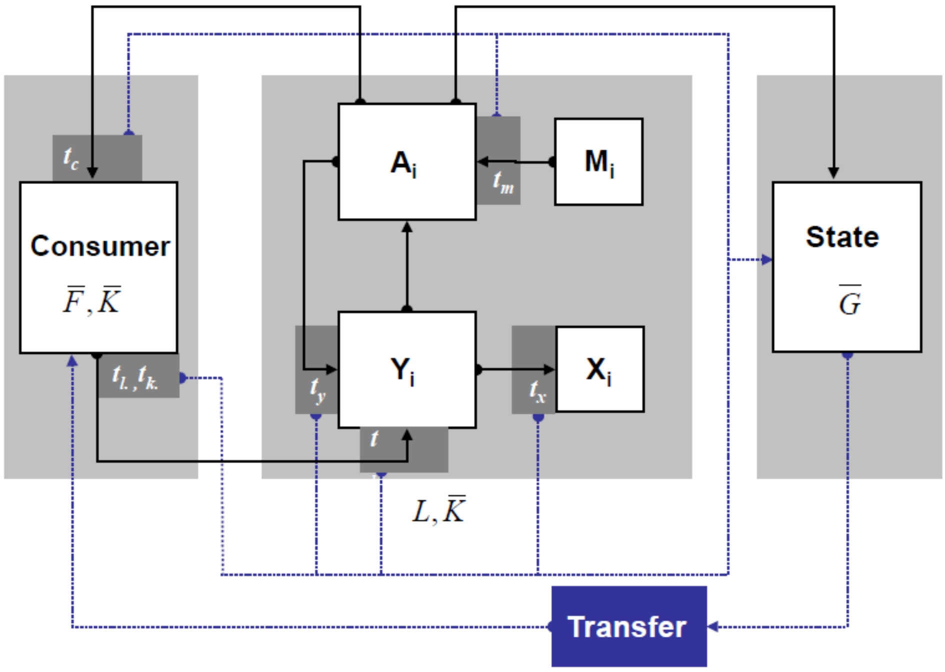
Figure 1-3 shows that Sweden lies at the top-end in terms of penetration of non-fossil fueled electricity generation in an EU perspective, enjoys relatively low electricity prices in a system where wind is playing an increasingly important role.

1.1.3 CGE-CERE 1.0

The core CGE model adopts a canonical general equilibrium representation of economic activities combining assumptions on the optimizing behavior of economic agents with the analysis of equilibrium conditions. Decisions about the allocation of resources are decentralized, and the representation of behavior by consumers and firms in the model follows the standard microeconomic optimization framework: producers employ primary factors and intermediate inputs at least cost subject to technological constraints; consumers with given preferences maximize their well-being subject to budget constraints. Three classes of conditions characterize the economic equilibrium for a standard Arrow-Debreu general equilibrium model: zero-profit conditions for constant-returns-to-scale producers, market-clearance conditions for all goods (incl. factors), and income-balance conditions for the representative agent in each region. An equilibrium allocation determines the three fundamental classes of economic variables: zero-profit conditions pin down the activity levels of production, market-clearance conditions determine prices for goods (incl. factors), and income-balance conditions identify the income levels of the representative agents

CGE models employ data from input-output tables together with elasticities that govern how responsive supply and demand are to price changes. They are used to compute ex-ante the outcome of a policy change relative to an observed state of affair. The quintessence of CGE analysis is the combination of general equilibrium theory with economic data to derive quantitative insights into the efficiency effects and distributional implications of policy. Key features of the economy-wide framework for the Swedish economy include (i) the comprehensive coverage of production activities including inter-industry linkages as represented by input-output data, (ii) the inclusion of final consumption activities (private, government, and investment), (iii) the representation of existing government policies (e.g., taxes and transfers), (iv) a consistent representation of origination and spending of household and national income, and (v) supplementary accounting of physical energy and carbon flows.

Figure 4 depicts the generic structure of the generic small-open economy model. A representative consumer receives income from labor (L) and capital (K) where the latter also include sector-specific resources. Labor and non-sector specific capital are intersectorally mobile across sectors of the domestic economy. Primary factors are used together with intermediate inputs for production Yi of commodity i. Production is specified through constant elasticity of substitution (CES) cost functions with several levels to capture substitution possibilities in domestic production sectors between capital, labor, energy and non-energy intermediate inputs.



F	=	Time endowment	Y_i	=	Production of good *i*
L	=	Labor supply	X_i	=	Export of good *i*
K	=	Capital	A_i	=	Armington production of good *i*
G	=	Government demand	M_i	=	Import of good *i*

Figure 4 Generic structure of CERE-CGE 1.0

On the output side, production is split between domestic market supply and exports Xi. As an equivalent to the CES function on the input side, a constant elasticity of transformation (CET) function describes the trade-off between domestic market supply and exports given relative prices (the production possibility frontier).. Final consumption demand is determined by the representative household who maximizes utility subject to a budget constraint with fixed investment (savings) demand. The household’s total income consists of net factor income and transfers. As in production, substitution possibilities in consumption are described by a CES (expenditure) function which captures price-responsive trade-offs between consumption goods. All goods used on the domestic market in intermediate and final demand correspond to a CES composite Ai of the domestically produced variety and a CES import aggregate Mi of the same variety from abroad, the so-called Armington good. Domestic production either enters the formation of the Armington good or is exported to satisfy the import demand from abroad.

Foreign closure of the model is warranted through a balance-of-payment (BOP) constraint which demands that the total value of exports equals the total value of imports accounting for an initial BOP deficit or surplus given by the base year statistics. The BOP constraint thereby determines the real exchange rate which indicates the endogenous value of the domestic currency vis-à-vis the foreign currency. In the small-open economy setting, Sweden is treated as small relative to the world market. That is, we assume that changes in Swedish import and export volumes have no effect on international prices, i.e. the terms of trade: Export and import prices in foreign currency are considered as exogenous. The government raises revenue from import tariffs tm, export duties tx, taxes ty on outputs and inputs to production, sales taxes tc to final consumers, as well as taxes on labor tl and capital tk. Tax revenues finance a fixed level of public good provision. Lump-sum transfers between the representative household and the government balance the government budget.

CO2 emissions in production and consumption are linked in fixed proportions to the use of fossil fuels with CO2 coefficients differentiated by the specific carbon content of fuels. CO2 emission abatement can take place via fuel switching (interfuel substitution) or energy savings (either by fuel-non-fuel substitution or a scale reduction of production and final demand activities). CO2 abatement requirements are introduced by means of an additional constraint that holds CO2 emissions to a specified limit. Scarcity rents on CO2 emission constraints emerging as revenues from emission taxes or auctioned emission allowances accrue to the government. Emissions of CO2 are tracked by emission coefficients associated with the use of fossil fuels. Emission abatement can take place by fuel switching (inter-fuel substitution) or fuel savings (either by fuel-non-fuel substitution or by a scale reduction of production and final demand activities).

The core model readily tracks key economic indicators at the macroeconomic level such as GDP, final consumption, or factor remuneration as well as economic indicators at the sectoral level such as output, export, or import. However, it neither accounts for international spillover effects via endogenous terms of trade nor for household heterogeneity. We cover this in CERE-CGE 2.0, reported below.

1.1.4 Base data for simulations

We use GTAP 2011 base year data and include EU climate and energy package 2030 (ETS and non-ETS targets). This entails national input-output tables for 140 countries and 57 sectors. We aggregate to Sweden, rest of EU (including Norway) and rest of the world (RoW). In addition, the data includes energy flows and carbon emissions. We use energy carriers: crude oil (cru), coal (col), gas (gas), refined oil (oil), electricity (ele). We delignate Energy- and energy intensive sectors (EITE) based on electricity use and trade intensity. We make Business-as-usual (BaU) projections on GDP, fuel prices, energy demands, and CO2 pricing. In this environment we then scale down Sweden’s nuclear capacity. In particular, we model electricity generation bottom-up, so that we have enough detail for our simulations. Various elasticities are needed, these are picked from the extant literature (e.g. interfuel substitution elasticities and fuel supply elasticities).

There are a number of caveats that should be noted, beyond the assumptions we need to make about functional forms. First, there is uncertainty of exogenous BaU projections, since we cannot know the economic developments in the future with any certainty. The model does not include any transitional adjustment cost, nor can it handle risk. At this level of abstraction, we cannot handle value of lost load or any other intermittent effects on the electricity system. The key economic impacts will in the abstract work via endowments (how factor earnings are affected), technology (how easily production can adjust to nuclear policy variation) and preferences (how will changing prices affect consumer behavior).

1.1.5 The scenarios

We consider several phase-out scenarios to 2030, i.e. gradual reduction of nuclear power from business-as-usual (BaU) and use the following short-hand for the scaling factor (0 meaning that capacity is reduced to 0), 75% (NUC75), 50% (NUC50), 25% (NUC25), 0% (NUC0). In addition, we constrain hydro, gas and coal use in Sweden to the BaU values (the reduction of nuclear power cannot be met by expanding hydro, although efficiency improvements are available). Instead, we consider possibilities of expanding renewable power by varying the supply elasticity (0.5; 1; 2). There is a switch in the model, so that fossile fuel-based generation replacement options can be turned on or turned off.

1.1.6 Simulation results

Figure 5 displays results for the electricity generation sector.

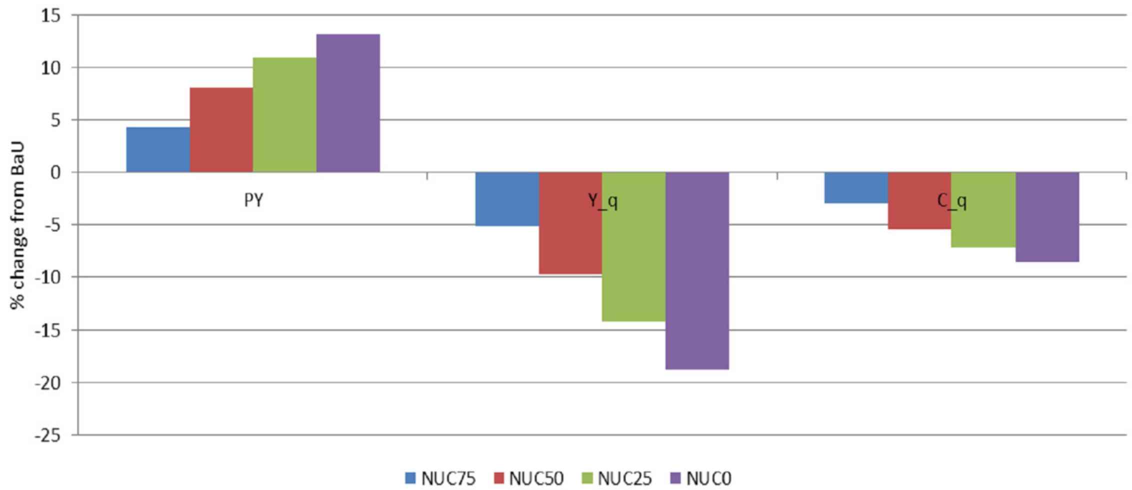


Figure 5 Effect on electricity generation. Py = market value of generation, Y_q= generation (quantity), C_q = Domestic consumption.

The results are as expected, electricity becomes more expensive, generation is reduced as is domestic consumption of electricity . Figure 6 indicates how the generation mix is changing and how the "nuclear gap" is filled.

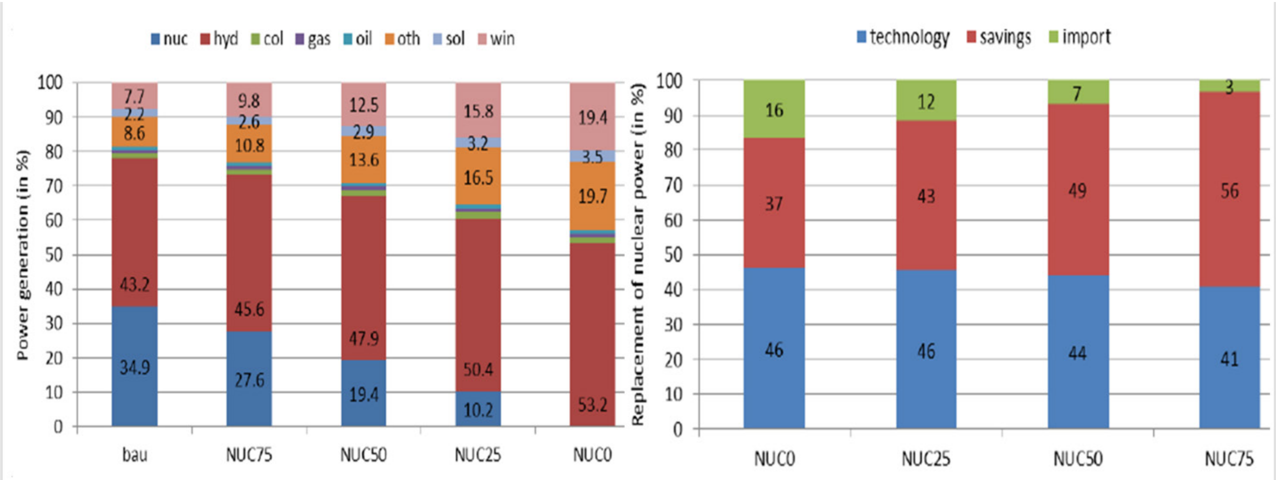


Figure 6 Changing generation mix and how to fill the "nuclear gap"

The left panel shows how hydro and wind assume an increasingly important role. There is a constraint on hydro-expansion, but efficiency improvements of the turbines are still possible[1]. The The right-hand panel suggests that we can fill the "nuclear gap" by (i) increasing imports , (ii) reducing consumption and (iii) efficiency improvements.

Next, we turn attention to the EITE industries, that are likely to be most affected by the downscaling of nuclear. In CGE-CERE 2.0, reported below, we scrutinize in more detail assumption about the shifting of costs forward to the world market and how this can alleviate some of the burden for the EITE industries (in the context of climate policy). We consider four sectors, non-metal mining (nmm), pulp and paper (ppp), iron and stell (i_s) and non-ferrous metals (nfm). Figure 7 shows the projected change in their production.

[1] See e.g. the summary of current research at Energiforsk https://www.energiforsk.se/media/26505/nyheter-och-resultat-fra-n-svc.pdf

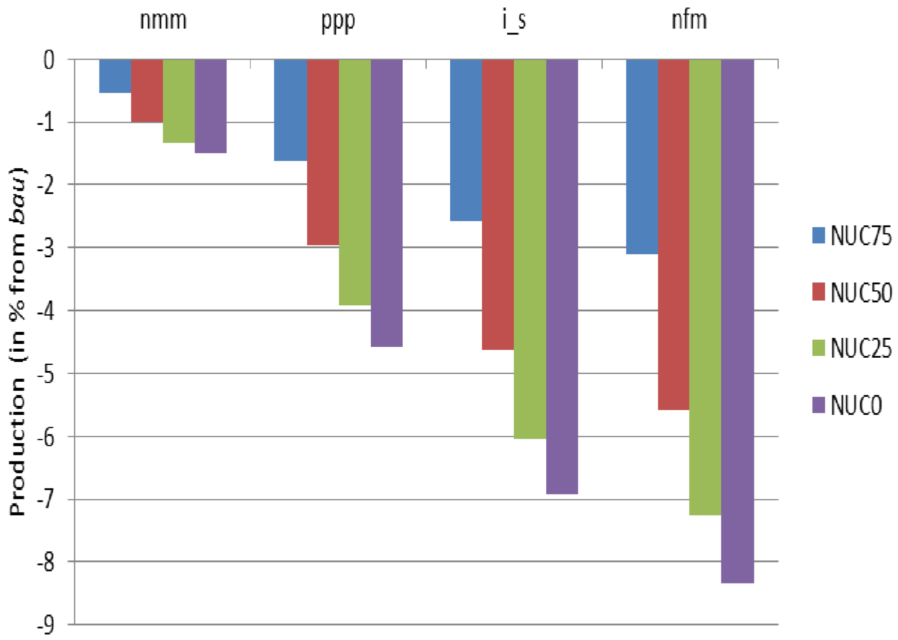


Figure 7 Effects on production (% change from BaU) for non-metal mining (nmm), pulp & paper (ppp), iron & steel (i_s) and non-ferrous metals (nfm)

The results are as expected, suggesting that these industries will take a hit from the higher electricity prices and adjust by scaling down production. Observe that the resources thus saved, in terms of labor and real capital etc, will find alternative employment; the model is static and can be interpreted in terms of long-run developments, as the economy moves from one (assumed) equilibrium to the other. Adjustment costs are not included, so that any additional costs for involuntary unemployment of resources are not included in the costs.

As a final illustration, we compute the loss of real income, here simply the change in real GDP, see figure 7.

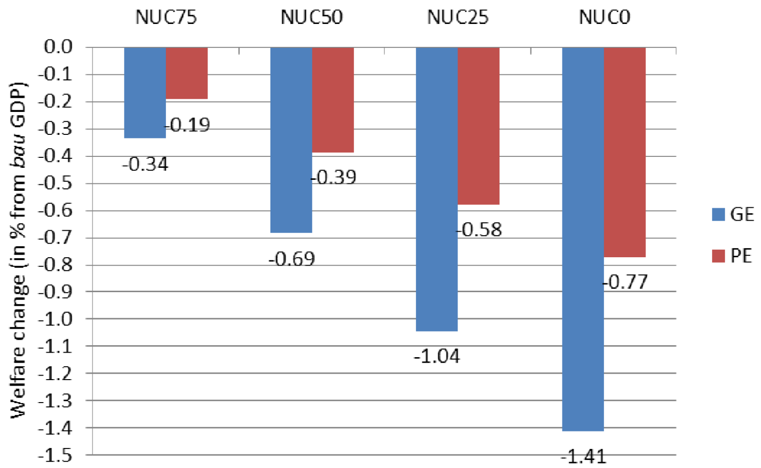


Figure 8 Real income changes from scaling down nuclear. GE is the real income loss taking into account all repercussions, PE is a simplified version, using only information about changes in the electricity market

The real income loss is to the order of 1%. Observe that there are winners and losers among different sectors, when we take the whole economy into account. This is because resources move to the activity in which it finds the highest return. Consequently, some sectors will actually benefit from a nuclear shutdown. This higher income will end up in the hands of the consumer, because the consumer owns the firms (the precise ownership structure (foreign vs domestic) of domestic production factors is ignored in these calculations, since it would require very detailed data.). A sensitivity analysis shows that the economic costs of scaling down nuclear depends also on the supply elasticity of renewables and an option to switch into fossile fuels. Closing down nuclear without any fossile fuel replacements increases the cost by about 0.2% of GDP.

1.2 CLIMATE POLICY: ANALYSIS USING CGE-CERE 2.0

Despite of seemingly wide-spread support for climate change mitigation, policy makers are reluctant to make more stringent use of CO2 emission pricing. This reluctance can be traced back to concerns on the regressive impacts of environmental regulation and the threat of adverse competitiveness effects which could lower the overall performance of the domestic economy. Environmental regulation creates cost and rents which translate into the incidence for households via changes in commodity prices (the expenditure side), factor remuneration and potential transfers (the income side). On the expenditure side, environmental regulation will be regressive to the extent it increases prices for commodities where low-income households tend to spend larger shares of their budgets. Such commodities typically include electricity, home heating fuels, gasoline, and other energy-intensive goods. Obviously, the incidence on the expenditure side will hinge also on the relative ease of how consumers can substitute away from more costly commodities. On the income side, environmental regulation changes the productivity and thus the remuneration to labor, capital, and specific resources (e.g., energy resources). More specifically, emission regulation will drive down the rents to specific resources in emission-intensive industries with inelastic supply characteristics – a cost increase on the input side which cannot passed through via higher output prices will be shifted back to (inelastically supplied) factors of production, such as resource rents or technology-specific capital. Another key driver of the incidence is how rents from regulation are recycled. Regulatory rents such as emission tax revenues can be recycled by the government explicitly via direct transfers or tax reforms that attenuate regressive effects (for example, tax reductions in favor or low-income groups such as payroll tax rebates or higher income tax thresholds).

In the impact assessment of policy reforms, economists have tended to focus on the criteria of economic efficiency, i.e., a policy's aggregate economic effects being agnostic on the distribution of cost and benefits across heterogeneous economic agents. The most prominent strand of literature in this regard deals with cost-effectiveness analysis in which policy choices are ranked in terms of their net economic cost to achieve a given policy target. For the political feasibility of policy reforms, however, the crucial question is who gains and who loses. As a matter of fact, regulatory policies that impose a heavy burden on low income individuals can be very costly from a social perspective since they may undermine social cohesion. Taking into account distributional effects of policy interference across heterogeneous households is thus essential – any individual's net gain or loss as a fraction of income may greatly exceed the aggregate economy-wide gain or loss as a fraction of income.

Regarding the impacts of climate policy regulation, international spillovers play a critical role. Emission abatement in open economies not only cause adjustment of domestic production and consumption patterns but also influence international prices via changes in exports and imports. Changes in international prices – the so-called terms of trade –imply a secondary benefit or burden which can significantly alter the economic implications of the primary domestic policy. Some countries may shift part of their domestic abatement costs to trading partners ("beggar-thy-neighbor" policies), while other abating countries face welfare losses from a deterioration of their terms of trade. International market responses are at the core of competitiveness and leakage concerns. When domestic industries face higher regulatory cost to international rivals, this incentivizes the relocation of these industries abroad. The competitiveness channel thereby amplifies adverse production and employment impacts for energy-intensive and trade-exposed industries in countries that advance with more stringent emission pricing. At the same time, shifts in comparative advantage across countries may severely hamper the global cost-effectiveness of domestic emission abatement through so-called emission leakage, i.e., the relocation of emissions to parts of the world economy subject to no (or weaker) regulation.

Single-country impact analyses typically abstract from changes in international prices due to domestic abatement policies, implicitly assuming infinite elastic export supply and import demand of traded goods from the rest of the world. Given the importance of international spillovers and household heterogeneity for the impact assessment of climate policies, we thus extend CERE-CGE 1.0 i.e., the single-country CGE model of the Swedish economy described in the precious section. In order to account for the international spillovers, key trading partners are explicitly represented in their domestic production and consumption patterns while being linked through bilateral trade flows. The CERE-CGE 1.0 can only partially address the incidence of policy regulation by tracking induced structural change across industries and quantifying the implications for aggregate factor earnings. A detailed incidence analysis calls for the differentiation of the composite (representative) consumer into heterogeneous household groups. We develop a quantitative framework which integrates a detailed micro-household simulation (MS) setting into a multi-sector computable general equilibrium (CGE) framework. The advantage of the CGE–MS combination is that we can analyze 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. For the combination of the CGE and MS components we draw on a powerful iterative coupling algorithm. One advantage of this coupling approach is that the two model components remain numerically tractable for large numbers of households and thereby also makes the numerical solution process less time-consuming.

1.2.1 Model framework and data

We start from CGE-CERE 1.0 model which covers inter-sectoral linkages and price-dependent market feedbacks across the Swedish economy. The core model is then extended along two dimensions: (i) a multi-region setting with bilateral trade flows to capture international market responses via endogenous terms of trade, and (ii) the disaggregation of the Swedish composite household into multiple households to capture important differences in expenditure and income patterns across heterogeneous households. The principal data sources compromise (i) the GTAP database with multiple regional input-output tables for the multi-region CGE extension and (ii) the European Household Budget Survey (HBS) and the Statistics on Income and Living Conditions (SILC) for the Swedish household disaggregation.

1.2.2 The Multi-region model

The single-country small-open economy (SOE) model operates on the assumption that production and consumption decision in a country do not affect world prices. In our multi-region extension, we adopt the standard Armington assumption of regionally differentiated goods to characterize the structure of bilateral trade flows where imported and domestically produced differentiated goods are combined in a constant elasticity of substitution (CES) demand system.

Figure 9 provides a flowchart of the basic economic transactions in the multi-region CGE model. Production Y_{ir} of commodity i in each region r is given as a nested constant-elasticity-of-substitution function which captures price-responsive substitution possibilities between factor and intermediate inputs.[2] Production

[2] Note that the index *i* compromises all sector outputs as well as the final consumption composite (*i* = *C*), the public good composite (*i* = *G*), and the investment composite (*i* = *I*).

output enters final demand of the representative agent (Y_{Cr}, $\bar{Y}_{Ir}$, $\bar{Y}_{Gr}$), export demand X_{ir} and input demand for Armington production A_{ir}. Armington production for each good i in region r is based on a CES technology that combines the domestically produced good and imports M_{is} from other regions s. Armington outputs A_{ir} serve as intermediate inputs to the production Y_{ir} of all commodities including final demands.

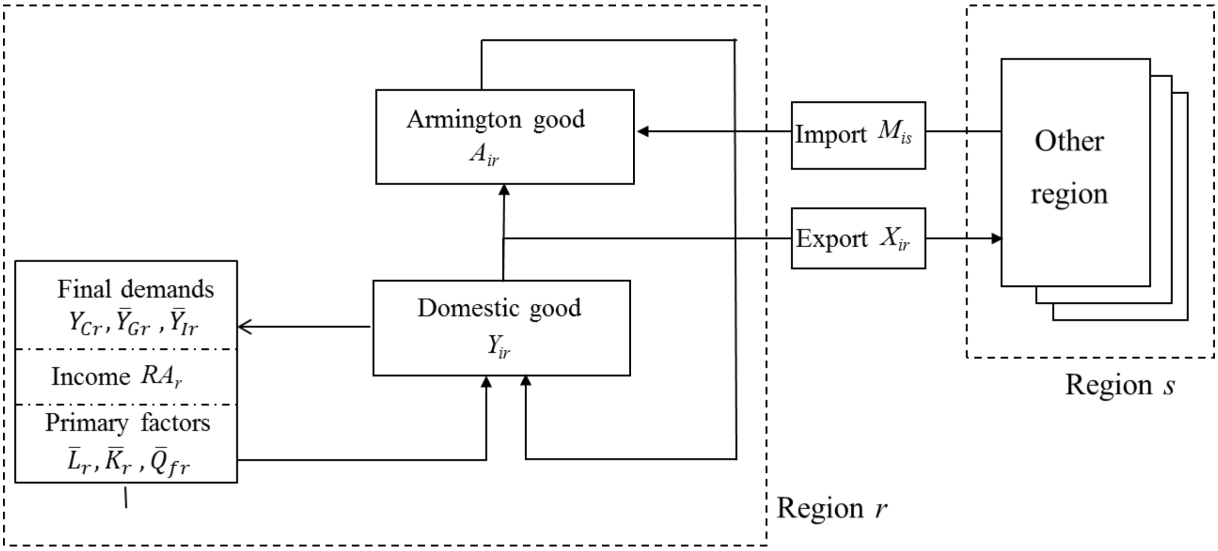


Figure 9 Generic structure of CERE-CGE 2.0

An important implication of the Armington assumption in a multi-region setting is that production and consumption decisions in a given country will affect world prices and the magnitude of this effect will mainly depend on the elasticity estimates (a measure of country-level implicit market-power). To re-state this important mechanism again: Even in the absence of market power by individual firms, the Armington assumption of product heterogeneity provides implicit market power in a perfectly competitive market conduct which is the higher the larger are the trade flows and the smaller are the demand elasticities for the traded goods by trading partners.

While the small-open economy and the multi-region model versions are based on the same data and employ the same representation of production technology and consumer preferences, their impact assessment will differ through their impacts on the terms of trade, i.e. the trade closure. In the bilateral multi-region trade setting, the Armington assumption introduces indirect terms-of-trade effects (measured as the ratio of a country's exports to its imports in value terms) which can dominate the direct effects of policy reforms for the domestic economy (when abstracting from international price changes).

We can employ the small-open economy and multi-region models in parallel to decompose the contribution of changes in terms of trade to economic outcomes. For the particular policy illustration on emission abatement (see section 3), our results suggest that trade closures matter a lot.

1.2.3 Microsimulation sub-model

A microsimulation (MS) model characterizes households by their income through factor endowments and transfers (income channel) and describes how the disposable income after savings decisions is spent across consumption categories (consumption/expenditure channel). The core of the MS model is an econometrically estimated demand system which captures price-responsive behavior via own-price, cross-price and income elasticities. Data from income and expenditure surveys is used to estimate the demand systems which then determines 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.

One wide-spread demand system for the characterization of consumer behavior is the Almost Ideal Demand System (AIDS). The AIDS model provides a convenient linear first-order approximation to any demand system while satisfying economic consumption theory axioms. The log-linear approximation (LAIDS) of demand functions is as follows:

$$w_i = \alpha_i + \sum_{i=1}^{n} \gamma_{ij} ln\, p_j + \beta_i ln\left({}^{Y}/_{\tilde{p}}\right) + t + d + e_i \qquad [1]$$

where: w_i represents the budget share associated with good i for a particular household, α_i is a constant, γ_{ij} is the the slope coefficient associated with the j good in the i share equation, p_j is the price of good j, β_i is the slope coefficient for real income, $\tilde{p}$ stands for the geometric Stone price index (The Stone price index is defined as follows: $\log \tilde{p} = \sum_{i=1}^{n} w_i ln\, p_i$), Y is household income (hence, $Y/\tilde{p}$ represents real income), t denotes the time trend variable, d is a set of dummy control variables for household characteristics, and e_i denotes the error term. The adding-up and homogeneity restrictions of equation [1] are as follows:

$$\sum_{i=1}^{n} \alpha_i = 1 \qquad [2]$$

$$\sum_{i=1}^{n} \gamma_{ij} = 0 \qquad [3]$$

$$\sum_{i=1}^{n} \beta_i = 0 \qquad [4]$$

and the symmetry condition is given by:

$$\gamma_{ij} = \gamma_{ji} \qquad [5]$$

Finally, the sum of w_i must satisfy:

$$\sum_{i=1}^{n} w_i = 1. \qquad [6]$$

1.2.4 Coupling of CGE and MS models

The main challenge for computing equilibria in a CGE model with a large number of households is dimensionality: the number of simultaneous variables and equations becomes large and may create numerical problems for solution algorithms. To overcome dimensionality restrictions, we employ a sequential recalibration algorithm which solves a market economy with many households through the computation of equilibria for a sequence of representative agent (RA) economies. The algorithm decomposes the numerical problem into two sub-problems and employs an iterative procedure between them to find the equilibrium of the underlying model. The first sub-problem computes candidate equilibrium prices from a version of the CGE model where the household demand side is replaced by a single RA. The second sub-problem solves a partial equilibrium (PE) relaxation of the underlying model by evaluating demand functions for each of the households given candidate GE prices from the RA problem. The iterative procedure between both sub-problems involves the re-calibration of preferences of the RA in each region based on PE quantity choices by "real" households.

By repeatedly resolving the CGE 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 heterogeneous households. The combined CGE–MS approach has the advantage of numerical tractability and reduced CPU time with respect to large numbers of households in income-expenditure surveys. Another advantage of the iterative linkage is that we can keep with nested CES in the CGE characterization of the RA household preference to approximate the GE-consistent response of a more sophisticated demand system in the MS model

1.2.5 Data

For the CGE model, base-year data and exogenous elasticities determine the free parameters of functional forms that characterize technologies and preferences. We parameterize our model using empirical data for 2011 from the Global Trade Analysis Project (GTAP version 9). As explained above, the GTAP data features detailed national accounts on production and consumption (input-output tables) together with bilateral trade flows, initial tariff rates, export taxes as well as other indirect taxes. In addition, data on fuel-specific emissions by region, industries and final demand segments are included. The dataset also provides trade Armington elasticities as well as income and price elasticities for final demand. Users can flexibly select an appropriate level of sectoral and regional aggregation from the GTAP 9 dataset to target a representation that is relevant to the analysis of interest. For our illustrative economic impact assessment of CO_2 emission pricing the data set is aggregated to 20 sectors and 3 regions. As to sectors, we explicitly represent all primary and secondary energy carriers of the GTAP dataset (coal, gas, crude oil, refined oil products, and electricity) to capture differences in CO2 intensity and the degree of interfuel substitutability-Final consumption of Swedish households is provided for across six composite consumption categories (food, housing without energy, electricity and heating, transport without durables, education and leisure, other goods and services, durables) where GTAP production goods enter according to a consumption bridge matrix.

For the parametrization of the microsimulation model, we employ household survey data which indicates how aggregate household expenditure for different commodities and income from different production factors are distributed among single households. In the present analysis, we have disaggregated the representative agent (RA) in the CGE model representation of Sweden into 10 different income groups (deciles). On the consumption side, we use the Swedish data from the European Household Budget Survey (HBS) to characterize household expenditure patterns. The HBS is a representative cross-sectional survey of the Swedish population collecting annual information on consumption patterns as well as socio-economic characteristics for around 2,000 households. We can calculate the consumption shares across income deciles by COICOP (Classification of Individual Consumption by Purpose) category at the 2-digit level, i.e. 47 consumption groups. To link the output per production sector and the consumption by private households in terms of consumption expenditure categories we make use of a production-consumption bridge matrix, the so-called "Z-matrix". Finally, we must calculate the income sources by income decile. Since this information is not included in the HBS, the income source are compiled from the Statistics on Income and Living Conditions (SILC). The SILC, like the HBS, is a representative survey of the Swedish population providing cross-sectional and longitudinal microdata on income, poverty, social exclusion and living conditions. The sources of income in the input-output data underlying the CGE model refer to labor, capital and transfers. The correspondences to the SILC data are as follows: (i) labor includes wages and salaries, (ii) capital includes cash benefits or losses from self-employment, interest, dividends, profits (returns) from capital investments and income from rental of a property or land, (iii) transfers include all transfers from the government to the households such as unemployment transfers, disability transfers, education-related allowances, etc. To consolidate data sources, we scale the spending and demand data from the EPF in line with the data aggregated from the IO table; similarly, we scale the household revenue data. Due to missing data on savings by households in the EPF, we distribute the aggregated savings reported in the IO data across households according to the weight of income from capital in their respective revenues. In order to achieve a tight handshake between the aggregate household data in the CGE model and the disaggregate household data in the MS model, several weighting and scaling adjustments have to be done.

Figure 10 visualizes the expenditure and income patterns for Swedish households at the decile level (households *h01*, *h02*, ..,*h10*) for the year 2011.

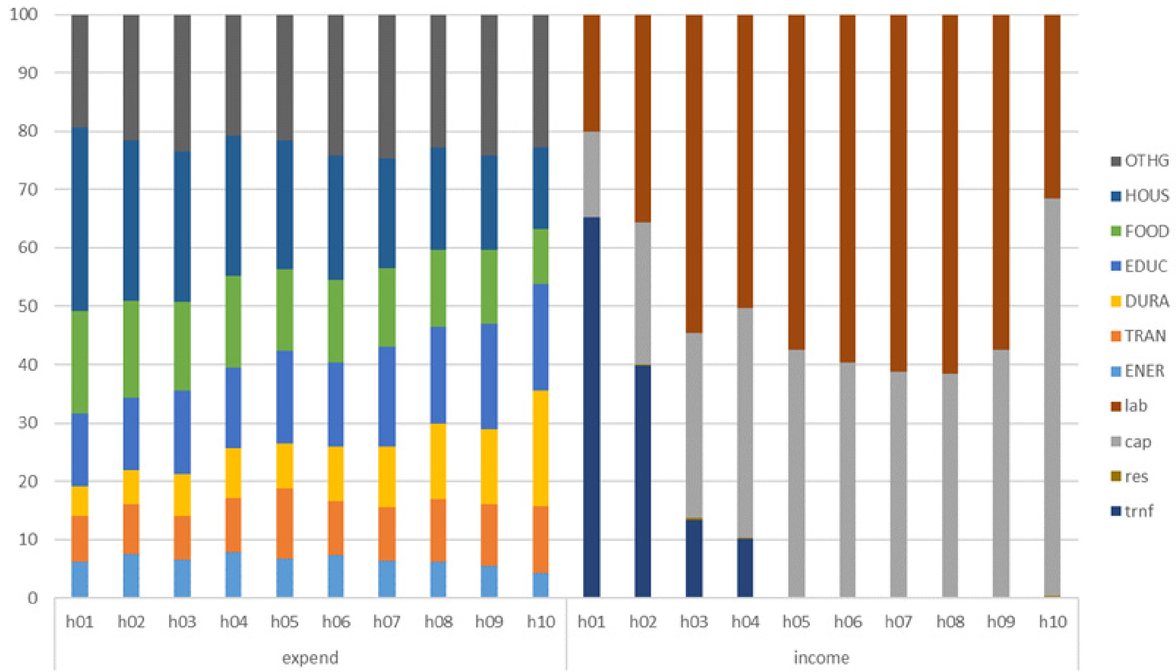


Figure 10 Base-year (2011) expenditure and income patterns across Swedish income deciles Key: expend (expenditure) – OTHG (Other goods and services), HOUS (Housing without energy), FOOD (Food), EDUC (Education & leisure), DURA Durables, TRAN (Transp

1.2.6 Model implementation

Technically, the model and data routines are implemented in GAMS (Generalized Algebraic Modelling System) using MPSGE (Mathematical Programming System for General Equilibrium). GAMS is a higher-level model language for the development of large-scale mathematical programs and the processing of extensive datasets. The fundamental strength of GAMS, whose notation closely follows standard matrix algebra, lies in the ease with which mathematically-defined models can be formulated and solved. To facilitate the formulation of the large-scale CGE model, we use the Mathematical Programming System for General Equilibrium analysis (MPSGE). MPSGE which works as a subsystem in GAMS is a modelling language specially designed for solving general equilibrium models. It provides a transparent and very effective way to write down and analyze complicated systems of nonlinear inequalities that characterize the fundamental conditions for an economic equilibrium. MPSGE thereby can reduce markedly the setup cost of producing an operational model and the cost of testing alternative specifications.

1.2.7 Illustrative simulation analysis

The main objective of our illustrative simulation analysis is to highlight the importance of household disaggregation and international spillovers for the economic appraisal of policy interference. We investigate a core policy scenario where Sweden (SWE) and the rest of the EU (REU) advance in climate policy with commitments to reduce their regional CO2 emissions by 10% as compared to the no-policy case, the so-called business-as-usual (BaU) – in the BaU the rest of the world (ROW) abstains from climate policy regulations. Both – SWE and REU – levy CO2 prices that are sufficiently high to meet their regional emission reduction target (alike we can think of regional emission trading systems with a CO2 emission budgets at 90% of the BaU levels where the associated allowance price would correspond to the aforementioned CO2 tax). To elaborate on the importance of international market responses, we consider four model variants with alternative trade closures:

soe: This variant considers Sweden as small open economy. The economic impact assessment of Swedish emission pricing abstracts from international spillover effects – there are no changes in international prices

mrt:: This variant considers a multi-region model with endogenous terms of trade where Sweden and the rest of EU undertake domestic emission pricing while the rest of the world abstain from climate policy action.

mrt_swe: This variant is identical to variant mrt except for that only Sweden undertakes domestic emission pricing. We hence account for international spillover effects of Swedish climate policy in the absence of any policy reforms in other countries and can quantify how Swedish action affects economic performance (and emissions) in other regions.

mrt_reu: This variant is identical to variant mrt except for that only the rest of Europe undertakes domestic emission pricing. We hence account for international spillover effects of climate policy by the rest of Europe in the absence of any policy reforms in other countries and can quantify how action on behalf of rest of Europe affects economic performance (and emissions) in other regions.

In the refined incidence analysis, we report economic impacts for Swedish households at the income decile level across all the four model variants. Revenues from emissions pricing are recycled lump-sum to the household(s) while maintaining the BaU level of public good provision. In our core scenario, households benefit from revenue recycling in proportion to their shares in initial transfers, i.e., the larger the household's share in initial BaU transfers the higher is the amount of money it receives from carbon rents. If not stated otherwise, all simulation results below are reported in percentage change from BaU levels.

We start the discussion of results with the environmental impacts of emission pricing. Figure 11 displays the CO2 emission reductions for the three model regions – SWE (Sweden), REU (rest of the EU), and ROW (rest of the world) – across the four model variants. Clearly, the impacts just mimic the regulatory design, i.e., whenever SWE and REU are active regions in the model variant they meet the mandated emission reduction of 10% by means of adequate economy-wide CO2 emission pricing. Environmental spillover effects of Swedish climate policy stand-alone seems to be negligible (at least in absolute terms), while emission pricing of REU triggers some increase in emissions elsewhere due to shifts in comparative advantage.

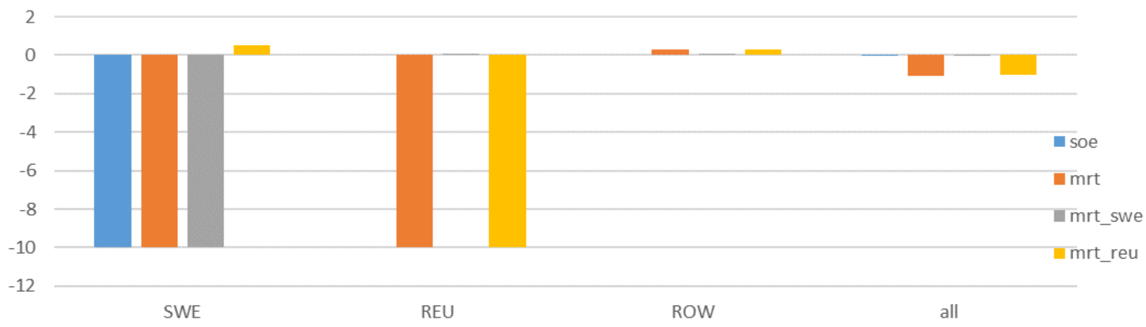


Figure 11 Emission reduction (in % from BaU)

When we investigate environmental effectiveness of sub-global action more rigorously, the potentially counterproductive implications of spillover effects become more apparent. The standard metric here is the so-called leakage rate defined as the change of emissions in countries without emission regulation over the emission reduction in regulating countries. Figure 12 reports these leakage rates across the model variants.

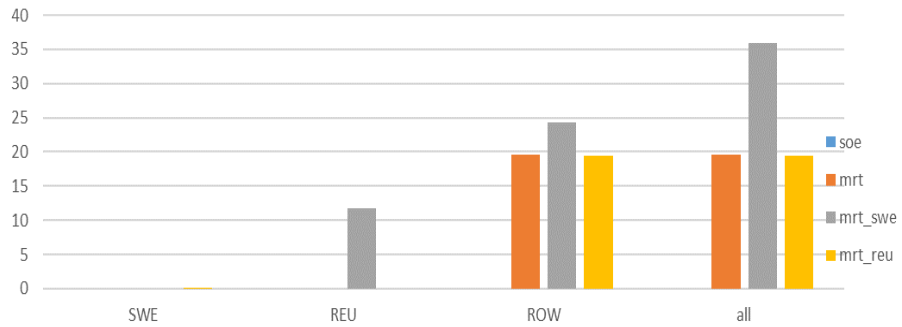


Figure 12 Leakage rate (in %)

By definition, leakage for the *soe* variant is zero. However, we also see that in multi-region model variants the leakage rate is highest for the case of Swedish CO_2 emission pricing only. This result just confirms the general intuition on the magnitude of leakage rates as a function of emission pricing coverage: The smaller the regional coverage of emission pricing, the higher is ceteris paribus the leakage rate.

Next, we turn to the level of emission pricing in regions with climate policies to reach the respective regional emission reduction targets. Figure 13 indicates these marginal abatement cost across the different model variants.

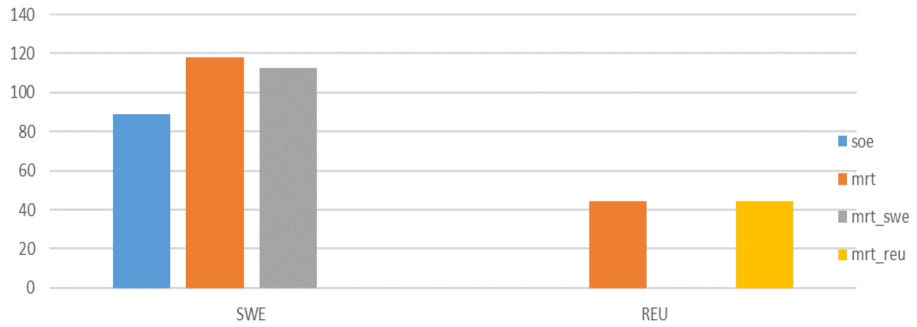


Figure 13 Marginal abatement cost (in $US per ton of CO2)

The first insight is that the ease of carbon substitution implied by benchmark data and elasticities is much higher in REU than in SWE and accordingly the CO2 prices for SWE range substantially higher than for REU. One major reasoning behind this finding is that the Swedish economy stands out for a much lower level of CO2 intensity – in particular with respect to electricity generation (which is dominated by nuclear and hydro) – as compared to the rest of the EU.

In the absence of second-best effects such as initial tax distortions or market power (in our case, the Armington assumption implies market power for countries in the multi-region setting even when we assume that all industries feature a perfect competition) the level of marginal abatement cost for regional action (no cross-country emissions trading) is directly correlated with the level of inframarginal abatement cost (graphically speaking the area under the abatement cost curve). However, if we account for terms-of-trade effects (as for other 2nd best situations or just international emissions trading) the marginal abatement cost is typically not a good predictor of the overall economic adjustment cost to emission constraints.

Figure 14 reports economy-wide adjustment cost as percentage loss in BaU gross domestic product. We see that – among the three scenarios which involve explicit CO_2 emission pricing in Sweden – the GDP loss for Sweden is highest in the *soe* variant, followed by variants *mrt_swe* and *mrt*. When accounting for changes in international prices, Sweden can shift over part of its domestic abatement burden via higher prices to trading partners (*mrt_swe*), hence GDP losses in *soe* would overstate the economic losses of Swedish unilateral action. When we consider simultaneous abatement action by the rest of the EU, Sweden's main trading partner, then GDP losses from a Swedish perspective further decline as adverse shifts in comparative advantage on an equal-level playing field are more balanced out.

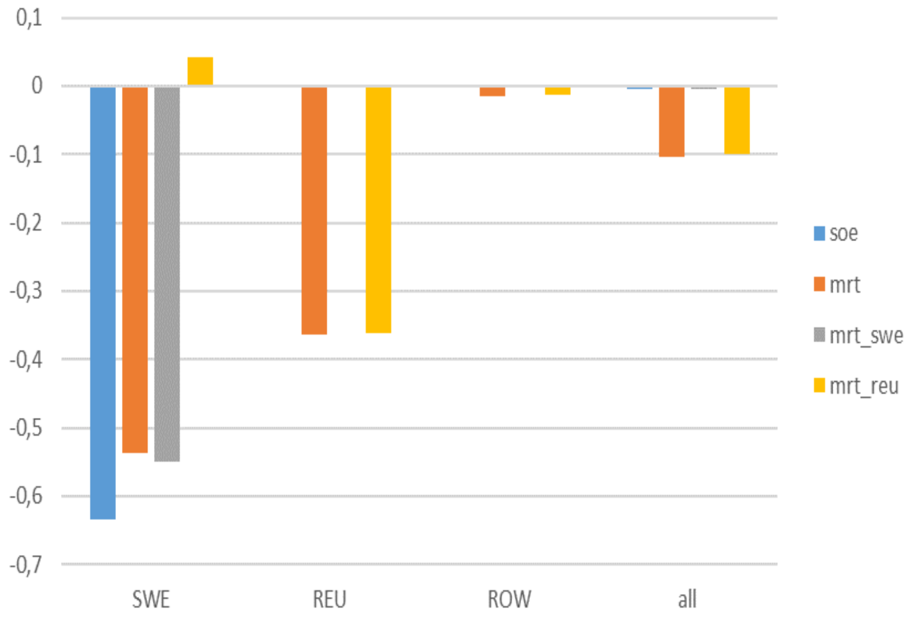
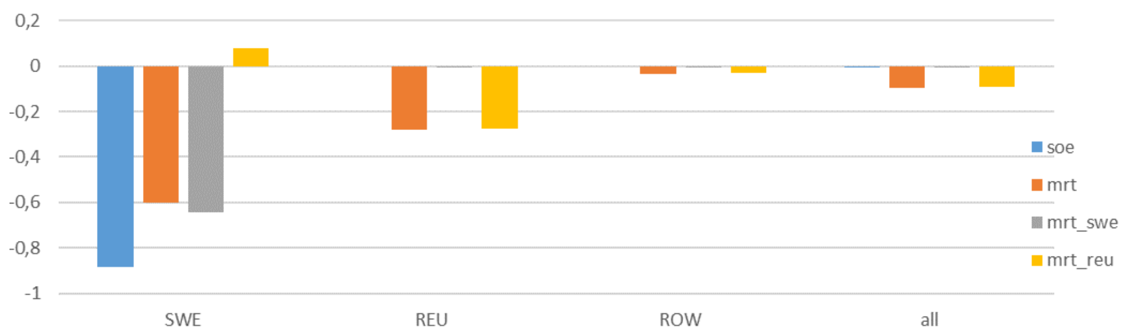


Figure 14 GDP (in % from BaU)

It should be noted, however, that GDP is not a proper metric for rigorous welfare analysis. Welfare changes of policy reforms are typically calculated as the policy-induced change in consumer utility based on the indirect utility function in order to give it a monetary value. Technically, welfare changes are best described as "equivalent" variation in income. The Hicksian equivalent variation (HEV) in income – as the common welfare metric employed in CGE analysis – denotes the amount which is necessary to add to (or deduct from) the benchmark income of the household such that the household enjoys a utility level equal to the one in the counterfactual policy scenario on the basis of ex-ante relative prices. In our current model setting with fixed savings (investment) and a constant public good provision the change in HEV corresponds to the change in real consumption relative to BaU consumption levels.



Figur 15 Welfare (in % HEV of BaU income)

Figure 15 reports the welfare implications of emissions pricing in terms of HEV. We see that HEV impacts reveal the same qualitative patters as with GDP (which must not be necessarily the case) but are slightly more accentuated for Sweden and less pronounced for the rest of the EU.

Since policy-makers and the general public are more familiar to the GDP metric than to HEV, an elegant bypass to maintain coherent welfare analysis is to report welfare effects as changes HEV (money metric utility) with respect to the gross domestic GDP in the BaU -- see Figure 16.

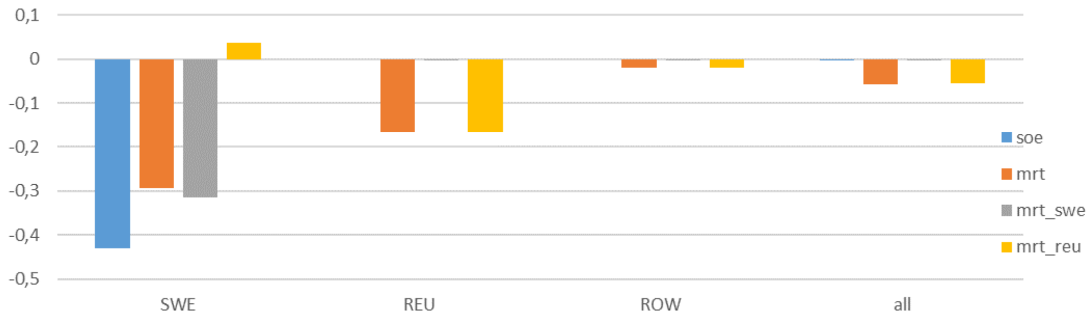
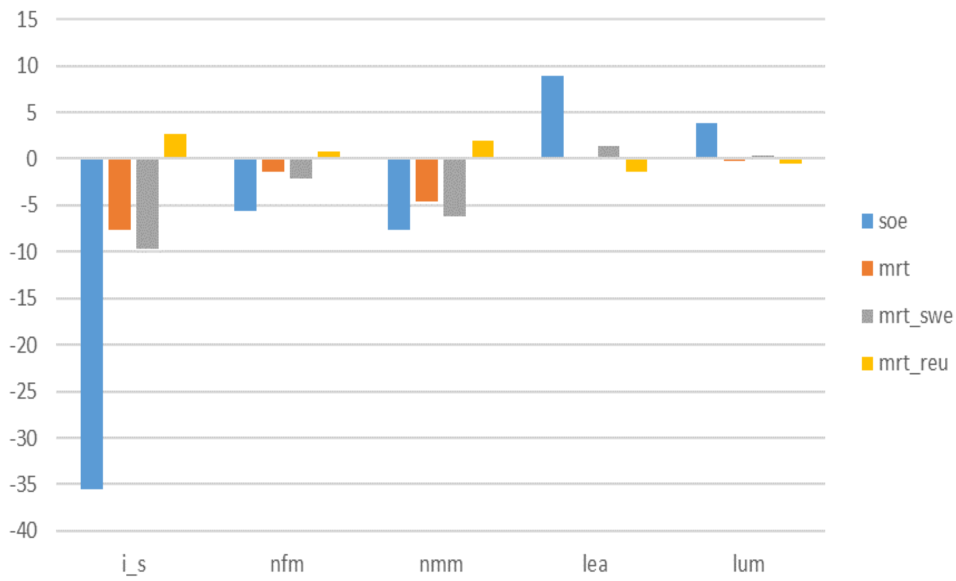


Figure 16 Welfare (in % of BaU – GDP)

Figure 16 provides a single snapshot of the competitiveness effects for Swedish industries triggered by emission pricing across the different model variants. As expected, carbon-intensive and trade-exposed industries such as iron and steel (i_s) or non-ferrous metals (nfm) suffer from emission pricing. Yet, we see that omission of international spillover effects greatly overstates the implied structural change. More specifically, the output reduction for the Swedish iron and steel industries is estimated to be around six times higher in the *soe* variant as compared to the *mrt* variant.



Figur 17 Output effects in selected Swedish industries (in % from BaU)

Finally, we turn to the refined analysis of the incidence from emission pricing where we focus on Sweden in our illustrative simulation analysis.

Figure 17 decomposes the total welfare effect for the representative agent in Sweden into changes on the income side and the expenditure side – measured in billion US dollars. We see that emission pricing in Sweden depresses factor productivity and hence their real returns (in our static model setting all factor endowments are fixed and we also abstract from an endogenous labor-leisure choice). The accounts on transfers (trnf) and CO_2 rents (co2rev – either revenues from taxes or likewise auctioned CO_2 emission allowances) in sum yield a net positive revenue effect for the representative agent while keeping public good provision at BaU levels. Savings (investment) which are fixed at the BaU level slightly decline when denominated in the consumption price index of the Swedish economy (in other words the price index for the savings/investment good declines in real terms) but overall the disposable income for real consumption decreases – the latter is reflecting the aggregate negative welfare effect measured in money-metric utility of the representative agent as reported in Figure 8 above.

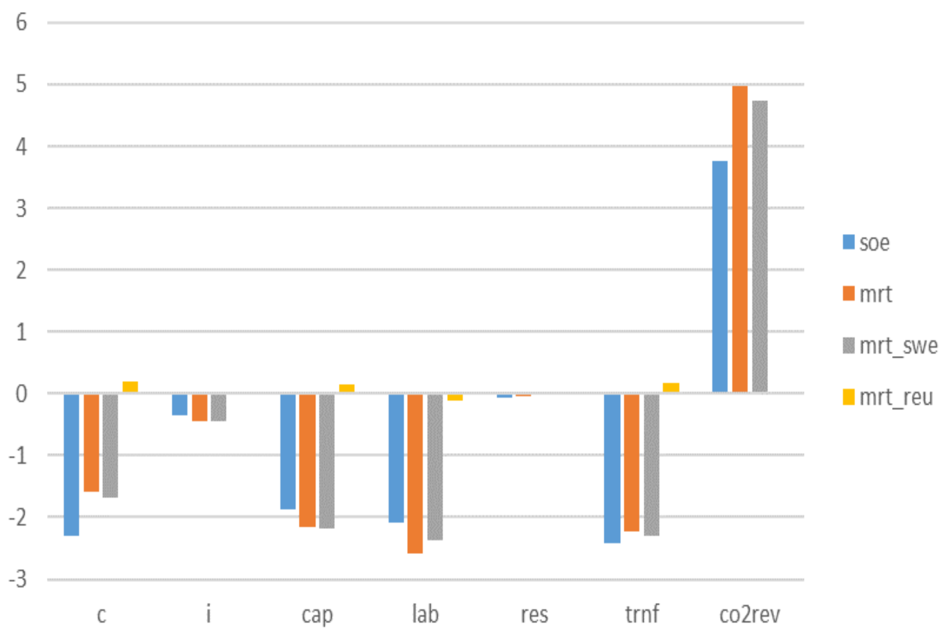


Figure 18 Welfare decomposition (in bn USD)

We can further track the channels for the incidence of emission pricing to real price changes for consumption goods on the expenditure side and real price changes for factors on the income side – see Figures 12 and 13. We see that on the consumption side energy-intensive goods become relatively more expensive. With respect to factor earnings, emission pricing in particular drive down the rents on factors that are specific to the production of carbon-intensive primary energy goods (most notably coal).

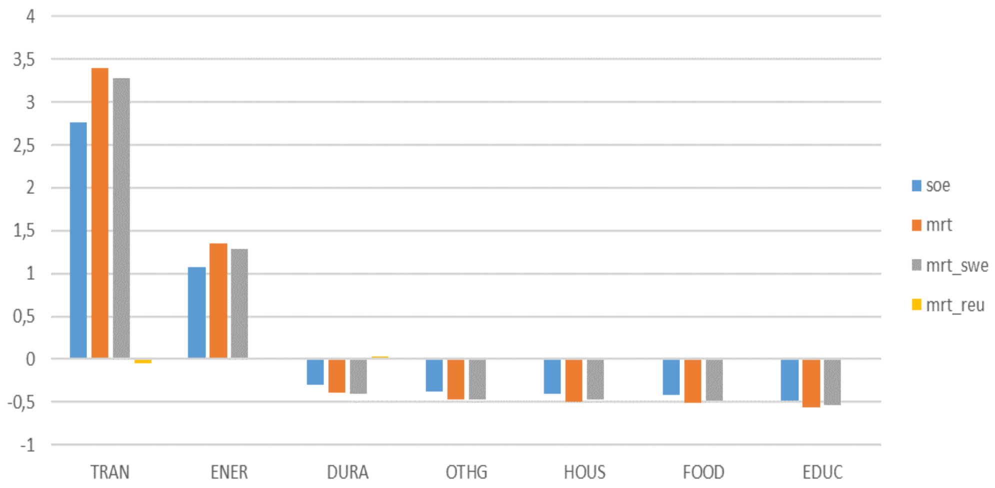
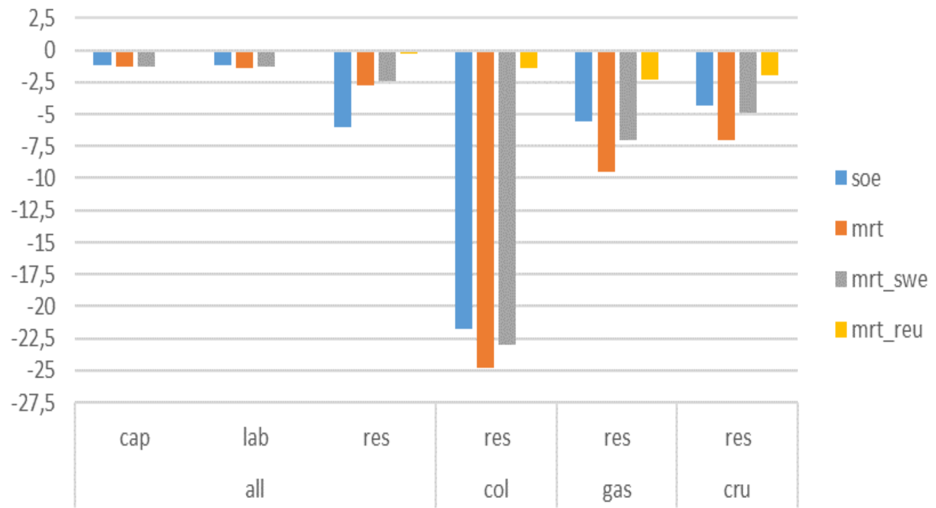


Figure 19 Price changes of composite consumption goods (in % from BaU)



Figur 20 Factor price changes (in % from BaU)

Figure 20 details the incidence of emission pricing across Swedish households by income decile. For our specific assumptions on revenue recycling where carbon rents get redistributed proportional to initial transfer shares across income deciles (see Figure 3), the seemingly regressive effects of higher energy prices translate into an overall progressive impact. Even more: Not only are the cost of emission pricing borne to a larger extent by richer households but the poorer household become even better off as compared to the BaU.

We can summarize the individual effects on different households from an overall societal perspective when adopting a social welfare function (SWF) with an assumed elasticity of the marginal utility of consumption – capturing the degree of inequality aversion.

A common specification is based on a constant relative inequality aversion:

$$SWF = \frac{1}{(1-1/\sigma)} \sum_r P_h W_h^{1-1/\sigma}$$

where W_h represents the money-metric per-capita welfare level in household class h, $1/\sigma$ is the inequality-aversion coefficient, and P_h denotes the number of people in household class h. In our analysis, we present welfare changes as changes in the equally distributed equivalent per capita income ($yEDE$) as defined by Atkinson:

$$\frac{1}{(1-1/\sigma)} \sum_h P_h y_{EDE}^{1-1/\sigma} = \frac{1}{(1-1/\sigma)} \sum_r P_h W_h^{1-1/\sigma}$$

Trade-offs between efficiency and equity are then tractable through alternative choices of the inequality-aversion parameter $\varepsilon = 1/\sigma$. For a zero value of ε, we assume a Rawlsian perspective, where it is the welfare level of the poorest household that determines social welfare. On the other extreme, as ε takes over an infinite value, we are agnostic on the distribution of policy cost and adopt a utilitarian (Benthamite) perspective on efficiency where utility changes of individual households are perfectly substitutable.

Figure 21 summarizes the welfare effects of emission pricing across Swedish households from an aggregate societal perspective for alternative degrees of inequality aversion. The key take away is that appropriate designs of revenue recycling make richer households bear the burden of emission pricing, while poorer household can be made better off.

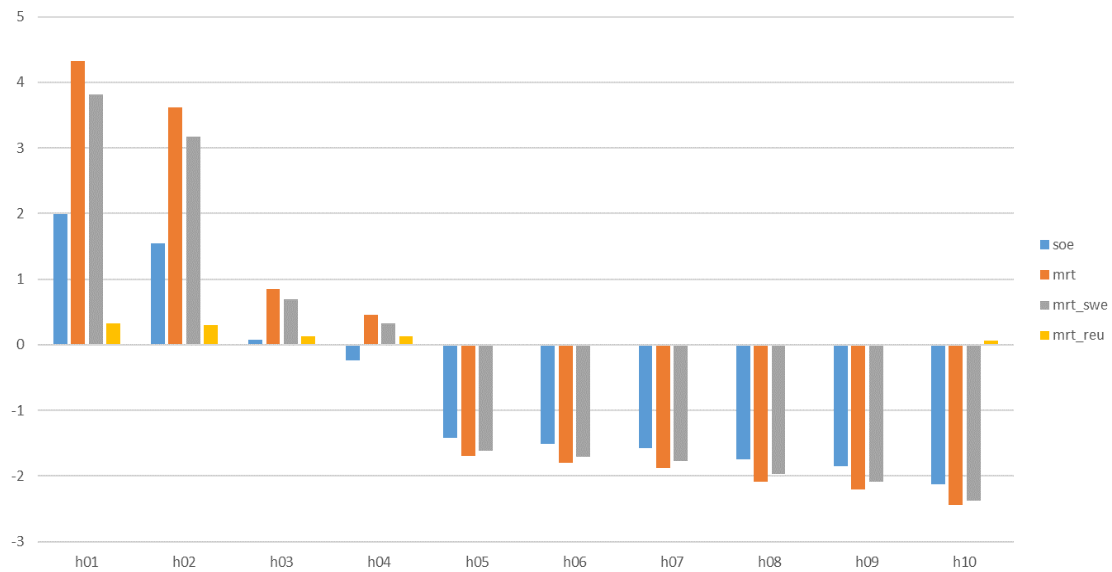


Figure 21 Incidence of emission pricing across Swedish households (in % HEV of BaU income)

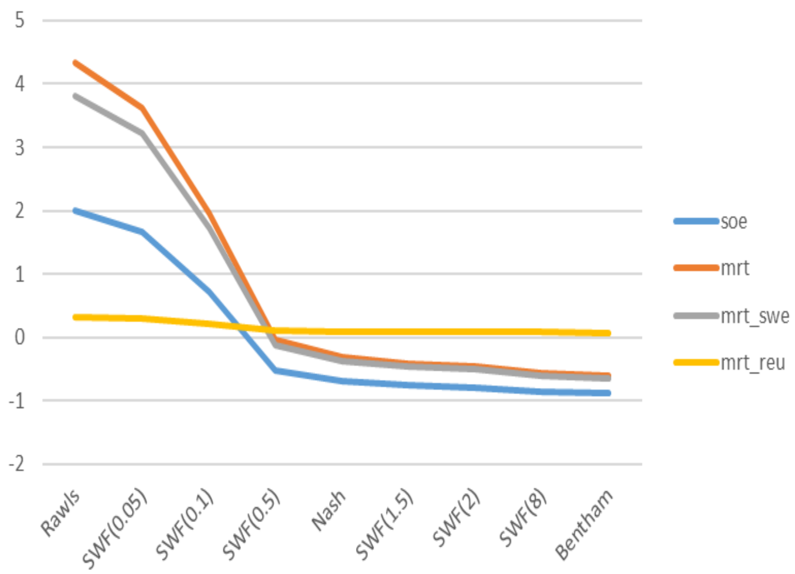


Figure 22 Social welfare in Sweden (in % HEV of BaU income)

1.3 DISCUSSION

Rational environmental policy design thus must balance environmental targets with economic efficiency and social equity concerns. Economists have tended to focus on the criteria of economic efficiency, i.e., a policy's aggregate economic effects being agnostic on the distribution of cost and benefits across heterogeneous economic agents. The political feasibility of regulation, however, depends importantly on the distribution of costs and benefits (rents) across heterogeneous households of the society. For open economies, the magnitude of these effects may in addition critically hinge on international spillover effects.

To provide a rigorous impact assessment of the efficiency and distributional impacts triggered by Swedish climate policies, we have extended a pre-existing CGE model of the Swedish economy along two dimension: First, we have combined the CGE model with a microsimulation model of income-expenditure patterns across households. The integrated modeling framework does not only feature a rich representation of household heterogeneity for refined incidence analysis but accounts for important inter-sectoral linkages and price-dependent market feedbacks across the whole economy. Furthermore, we have extended the small-open economy framework towards a multi-region setting with bilateral trade flows and endogenous international prices to capture international spillover effects. In our illustrative policy simulations, we have highlighted the importance of household heterogeneity as well as trade closure for the economic appraisal of Swedish climate policy. benefits and costs of certificates.

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2 General Equilibrium Cost-Benefit Analysis

2.1 ELECTRICITY CERTIFICATES: A GENERAL EQUILIBRIUM COST-BENEFIT ANALYSIS

We provide an extensive cost-benefit analysis of scrapping the Swedish electricity certificate system in Johansson & Kriström (2019), in which we provide details of the theory and the empirical analysis. In the sequel, we summarize the most important conclusions of the paper. The starting point is an economy-wide model that in principle takes into the interaction between all markets in a market economy; it is substantially less data-intensive than the typical large-scale CGE-model. Our main theoretical result is a rather simple formula that displays the benefits and the costs of closing the system down. It is a first-order approximation, in the sense that we need not make any particular assumptions about the functional forms used. While the reform is "large" by almost any way definition of what a large project entails, it is small relative to the size of the Swedish economy, which provides some motivation for the first-order approximation. If a change is small enough, it can almost always be approximated by a linear function. The paper has a literature review, including the motivation for using subsidies to support renewable energy. Motives, which we critically examine, include "green jobs", energy security and climate benefits.

Since the paper was written, an important study has surfaced by Greenstone et al (2019). It examines the economics of renewable portfolio standards (RPS), a state-level initiative in the U.S., requiring electric utilities to gradually increasing the proportion of electricity that comes from renewable sources. Thus, RPS shares many characteristics with the Swedish-Norwegian certificate system. According to Greenstone et al (2019), previous analyses of the economics of RPS have not fully addressed (i) intermittency costs (ii) cost of added grid infrastructure and (iii) premature retirement of coal- and nuclear power plants. These issues are relevant for our benefit-cost analysis as well, to which we now turn. We do not look in detail at the cost items suggested by Greenstone et al (2019); we simply note that an inclusion of these costs would only serve to strengthen our final conclusion.

2.1.1 The Swedish electricity certificate system

The Swedish electricity certificate system, introduced in 2003, will be terminated in 2045. For each megawatt hour renewable electricity produced, certified producers receive an electricity certificate from the government. The energy sources that are entitled to electricity certificates are wind power (the dominating source in the system), some hydropower, certain biofuels, solar energy, geothermal energy, wave energy and peat in CHP plants. New installations put into operation after the introduction of the electricity certificate system have the right to electricity certificates for 15 years until the end of 2045. Holders can sell their electricity certificates in a market where the price is determined by the law of supply and demand. The electricity certificates thus provide an extra income for renewable electricity generated, on top of revenues from sold electricity. Buyers have so-called quota obligations. In practice, these are primarily electricity retailers (energy-intensive industry is exempted) that simply pass on the certificate cost to buyers of electricity.

Since 1 January 2012, Sweden and Norway have a common market for electricity certificates. Within the common market, the goal is to increase electricity production by 28.4 TWh from 2012 to 2020. Sweden also aims to increase renewable electricity production by another 18 TWh by 2030.

Quotas for the years 2003 through 2045 are illustrated in Figure 23.

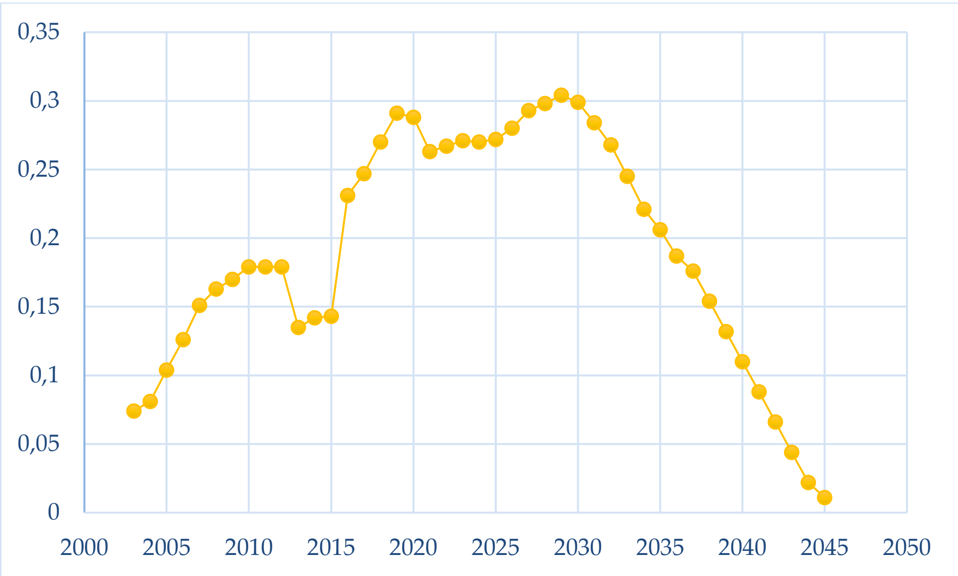

Figure 23 Quotas 2003-2045

The number of issued certificates by source is in Figure 24.

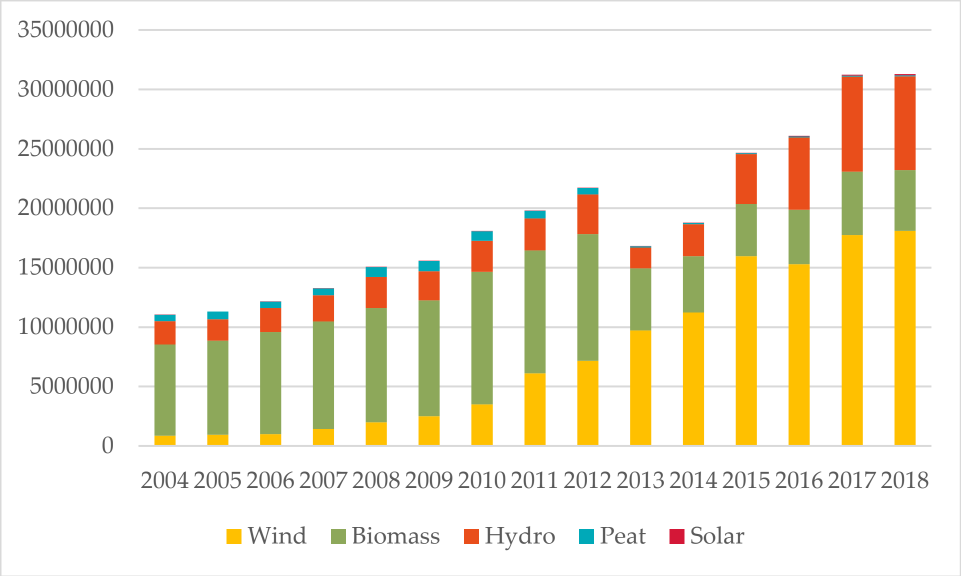

Figure 24 Number of issued electricity certificates Source: https://www.ekonomifakta.se/fakta/energi/styrmedel/elcertifikat/. Each certificate corresponds to 1 MWh of electricity generation.

At the start of the system, about 8% of the total number of issued certificates went to wind-power, this share had by 2018 increased to almost 58%. By contrast, over the same period biomass reduced its share from about 70% to less than 20%. This suggests an increasing competitiveness of wind. Note that the number of issued certificates is not necessarily the same as the number of cancelled certificates any given year.

Figure 25 Price of certificates (SEK/MWh). Source: https://www.ekonomifakta.se/fakta/energi/styrmedel/elcertifikat/

The price (Figure 25) of a certificate has displayed a downward trend since about 2009 and the price is predicted to be around zero in 2021, if the system remains unchanged. Organizations, such as those representing windpower, have recently been critical towards the system, whence the lowering of prices is an issue for mainly older plants, while newer plants are competitive at prevailing market prices of electricity.

2.1.2 Economic analysis

The aim of our economic analysis of the electricity certificate system is to illustrate how Swedish residents' welfare is affected. They can be affected as capital owners, e.g. of wind turbines; as wage earners, e.g. through employment in the construction of power plants; as consumers, eg. via the price impact of the certificates; as taxpayers, e.g. via VAT on electricity, and from a change of emissions of harmful substances from power production.

How the individual "summarizes" the impact on his welfare is nothing we can observe (or measure on any reasonable scale). What we can do, however, is to try to transform the impact of the certificates on individuals' welfare into an observable measure, money. Sometimes this is a straightforward measurement, e.g. when the individual's capital and /or salary is affected, or a changed tax burden. With regard to the impact on health of emissions, the measurement problem becomes more complicated.[3] Emissions are typically not priced in markets, the EU-ETS being an important exception. Prices on emissions are sometimes estimated indirectly, via damage costs. Property prices are affected by emissions, and with the help of statistical techniques, the impact of environmental impact on property prices can be calculated. In other cases, one uses interviewing techniques. One simply asks how much the individual is willing to pay to avoid the consequences of emissions (or the least compensation the individual must get to accept the emissions).

Because we are currently “in the middle of” the certificate's active period (2003–2045), we have carried out three different computations:

1. An ex post analysis for the period 2003–2017.
2. An ex ante analysis for the period 2018-2045.
3. An in-medias res analysis for the period 2003–2045.

In the table below, we summarize the results for the calculation for the period 2003–2045; the values have been rounded to billion SEK. The annual values have been discounted to the start year with an interest rate of three per cent (the sensitivity of the results to the choice of discount rate level is examined in the study).

[3] There is a huge literature, not the least in the US, estimating the value of preventing a fatality (or the value of a statistical life). Often observed/estimated wage-risk tradeoffs in markets are used for this purpose. But there are also many attempts to use survey techniques. Somewhat surprising, survey techniques, i.e., asking for the willingness-to-pay for a risk reduction, typically produce smaller values than techniques employing market data.

The alternative to the electricity certificates is "business as usual". The table thus shows what a particular category would have won or lost if the electricity certificates had never been introduced.

Table 1 The costs and benefits of scrapping the certificate system. Bill SEK.

Category	*Bill SEK*
Consumers of electricity	*102*
Capital owners	*-81*
Taxpayers, electricity tax	*-7*
Taxpayers, VAT	*-3*
Environmental quality	*-2*
Total	*9*

According to this calculation, electricity consumers would have been winners if the electricity certificates were never introduced. They would have saved just over SEK 100 billion through lower electricity prices. Owners of certificated power plants suffers a profit loss of just over SEK 80 billion. Tax income is reduced because the certificates are subject to VAT and energy tax. Furthermore, the loss of income results in reduced consumption for capital owners and thus another loss of VAT. It is assumed here that the increased electricity demand when the electricity price falls is met by coal power. This leads to emissions of various gases and particles that affect the health and the environment. The cost of these emissions is estimated at about SEK 2 billion. In total, the Swedish economy would have gained about SEK 9 billion if the electricity certificates had never been introduced. This assumes that all citizens are assigned the same weight in the calculation, i.e. we simply summarize the different (at least partially overlapping) categories in the table.

2.2 DISCUSSION

There are obviously policy issues involved that deserve discussion. If the intention was to reduce harmful emissions of greenhouse gases, the certificates were “overrun” by the EU ETS.

Nevertheless, policy makers may have targets for domestic emissions. However, it is hard to put a price tag on measures that reduce domestic emissions but have zero impact on global emissions, i.e., merely reshuffles emissions across countries and hence aggravates attempts by other countries to reduce their emissions. The revision of the EU-ETS may dampen the “waterbed effect” in the coming 2021-2030 trading period. This is because the cap itself may change following a change in the demand for carbon permits. The importance of this effect is debated and is not included in the calculations. In any case, it seems as the ambition rather has been to achieve (over time more and more ambitious) targets with respect to the number of TWh supplied by certain types of renewable sources (wind, solar, and so on).

Our analysis assumes that the time pattern for the addition of renewable sources would have been the same in our two scenarios (realized versus alternative). This assumption provides a kind of lower bound for the social loss of introducing the certificates. A more realistic assumption with respect to the alternative scenario is as follows. In the absence of certificates, the construction of renewable power plants would have been slower than in the observed scenario. The reason for this claim is a quite fast – and from the small open economy's point of view exogenous – technological development. Over time, this development has lowered variable as well as fixed costs of wind farms and other renewable power technologies. As noted, newer windpowerplants are competitive even without subsidies. Therefore, in the alternative scenario we would most likely have ended up with about the same installed capacity as the one observed. Investing at later points in time and using cheaper technologies would have saved costs to society. This claim is supported by recent proposals to “close” the certificate system i.e., not allocating certificates to plants becoming operational beyond a certain point in time; in December 2017 the Swedish government commissioned its Energy Agency to design such a stop mechanism.

One could possibly argue that there are ethical reasons for contributing to an international journey towards a sustainable world. On the other hand, there are also strong reasons for economizing on taxpayers' money. However, providing advice on such ethical issues is beyond our area of competence. Our more modest mission has been to apply economic theory to improve the decision basis for the selection of policy instruments in the future.

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ECONOMY-WIDE ANALYSIS OF SWEDISH NUCLEAR POWER AND ELECTRICITY CERTIFICATES

Här analyseras svensk energi- och klimatpolitik i ett övergripande perspektiv. Grundtanken har varit att studera hur ekonomins alla marknader anpassar sig till olika policy-förändringar.

Forskarna har använt en beräkningsbar allmän jämviktsmodell på konsekvenserna av minskad kärnkraftskapacitet och klimatpolitik, och gjort en samhällsekonomisk lönsamhetsbedömning för att belysa elcertifikatens samhällsekonomiska intäkter och kostnader. I båda fallen betraktas en liten öppen ekonomi med fungerande konkurrensmarknader.

Resultaten visar att en nedskalning av kärnkraften kostar ungefär en procent av BNP per år. Att ”gå före” i klimatpolitiken ger också betydande kostnader. Att avstå ifrån att införa elcertifikatssystemet hade sparat, sett över hela ekonomin, i storleksordningen 10 miljarder. En viktig del har varit att studera fördelningseffekter. Resultaten visar att det går att utforma klimatpolitiken så att den inte främst drabbar låginkomsttagare via kompenserande transfereringar. Till stöd för analysen har forskarna också detaljstuderat hur de svenska hushållen påverkas av elprishöjningar.