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Residential energy efficiency policies: Costs, emissions and rebound effects

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ABSTRACT

Ambitious energy efficiency goals constitute an important part of the EU's road to a low-carbon society. While the introduction and restructuring of climate policy instruments is taking place rapidly, knowledge of how the instruments interact is lagging behind. This analysis looks at the 2030 policy goals for residential energy efficiency and how they interact with targets for restricting CO_2 emissions. The case studied is Norway, which has committed to new climate policy targets for 2030 in line with the EU. A multi-sector computable general equilibrium model of the Norwegian economy is used to explore the cost, emission and energy rebound effects of alternative interpretations of the policy underlying the proposed 2030 energy efficiency goal. The model incorporates bottom-up information on energy efficiency investments and takes account of both energy and process emissions. The economic costs of the energy efficiency policies are found to be high: equivalent to a welfare loss of 1%. The costs rise when energy efficiency policies interact with carbon pricing. Economy-wide rebound amounts to nearly 40%, mainly because energy-intensive, trade-exposed industries expand. As emissions from these industries stem from both combustion and industrial processes, total CO_2 emissions increase by 2.4%.

1. Introduction[1]

Ambitious energy efficiency goals constitute an important part of the EU's road to a low-carbon society for 2030. The EU 2030 climate and energy framework (see [1]) includes targets to abate greenhouse gas emissions by at least 40%, raise the share of renewable energy by at least 27% and increase energy efficiency by at least 27%. In spite of the updated Winter Package of November 2016 (see [2]), the energy efficiency target is still the least specific part of the 2030 goals.[2]

This article analyses different ways to operationalize the 2030 energy efficiency policies and how achieving different targets are likely to influence economy-wide energy use, emissions and social economic costs. Particular attention is devoted to studying how energy efficiency policies interact with carbon pricing. In accordance with political signals (see [3]), the focus is on residential buildings and a 27% energy efficiency improvement in this sector is analysed. The case studied is Norway, which has committed to new climate policy targets for 2030 in line with EU targets, see [4] and [5]. Earlier policies in this field have mainly been based on standards for new buildings, investment subsidies, metering systems and energy labelling, see [6]. However, these have not delivered energy savings of the desired magnitude. A multi-sector Computable General Equilibrium (CGE) model is used in this paper to examine two different interpretations of the 27% energy efficiency target: (i) a cap on residential energy use and (ii) a cap on residential energy intensity.

This study makes four contributions. First, the costs of investing in improved energy efficiency are modelled by integrating bottom-up data on future costs and the potentials of energy efficiency technologies into the CGE model. The traditional CGE model approach has regarded energy efficiency as a cost-free, autonomous productivity growth process, see e.g., [7,8]. The bottom-up method for quantifying the costs of residential energy efficiency has resemblances with previous approaches for representing the costs of emission abatement using engineering knowledge, see [9,10] and

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[1] Abbreviations: CGE: Computable general equilibrium; SNOW-NO: Statistics Norway's world model – Norway; GAMS: General algebraic modelling system; MPSGE: Mathematical programming system for general equilibrium analysis; GTAP: Global Trade Analysis Project; CES: Constant elasticity of substitution; CET: Constant elasticity of transformation; EITE: Emission-intensive and trade-exposed; EUR: €.

[2] [2] suggests increasing the energy efficiency goal to at least 30%.

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[11]. Second, energy rebound effects are investigated in an economy-wide perspective that also takes account of the investment costs borne by households. This combination provides new insight into the major mechanisms behind energy rebound effects since previous contributions omit investment costs and/or cross-sector effects, see [12–14].

Third, the study contributes to the literature on how multiple policy instruments and targets in energy and climate policy interact. Earlier findings show that they tend to partly overlap or even counteract each other, see [15–18]. So far, energy efficiency policies have rarely been included in such interaction studies, as pointed out in [19] and [20]. This study finds that energy efficiency policies may increase carbon emissions, and when they are applied along with carbon pricing, the problem is aggravated. This is mainly attributable to increased emissions from manufacturing processes. Accounting for these process emissions is the fourth contribution made by this study. Apart from a few exceptions (such as [11,21]), process emissions are not included in CGE models.

2. Methodology

The methodology of this study involves two main steps: first, modelling and calibrating the Norwegian economy in a simultaneous system of equations that constitutes a multi-sector CGE model and, second, simulating the modelled system under different policy assumptions that form the baseline and energy efficiency policy scenarios.

The procedures of the first step, *the multi-sector CGE model*, are briefly presented in Section 2.1. It starts with an overview of the model in Subsection 2.1.1. Then, the procedures of the two specific modelling contributions of this paper are presented in detail: process emissions (Subsection 2.1.2) and energy efficiency investments in housing (Subsection 2.1.3).

The procedures of the second step, *simulation of the scenarios*, are described in Section 2.2, starting with the baseline scenario with no energy efficiency policies (Subsection 2.2.1), before proceeding to the scenarios with energy efficiency policies (Subsection 2.2.2).

2.1. The multi-sector CGE model

2.1.1. Overview of the model

A CGE model that describes the Norwegian economy, SNOW-NO[3] is used in the analysis. The model describes market interactions among all sectors of the economy: 41 production sectors and households (see the list of sectors in Table A1 of Appendix A), as well as cross-border trade interactions. Hence, it makes it possible to study economy-wide impacts of energy efficiency policies that are introduced to one sector of the economy. The CGE model is calibrated to Norwegian National Accounts data for 2011.

The model assumes optimising agents: producers maximise profits and the representative consumer maximises welfare. The model finds equilibrium prices and quantities by simultaneously solving the set of equations that satisfy the profit-maximisation and welfare-maximisation conditions. This determines production, consumption, export and import levels for all goods, input use in each industry, prices of all goods and input factors (labour, capital and energy resources), and CO_2 emissions.

The 41 sectors are assumed to produce one good each. There are five energy-producing industries: coal, oil and gas extraction,

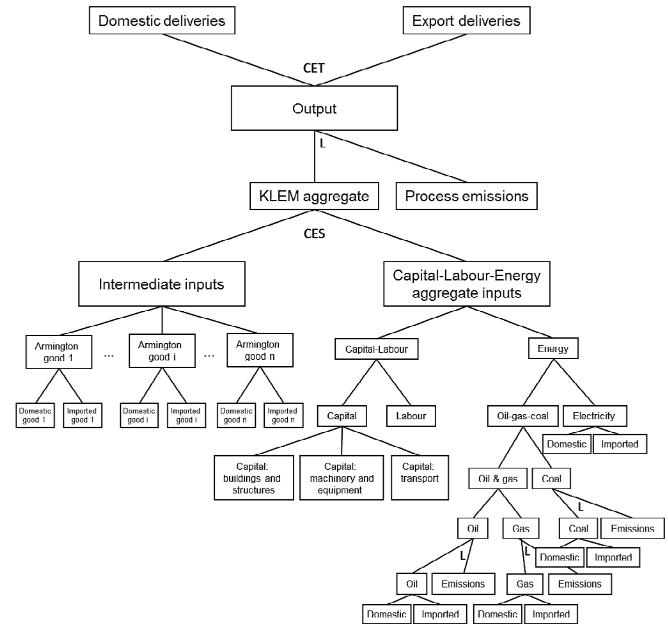

Fig. 1. Production technology, nested CES structure. L denotes nests with Leontief structure, i.e. no substitution possibilities.

refined coal and oil products, gas distribution, and electricity. In addition, there are 18 final consumption goods (including six energy goods, see the list in Table A2 of Appendix A). The consumer's choice of different goods is described in detail in Subsection 2.1.3 below. The production technologies of all commodities (incl. final consumption goods) are described by nested Constant Elasticity of Substitution (CES) functions, that describe the combinations of capital, labour, energy and intermediates in each industry, see Figs. 1 and 2.[4] For most commodities, the combination of capital, labour, energy and intermediate products that is used in production can change, depending on prices. For production of fossil fuels (coal, gas and oil), all inputs except the sector-specific fossil fuel resource are aggregated in fixed proportions (Fig. 2).

Total supply of labour and capital in the economy are given, but labour and capital are perfectly mobile between industries, implying that investments can take place gradually. The model is of a small, open economy; thus, the world market prices are considered as exogenous. Domestic and imported goods are considered imperfect substitutes, see [22].[5]

2.1.2. Modelling emissions from energy use and industrial processes

CO_2 emissions from both energy use and industrial processes are modelled. Energy-related CO_2 emissions are linked in fixed proportions to the use of fossil fuels, with CO_2 coefficients differentiated by the specific carbon contents of the fuels; see Figs. 1 and 2. The disaggregation of energy goods into coal, crude oil, natural gas, refined oil products and electricity is essential in order to differentiate energy goods by CO_2 intensity and degree of

[3] The model SNOW-NO (Statistics NOrway's World model – NOrway) is developed in GAMS/MPSGE (see [36,37]) in order to study energy and environmental policies and strategies, see [38].

[4] The nested CES function (see [39]) is standard in CGE models and a particular feature of models in the MPSGE format. The functions nest inputs and quantify their use according to values for substitution elasticities and share parameters. The quantifications differ among commodities and are based on conventional estimations, see [40–43], in addition to other pertinent literature as collected in the GTAP database, see [44]. See [32] for a discussion of the appropriability of the CES functional form.

[5] The quantification of Armington substitution elasticities is based on estimates in [45].