Publizierbarer Endbericht

Gilt für Studien aus der Programmlinie Forschung

A) Project Data

General information about the project	
Short title:	FARECarbon
Long title:	Fair and effective carbon pricing for Austria: insights from model comparison
Recommended form of citation:	Köberl, J., Kulmer, V., Bachner, G., Kettner-Marx, C., Kirchner, M., Kortschak, D., Leoni, T., Mayer, J., Sommer, M., Splitter, N., Wallenko, L. (2023). Fair and effective carbon pricing for Austria: insights from model comparison, Final report.
Program (incl. year):	Austrian Climate Research Programme 12th Call 2019
Period:	01.11.2020 – 30.04.2023
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Project and cooperation Partners (incl. Province):	Austrian Institute of Economic Research (Vienna) University of Graz, Wegener Center for Climate and Global Change (Styria) University of Natural Resources and Life Sciences, Center for Global Change and Sustainability (Vienna) Climate Change Centre Austria (Vienna/Styria)
Keywords:	CO_2 pricing, distribution effects, multi-model comparison, inequality
Total project costs:	249,428 €
Funding sum:	249,428 €
Klimafonds-Nr:	KR19AC0K17507
Date of creation:	21.07.2023

B) Project overview

1 Kurzfassung

Motivation & Ziele

Um die Klimakrise zu bewältigen, braucht es eine grundlegende Dekarbonisierung unserer Wirtschaft und Gesellschaft. Dies erfordert ein breites Bündel an klimapolitischen Maßnahmen, einschließlich der Bepreisung von CO_2. Die Bepreisung von CO_2 und insbesondere CO_2-Steuern sind jedoch nicht unumstritten und werden in Wissenschaft und Politik ausgiebig diskutiert. Die Forschung spricht sich für CO_2-Steuern als wesentlichen Eckpfeiler der Klimapolitik aus, da sie Emissionen durch Anreize für emissionsärmere Aktivitäten erheblich reduzieren können. Außerdem sind Steuern auf Emissionen aus ökonomischer Sicht sowohl wirksam als auch effizient und schneiden häufig besser ab als andere Instrumente. Aufgrund des potentiell verzerrenden Charakters einer CO_2-Steuer werden die Auswirkungen auf die Wirtschaft und die Verteilungseffekte jedoch intensiv diskutiert und sollten sorgfältig untersucht werden. Um politisch durchsetzbar und gesellschaftlich akzeptabel zu sein, muss die Ausgestaltung einer CO_2-Steuer bzw. allgemeiner einer CO_2-Bepreisung (und ergänzender Ausgleichsmechanismen, die potenzielle negative Wettbewerbs- und Verteilungseffekte abmildern) verschiedene – manchmal widersprüchliche – Kriterien erfüllen: Sie sollte effektiv, wirtschaftlich effizient und gleichzeitig sozial gerecht sein und einen Ausgleich zwischen privaten, öffentlichen und unternehmerischen Interessen schaffen. Um die Auswirkungen einer CO_2-Bepreisung für verschiedene Akteure zu bewerten, ist daher eine gesamtwirtschaftliche Modellierung erforderlich. Je nach verwendetem ökonomischen Modellierungsansatz, Studienaufbau und Zieldimension ergeben sich jedoch unterschiedliche und manchmal widersprüchliche Ergebnisse und damit auch abweichende Politikempfehlungen zur Implementierung einer CO_2-Bepreisung.

Ziel von FARECarbon war es, (i) Modellunsicherheiten zu identifizieren und die Bandbreite der Effekte einer CO_2-Bepreisung zu analysieren, und (ii) Empfehlungen für die Umsetzung der CO_2-Bepreisung für Nicht-ETS-Sektoren[1] in Österreich abzuleiten.

Aktivitäten & Methoden

In FARECarbon wurde ein von Stakeholdern unterstützter Multi-Modell-Vergleich von makroökonomischen Modellen für Österreich durchgeführt. Abgestimmte CO_2-Preis- und Rückvergütungsszenarien wurden mit verschiedenen makroökonomischen Modellen simuliert, die auf unterschiedlichen Wirtschaftstheorien und Annahmen beruhen, sowie einem nachgelagerten Mikrosimulationsmodell. Diese Simulationen bieten eine solide Grundlage für politische Entscheidungsträger:innen, indem sie die Bandbreite der erwarteten Auswirkungen und die damit verbundenen Unsicherheiten veranschaulichen. Die enge Zusammenarbeit mit den Stakeholdern während des gesamten Projekts führte einerseits zur Definition abgestimmter Politikszenarien und

[1] Sektoren, die nicht von der CO_2-Bepreisung im Emissionshandelssystem (ETS) auf EU-Ebene erfasst sind, wie Verkehr oder Gebäude.

stellte andererseits die Integration der unterschiedlichen Perspektiven der Stakeholder in die Entwicklung eines Vorschlags zur Weiterentwicklung der CO_2-Bepreisung und möglicher Begleitmaßnahmen (z. B. die Einnahmenverwendung) in Österreich sicher.

Ergebnisse & Schlussfolgerungen

Unsere Analysen zeigen unterschiedliche makroökonomische Wirkungsketten der CO_2-Bepreisung in zwei gängigen Modellierungsansätzen (neoklassisch und neokeynesianisch) auf. Während es bei zwei Hauptwirkungsketten Gemeinsamkeiten in Form von Produktivitätsverlusten und einer Verlagerung hin zu arbeitsintensiven Sektoren infolge der CO_2-Bepreisung in Nicht-ETS-Sektoren gibt, finden wir erhebliche Unterschiede in der Art und Weise, wie Wirkungsketten am Arbeitsmarkt, Kapitalmarkt, Güter- und Dienstleistungsmarkt und im öffentlichen Haushalt Preise, Einkommen und Konsum beeinflussen. Ein entscheidender Unterschied besteht auch darin, wie der (private und öffentliche) Konsum auf Einkommensänderungen reagiert. Die Art der Einnahmenverwendung kann die Wirkungsketten verstärken oder abschwächen - was sich zum Teil ebenfalls zwischen den Modellvarianten unterscheidet.

Diese strukturellen Unterschiede hervorzuheben, kann die Bandbreite der potenziellen Auswirkungen einer CO_2-Bepreisung über verschiedene makroökonomische Disziplinen hinweg offenlegen und ermöglicht politischen Entscheidungsträger:innen, eine hinsichtlich der zu erwartenden Auswirkungen robuste CO_2-Bepreisungsvariante unter Berücksichtigung des aktuellen Zustands und der aktuellen Struktur der Wirtschaft auszuwählen. Bezüglich robuster Politikoptionen für die Einnahmenrückführung zeigen unsere Analysen, dass eine Senkung der Lohnnebenkosten zwar die Wirtschaftstätigkeit ankurbeln kann, aber nicht in der Lage ist, die regressiven Auswirkungen der CO_2-Besteuerung abzumildern. Der gegenteilige Effekt ist bei der Rückführung der Einnahmen in Form von Klimabonuszahlungen zu beobachten. Das höchste Potenzial für eine dreifache Dividende, d.h. positive ökologische, makroökonomische und verteilungspolitische Effekte der CO_2-Bepreisung in Kombination mit der Einnahmenrückführung, liegt in einer Kombination dieser beiden Optionen. Nachgelagerte Mikrosimulationen deuten bei einem solchen Policy-Mix auf eine Verbesserung der Einkommensgleichheit, aber auch auf einen Anstieg der Lebenshaltungskosten, vor allem für Haushalte in dünn besiedelten Gebieten, hin.

2 Executive Summary

Motivation & goals

To solve the climate crisis, a fundamental decarbonization of our economy and society is needed. This requires a comprehensive mix of climate policy measures, including the pricing of carbon emissions. Carbon pricing – and particularly carbon taxes – are highly debated in the scientific and policy arena. Research argues for carbon taxes as an essential cornerstone in future climate policy as they may substantially reduce emissions by incentivizing lower carbon activities. Moreover, from an economic point of view, emission taxes are both effective and efficient, often outperforming other instruments. However, due to the potentially distortionary character of a carbon tax, effects on the economy and distributional impacts are discussed intensively and should be carefully examined. For political feasibility and social acceptability, the design of a carbon tax or carbon pricing in general (and complementary compensation mechanisms that mitigate potential negative competitiveness and distribution effects) has to fulfil various – sometimes contradicting – criteria: It should be effective, economically efficient and at the same time socially fair, balancing private, public and business interests. Thus, when assessing the effects of carbon pricing for different actors, economy-wide modelling is needed. However, depending on the used economic modelling approach, study setting and target measure, there are different and sometimes contradictory results and hence divergent policy recommendations on how to implement carbon pricing.

The main objectives of FARECarbon were (i) to identify model uncertainties and inform the debate on the effects of carbon pricing, and (ii) to develop recommendations on the design of carbon pricing for Non-ETS sectors[2] in Austria.

Activities & methods

FARECarbon employed a stakeholder-assisted multi model comparison of carbon pricing in Austria. In a nutshell, concerted policy scenarios were simulated with different macroeconomic models, which are rooted in different economic theories and assumptions, and a downstream microsimulation model. These simulations provide a sound basis for policymaking by illustrating the range of expected effects and related uncertainties, a so called "options space". The close collaboration with stakeholders throughout the project on the one hand resulted in the definition of concerted policy scenarios and on the other hand ensured the integration of stakeholders' perspectives in the development of recommendations for the further development of carbon pricing and associated supporting measures (e.g. revenue recycling) in Austria.

Results & conclusions

Our analyses highlight different macroeconomic impact chains of carbon pricing policies across two common modelling approaches (Neoclassical and New Keynesian). While there is commonality regarding two primary impact chains, i.e., loss in productivity and a shift towards labor-intensive sectors due to carbon pricing in non-ETS sectors, we find substantial differences in how impact chains in the labor market, capital market, goods and services market, and the public budget affect prices, income, and consumption. A crucial difference can also be identified in how consumption (both private and public) reacts to changes in income. Revenue recycling measures can amplify or mitigate against impact chains – which may also differ between model variants.

Highlighting theses structural differences can shed light on the bandwidth of potential impacts of carbon pricing across different macroeconomic disciplines and allows policymakers to select a carbon pricing policy that is robust in terms of expected impacts, considering the current state and structure of the economy. With respect to robust policy options for revenue recycling, we find that a reduction in non-wage labor costs can boost economic activity but is not able to mitigate the regressive effects of carbon pricing. The opposite is true for revenue recycling via climate bonus payments.

[2] That is, sectors not covered by carbon pricing in the emission trading system (ETS) at the EU level, such as transport and buildings.

The highest potential for a triple dividend, i.e. positive ecological, macroeconomic and distributional effects of carbon pricing in combination with revenue recycling, lies in a combination of these two recycling options. Downstream microsimulations indicate improvements in income equality for such a policy mix, but also increases in the cost of living, particularly for households in thinly populated areas.

3 Background and goals

Initial situation and motivation for the project

In order to solve the climate crisis and mitigate its fatal consequences (Hoegh-Guldberg et al., 2019; IPCC, 2018; Lenton et al., 2019), a fundamental decarbonization is required. However, current efforts do not suffice to reach this goal (Rockström et al., 2017).

Under "The European Green Deal", the European Commission (EC, 2019) has set ambitious targets and milestones to decarbonize the European Union until mid of the century. Besides radical technological changes, a comprehensive policy mix that takes into account social considerations is needed to meet these emission reduction targets, with carbon pricing as a core pillar. Carbon pricing – and particularly carbon taxes – are highly debated in the scientific and policy arena. Research argues for carbon taxes as an essential cornerstone in future climate policy as they may substantially reduce emissions by incentivizing lower carbon activities (Mattauch et al., 2019). According to economic theory, carbon taxes are both effective and efficient, often outperforming other instruments (Fischer and Newell, 2008; Goulder and Parry, 2008). Yet, although carbon taxes have the advantages to be easily implemented, based on existing structures, entailing low administrative costs and provide a stable fiscal incentive for emission reduction, they are among the least used climate policy instruments (Carratini et al., 2017; Barrage et al., 2020). This low penetration is largely due to concerns about the potentially distortionary character and regressive nature of carbon taxes. Consequently, in order to ensure political feasibility and enhance social acceptability, the design of a carbon tax or carbon pricing in general has to fulfil various criteria (Klenert et al., 2018; Andersson, 2019): It should be effective, economically efficient and at the same time socially fair, balancing private, public and business interests. Thus, when assessing the effects of carbon pricing for different actors, economy-wide modelling is required. However, depending on the economic modelling approach, study setting and target measure, there are different and sometimes contradictory results and hence divergent policy recommendations on how to implement carbon pricing.

Objectives of the project

The main objectives of the project FARECarbon were (i) to identify model uncertainties and inform the debate on the effects of carbon pricing, and (ii) to develop recommendations on the design of carbon pricing for Non-ETS sectors[3] in Austria.

[3] That is, sectors not covered by carbon pricing in the emission trading system (ETS) at the EU level, such as transport and buildings.

To meet these objectives, FARECarbon performed a stakeholder-assisted multi-model comparison of three sophisticated macroeconomic models of Austria: the New Keynesian input-output model DYNK (Kirchner et al., 2019; Sommer and Kratena, 2019) and the Neoclassical Computable General Equilibrium (CGE) models WEGDYN_AT (Mayer et al., 2021) and ECON_AT (Kulmer and Seebauer, 2019; Kulmer, 2013). Moreover, a microsimulation model in the form of an Exact Affine Stone Index (EASI) demand system was coupled to DYNK to study distributional impacts on different household groups in further detail. FARECarbon strived to shed light on the manifold potential effects of implementing carbon pricing for the Non-ETS sectors by taking a comprehensive perspective, including the assessment of side effects such as equity and fiscal effects and the identification of adjustment measures for mitigating potential negative impacts. Furthermore, the project aimed to integrate various views and to consider institutional restrictions by involving a wide and transdisciplinary group of stakeholders engaging in a dialogue to enable broad acceptance of the project results and co-created policy recommendations.

4 Project content and result(s)

FARECarbon was structured as an iterative process, resulting in robust, model-based and co-generated recommendations for carbon pricing in Austria, including compensation mechanisms. It consisted of six interlocking content-related work packages (see Figure 1), complemented by a project management work package (WP7).

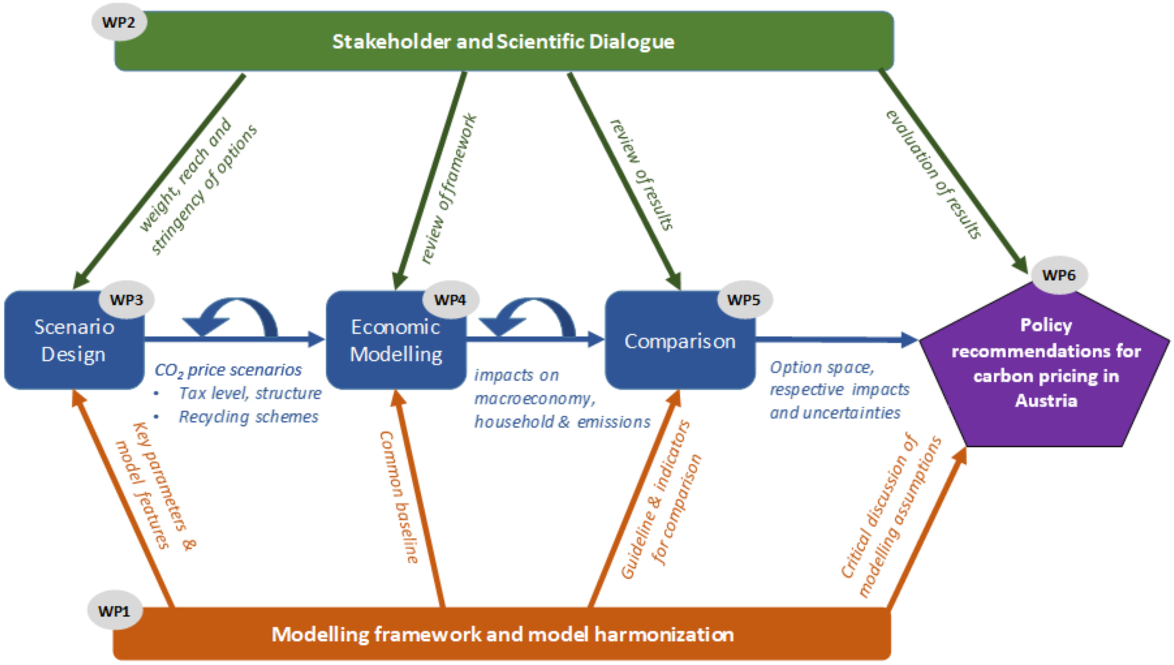


Figure 1: Overview of work packages and their relations

WP1: Modelling framework and model harmonization

Goals

In WP1, we aimed at building the modelling comparison framework, defining a set of common scenarios for the overall analysis, defining common indicators for impact quantification, and providing guidelines for the comparison of model features and model results in WP5.

Activities & key results

In WP1, we laid the cornerstone for the systematic cross-model feature comparison in WP5, by providing a systematic and transparent comparison of the most essential (differences in) parameter assumptions and modelling features. The comparison included (i) general features such as dynamics, closures, technological treatment, etc., (ii) implementation of carbon pricing and emission growth, and (iii) other assumptions such as elasticities, energy efficiency improvement, growth drivers, etc. The overview of the critical parameters and modelling features of the three macroeconomic models DYNK, WEGDYN_AT and ECON_AT, which served as basis for the systematic model comparison, is shown Table 5 in the Appendix.

Based on literature review and discussions within the consortium, we defined a harmonized baseline scenario regarding population growth, climate policy efforts (i.e. emissions development) and GDP growth, shared by all macroeconomic models in WP3. We used the "With Existing Measures" (WEM) scenario from UBA and its underlying assumption with respect to GDP growth and technological change as a guideline (Anderl et al. 2019). Moreover, we were guided by the Impact Assessment of the 'Fit for 55' Package (European Commission, 2021) to assume ETS price development up to 2030 (see Table 1 in the description of WP3). Given the targets, each model used total factor productivity (TFP) growth rates, energy efficiency improvements or other parameters to calibrate their baseline in WP4.

To enable a systematic comparison of results across models and carbon pricing scenarios in WP5, we identified common indicators and measures for impact quantification. These indicators had to fulfill two criteria: reflect the objective of FARECarbon of effective, economically efficient and socially fair carbon pricing on the one hand and being producible by each model on the other hand. The following indicators and measures were selected for this purpose:

- *Carbon emissions*: ETS, Non-ETS, process and total emission
- *Macroeconomic indicators*: GDP and GDP decomposition on income and expenditure side, imports, exports, investment, carbon pricing revenues (ETS and Non-ETS separate)
- *Industry output*: Output value and prices
- *Private consumption spending*: Private consumption and welfare indicator by household group
- *Public demand*: Public consumption
- *Prices*: Factor prices and consumer price indices

WP2: Stakeholder and Scientific Dialogue

Goals

Our main objective in WP2 was to establish a continuous involvement of political, public and scientific stakeholders in order to discuss, prioritize, weight and contrast findings as well as methodological steps throughout the project lifetime.

Activities & key results

We established three different formats of stakeholder involvement: (i) a stakeholder steering committee (SSC), (ii) a scientific advisory board (SAB), and (iii) stakeholder workshops.

Stakeholder Steering Committee (SSC)

The SSC was installed at the beginning of the project to ensure a close link to the current political debate and for the continuous discussion and review of preliminary findings and relevant milestones. In total, the SSC consisted of six members with representatives from the Federal Ministry for Climate Action, Environment, Energy Mobility, Innovation and Technology (BMK), the Federal Ministry of Finance (BMF), the Austrian Chambers of Labor and the NGO Global 2000. The (online) meetings started at a quarterly basis and were changed to occasion-related scheduling at a later stage.

Scientific Advisory Board (SAB)

In addition to the SSC, the project team exchanged with the international SAB, consisting of Tom Kober (Paul Scherrer Institute), Mikael Skou Andersen (Aarhus University) and Sara Wong (Escuela Superior Politécnica del Litoral). The SAB critically commented on preliminary results and paper drafts and provided focused inputs from their own research activities.

Stakeholder Workshops

Moreover, three stakeholder workshops with representatives from administration, research, NGOs and interest groups were organized in the course of FARECarbon. The two workshops at the beginning of the project (2 March & 6 March 2021) aimed at developing carbon price scenarios and deciding on revenue recycling measures to be simulated in FARECarbon (see WP3). Due to the COVID situation at that time, they were both held online. The third stakeholder workshop, organized as a hybrid event, took place in the final stage of the project (16 March 2023) and aimed at disseminating FARECarbon results and co-developing policy recommendations for carbon pricing in Austria (see WP6).

WP3: Scenario Design

Goals

The goal of WP3 was to define carbon price and revenue recycling scenarios in close cooperation with stakeholders and based on theoretical and empirical evidence from the literature.

Activities & key results

A thorough review of the literature on carbon pricing and revenue recycling – covering both (theoretical) scientific literature and available empirical evidence from countries or regions where carbon pricing in non-ETS sectors had already been implemented – built the basis for scenario development. Based on this literature review, the key parameters of the scenarios were defined in two online workshops with researchers and stakeholders in March 2021 (see also WP2). Following political developments at the national and supra-national level (presentation of the EU "Fit for 55" package in July 2021 and of the Austrian plans for the implementation of a carbon price in September 2021), the scenarios were adapted in autumn 2021 and the modifications discussed with the SSC. The final set of carbon price scenarios used in FARECarbon includes two main scenarios for the evolution of carbon pricing in Austria and five options for revenue recycling.

Both pricing scenarios share the assumption that the assessment basis is fossil fuel use in sectors not covered by the EU emission Trading Scheme (EU ETS). The carbon price hence applies primarily to transport and buildings as well industry not included in the EU ETS. Pricing scenario A illustrates a moderate price development. A carbon price level as defined by the Austrian government is assumed for the period 2022 to 2025 (see Table 1); afterwards the price is assumed to linearly increase to 90 € per ton of CO_2 (in current prices). This increase between 2025 and 2030 amounts to approximately 10% p.a., a growth rate that e.g. was also assumed by Edenhofer et al. (2019), developing a lower carbon price path for Germany until 2030[4]. The more ambitious pricing scenario B starts with a price of 50 € per ton of CO_2 – i.e. the average price level observed in the EU ETS between January and October 2021 – which is then linearly increased to 156 € per ton in 2030. This price increase corresponds to the increase of the carbon price for current Non-ETS sectors up to 2030 as assumed in the 'Mix-CP' scenario in the Impact Assessment of the 'Fit for 55' Package (European Commission, 2021).

Table 1: Assumed development of carbon prices by scenario in €/tCO_2

	Non-ETS price scenario A		Non-ETS price scenario B		ETS price scenario (baseline)	
	nominal	real	nominal	real	nominal	real
2022	30	27	50	46	50	46
2023	35	31	…..		linear increase	
2024	45	40	linear increase		…	
2025	55	48	…		69	60
2026-2029	linear increase				linear increase	
Target 2030	**90**	**73**	**156**	**127**	**102**	**83**

Note: Real prices refer to the price level 2015; *ETS price already active in baseline in order to isolate effects of non-ETS CO_2 pricing.

Recycling scenarios were chosen based on two deliberations: First, they should be able to significantly mitigate the impacts of carbon pricing on vulnerable households and/or cushion negative impacts on competitiveness for industry. Second, a reasonable implementation of the scenarios in the models should be feasible. Since neither of the used macroeconomic and microsimulation models can, for example, adequately model

[4] The Austrian price path corresponds to the price development defined for the German emissions trading system in the period until 2030.

green spending – i.e. investments in energy efficiency, renewable energy sources, etc. – we refrained from analyzing such a recycling option. The following options were defined to be simulated in WP4:

1. Non-Targeted Recycling (NTR): Use of revenues to increase the provision of public goods without any specific earmarking.

2.a Climate Bonus Recycling (CBR): Revenue recycling via equal per capita payments to all Austrian households.

2.b Climate Bonus Recycling for low-income households (CBRlow): Revenue recycling via equal per capita payments to low-income households.

3. Non-wage Labor Cost Reductions (LCR): Use of revenues to reduce employers' non-wage labor costs, whereby labor costs are assumed to become cheaper for employers, but wages remain the same for employees.

4. Value Added Tax Reductions (VTR): Revenues are used to further decrease the value added tax on basic necessity goods currently covered by reduced rates (e.g. food and beverages, books, etc.).

5. Combination of Reductions in Non-wage Labor Costs and Climate Bonus Payments (MIX, MIXlow).

For all recycling scenarios revenue neutrality is assumed, i.e. all revenues generated by carbon pricing are used for the recycling measures.

WP4: Economic Modelling

Goals

The main objective of WP4 was to carry out the modelling analysis according to the previously defined framework conditions (from WPs 1-3) and to interpret the generated results individually in preparation for the comparison of model results in WP5.

Activities & key results

WP4 comprised the core modelling activities of FARECarbon. Based on the general framework conditions (WP1), stakeholder input (WP2) and specific scenario assumptions (WP3), the selected carbon pricing and revenue recycling scenarios were quantitatively analyzed by the three macroeconomic models DYNK, WEGDYN_AT and ECON_AT (see section C for further details on the single models).

In a first step, the underlying emission databases were refined and updated to ensure that all three models used the same dataset. Following the update of the emissions inventory, the baseline scenarios of the models were harmonized. We used (i) the Impact Assessment of the 'Fit for 55' Package to assume ETS price development up to 2030 as well as (ii) the "With Existing Measures" (WEM) scenario and its underlying assumption with respect to GDP growth and technological change. Note that these development paths were used as a guideline and not as a hard calibration target, as some flexibility was needed for the different models.

In a second step, the carbon price and revenue recycling scenarios as defined in WP3 were implemented and simulated by each model. Since both CGE models (WEGDYN_AT and ECON_AT) turned out to produce quite similar results, in-depth analyses focused on the comparison between CGE and input-output model in the form of WEGDYN_AT and DYNK. Below, we thus only describe the final results of these two macroeconomic models.

In addition to the macroeconomic model runs, a microsimulation model in the form of an Exact Affine Stone Index demand system – referred to as EASI_AT in the following – was coupled to DYNK to study distributional impacts on different household groups in further detail. The coupling followed a unidirectional soft-link approach: for the baseline and each considered recycling scenario, changes in consumption expenditures and in commodity prices in DYNK were transferred to EASI_AT.

In the following, the major results of the two macroeconomic models DYNK and WEGDYN_AT in terms of macroeconomic effects and emissions are summarized. For the distributional effects indicated by the macroeconomic models and the microsimulation model, see the WP6 description below. Each time, results are primarily discussed for price scenario A. Generally, results for price scenario B were structurally very similar to scenario A, but more strongly (positively or negatively) pronounced, as shown exemplarily in Figure 2 for the impacts of carbon pricing and revenue recycling on GDP in DYNK.

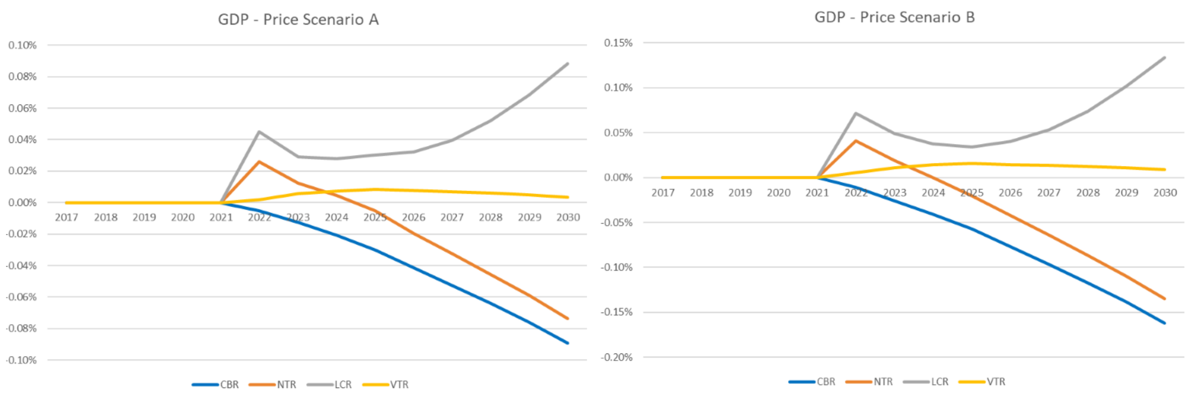


Figure 2: Impacts (i.e. baseline deviation) of different carbon price paths on GDP according to DYNK.

Key results of WEGDYN_AT

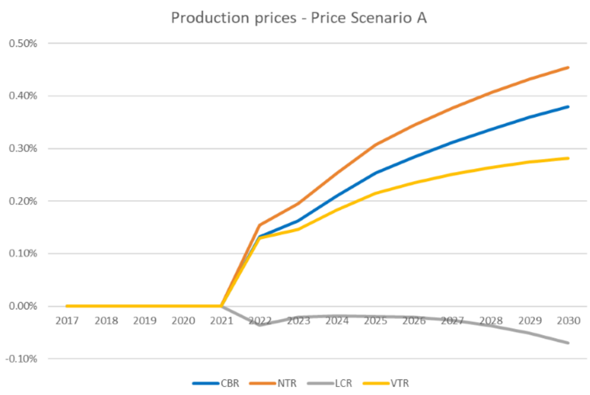
WEGDYN_AT was run in two alternative versions: one with existing unemployment and another one with employment on the labor market. Under the former version a minimum real wage is introduced (wages are "sticky"). If the wage rate would fall below this level, people would choose to supply less labor to the market, creating unemployment. Hence the rate of unemployment is endogenously changing. Under the latter version, labor is fully employed, implying that the real wage is able to change such that the labor market is cleared.

Macroeconomic effects: Generally, the impact on GDP is modest across all scenarios and model closures (i.e., full employment [Full] or unemployment [Unemp] at the labor market), lying in the range of -0.61% to +0.4% compared to the baseline by 2030. The same holds for total welfare (the sum of real consumption expenditures by private households and the government), with a range of -0.6% to +0.17% and private welfare, with a range of -0.98% to +0.15%. From the perspective of total welfare, recycling via non-wage labor cost reductions (LCR) performs best under [Unemp] and recycling via VAT reductions (VTR) performs best under [Full]. The different outcomes of [Unemp] and [Full] indicate that a lot of structural uncertainty can arise already within one model depending on the respective closure rules in place, since relative prices react very sensible to these assumptions.

Effects on emissions: The reduction of emissions resulting from the imposition of a carbon price is very similar throughout all scenarios and labor market variants. Overall emissions (ETS and non-ETS) decline by -4.51% to -5.50% compared to the baseline by 2030. Since the implemented CO_2 price affects non-ETS CO_2 emissions only, the effect is more strongly pronounced for the latter with a decline of emissions ranging from -6.74% to -7.54%. The decline of emissions in ETS sectors arises only indirectly from the general reduced market activity and amounts to -1.55% to -2.43%. Note that an increase in the carbon price by 70% compared to scenario A (i.e. carbon price scenario B) pushes the decrease in overall emissions only about 56% (or 2.5%-points) further.

<u>Key results of DYNK</u>

Macroeconomic effects: Recycling via lump-sum payments (CBR) shows the most negative macroeconomic development (see Figure 2 (left) and Figure 3). While there is an increase in private consumption, the trade balance is negatively affected: exports decrease due to the worsening of the terms of trade and imports increase due to the import intensity of private consumption. Reductions in the VAT (VTR) show immediate positive impacts due to price decreases, which strengthens domestic production. Production prices increase, but to a lesser extent than in CBR, which results in a better trade balance than in CBR. Reductions in non-wage labor costs (LCR) have a strong impact on employment demand and therefore on wages and private consumption. The production price decrease due to the labor cost reduction is overcompensating the price increase caused by higher demand. Impacts on GDP are the most positive among all scenarios. Using the revenues to increase the provision of public goods (NTR) initially results in a positive impact on domestic production and employment due to the labor intensity of public consumption. However, in the mid-run, the positive impact is overcompensated due to rising prices on the labor market. Without the price-dampening element as in LCR, costs for labor rise stronger than the positive GDP impact caused by public demand, turning real GDP impact into negative values



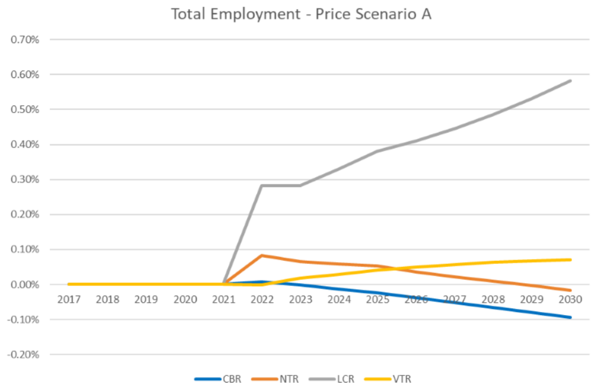


Figure 3: Impacts (i.e. baseline deviation) of carbon pricing on production prices and employment according to DYNK.

Effects on emissions: The impact of carbon pricing on non-ETS emissions (excluding fuel export in vehicles) is basically uniform across all recycling scenarios. That is, by 2023 non-ETS emissions deviate on average by -5.4% compared to the baseline development. Note that in carbon price scenario B, emission reduction reaches 8.2% by 2030. Hence, an increase of the carbon price of over 70% (156 €/ton vs. 90 €/ton) pushes the decrease of emissions only 52% further (8.2% vs. 5.4%) down. This shows that those sectors, which can react to carbon pricing start to reach low levels of emissions and cannot reduce further limits. Other sectors that have limited possibilities (e.g. commodity transport) try to transfer the price increase to the consumer.

WP5: Comparison

Goals

The main goals of WP5 included (i) a cross-model feature comparison, (ii) a systemic state-of-the-art comparison of modelling results and (iii) the assessment of different types of uncertainty. All relevant results of WP5 are provided in detail in a Working Paper (Kirchner et al., 2023), available on the FARECarbon website (https://farecarbon.joanneum.at/). Here, we summarize the most important findings.

Activities & key results

To identify structural uncertainty and thus differences in impact chains between the two macroeconomic models WEGDYN_AT and DYNK, we applied an inter-model comparison analysis (Rosenzweig et al., 2017; Warszawski et al., 2014). This required:

(1) a qualitative screening of (a) uncertainties and (b) structural differences between the models by applying uncertainty framework tables (Walker et al., 2003) and by a side-by-side comparison of key assumptions and characteristics (see below),

(2) a harmonization of model input data, output data and scenario parameters (see WP 4), and

(3) identifying and comparing the impact chains that drive the quantitative outputs of model simulations of carbon pricing and revenue recycling policies (see below).

Cross model feature comparison

An overview of relevant (but not exhaustive) features of and related uncertainties in the models is provided in Table 6 in the Appendix. It applies the uncertainty framework table (UFT) concept (Kirchner et al., 2021; Refsgaard et al., 2007; Walker et al., 2003). The UFT allows to qualitatively scan potential uncertainty locations in a model (framework) and how these uncertainties can be categorized and addressed (types of uncertainties). We are particularly interested in uncertainties that are relevant for inter-model comparisons. Hence, we specifically investigate the impact of model structure uncertainty expressed as scenario uncertainty (cell colored in black in Table 6), as this is also where differences in theoretical assumptions and thus impact chains between Neoclassical and New Keynesian models manifest themselves. Such uncertainties comprise differences in production and consumption functions, labor and capital markets, factor market closures, trade closure and government closure.

General differences regarding default assumptions of the economy in the two models are:

- In a CGE model with scarce production factors, such as WEGDYN_AT, the economy is implicitly assumed to be in a boom phase. A positive demand shock, e.g. through financial or real demand stimuli, is ineffective because firms' order books are full and production is at full capacity. Hence, the consequences of additional demand are either crowding out (e.g. less consumption for higher investment) and/or changes in relative price levels ("overheating" for some products).
- In a demand-driven New Keynesian model such as DYNK, the economy is assumed to be in an output gap situation. Exogenous stimuli result in a positive impact output. It is assumed that capital is not scarce but labor supply can be a limiting factor. At a high unemployment rate a stimulus results in increasing real production but at low rates the pressure on wages increases. This push in wage rates represents the scarcity of labor and reduces the real production via inflation.

Alternatively, this fundamental difference can be interpreted as long-term versus short-term perspective, with WEGDYN_AT representing long-term reactions to exogenous shocks while DYNK represents short-term reactions to exogenous shocks assuming unconstrained capital.

Table 7 in the Appendix provides a detailed overview of structural differences. Many structural differences are rather small and not likely to lead to vastly different results for carbon pricing scenarios overall, especially those regarding the production structure such as coverage of production sectors and technologies, sectoral production functions or elasticities of substitution. Table 2 highlights structural differences that are likely to lead to significantly different results between the models. Here, we identify three distinct impact chains: (1) price (market) channels, (2) income channels, and (3) consumption channels.

To assess the impact of these channels we look at the following indicators from the model simulations:

- Consumer price indices → Price channels

- Income → Income channels
- Welfare → Consumption channels

These three indicators are each considered separately as private, public, and total effects. Welfare is approximated through real consumption possibilities. Since the provision of public goods also contributes to welfare, total welfare is the sum of private and public consumption possibilities (see Mayer et al., 2021 for a discussion on this issue). We assume that, public consumption is distributed equally per capita (since there is uncertainty regarding the household specific private gains from public consumption, we assume that welfare gains from public consumption are distributed equally per capita, which makes it possible to look into household-specific welfare effects). Income is measured as private household disposable income and public revenue.

Table 2: Important structural differences between the models

Impact channel	Structure	WEGDYN_AT		DYNK	
Price (market) channels	Labor	Supply & demand reactions	→ supply constrained	Slow reaction to changes in demand	→ supply constrained
	Capital	Supply & demand reactions		Demand reactions	→ demand oriented
	Goods and Services	Supply & demand reactions		Demand reactions	
Income channels	Private household income	Labor income is fully transferred to households Capital income is fully transferred to households		Labor income is fully transferred to households Capital income is transferred as a fixed share of net surplus[5]	
Consumption channels	Public consumption	Endogenous → reacts to changes in tax revenue		Exogenous (nominal) → no reaction to changes in tax revenue	
	Private saving rate[6]	Exogenous → fixed share of income is saved		Endogenous → difference between disposable income and consumption	
	Private consumption functions	Nested CES-functions with substitution possibilities. Income elasticities not considered		Explicit representation of durable, non-durable as well as energy commodities and services. Income elasticities considered	

Analysis of results

We provide an assessment of impact chains and model results for each of the four carbon pricing and revenue recycling scenarios. We thereby focus specifically on highlighting impact chains and provide a general description of the isolated carbon pricing effects, as the impact chains underlying this price shock are present in all scenarios. When describing impact chains, we apply ceteris paribus assumptions to highlight a specific mechanism. This helps to disentangle a specific effect from the multitude of feedbacks between impact chains in the models. A comparison of policy scenario results is provided in WP6.

[5] This income source represents the income from self-employment

[6] Note that while the private saving rate is fixed, private savings are still endogenous and depend on changes in income levels.

Carbon pricing impact chains

At least six impact chains are important in understanding isolated carbon pricing effects in both models, two of which are very similar across the models while the others reveal substantial differences. Notably, all these impact chains are interconnected, and the resulting net effect is determined by the interaction of all six (and further minor impact chains as well). Figure 8 in the Appendix illustrates the two primary impact chains that are similar across all model variants: (1) loss in productivity and (2) the shift towards labor intensive sectors (which might not be the case for CO_2 pricing in ETS-sectors). Figure 9 in the Appendix highlights differences in impact chains for (3) the labor market and Figure 10 in the Appendix identifies differences in impact chains for (4) the capital market, (5) the goods and service market, and (6) the public budget.

(1) Loss in productivity

In both models, carbon pricing in Non-ETS sectors induces, at first, a price shock that increases the costs of fossil fuel inputs for producers in these sectors and thus a markup price for goods and services accounting for CO_2 emissions. This price distortion together with a productivity shock due to cost and price increases can be understood as a loss of productivity with negative impacts on macroeconomic performance as current economic flows do not account for the social cost of carbon (see Figure 8 in the Appendix). The isolated effect of this would be reflected in a decrease in sector output and GDP.

(2) Shift towards labor intensive sectors

In both models, producers and consumers react to the price changes (1) via their production and consumption behavior and substitute CO_2 intensive inputs/goods and services by less CO_2 intensive inputs/goods and services or decrease inputs/consumption when substitution is not possible. This, of course, is the intended effect of carbon pricing, as it decreases CO_2 emissions. Thereby, another important "side-effect" occurs: Less CO_2 intensive inputs/goods and services are relatively more labor intensive (see Figure 8 in the Appendix). Therefore, we observe a shift towards more labor-intensive sectors in both models.

(3) Labor market effects

The aforementioned impact chains affect labor demand in two opposing ways: Loss in productivity (1) pushes labor demand down and the shift towards labor intensive sectors (2) pushes labor demand up. In all model variants loss in productivity will outweigh the shift towards labor intensive sectors, meaning that labor demand will decrease . How this effect impacts wage rates differs between models (see Figure 9 in the Appendix):

- 3a: In WEGDYN_AT[Unem] the real wage rate is fixed (minimum wage assumption). So, if household price index increases, real wages would decrease, leading to lower labor supply (people voluntarily leave the labor market, since their remuneration is not high enough) and thereby to scarcity, which in turn increases the nominal wage rate. Ultimately this process reaches equilibrium where the real minimum wage is met.

- 3b: In DYNK both overall lower labor demand and loss in productivity will lead to lower nominal and real wage rates and higher unemployment.
- 3c: In WEGDYN_AT[Full] the wage rate is flexible. Labor is scarce and fully employed. If labor demand increases, scarcity is increased, leading to a higher nominal wage rate. As the loss in productivity outweighs the effect of the shift towards labor intensive sectors, this will lead to a lower nominal and real wage rate.

Changes in the nominal wage rate in turn affect public and private income, as well as prices of goods and services and thus the reaction of producers and consumers. If the nominal wage rate increases, the prices of (especially labor-intensive) goods and services rise even more. Conversely, if the nominal wage rate decreases, prices may be lower than the exogenous markup imposed by carbon pricing.

(4) Capital market

Regarding prices for capital (WEGDYN_AT) or capital goods (DYNK), we identify opposing effects (see Figure 10 in the Appendix). WEGDYN_AT derives decreases in the price of capital: Both the loss in productivity (1) and the shift towards labor intensive sectors (2) lower demand for capital which leads to price decreases in the market. DYNK does not account for a capital market. It assumes that capital is fully mobile across sectors and supplied where demanded. A shift away from capital intensive commodities will i) increase wage rates in labor intensive sectors and ii) be indirectly reflected in decreasing investment activities. However, these effects are overlapped by the price transmission in DYNK caused by carbon pricing. Carbon pricing increases production costs directly and downstream throughout the system via the supply-chain and thereby lifts the prices of investment goods that are a proxy for the price of capital in DYNK. Consequently, the price transmission impact chains in DYNK lead to an increase in the price for capital goods even though the demand for capital shrinks. This price increase makes investments more expensive and increases nominal gross investment expenditure. Depreciation costs and interest revenues increase nominally.

(5) Goods and service market

We expect that consumer prices for goods and services will generally increase in both models, but substantially less in WEGDYN_AT than in DYNK (see Figure 10 in the Appendix).

In WEGDYN_AT supply and demand determine final market prices and quantities. Carbon pricing will push the supply curve upwards, while substitution possibilities in production will push the supply curve somewhat downward again (or dampens the upward shift). Considering the reaction by consumers (i.e. the demand curve) will then determine the new market equilibrium. *Ceteris paribus*, the market price increase will be lower than the markup by carbon pricing.

As a demand-oriented model, DYNK has no supply curves *per se* (everything that is demanded will be supplied without additional marginal cost), but producers adjust input shares and can thus reduce the effect of the price markup on output prices. Whatever is then demanded by consumers at these new consumer prices is supplied.

(6) Public budget

A very straightforward, yet quite important, difference between the models lies in their assumptions regarding the public budget. In WEGDYN_AT public budget is endogenous, i.e. public consumption is determined by public income. In DYNK, by contrast, the consumption of public goods is exogenously determined (nominally) and thus independent of public income (assuming that any deviation can be financed via public debt or is repaying debt). The underlying reason for this is that the consumption of public goods is driven by tax revenues but also by other factors, such as population growth. Real public consumption is influenced by changes in consumer prices in both models.

These opposing assumptions can amplify differences in model results, as public income goes in tandem with macroeconomic performance in WEGDYN_AT, i.e. negative or positive macroeconomic impacts are mirrored in WEGDYN_AT as an endogenous reaction of public consumption, but not in DYNK.

Overall effects

To summarize, the final macroeconomic effect is the result of a multitude of model impact chains, but largely driven by

- price channels (labor, capital, goods and services market),
- income channels (labor and capital market, public income), and
- consumption channels (private households, producers, public consumption).

Some of the model structures (productivity losses, producer and consumer behavior) are very similar, but others (labor & capital market, goods and service market, public budget) can be so substantially different that model results might not only differ in magnitude but also in direction.

Carbon pricing policy scenarios

Table 3 shows how carbon pricing policies considered affect the two primary carbon pricing impact chains. Compared to the hypothetical case of a scenario where the revenues from carbon pricing leave the system all recycling revenues mitigate the loss in productivity as they lead – ceteris paribus– to more consumption (albeit with differences in quantity and consumption patterns) they either amplify (NTR & LCR) or mitigate (CBR & VTR) the shift towards labor intensive sectors.

Table 3: Impact of carbon pricing policy scenarios on the two primary carbon pricing impact chains

	Non-Targeted Recycling (NTR)	**Climate Bonus Recycling (CBR)**	**Non-wage Labor Cost Reductions (LCR)**	**Value Added Tax Reductions (VTR)**
Effect of recycling measures	Increased public consumption → positive effect on economic output	Increased household income → higher consumption	Lower labor costs → prices reduced → more consumption	Prices reduced → more consumption
(1) Loss in productivity	**Mitigated** [public consumption boosts economic output]	**Mitigated** [private consumption boosts economic output]	**Outweighed** [consumption boosts economic output]	**Mitigated** [consumption boosts economic output]
(2) Shift toward labor intensive sectors	**Amplified** [public consumption is labor intensive]	**Mitigated** [private consumption is capital intensive]	**Amplified** [labor cost is further reduced]	**Mitigated** [VAT reductions applied are capital intensive]

Figure 4 shows the results for all carbon policy scenarios and all three impact channel indicators. A detailed description of these results is available in Kirchner et al. (2023). Below, we point out the main findings.

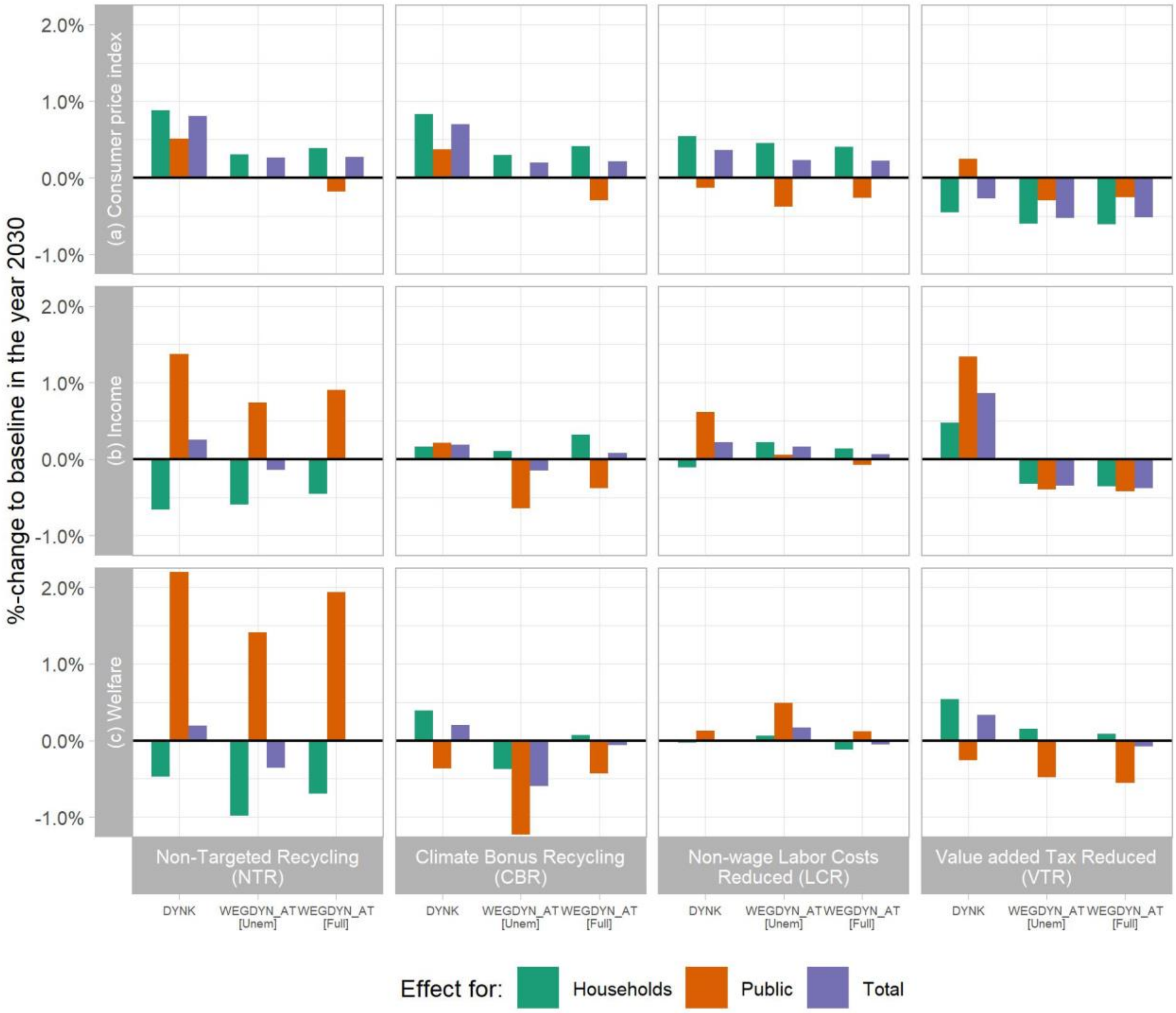


Figure 4: Model results for the three impact channel indicators

Besides differences in magnitude, our model comparison analysis reveals cases where the impacts of carbon pricing policies on our main indicators (prices, income, and welfare) differ in direction. This is especially true where differences in magnitudes between public and household impacts are big enough to result in opposite total effects (see e.g., welfare in the NTR & VTR scenarios and income in the NTR & CBR scenarios). Even if results are similar, the underlying impact chains may differ (e.g., in NTR loss in real income is caused by overall price increase in DYNK, whereas it is mainly driven by losses in capital income in WEGDYN_AT[Unem]).

We find the highest agreement between the models in the NTR scenario. Since the NTR scenario comes closest to a "pure" (hypothetical) carbon price shock scenario without any revenue creation and recycling, this indicates that the aggregate net effect of carbon pricing is similar, even though (1) carbon price impact chains do differ structurally between the models and (2) prices for labor, capital, and producers as well as changes in the unemployment rate differ not only in magnitude but sometimes also in direction. These differences, however, do influence distributional effects (see WP6 as well as Kettner et al., 2023b) and appear in all other scenarios as well.

There is also much agreement in the LCR scenario (especially regarding price effects for labor, capital and producers), even though labor market impact chains are quite different between the models. Since impacts in the LCR scenario are very small and almost negligible compared to the baseline, these differences are still crucial in determining the direction of impact (e.g., household income in DYNK, private welfare in WEGDYN_AT[Full]).

The CBR and VTR scenarios show the largest differences in outcomes between the models. In the CBR scenario the main reason for this difference is the consumption channel, as in DYNK households react much more sensitive to income changes than in WEGDYN_AT (where a fixed share of income is saved). In the VTR scenario, the VAT reductions are not sufficient to outweigh the productivity losses in the WEGDYN_AT variants, hence we see opposing income effects between WEGDYN_AT and DYNK. Price reductions do mitigate these effects for welfare, but differences remain, especially for total welfare.

WP6: Co-created carbon pricing recommendations for Austria

Goals

WP6 aimed at developing co-created recommendations for carbon pricing in Austria and communicating the project results and policy recommendations to a broader audience.

Activities & key results

A hybrid stakeholder workshop was conducted on 16 March 2023 at the WIFO in Vienna, where the main project results (simulation results; key uncertainties) were presented to stakeholders in a non-technical manner. Based on the project results, policy recommendations for effective and fair carbon pricing and compensation mechanisms were developed together with the stakeholders. The main project results, focusing on policy design, were published in a Working Paper (Kettner et al., 2023a) and synthesized in a Policy Brief (Kettner et al., 2023b), both available on the project website (https://farecarbon.joanneum.at/).

Evaluation of carbon pricing policies

The recommendations published in the policy brief build on simulations of various carbon pricing and revenue recycling options (i.e. CBR, CBRlow, LCR, VTR, MIX, and MIXlow; see WP3) conducted with DYNK and WEGDYN_AT[Unemp]. The focus was put on these six scenarios as they were considered to have the potential to significantly mitigate the impacts of carbon pricing on vulnerable households and/or cushion negative impacts on competitiveness for the economy. The aim was to identify potentials for achieving a triple dividend, defined as a reduction in CO_2 emissions, positive effects on GDP and employment, and distributionally progressive improvements in household consumption possibilities.

As described above (see WP4), the analysis shows that all revenue recycling options lead to sizeable reductions in CO_2 emissions in non-ETS sectors and that, for each model, the differences between scenarios are negligible. Only the reduction of non-wage labor costs (LCR), however, is consistently associated with positive macroeconomic outcomes in terms of GDP and unemployment. In this regard, we observe that DYNK leads to a more nuanced assessment of the macroeconomic implications of carbon pricing, with less positive effects than WEGDYN_AT for the LCR scenario but also markedly less negative effects for the CBR and broadly neutral effects for the VTR scenarios.

To investigate the distributional impact of the different policy scenarios, we take a closer look at changes in real consumption possibilities across the household income distribution. As we can see from Figure 5, model choice can have a considerable impact on the assessment of revenue recycling options. Including distributional concerns in the assessment makes it considerably more difficult to identify desirable policy options. Only the climate bonus payment scenario (CBR) consistently produces a progressive distributional outcome in both models. This recycling option, however, leads to negative economic effects for households in the upper segments of the income distribution. A reduction in VAT (scenario VTR) achieves positive impacts, without large variation between different groups. The scenario with non-wage labor cost reductions (LCR) has to be assessed differently, depending on the model chosen: It leads to minor, negative deviations from the baseline in DYNK, with virtually no change in the lowest quintile and a progressive reduction in consumption possibilities of up to -0.2% at the top of the income distribution. In WEGDYN_AT, the effect is regressive, increasing from -0.1% in the first to +0.2% in the fourth quartile. In WEGDYN_AT, for the higher income quartiles, Q3 and Q4, higher capital income dominates the increase in the consumer price index and leads to positive changes in real consumption expenditure; for the two lower income quartiles the increase in the consumer price index dominates higher nominal income, resulting in a decrease in real consumption expenditure. These differences in outcome are modest in absolute terms, but they highlight how different model assumptions can impact the assessment of policy options.

Extending carbon pricing to non-ETS sectors is likely to affect households asymmetrically across regions. This is primarily because of differences in energy consumption patterns for transport and housing associated with the degree of urbanization, but also because of regional differences in economic structure and labor markets. The distributional impact of different revenue recycling options should therefore also be assessed from a regional perspective. While both DYNK and WEGDYN_AT allow distinguishing several types of regions, based on population density, for reasons of space here we limit our analysis to contrasting results for the city of Vienna and the most peripheral regions from the DYNK model. The two models show that the regional impact of carbon pricing and revenue recycling options is not straightforward. Overall, in DYNK households in lesser populated areas are affected more negatively by carbon pricing than households in urban areas. This is in line with the expectation that, in rural areas, households rely more heavily on individual motorized transport and often face higher heating costs, thus shouldering a higher share of the carbon pricing. None of the revenue recycling scenarios, while cushioning the negative effects or generating positive effects for all households, reverses this general pattern. The results essentially show level differences between urban and peripheral regions, confirming the distributional impacts discussed in the previous paragraphs. In WEGDYN_AT, on the contrary, differences between regions are less pronounced and, in most scenarios, it is households in the city of Vienna rather than those in the rural areas that face less favorable outcomes. This is especially true for the CBR scenario, which has a negative effect on consumption possibilities in Vienna except for the households in the bottom income quartile, while the effect is positive in the rural regions except for the top quartiles. In the VAT scenario, in contrast, the outcome is almost identical along the household income distribution, regardless of regional differences.

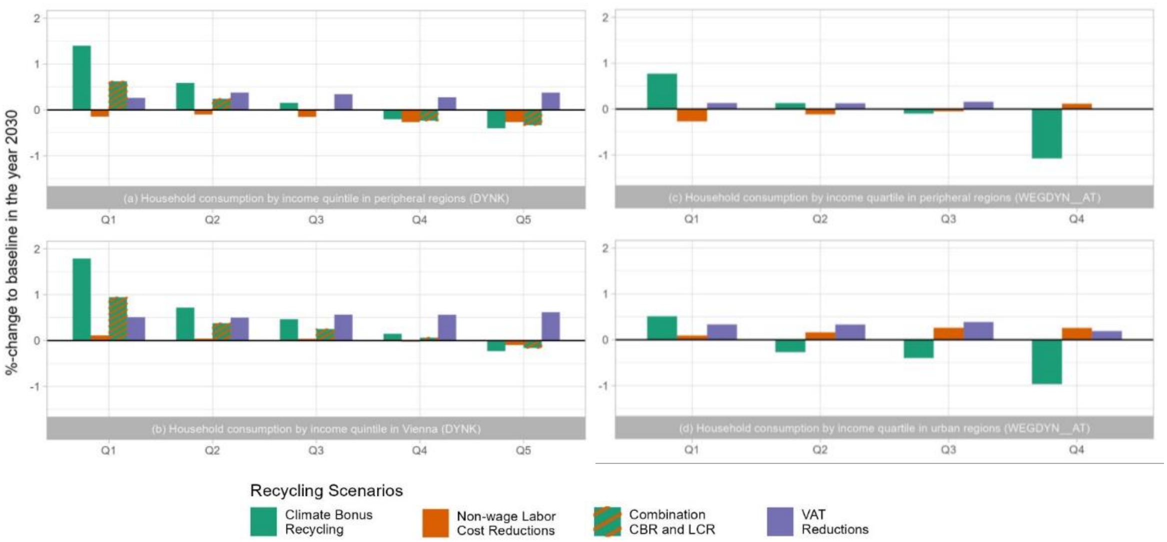


Figure 5: Effects of the policy scenarios (carbon price scenario A + recycling options) on real consumption by household income class and area of residence

To achieve a triple dividend, a combination of different revenue recycling options seems sensible. Only the reduction in non-wage labor costs leads to positive macroeconomic effects in both models and only the climate bonus leads consistently to desirable distributional outcomes. We thus assess a combination of the CBR and LCR revenue recycling options (MIX). The results, based on DYNK, indicate that combining a climate bonus with a reduction in non-wage labor costs does indeed result in a slight reduction in unemployment (-0.2%), leaves GDP unchanged and boosts the consumption possibilities of low- to medium-income households (between 0.8% in the first and 0.1% in the third quintile). When we target the climate bonus only on low to middle-income households (MIXlow), we achieve a more progressive result and thus a stronger reduction in household income inequality. In a next step, we look in more detail at the distributional impact of different options and highlight differences in assessment between macro- and micromodels.

Table 4 shows the aggregate results from the microsimulation model EASI_AT for the carbon price scenario A and the six recycling schemes. Results for scenario B with higher carbon prices are provided in the Appendix of Kettner et al. (2023a). Revenue recycling via a climate bonus (CBR) has a progressive impact on household income distribution and thus reduces inequality measured by the Gini index. Not surprisingly, the effect on the Gini index is even stronger in the CBRlow scenario, where the transfer is targeted at low- and middle-income households. Reducing the VAT has hardly any impact on inequality, while the reduction in non-wage labor costs increases the Gini index very slightly and the policy-mix scenarios lead to a clear reduction in inequality.

Whereas the results from the microsimulation model on inequality are in line with those from DYNK, we find differences regarding the income indicators. In EASI_AT, VTR is the only recycling scheme that leads to a clear increase in income, both measured at the mean and at the median. With the exception of CBRlow, where the median income increases marginally compared to the baseline, all other scenarios result in lower mean and median household incomes. The CoL index mirrors the results of the change in median income. The recycling scenarios VTR and CBRlow are the only ones resulting in a decrease of the cost of living, while LCR causes the highest increase.

Table 4: Aggregated results for the carbon price scenario A and different recycling schemes on private households

	Gini index	*Gini index (%-change to baseline)*	*CoL index (%-change in cost of living to baseline)*	*%-change in mean equivalent income to baseline*	*%-change in median equivalent income to baseline*
Baseline	0.2539	-	-	-	-
CBR	0.2509	-1.21%	+0.28%	-0.55%	-0.60%
CBRlow	0.2469	-2.77%	-0.29%	-0.33%	+0.13%
LCR	0.2541	+0.06%	+0.69%	-0.66%	-0.80%
VTR	0.2539	-0.01%	-0.78%	+0.80%	+0.59%
MIX	0.2525	-0.57%	+0.48%	-0.61%	-0.74%
MIXlow	0.2505	-1.35%	+0.20%	-0.50%	-0.32%

Figure 6 shows the relative change in cost of living (CoL) for carbon price scenario A and the different recycling scenarios across expenditure quintiles, differentiating between different degrees of urbanization. Households in regions with the highest degree of urbanization (i.e. Vienna) experience somewhat higher positive or less negative impacts from carbon pricing on the cost of living across all price scenarios, recycling scenarios and quintiles than households in rural regions. Carbon pricing in combination with the recycling scenarios CBRlow, CBR, MIX, and MIXlow has a progressive impact on CoL.

Table 8 in the Annex provides additional distributional insights, showing for every recycling option the share of households with a lower cost of living than in the baseline. With the exception of the thinly populated areas, the CBR option reduces living costs for virtually all households in the first and a majority of households in the second quintile of the income distribution. Stronger targeting (CBRlow) generates positive effects also for most households in the third quintile, including about half of the middle-income households in thinly populated areas. A similar pattern emerges from the MIX and MIXlow scenarios, although with benefits restricted to smaller proportions of households.

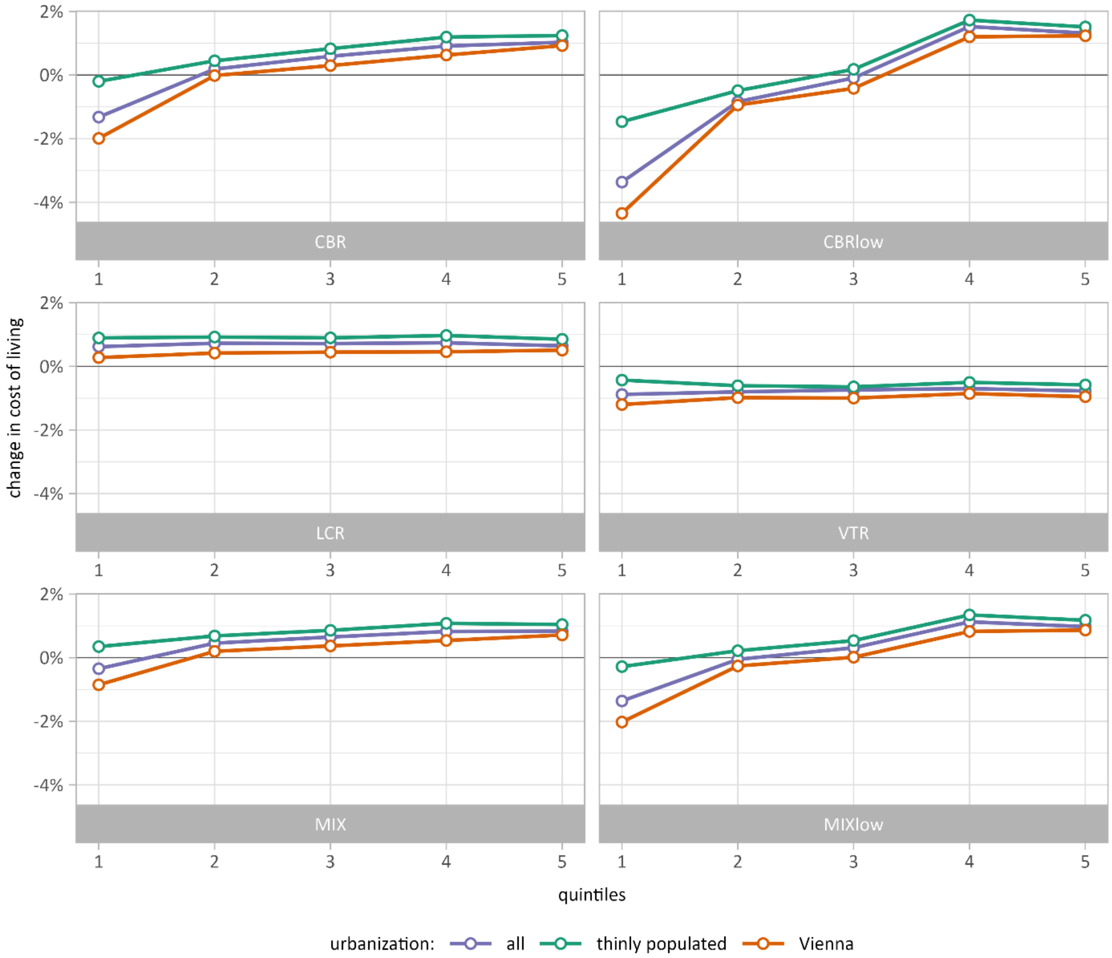


Figure 6: Relative change in the cost of living of private households for carbon price scenario A and different recycling scenarios across expenditure quintiles, differentiating between different degrees of urbanization

In general, results from EASI_AT highlight that the higher consumer prices, as a result of carbon pricing, determine the higher cost-of-living impacts. Still, in terms of equality, we find a decrease in the Gini index and hence an improvement in equality in four recycling scenarios.

Policy recommendations

In summary, the following policy recommendations can be derived from the model analyses in FARECarbon and the discussions with stakeholders:

- Carbon pricing can make a significant contribution to reducing greenhouse gas emissions in the transport and buildings sectors, but a comprehensive mix of instruments is required to achieve the climate targets.
- In combination with appropriate revenue recycling options, carbon pricing can achieve multiple dividends; while a double dividend can be achieved through different policy options, the simulation results show that triple dividends significantly increase challenges for optimal policy design.
- Achieving a triple dividend (i.e. positive ecological, social and economic effects) requires a combination of different rebate measures (climate bonus payment and reductions in non-wage labor costs). If the objective is an increase in

competitiveness, a reduction in non-wage costs should be aimed for. If the objective is to reduce the burden on lower incomes, climate bonus payments are most effective.

- Restricting climate bonus payments to lower incomes can lead to higher economic growth, and will also be required following the introduction of the European Emissions Trading Scheme for transport and buildings in 2027, as the new Emissions Trading Directive specifies a focus of revenue allocation on low-income households.
- A differentiation of climate bonus payments by region is not considered necessary, since on the one hand, the evidence from the model simulations is not clear-cut regarding the distributive effects and on the other hand, the regional differences turn out to be very small.

5 Conclusions and recommendations

Our analysis has highlighted different macroeconomic impact chains of carbon pricing policies across two common modelling approaches (Neoclassical and New Keynesian). While there is commonality regarding two primary impact chains, i.e., loss in productivity and a shift towards labor intensive sectors due to carbon pricing, we find substantial differences in how impact chains in the labor market, capital market, goods and services market, and the public budget affect prices, income, and consumption. A crucial difference can also be identified in how consumption (both private and public) reacts to changes in income. Revenue recycling measures can enhance or mitigate carbon pricing impact chains – which may also differ between model variants.

Highlighting theses structural differences can shed light on the bandwidth of potential impacts of carbon pricing across different macroeconomic disciplines and allows policymakers to select a carbon pricing policy that is robust in terms of expected impacts, considering the current state and structure of the economy. We recommend expanding such analyses and including more macroeconomic disciplines and modelling approaches (e.g. agent based models, system dynamics).

With respect to robust policy options for revenue recycling, we find that a reduction in non-wage labor costs can boost economic activity but is not able to mitigate the regressive effects of carbon pricing. The opposite is true for revenue recycling via climate bonus payments. The highest potential for a triple dividend, i.e. positive ecological, macroeconomic and distributional effects of carbon pricing in combination with revenue recycling, lies in a combination of these two recycling options. Downstream microsimulations indicate improvements in income equality for such a policy mix, but also increases in the cost of living, particularly for households in thinly populated areas.

Macroeconomic models might not be sufficiently detailed for identifying a triple dividend and address distributional issues, which can be avoided by linking top-down macroeconomic models with microsimulation models. This aspect of the analysis could still be enhanced for Austria by an iterative linking of DYNK and EASI_AT allowing for feedbacks, or by including more information on the income components of the different household types in DYNK. Moreover, carbon pricing just constitutes one element in the policy mix needed for achieving the emission reduction targets. Other instruments, such as bans of fossil heating systems or of cars with combustion engines but also subsidies, might entail different effects regarding a potential triple dividend and should also be addressed by respective macro- and micro policy assessments.

C) Project details

6 Methodology

General remarks on the chosen methodology

To ensure political feasibility and enhance social acceptability, the design of carbon pricing has to fulfil various criteria: It should be effective, economically efficient and at the same time socially fair, balancing private, public and business interests. Thus, when assessing the effects of carbon pricing for different actors, economy-wide modelling is required. However, depending on the economic modelling approach, study setting and target measure, there are different and sometimes contradictory results and hence divergent policy recommendations. To identify robust policy options and derive robust recommendations for carbon pricing and revenue recycling for Austria, we performed a stakeholder-assisted multi model comparison in FARECarbon, using Computable General Equilibrium (CGE) and macroeconomic Input-Output (IO) models.

CGE models and macroeconomic IO models are state of the art approaches for studying the macroeconomic effects of carbon pricing. Both model classes are based on input-output tables and thus structure the economy into different inter-linked production sectors and final demand agents. Hence, these models capture the whole market economy of a country and allow for indirect and cross-sectoral effects.

The basic idea behind CGE models is that all markets are in equilibrium which can be disturbed by an intervention (e.g. by the introduction of a tax or an enforced switch to a new technology), triggering relative price changes and quantity adjustments until a new general equilibrium emerges. From the difference between new and old equilibrium conclusions on how the economy reacts to the intervention are drawn. The adjustment process that leads to the new equilibrium is based on long-run neo-classical theory and driven by assumptions on the behavior of economic agents. Producers are assumed to maximize profits and consumers to maximize utility from consumption, subject to prices, factor and income availability as well as technological flexibility. The main characteristics of CGE models are thus that relative price changes drive the system towards a new equilibrium and that production factor supply constrains economic activity; i.e. there are no idle economic capacities.

Macroeconomic IO models, in contrast, allow for economies not working at full capacity utilization and for imperfection in markets. As opposed to CGE models, the price mechanism is not trimmed to balance all markets towards a general equilibrium. Behavior of the macroeconomic agents (e.g. industries, households) is based on econometric estimations which are derived from new-Keynesian as well as neo-classical economic theories such as unit cost minimization (industries), the buffer-stock model and the almost ideal demand system (households), as well as wage setting (labor market).

Model comparison projects are of key importance, since differences in models can be used to identify important processes and parameterizations as well as inform model-improvement efforts. In climate and weather science, it is state-of-the-art to employ ensembles of models to capture and quantitatively assess uncertainties at the different modelling stages. In economics, model comparison usually takes place across models that belong to the same model class (see e.g. Böhringer et al., 2012), but efforts of comparison across different model classes are scarce as modelling teams of different model classes work in different branches of the literature. Notable exceptions are Edenhofer et al. (2010), Jansen and Klaassen (2000), Kober et al. (2016) and Meyer and Ahlert (2019), who all deploy different macroeconomic model types but, do not explicitly embed their findings in a broader framework of uncertainties and, most importantly, do not offer a systematic comparison across different model types. Nevertheless, these studies indicate that uncertainties from differences in economic model classes are substantially larger than uncertainties from within-class differences. Thus, the approach of FARECarbon contributes to closing this major gap in the literature and strives to reduce this uncertainty. By comparing results from CGE and macroeconomic IO modelling, we address a major uncertainty in economic modelling, namely reflecting different macroeconomic states in which the introduction of a carbon tax is implemented. Scenario analysis by means of multi-model comparison as conducted in FARECarbon is an essential step in scoping the range of effects of policy actions in the light of climate change and should be state-of-art for concrete policy recommendations.

As macroeconomic models are somewhat limited in their detail of modelling private households and thus of analyzing distributional aspects, stand-alone microsimulation models are usually applied in the literature to study the distributional impacts of carbon pricing on private households in detail. However, these models only consider direct price effects and are rather limited in terms of investigable recycling options, with the literature mainly comprising scenarios on different variants of public sector transfer payments to households (see e.g. Tovar Reaños and Lynch, 2022; Tovar Reaños and Wölfing, 2018; Berry, 2019; Eisner et al., 2021). In FARECarbon, we thus couple the microsimulation model EASI_AT via a unidirectional soft link to the macroeconomic model DYNK, which allows us to go a step further than conventional microsimulation modelling and consider both, indirect price effects and a wider variety of recycling scenarios within our microsimulations.

Description of the models applied in FARECarbon

WEGDYN_AT is a recursive-dynamic Computable General Equilibrium (CGE) model of the small open economy Austria. It is calibrated to the Social Accounting Matrix of 2014 and comprises 81 economic sectors. Special focus is on the coverage of energy technologies (bottom-up technology detail for electricity, heat and gas generation), transportation (12 distinct modes of transport) and household representation (12 types based on income quartile and area of residence). In contrast to New Keynesian models, CGE models depict the economy as a closed system of monetary flows of goods and services in equilibrium. In response to an economic shock (e.g. carbon pricing), output levels and relative prices adapt immediately until a new equilibrium is reached In terms of closures, WEGDYN-AT assumes a fixed saving rate and a fixed current account balance. Moreover, it allows for two different labor market closures: (i) one allowing for classical unemployment that adjusts to the fixed baseline real wage (WEGDYN-AT[Unemp]) and (ii) one with full employment (fixed labor supply) accompanied by a flexible real wage that adapts to ensure full utilization of labor (WEGDYN-AT[Full]). Foreign trade is illustrated via the Armington assumption (Armington, 1969) of product heterogeneity (i.e. imported and domestic goods are imperfect substitutes). Welfare is measured as Hicksian equivalent variation, depicting all consumption possibilities of households and the government. The foreign exchange price is selected as numéraire.

ECON_AT is a recursive-dynamic, multi-sector, small open economy, single country CGE model of Austria. It differentiates between six household groups, representing heterogeneous energy and transport consumption via varying constant elasticity of substitution (CES) utilities and heterogeneous preferences. The model comprises 74 sectors, divided into energy sectors, non-energy sectors, material sectors and passenger transport. The latter is incorporated via bottom-up representation of passenger transport technologies (fossil-fuel, electric, hybrid-electric and fuel cell).

The ***DYNK*** (Dynamic New Keynesian) model is a macroeconomic model covering the economic activities of multiple sectors (up to 74 production sectors) in a single region and using econometric estimations based on both Neoclassical and New Keynesian theory. The DYNK modelling approach bears some similarities with DSGE (Dynamic Stochastic General Equilibrium) models, as it explicitly describes an adjustment path towards a long-run equilibrium. The term 'New Keynesian' refers to the existence of a log-run full employment equilibrium, which will not be reached in the short run, due to institutional rigidities. Depending on the magnitude of the distance to the long-run equilibrium, the reaction of macroeconomic aggregates to policy shocks can differ substantially. DYNK is an input-output model in the sense that it is demand driven, as all what is demanded is produced. In the DYNK model, the treatment of demand is especially elaborated and captures consumption (private and public), investment and exports, which are endogenous, explained by consumer behavior. Domestic consumption is represented by 20 household types (income quintiles x four areas of residence) that differ in income and consumption structures. Monetary flows of the IO structure of the model are linked to physical satellite accounts data for energy and GHG emissions.

For a comparison of critical parameters and modelling features of the three macroeconomic models, see Table 5 below.

Table 5: Overview of critical parameter assumptions and modelling features

Cross-model feature comparison			
	WEGDYN_AT	**ECON_AT**	**DYNK**
Type	**CGE**	**CGE**	**Macroeconomic IO**
Sectoral detail	81	74	74
Representation of technologies	Specific consideration of 12 transport and 20 energy technologies	Bottom-up representation of 4 passenger transport technologies	Explicit representation of ambient heating and electricity demand as well as 26 energy sources
Representation of households	12 differentiated by income (quartiles) and location (urban, semi-urban, periphery)	6 differentiated by energy consumption, with heterogeneous preferences	5 household income groups with heterogeneous preferences specifically for durable; nondurable and energy commodities

Sources and structure of household income	wages, capital income, transfers	wages, capital income, transfers	wages, capital income, transfers
Coverage of taxes (types of taxes)	- production taxes (output tax; each EUR of output is taxed) - labor taxes (input based, whenever labor is used as input, it is taxed; no explicit differentiation between wage tax [Lohnsteuer] and ancillary wage costs [Lohnnebenkosten]) - capital taxes (input based, whenever capital is used as input, it is taxed) - export taxes - transfers from government to household (unemployment benefits and other transfers separately) - CO_2 tax	- production taxes (output tax; each EUR of output is taxed) - labor taxes (input based, whenever labor is used as input, it is taxed; no explicit differentiation between wage tax [Lohnsteuer] and ancillary wage costs [Lohnnebenkosten]) - capital taxes (input based, whenever capital is used as input, it is taxed) - export taxes - transfers from government to household - CO_2 tax	- taxes-less-subsidies (IO category) - income tax - social contributions (employer & employee) - carbon tax (endogenously computed as an add-on to taxes-less-subsidies)
Dynamics	Recursive dynamic with 1 year time steps	Recursive dynamic with 1 year time steps	Recursive dynamic with 1 year time steps;
Labor market	two options: 1) classical unemployment via minimum wage (with flexible labor supply) 2) full employment (with flexible wages that clear the market)	Default: full employment (with flexible wages that clear the market)	Labor market is "sticky" - depends on previous years': consumer price index, wages and sectoral / overall labor productivity performances
Capital market	default setup: full employment of capital with capital rent being flexible to clear market (i.e. all capital is used); capital is generic and fully mobile across sectors (no sector specific capital)	default setup: full employment of capital with capital rent being flexible to clear market (i.e. all capital is used); capital is generic and fully mobile across sectors (no sector specific capital)	
Investment and capital accumulation	Each hh with specific fixed saving rate (fixed fraction of income is saved and then invested); builds up capital stock over time	Each hh with specific saving rate	Investments are fixed share of lagged sector's surplus i.e. represent the historic investment activities; no closure and no crowding out; Saving as difference between disposable income and consumption
Population growth	Exogenous population growth, driving labor supply;	standard labor growth rates (differing by labor type)	Population and Labor Force is exogenous
Factor market closures	Capital is fully employed and mobile across sectors, with flexible rents. Downward rigid wages on labor market with endogenous labor supply	Factors are fully employed and mobile across sectors.	Imperfect labor market with wage bargaining
Representation of trade	Armington assumption of product heterogeneity; small open economy assumption	Armington assumption of product heterogeneity; small open economy assumption	Endogenous import shares by user using estimated price elasticities (KLEMD-Translog) and export price elasticities Armington elasticities for private consumption
Consumption modules	CES consumption functions by household	CES consumption functions by household	Explicit representation of durable, non-durable and energy commodities and services (mapping to COICOP and CPA classification)
CO_2 emissions	Endogenous coverage of ETS and non-ETS CO_2 emissions, including industrial process emissions;	Exogenous coverage via CO_2 coefficients of energy sources (e.g. coal, oil, gas, electricity)	CO_2 coefficients of 26 energy carriers and full link of physical energy flows and products ;

CO_2 emissions data	UNFCC inventory; mapped via energy demand to production sectors (and respective energy inputs); for process emissions Leontief fixed shared emissions to output	UNFCC inventory; mapped via energy demand to production sectors (and respective energy inputs); for process emissions Leontief fixed shared emissions to output	UNFCC inventory; mapped via energy demand to production sectors (and respective energy inputs); for process emissions Leontief fixed shared emissions to output
CO_2 pricing	Either via CO_2 tax on direct CO_2 emissions (flexible quantity of emissions), or via Emission-Trading-Scheme (flexible CO_2-price)	Increase implemented on existing energy prices depending on their CO_2 coefficient; No direct coverage of a CO_2 price or CO_2 emission cap	Exogenous Mark-up on existing Commodity tax structure (TLS, Taxes-Less-Subsidies) of IO-Tables; Mark-up is based on CO_2-Content of the commodity
Foreign Trade assumption	Trade closure	Trade closure	Export is exogenous
Growth rates/ growth drivers	exogenous GDP and population growth from SSPs are given; GDP growth is then calibrated by endogenous TFP parameter (this is fixed in counterfactual)	exogenous growth parameters for labor, GDP	exogenous growth parameters for labor, GDP
Special sectoral coverage	Electricity generation by source; motorized individual transport and land transport sectors are disaggregated	Passenger Transport sector: bottom up representation of technologies diesel/benzene, PHEV, EV and FCEF (can be removed in case needed)	Disaggregation of Energy Sector in Electricity/District Heat/ Gas Distribution
AEEI	1.5% p.a. Energy input in production function is reduced, while output remains constant (i.e. efficiency increase)	implemented; but not with a strict number/calibration	Sectoral KLEMD-structure follows Historic trends (based on WIOD)
Labor augmented technological change in passenger transport	Not implemented;	cost improvement rate varies by technology and labor driven: relation of skilled labor total employment which impacts technological change	Not implemented;
Sectoral production functions	CES or Leontief	CES or Leontief	Input Share Unit Price Approach (KLEMD) - other variants available; Nested Energy Input Share Function
Elasticities in domestic production:			
elasticity of substitution between (LK) and E-nest (technological improvement)	Koesler and Schymura (2015): Okagawa and Ban (2008); own assumptions	Koesler and Schymura (2015)	Endogenous elasticity depending on factor share in each sector (Translog KLEMD)
elasticity of substitution within energy bundle	Koesler and Schymura (2015): Okagawa and Ban (2008); own assumptions	Okagawa and Ban (2008)	Endogenous elasticity depending on fuel share in each sector (TRANSLOG fuels)
Armington elasticity	GTAP	GTAP: Dimaranan,B.V., McDougall,R.A., 2002.	-
Elasticities in domestic demand:			
substitution between energy goods	own assumptions based on standard values in the literature	0.2 to 0.4 (depending on HH type) Source: (Bosetti et al.(2006, 2015)and Paltsev et al.(2005))	depending on sector (TRANSLOG SUR-Estimation based on IEA-Prices and Eurostat Energy-Balances)
substitution between consumption and saving	fixed savings rate		saving is the residuum
substitution between non-energy and energy goods	own assumptions based on standard values in the literature	0.5 to 0.7 (depending on HH type) Source: (Bosetti et al.(2006, 2015)and Paltsev et al.(2005))	No substitution elasticity. The demand for energy has own-price elasticities and is set. The remaining budget is used for non-energy products.

Additional assumptions regarding HH demand specification	differences in consumption structure across HHs.	urban areas offer a higher set of consumption possibilities than rural areas and hence more flexibility, (ii) households in urban areas have a higher income on average than households in rural areas and hence substitute easier between products and (iii) households with lower income and no car access are least flexible regarding their consumption possibilities.	-

EASI_AT is a static microsimulation model for Austria, parameterized by the Exact Affine Stone Index (EASI) demand system, simulates the effects of exogenously given price changes on private household demand. It is an updated version of the model used in Eisner et al. (2021), which itself is based on Lewbel and Pendakur (2009). EASI_AT is estimated based on a pooled cross-section data set of 29,235 households. Data stems from the four most recent waves of the Austrian Household Budget Survey (HBS), i.e. 2004/05, 2009/10, 2014/15, 2019/20, provided by Statistics Austria. The model comprises eight commodity groups: motor fuels, electricity, heating, housing, food, non-durables, durables and others. To account for heterogeneous household preferences, EASI_AT includes socio-demographic variables and housing attributes that allow differentiating the consumption behavior of different groups in society. This includes household composition, built year of the dwelling, primary energy source of the heating system, floor space, age of the main person in the household, legal status of the dwelling (rented or owned), and the degree of urbanization of the dwelling location. To measure the distributional impacts of carbon pricing on private households as indicated by the microsimulation model EASI_AT, we use three different indicators, i.e. the GINI index, the cost of living (CoL) index, and equivalent income. The Gini index (Gini, 1912) is a measure of statistical dispersion and intended to indicate the income or wealth inequality across the population. An index of zero indicates total equality, an index of 1 total inequality. The cost of living index measures the relative change in total expenditure[7] required by a private household to maintain the initial level of utility after a change in prices (see e.g. Lewbel and Pendakur, 2009). The applied version of the index also accounts for any potential compensating transfers accompanying this change in prices. Equivalent income (or expenditure), by contrast, is the income level that gives the same utility as the initial income level with changed prices (see e.g. King, 1983; Creedy and Sleeman, 2016; Tovar Reaños and Wölfing, 2018).

Description of the overall approach

The overall approach is illustrated based on the project structure – an iterative process consisting of six interlocking content-related work packages (see also Figure 1).

- **WP1** set up the methodological framework and ensured model harmonization. Special emphasis was placed on the baseline scenario, to which the CO_2 price

[7] Note that in demand systems, consumption expenditure is a proxy for income.

scenarios were compared. Furthermore, a set of shared indicators for quantifying policy impacts (e.g. on the macroeconomy, households and emissions) were defined. WP1 also provided guidelines for model comparison and a critical discussion of modelling assumptions.

- **WP2** acted as a recurring pivotal point for discussion, weighting and contrasting findings throughout the project with various stakeholders and scientific experts, by means of workshops, quarterly meetings as well as conference calls. Thus, in combination, WP1 and WP2 set the framework conditions for the work-packages on modelling (WPs 3, 4, 5).
- **WP3** developed CO_2 price scenarios based on a detailed literature review and in close cooperation with stakeholders from various fields. Therein, special emphasize was put on the structure of the carbon tax and revenue recycling options and particular attention was paid to the distributional impacts of CO_2 taxes.
- **WP4** comprised the core modelling activities. Based on the general framework conditions (WP1), stakeholder input (WP2) and specific scenario assumptions (WP3) different carbon pricing scenarios were simulated with the macroeconomic and microsimulation models applied within FARECarbon.
- **WP5** discussed the results regarding the magnitude and direction of effects across the macroeconomic models, but also contrasted the effects regarding stringency of different policy scenarios, thereby addressing and assessing the various types of uncertainty. A particular focus was on identifying structural uncertainty and thus differences in underlying model impact chains, i.e. the causal relationships inferred in the models. Structural uncertainty focuses on how different structures and assumptions between models (e.g., behavioral functions, system processes, etc.) may affect the outcomes of the same policy or driving force. See Table 6 in the Appendix for the uncertainty framework table applied in FARECarbon.
- **WP6** compiled the policy recommendations in close collaboration with stakeholders, focusing on robust policy options with a potential for a triple dividend, i.e. positive ecological, macroeconomic and distributional effects.

7 Work plan and time schedule

Figure 7: Initial work plan and time schedule

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	18	20	21	22	23	24
WP1: Modelling framework and model harmonization																								
Baseline scenario				M1.2																				
Guideline and Framework				M1.1										M1.4										
Indification of indicators							M1.3																	
WP2: Stakeholder and Scientific Dialogue																								
Stakeholder Workshops				M2.1																M2.4		M2.5		
SSC involvement		M2.2												M2.3										
SAB involvement																								
WP3: Design of carbon taxation scenarios																								
Scenario Design		M3.1		M3.2	M3.3		M3.4																	
WP4: Economic Modelling																								
Model calibaration								M4.1																
Scenario simulation												M4.2												
Interpretation of results															M4.3									
WP5: Comparison and synthesis of modelling results																								
Cross-model feature comparison						M5.1																		
Systematic comparison of results																M5.2								
Uncertaintiy assessment																		M5.3		M5.4	M5.5			
WP6: Co-created CO2 tax policy proposal																								
Co-created policy proposal																						M6.2	M6.3	
Communication of results		M6.1																						
WP7: Project management and scientific dissemination																								
Coordination and management	M7.1						M7.2					M7.3	M7.2						M7.2					M7.4
Scientific communication																								M7.5

List of milestones

M1.1 Overview of critical parameter assumptions and modelling features completed
M1.2 Harmonized baseline scenario selected
M1.3 Shared measures for quantifying impacts identified
M1.4 Guidelines for systematic model comparison

M2.1 Input for Scenario Design Stakeholder Workshops in Graz and Vienna
M2.2 SSC kick off meeting regarding objectives of FARECarbon and participation
M2.3 Intermediate evaluation and if required adaptations of the quarterly SSC meeting
M2.4 Input for Stakeholder Workshop for development of co-created policy proposal
M2.5 Final Project Workshop Documentary

M3.1. Literature review completed
M3.2 Stakeholder workshop in Vienna
M3.3. Stakeholder workshop in Graz
M3.4. Definition of carbon taxation scenarios completed

M4.1: Calibrated baseline trajectories until 2030 for each model finished
M4.2: Scenario analysis for each model finished
M4.3: Interpretation of individual model results finished

M5.1 Cross-model feature comparison completed
M5.2. Recommendations on state-of-the-art modelling comparison derived
M5.3 Analysis of results completed
M5.4 Input for final stakeholder workshop
M5.5 Final working papers

M6.1 Project website set up
M6.2 Stakeholder Workshop for development of co-created policy proposal
M6.3 Co-created policy proposal for an Austrian carbon tax finished
M6.4 Policy brief and media statements on co-created policy proposal for an Austrian carbon tax published

M7.1: Kick-off meeting
M7.2: Project team meetings (at least semi-annually)
M7.3: Interim report to Climate & Energy Fund
M7.4: Final report to Climate & Energy Fund
M7.5: Academic papers submitted

8 Publications and dissemination activities

Scientific publications

- Kirchner, M., Wallenko, L., Mayer, J., Sommer, M., Bachner, G., Kettner-Marx, C., Leoni, T., Mayer, J., Splitter, N., Köberl, J., Kulmer, V. (submitted July 17, 2023). Modelling the economy-wide effects of unilateral CO_2 pricing un-der different revenue recycling schemes in Austria - Part A: Identifying structural model uncertainties, Energy Economics.
- Kettner-Marx, C., Leoni, T., Köberl, J., Kortschak, D., Kirchner, M., Sommer, M., Wallenko, L., Bachner, G., Mayer, J., Splitter, N., Kulmer, V. (submitted July 17, 2023). Modelling the economy-wide effects of unilateral CO_2 pricing under different revenue recycling schemes in Austria - Part B: Potentials for a triple dividend, Energy Economics.
- Wallenko, L. (2022). The eco-social tax reform in Austria: economy-wide and distributional effects of a CO_2 tax under a region-specific revenue recycling scheme, master's thesis at the University of Graz. https://unipub.uni-graz.at/obvugrhs/content/titleinfo/8285735/full.pdf
- Wallenko, L., Bachner G., Mayer, J. (in preparation). The eco-social tax reform in Austria: economy-wide and distributional effects of a CO_2 tax under a region- and income-specific revenue recycling scheme

Project workshops

- First FARECarbon stakeholder workshop on the development of carbon price scenarios and revenue recycling schemes, online, 04.03.2021
- Second FARECarbon stakeholder workshop on the development of carbon price scenarios and revenue recycling schemes, online, 16.03.2021
- Third FARECarbon stakeholder workshop on the presentation of the project results and the derivation of policy recommendations for carbon pricing in Austria, hybrid, WIFO (Vienna), 16.03.2023

Presentations at conferences and other external events

- Oral presentation by M. Kirchner in the course of Lectures for Future, FH Wien, online, 10.06.2020. Title: Climate Change and Economics: Selected insights & critical appraisal
- Oral presentation by M. Kirchner in the course of Lectures for Future, vetmed, online, 27.10.2020. Title: Climate Change and Economics - Pitfalls and Lessons Learned
- Oral presentation by V. Kulmer at the 11th edition of Klima- und Energieforum Steiermark (online), 01.03.2021. Title: CO_2-Bepreisung: Energie als Drehpunkt der Klimapolitik?

- Poster presentation by V. Kulmer on behalf of the entire project team at the ACRP poster session of the 21st Austrian Climate Day (online event), 12.-13.04.2021. Title: Fair and effective carbon pricing in Austria: insights from model comparison. Winner of the 2nd place at the CCCA Poster Award – the poster convinced the jury in terms of visual and content presentation, scientific quality and innovation as well as social relevance.
- Oral session presentation by J. Mayer at the 26th Annual Conference of the European Association of Environmental and Resource Economists (EARE), online, 24.06.2021. Title: Is carbon pricing regressive?
- Oral student presentation by J. Mayer at the EARE summer school in Seggauberg, Austria, 02.10.2021. Title: Is carbon pricing regressive?
- Oral presentation by M. Sommer at the ESEE 2022 Conference in Pisa, 15.06.2022. Title: Carbon Pricing in Austria. An Analysis of the Macroeconomic, Distributive and Ecological Effects.
- Oral presentation by C. Kettner-Marx at the ESPANET2022 Vienna conference, 16.11.2022. Title: Balancing Social and Ecological Goals: Redistribute Options for Carbon Pricing in an Ecological Tax Reform.
- Oral presentation by C. Kettner-Marx at the third (LIS)^2ER workshop in Luxembourg, 01.12.2021. Title: Balancing Social and Ecological Goals: Redistribute Options for Carbon Pricing in an Ecological Tax Reform.

Interviews and panel discussions

- Radio interview by V. Kulmer about distributional and economic effects of carbon pricing, FM4 Klimatalks, 18.09.2020.
- TV discussion participation by C. Kettner on eco-social tax reform, PULS24 Milborn, 31.05.2021

Policy statements

- Wegener Center Statement "Österreichs ökosoziale Steuerreform. Eine Einordnung und Einschätzung ihres Beitrags zur Erreichung der Klimaziele" (authors: K. Steininger, B. Bednar-Friedl, G. Bachner, J. Mayer, S. Nabernegg, S. Borsky, Wegener Center, Uni Graz). Available at: https://wegcenter.uni-graz.at/de/downloads/

Policy Briefs

- FARECarbon Policy Brief: Ergebnisse aus Modellanalysen für Österreich zur optimalen Gestaltung einer CO_2-Bepreisung mit Einnahmenrückvergütung. https://farecarbon.joanneum.at/wp-content/uploads/2023/07/FARECarbon_Policy_Brief_de.pdf

Project website

- https://farecarbon.joanneum.at

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10 Appendix

Table 6: Uncertainty framework table (UFT) for the macroeconomic models considered (Source: own); note: cells colored in black and grey were of particular focus for the analysis in FARECarbon

Location (Manifestation) of uncertainty		**Type (Expression) of uncertainty**			
		Statistical	**Scenario**	**Qualitative**	**Ignorance**
		If both outcomes and probabilities are known	If probabilities are unknown, but at least some outcomes are known.	If at least some (qualitative) uncertainties exist and at least some outcomes are known.	If things are either (1) unknown or (2) deliberately ignored
Context	System boundaries				Simplified trade (Austria and Rest of World)
	System resolution				Sectoral detail Household types Annual simulations Technologies Tax types Coverage of GHG emissions
Inputs	System data	GHG emission data Economic data Behavioral estimations			
	System drivers		Population Prices Technologies		Non-market decision criteria not included
Model	Parameter calibration		Constants in behavioral equations		
	Structure		Production functions Consumption functions Labor market Capital market Factor market closures Trade closure Government closure		Unknown factors that affect behavior
	Hardware & software	Solver heuristics	Optimization solver choices		Errors in model code
Outcomes	Decision support			Perception and trust by stakeholders in model results	

Table 7: Structural differences (selection) between the macroeconomic models WEGDYN_AT and DYNK

Difference	Category	Structure	WEGDYN_AT	DYNK
Small	**Production**	Sectoral detail	81; Electricity generation by source; motorized individual transport and land transport sectors are disaggregated	74; Disaggregation of energy sector in electricity/district heating/gas distribution
		Representation of technologies	Specific consideration of 12 transport, 20 energy technologies and 2 primary steel production technologies	Explicit representation of ambient heating and electricity demand as well as 26 energy sources
		Production functions	CES or Leontief	Input Share Unit Price Approach (KLEMD); Nested Energy Input Share Function
		Elasticities of substitutions	(LK) vs energy: Koesler and Schymura (2015); Energy sources: Okagawa and Ban (2008) & own; Energy goods: own & standard literature Transport: Puwein (2009)	Endogenous elasticity depending on factor share in each sector (Translog KLEMD) as well as fuel share in each sector (Translog FUELS) Source for coefficients: econometric estimations based on WIOD
	Taxes	Coverage of taxes (types of taxes)	- production taxes (output) & capital taxes (input) & export taxes - labor taxes (input): income tax and social contributions not differentiated - government transfers to household; - CO_2 tax	- taxes-less-subsidies (TLS) comprises production, capital and export taxes - labor taxes (input): income tax and social contributions differentiated - government transfers to household; - CO_2 tax
		Carbon pricing	Either via CO_2 tax on direct CO_2 emissions (flexible quantity of emissions), or via Emission-Trading-Scheme (flexible CO_2 price)	Endogenous mark-up on existing TLS structure of IO-Tables; mark-up is based on CO_2 content of commodity, CO_2 price (exogenous) and energy commodity prices.
	Emissions	CO_2 emissions	Endogenous coverage of CO_2 emissions, including industrial process emissions	CO_2 coefficients of 26 energy carriers; full link of physical energy flows and products
	Households	Representation of households	12 differentiated by income (quartiles) and residence location (urban, semi-urban, periphery) and heterogeneous preferences	15 differentiated by income (quintiles) and residence location (urban, semi-urban, periphery) with heterogeneous preferences
Medium	**Trade**	Representation of trade	Armington assumption of product heterogeneity; small open economy Trade closure	Armington assumption for private consumption; small open economy Endogenous import shares but exogenous export
	Private consumption	Consumption Module	CES consumption functions by household	Explicit representation of durable, non-durable & energy commodities and services
High		Investment and capital accumulation	Each household with specific fixed saving rate (fixed fraction of income is saved and then invested); builds up capital stock over time	Investments represent the historic investment activities; no closure and no crowding out; saving: difference between disposable income and consumption
	Income	Income of private households	Income from labor and capital is fully transferred to households	Income from labor is fully transferred; Income from capital is based on a fixed share of net surplus from production → aligns with sectoral national accounts
	Markets	Labor	1) classical unemployment via minimum wage (with flexible labor supply) 2) full employment (with flexible wages that clear the market)	Labor market is "sticky" - depends on previous years: consumer price index, wages and sectoral / overall labor productivity performances
		Capital	full employment of capital with capital rent being flexible to clear market (i.e. all capital is used); capital is generic and fully mobile across sectors (no sector specific capital)	No explicit capital market; all capital is used, generic and fully mobile across sectors Capital stocks are not explicitly modelled; Price transmission from changes in the cost of investment goods affects prices for capital goods

		Goods and services	Finds new equilibrium price and quantity based on changes in supply and demand (supply constrained model)	Only accounts for changes in demand – all that is demanded will be supplied (demand driven model)
	Public budget	Public budget	Endogenous budget → public consumption reacts to changes in public taxes	Exogenous public consumption → will not react to changes in the public taxes

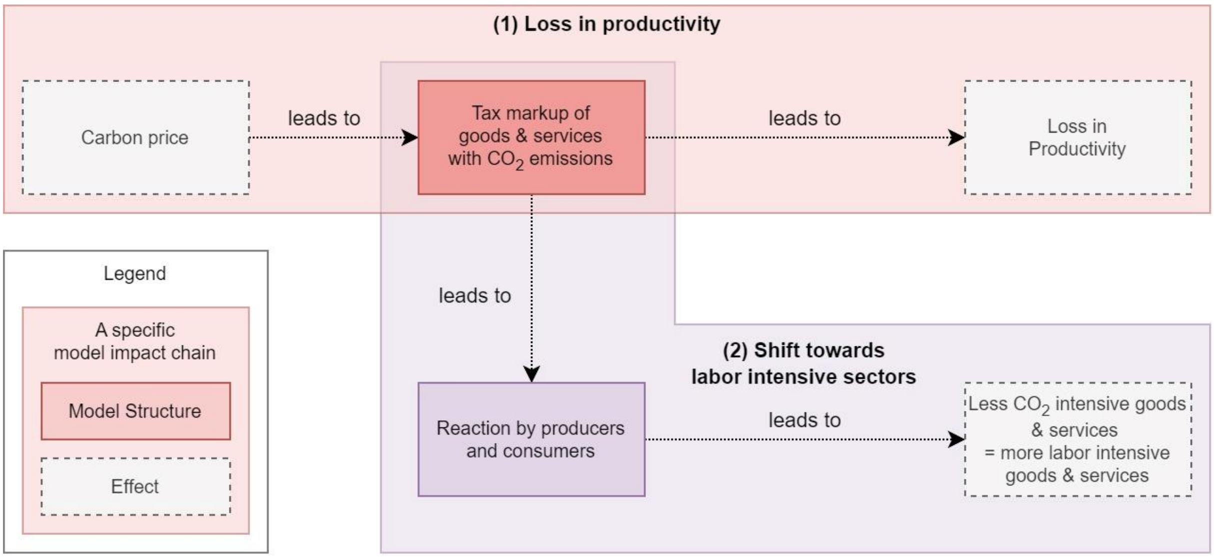

Figure 8: The two primary impact chains of carbon pricing that are similar across the models

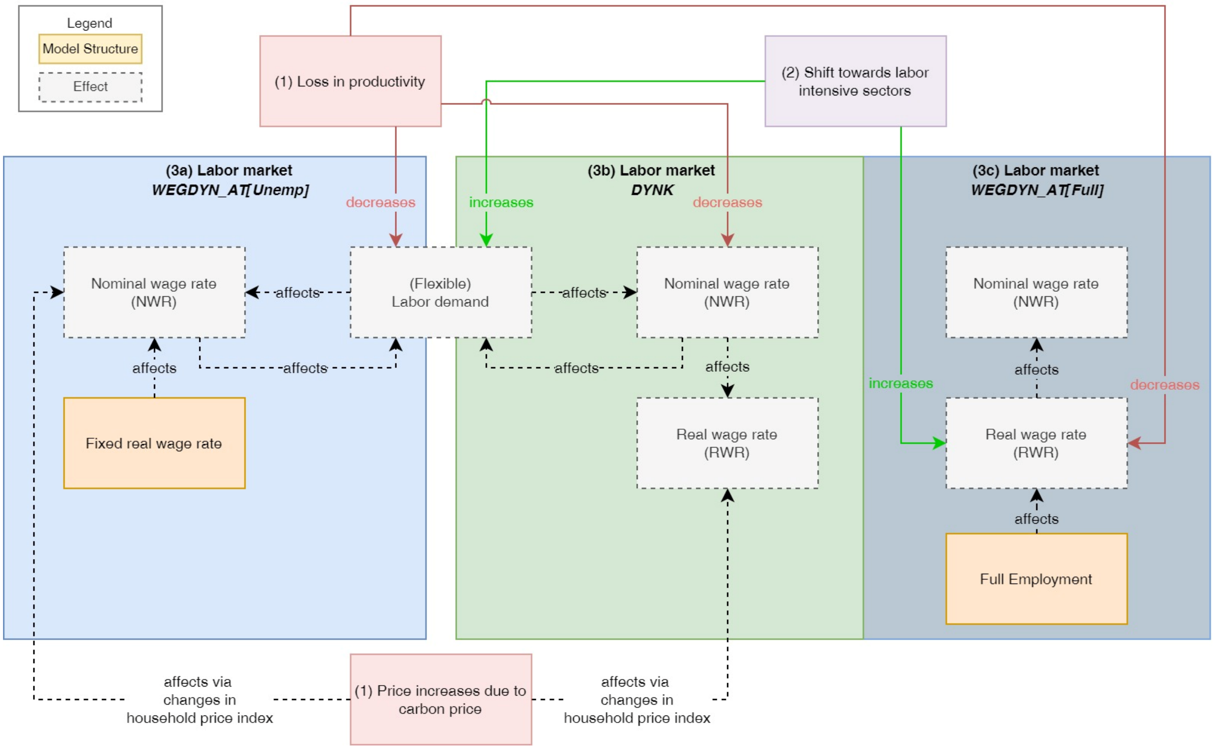

Figure 9: Labor market impact chains in the model variants and how they are affected by the first two impact chains.

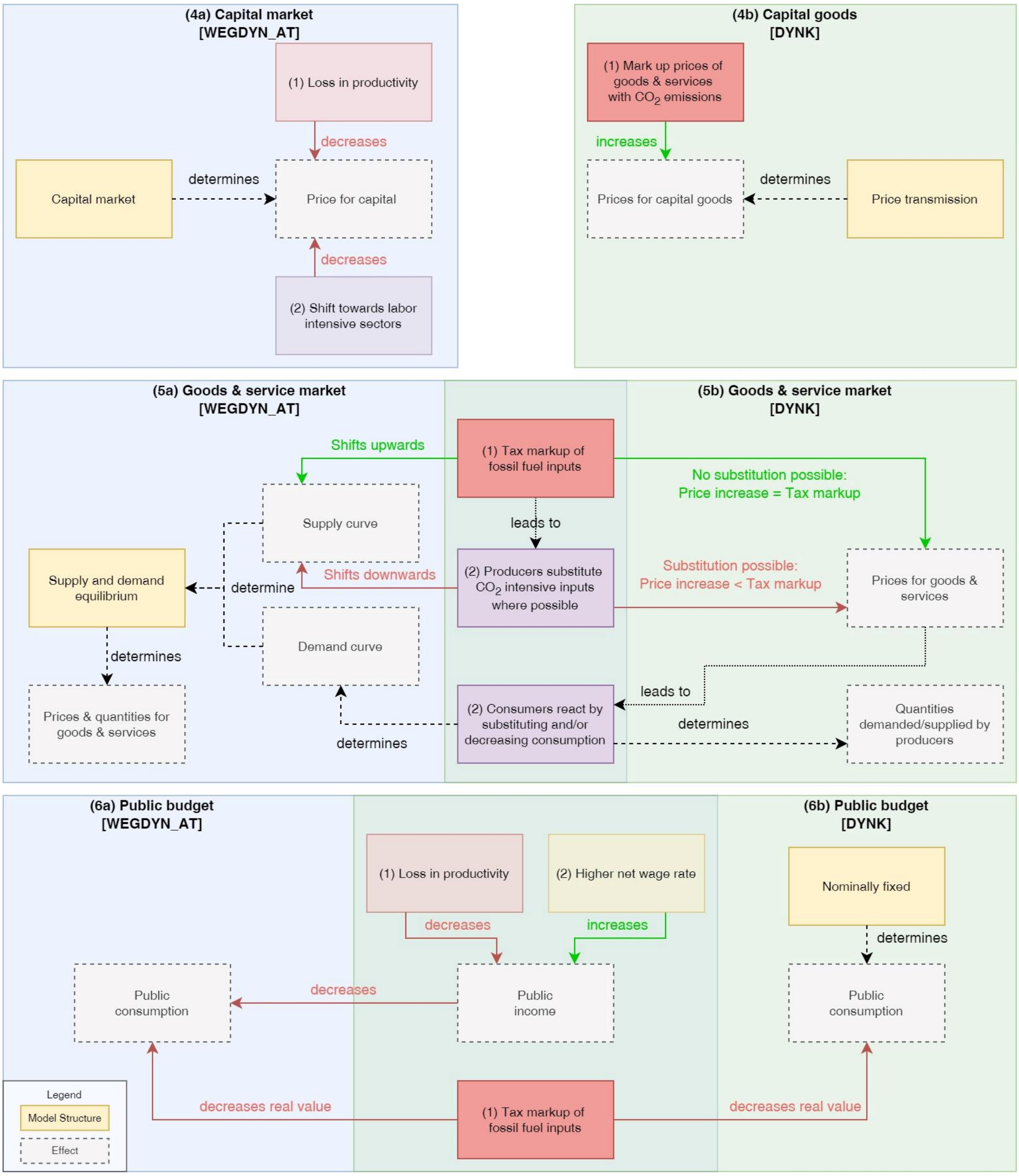

Figure 10: Model impact chains of carbon pricing for the capital market, goods and service market and the public budget.

Table 8: Share of households with a lower cost of living than in the baseline, in Carbon Price Scenario A

Scenario	*Region*[1]	*Q1*	*Q2*	*Q3*	*Q4*	*Q5*
CBR	*THIN*	0.67	0.31	0.00	0.00	0.00
	INMD	0.97	0.45	0.13	0.00	0.00
	DENS	1.00	0.82	0.40	0.10	0.00
	VIEN	0.99	0.66	0.30	0.00	0.00
CBRlow	*THIN*	0.94	0.78	0.46	0.00	0.00
	INMD	1.00	0.90	0.59	0.00	0.00
	DENS	1.00	0.98	0.88	0.00	0.00
	VIEN	1.00	0.93	0.84	0.00	0.00
LCR	*THIN*	0.00	0.01	0.00	0.00	0.01
	INMD	0.05	0.01	0.01	0.01	0.01
	DENS	0.26	0.39	0.30	0.21	0.04
	VIEN	0.51	0.23	0.19	0.04	0.02
VTR	*THIN*	0.72	0.77	0.84	0.78	0.83
	INMD	0.91	0.81	0.82	0.86	0.90
	DENS	0.94	0.98	0.91	0.94	0.97
	VIEN	0.94	0.90	0.94	0.93	0.95
MIX	*THIN*	0.42	0.20	0.00	0.00	0.00
	INMD	0.83	0.29	0.01	0.00	0.00
	DENS	0.88	0.66	0.36	0.15	0.00
	VIEN	0.92	0.53	0.29	0.00	0.00
MIXlow	*THIN*	0.69	0.42	0.23	0.00	0.00
	INMD	0.97	0.59	0.33	0.00	0.00
	DENS	1.00	0.85	0.55	0.00	0.00
	VIEN	0.99	0.76	0.54	0.00	0.00

[1]THIN … thinly populated, INMD … intermediately populated, DENS … densely populated, VIEN … Vienna

Diese Projektbeschreibung wurde von der Fördernehmerin/dem Fördernehmer erstellt. Für die Richtigkeit, Vollständigkeit und Aktualität der Inhalte sowie die barrierefreie Gestaltung der Projektbeschreibung, übernimmt der Klima- und Energiefonds keine Haftung.

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