Modelling the economy-wide effects of unilateral CO_2 pricing under different revenue recycling schemes in Austria - Identifying structural model uncertainties

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Abstract

Macroeconomic modelling is widely applied to assess the effects of carbon pricing. However, there remains substantial uncertainty on these effects within and especially across different modelling approaches. This paper identifies model structure uncertainties between a Neoclassical computable general equilibrium model (WEGDYN_AT) and a New Keynesian model (DYNK). Specifically, we reveal and isolate model impact chains, i.e. causal relationships within the models, that drive macroeconomic results. Our companion paper (Kettner et al., 2024) complements this analysis by identifying dividends and distributional effects from carbon pricing and deriving policy recommendations. Our analysis shows that model impact chains of carbon pricing and revenue recycling options can differ substantially and structurally between macroeconomic models, especially regarding the labor, capital, and goods & services market as well as the public budget. New Keynesian models likely show stronger reactions to external price shocks (like carbon pricing), but smoother effects in the labor market, with opposite effects for Neoclassical models. Assumptions regarding consumption behavior, such as the type of consumption function and respective nesting and elasticities, can significantly influence the effect of tax recycling options addressing household income. Further, we find that similarities in aggregate results can conceal differences in impact chains. Hence, the transparent description and documentation of model impact chains can support a better understanding of the potential bandwidth of macroeconomic effects of carbon pricing, including the identification of more robust outcomes, and thus aid policy support. Model structure uncertainty analyses should therefore be more widely applied, covering further approaches to modelling the impacts of carbon pricing (e.g. agent-based models, system dynamics).

Keywords: model comparison, macroeconomics, carbon pricing, structural uncertainty

1 Introduction

The last decade has seen a plethora of macroeconomic simulation studies on carbon pricing and revenue recycling policies. A common finding of these studies is that different options of revenue recycling (i.e. how revenue is used) can lead to different effects on important socio-economic indicators with diverse implications for double dividend[1] potentials (Freire-González, 2018; Goulder, 1995) or equity (Budolfson et al., 2021; Goulder et al., 2019; Kirchner et al., 2019; Klenert et al., 2018; Mayer et al., 2021).

Nonetheless, there is still no consensus in the macroeconomic literature on the absolute and relative impacts of carbon pricing policies (incl. associated revenue recycling options) on several socio-economic and ecological indicators. First, models based on different macroeconomic theories, such as New Keynesian and Neoclassic, may lead to varying results due to fundamental structural differences regarding factor and goods markets as well as agents' behavior. For instance, underlying labor market mechanisms may be very divergent in different types of models due to, i.a., sticky price or flexible wage assumptions as well as the possibility of changes in labor supply. Second, even if models of the same type are applied, results might differ substantially due to, e.g., macroeconomic closures, differences in the consideration of household characteristics or other behavioral functions and parameter values. Furthermore, usually New Keynesian and Neoclassical modelers do not cooperate much and often work in isolated camps, which makes a systematic comparison of models as well as uncertainty assessments difficult.

Hence, despite many individual studies on carbon pricing policies, little is known about structural uncertainties in macroeconomic simulations of carbon pricing and revenue recycling policies. In this paper, we focus specifically on the underlying model impact chains, i.e., the causal relationships derived from the models. This structural uncertainty is different from parameter/data uncertainty, which is typically addressed via statistical methods, such as Monte Carlo simulations (Abler et al., 1999; Wang and Chen, 2006). Structural uncertainty focuses on how different structures and assumptions between models (behavioral functions, system processes, etc.) may affect the outcomes of the same policy or driving force. Structural uncertainty differs from statistical uncertainty as it is usually impossible to assign numerical probabilities to structural assumptions (assumed impact chains). Hence, structural uncertainty may be expressed as a kind of "scenario" uncertainty (Kirchner et al., 2021; Walker et al., 2003), i.e. model types with different structural assumptions are treated as different scenarios and compared to one another. In a macroeconomic context such "scenarios" could be a policy that is either implemented during an economic boom phase or a recession. Importantly, these structural uncertainties may lead to uncertainty at the science-policy interface, potentially curbing climate action (Kunreuther et al., 2014).

A lot of progress has been made in inter-model comparison studies, which focus specifically on structural uncertainty, especially with respect to integrated assessment models (IAMs) (Keppo et al., 2021; Nikas et al., 2021; Rosenzweig et al., 2017, 2013; Warszawski et al., 2014). Quite often, comparison studies analyze scenario results (Jaxa-Rozen and Trutnevyte, 2021; van Vuuren et al., 2020), providing valuable information on potential uncertainty sources and their contribution (Guivarch et al., 2022), but such approaches of comparing results across models cannot provide detailed information on the causal impact chains that lead to the differences in results. Fewer studies have been conducted on specific macroeconomic model comparisons with focus on carbon pricing.

[1] Simply put, the double dividend means that the carbon price results in gross domestic product (GDP) increases and greenhouse gas emission reductions at the same time. For more nuanced definitions see, e.g., Goulder (1995).

Notable exceptions are Edenhofer et al. (2010), Jansen and Klaassen (2000), Kober et al. (2016), Meyer and Ahlert (2019), Böhringer et al. (2021) and Andreoni et al. (2023) who all use different models to assess carbon pricing policies, but do not explicitly embed their findings in a broader framework of uncertainties, usually reporting a bandwidth of uncertainty. Most importantly, they do not offer a systematic comparison across models with different assumptions regarding macroeconomic theory and only provide little or no information on structurally different impact chains. One exception is a study by Bachner et al. (2020) who focus on low-carbon transition pathways in the iron and steel industry, but not on carbon pricing policies explicitly. Furthermore, Keppo et al. (2021) explore and compare modelling issues of different global process-based IAMs, including Neoclassical (supply-led) and Keynesian (demand-led) models. They provide important insights with numerous examples, highlighting many issues relevant to this study, for example, how employment and capital markets are modelled. Given the broad range of their analysis, they can only hint at potential different impact chains, but cannot provide a detailed comparison. They encourage modelers to go beyond highlighting core assumptions, and to reveal also those hidden elsewhere in the models.

Systematic comparisons of impact chains across models with different macroeconomic foundations and with respect to carbon pricing policies are thus still lacking. We bridge this knowledge gap by applying two macroeconomic models of Austria’s economy that have been used to assess carbon pricing policies quite recently: a Computable General Equilibrium (CGE) model, *WEGDYN_AT* (Bachner, 2017; Mayer et al., 2021) based on Neoclassical economic theory, and a New Keynesian macroeconomic model that applies economic concepts from both Neoclassical and Keynesian economic theory, *DYNK* (Kirchner et al., 2019; Sommer and Kratena, 2019). *WEGDYN_AT* is employed with two different labor market model closures – one with classical unemployment (labor supply adapts endogenously according to a minimum real wage rate) and one with the assumption of full employment (that is balanced to equilibrium by a flexible real wage rate). Because previous publications by these models on carbon pricing were so far conducted independently, comparing their findings would not enable a systematic identification of structural uncertainties. Therefore, in this study, we align scenario assumptions and input parameters. However, we do not alter the underlying model structures on purpose, in order to reveal uncertainties from differences in the models’ default setups. This allows us, by tracing variables along impact chains and comparing results, to isolate structural uncertainties via differences in impact chains.

To summarize, this paper provides a qualitative and quantitative model comparison analysis in the context of carbon pricing to answer the following research questions:

1. What structural differences can be identified between Neoclassical and New Keynesian macroeconomic models in the context of carbon pricing?
2. What are the main impact chains, i.e., the causal relationships derived from the models, and how do they affect the results in the respective carbon pricing model simulations?

Note that we explicitly do not focus on the model results *per se* and specifically not on an assessment and comparison of the different policy scenarios – this is the focus of the companion paper (Kettner et al., 2024)[2]. Here, we focus on highlighting structural differences and impact chains across models.

The remainder of the paper is structured as follows: Section 2 provides a short overview of our methodological steps. Section 3 provides the qualitative model comparison assessment, identifying

[2] The working paper of Kettner et al. (2024) is currently available for download at https://farecarbon.joanneum.at/wp-content/uploads/2024/02/FARECarbon_Working_Paper_No_2.pdf. Depending on the journal’s guidelines it will be deleted if the working paper is accepted for publication.

and highlighting the most important model uncertainties and structural differences. Section 4 provides information on the setup of the quantitative model comparison assessment, including information on model harmonization and scenarios. Section 5 provides the comparison of the most important quantitative outcomes. Our findings are discussed in section 6 and we conclude with recommendations in section 7.

2 Overview of methodological steps

We aim to identify structural uncertainty and thus differences in impact chains between two macroeconomic models of Austria's economy by applying an inter-model comparison analysis (Rosenzweig et al., 2017; Warszawski et al., 2014). This requires the following methodological steps:

(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 section 3),
(2) a **harmonization** of model input data, output data and scenario parameters (see section 4), and
(3) the identification and comparison of the impact chains that drive the quantitative outputs of **model simulations** of carbon pricing and revenue recycling options (see section 5).

The following sections explain these three steps in detail.

3 Qualitative model comparison assessment

3.1 Uncertainty framework table

An overview of relevant (but not exhaustive) features of and related uncertainties in the models is provided in Table 1. 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). Note that our assessment does not aim to address all these issues, but an UFT helps to put one's uncertainty focus visually into perspective of all other uncertainties. Many of the statistical uncertainties are not an issue of the models *per se* but are rooted in underlying data sets that are often used by both models (e.g. economic data, greenhouse gas emission data). The same is true for exogenous system drivers (e.g. assumptions on population and price developments). Hardware and software errors may always be present but are very difficult to address.

We are particularly interested in uncertainties that are relevant for inter-model comparisons. This involves uncertainties that can be highlighted if models with similar (harmonized) system data and system drivers are applied. Hence, we specifically investigate the impact of model structure uncertainty expressed as scenario uncertainty (cell colored in black in Table 1), as this is also where differences in theoretical assumptions and thus impact chains between Neoclassical and New Keynesian models manifest. Such uncertainties comprise differences in production and consumption functions, labor and capital markets, factor market closures, trade closure and government closure.

In addition, a multi-model setting introduces a lot of overlap between the UFT categories "model structure" and "system resolution". System resolution defines some of the model structure, usually *a priori* to the model simulations. In a single model setting it will thus mostly be expressed as deliberately ignoring other potential resolutions (e.g. a more detailed sectoral structure or a different categorization of household types; see cell colored in grey in Table 1). However, in a multi-model setting, some aspects that are ignored in one model might be considered in the other. Here, we want to minimize differences in system resolution between the models by harmonization of input data, indicators, and scenario parameters; nevertheless many differences will remain. Those we consider to be part of model structure uncertainty.

Table 1: Uncertainty framework table (UFT) for the two macroeconomic models considered (Source: own) Note: cells colored in black and grey are of particular focus for this analysis

		Type (Expression) of uncertainty			
		Statistical	**Scenario**	**Qualitative**	**Ignorance**
Location (Manifestation) of uncertainty		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	

3.2 Description of models

3.2.1 General descriptions

For the analysis we use the models WEGDYN_AT and DYNK. WEGDYN_AT ("Wegener Center Recursive Dynamic CGE Model") is a single-country, multi-sector, small-open-economy CGE model of Austria (Bachner, 2017; Mayer et al., 2021). The model optimizes towards annual equilibria, in which long-term macro-balances hold and all markets are cleared simultaneously. Consumers maximize utility via consumption subject to budget constraints and consumption functions, whereas producers maximize profits subject to production functions. Income is generated via the provision of production factors (labor and capital) at the market. If not stated differently, markets are cleared via adjustments of relative prices and demanded/supplied quantities. All prices are indexed to unity (benchmark year 2014) and shown relative to the numéraire, which is the price of the foreign exchange. The recursive-dynamic model solves annual equilibria in yearly time steps. The single time steps are connected via capital accumulation. WEGDYN_AT offers a high resolution in terms of production sectors (81) and household types (12 types, differentiated by residence location and income) and places special emphasis on the transport and energy sectors. Economic growth is supply constrained, i.e., production factors are scarce by default. WEGDYN_AT is applied in two typically applied variants concerning the labor market: First, assuming full employment with a flexible real wage rate (WEGDYN_AT[Full]), and second, assuming classical unemployment via a minimum real wage (WEGDYN_AT[Unem]). These two variants depict two possible economic states, namely one with limited (fully used) capacities (similar as in a boom phase, which is the standard assumption in CGE models) and one with idle capacities on the labor market (similar to a phase of recession). Note that when using the term WEGDYN_AT we always refer to the general model structure identical in both labor market variants. If differences need to be highlighted, we specifically refer to WEGDYN_AT[Unem] or WEGDYN_AT[Full].

DYNK (Dynamic New Keynesian Model) is a macroeconomic input-output model that utilizes econometric estimations based on both Neoclassical as well as New Keynesian theory (Kirchner et al., 2019; Sommer and Kratena, 2019). DYNK includes some yearly recursive-dynamic elements with respect to the labor market (sticky prices) and households (change in income affects consumption). DYNK comprises (up to) 74 production sectors and 20 different household types (differentiated by residence location and income). Economic growth is to a large extent "demand-led", meaning that demand changes drive output growth in the model, but DYNK also captures total factor productivity via trans-log unit cost equations. In the short term, an equilibrium without full employment may exist; in the medium term, however, the natural unemployment rate is approached.

Given this setup of models and variants we are able to focus on key differences between default applications of WEGDYN_AT and DYNK, two models that are typically used for policy analysis and/or support.

The following section will highlight model structures relevant to carbon pricing. To keep this text short, we refer to Mayer et al. (2021)[3] for technical details on WEGDYN_AT and Kirchner et al. (2019)[4] for technical details on DYNK. Differences between these model versions and the ones applied here are described in appendix 9.5.

3.2.2 Model structures relevant to carbon pricing

While both macroeconomic models generally apply a top-down approach to climate change mitigation options by capturing abatement opportunities via price driven substitution possibilities and elasticities (i.e. elasticities of substitution in WEGDYN_AT and DYNK) they both offer a more detailed sectoral coverage and representation of technologies for the key sectors of mobility, energy, and steel. Both models account for carbon dioxide (CO_2) emissions (see section 4.1.1 for more details), but not for other greenhouse gases (GHGs). Two reasons apply for the omission of non-CO_2 GHGs not being critical: First, carbon pricing only addresses CO_2 emissions. Second, CO_2 currently constitutes the most important GHG in Austria, accounting for about 85% of total GHG emissions in 2021 (Umweltbundesamt, 2023). In addition to carbon taxation, both models cover the standard bandwidth of taxes and subsidies at macroeconomic level, such as production, capital, labor, and export taxes as well as government transfers to households. The allocation of sectors in EU-ETS (EU Emission Trading System) and Non-ETS sectors is provided in appendix 9.5.1. Table 3 in appendix 9.1 provides a detailed comparison of model structures relevant to the models in general as well as carbon pricing in particular.

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[3] See appendix B – supplementary data, downloadable from here (open access): https://ars.els-cdn.com/content/image/1-s2.0-S0140988321005181-mmc1.pdf [accessed 2024-02-28] and here for the mathematical core equations: https://static-content.springer.com/esm/art%3A10.1007%2Fs10113-016-1089-x/MediaObjects/10113_2016_1089_MOESM1_ESM.docx [accessed 2024-02-28]

[4] See technical supplementary material in appendix B, downloadable from here (only with access): https://ars.els-cdn.com/content/image/1-s2.0-S0301421518307535-mmc2.pdf [accessed 2024-02-28]

3.3 Structural differences and impact chains

Before assessing structural differences and impact chains between the models in detail, we point to the most fundamental difference, which is the assumption of the economic “status quo.” 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 on 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.

Note, that the long-term vs. short-term perspective is a simplification, as both models have features that could be labelled as long-term (e.g. fully mobile capital in DYNK) or short-term (e.g. the myopic behavior of agents in WEGDYN_AT) and both models have been applied in an Austrian policy context to support decision makers with mid-term to long-term timeframes, e.g. DYNK for the energy and climate scenarios 2030 and 2050 for the Austrian Environmental Agency (Umweltbundesamt, 2017) and WEGDYN_AT for the assessment of distributional effects of carbon pricing (Mayer et al., 2021). Our mid-term scenario applied here provides a timeframe (i.e. 2030) that lies between the assumed short-term (DYNK / Keynesian models) and long-term (WEGDYN_AT / CGE models) perspective of the models investigated. We view the difference in time perspective as a structural difference that manifests itself in the model impact chains, i.e. the attainment of market equilibria in WEGDYN_AT and sticky prices in DYNK. It remains reasonable to compare these features even though the models might represent a different time perspective.

From the comprehensive overview of structural differences between the two models (see Table 3 in the Appendix) we distill three key distinct impact chain dimensions that likely explain the differences in model results: (1) prices / markets, (2) income, and (3) consumption. These are described in Table 2 and the following sub-sections.

Table 2: Important structural differences between the models

<table>
<tr><th>Impact chain dimensions</th><th>Manifestation in variables or structures</th><th colspan="2">WEGDYN_AT</th><th colspan="2">DYNK</th></tr>
<tr><td rowspan="3">Prices / Markets</td><td>Labor</td><td>Supply & demand reactions</td><td rowspan="3">→ supply constrained</td><td>Slow reaction to changes in demand</td><td>→ supply constrained</td></tr>
<tr><td>Capital</td><td>Supply & demand reactions</td><td>Demand reactions</td><td rowspan="2">→ demand oriented</td></tr>
<tr><td>Goods and Services</td><td>Supply & demand reactions</td><td>Demand reactions</td></tr>
<tr><td>Income</td><td>Private household income</td><td colspan="2">Labor income is fully transferred to households.
Capital income is fully transferred to households.</td><td colspan="2">Labor income is fully transferred to households.
Capital income is transferred as a fixed share of net surplus.[5]</td></tr>
<tr><td rowspan="3">Consumption</td><td>Public consumption</td><td colspan="2">Endogenous → reacts to changes in tax revenue</td><td colspan="2">Exogenous (nominal) → no reaction to changes in tax revenue</td></tr>
<tr><td>Private saving rate[6]</td><td colspan="2">Exogenous → fixed relationship between real consumption and savings</td><td colspan="2">Endogenous → difference between disposable income and consumption</td></tr>
<tr><td>Private consumption functions</td><td colspan="2">Nested Constant Elasticity of Substitution (CES)-functions with substitution possibilities. Changes in real consumption (quantities) emerge endogenously via the combination of changes in (nominal) income and changes in consumer prices.</td><td colspan="2">Explicit representation of durable, non-durable as well as energy commodities and services.
Income elasticities considered.</td></tr>
</table>

3.3.1 Prices/markets

As a Neoclassical supply constrained model WEGDYN_AT accounts for flexible demand and supply adjustments in all three markets considered: the labor market, the capital market, and the goods and services market. Thus, relative prices of goods and services as well as those of labor and capital immediately react to exogenous shocks, such as the introduction of carbon pricing. Regarding the labor market the WEGDYN_AT[Unem] variant assumes flexible labor supply, which adjusts to the real wage rate (i.e., people decide to provide labor only at a certain minimum real wage rate). DYNK, by contrast and in accordance with New Keynesian economic theory, features a much more rigid labor market, where changes in nominal wage rates follow a “sticky price” assumption, i.e. changes do not only depend on labor demand changes but also on the previous year’s nominal wage rates, productivity and consumer price index (CPI) – the underlying assumption here is that wage negotiations play an important role in the labor market. Regarding the capital market and the goods and services market DYNK only accounts for demand reactions. As a demand-oriented model, it assumes that everything that is demanded (except labor) will be supplied without production constraints (at least in the short term). To reflect the need for a higher capital stock, sectoral

[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.

investment activities increase to meet the higher demand. Producers in DYNK react to price changes by substituting towards relatively cheaper goods, which in turn affects production prices (and thus also the price for investment and capital goods), but since DYNK does not account for supply curves, they cannot be adjusted as in WEDGYN_AT.

3.3.2 Income

Differences in labor and capital markets may be exacerbated by different income impact chains in the models. In WEGDYN_AT, it is assumed that household savings are equal to the investment volume (long-run identity) and that households are the owners of the economy's labor and capital stock. In contrast, DYNK only accounts for a share of capital income in the form of a fixed percentage of net surplus (representing wages from self-employment). The remaining surplus is used for investment in each sector according to the historic relation of sectoral surplus and investment. Consequently, household income in DYNK is based on wages and transfers and therefore only partly reacts to changes in the economy's surplus.

3.3.3 Consumption

In both models public and private consumption takes place. Public consumption is treated as follows. As a CGE model, WEGDYN_AT requires a closed system of monetary flows, i.e. the public budget is endogenous. The level of public consumption depends on public income (i.e. tax revenues) as well as the CES consumption function of the government. Hence, public consumption goes hand in hand with changes in macroeconomic performance (the tax base) and thus tax income, reacting to price changes. DYNK assumes an open system and makes exogenous assumptions on public consumption in nominal terms reflecting the population's need for public goods such as education, health, and defense. This means that public consumption will only be affected in real terms by changes in price indices of public consumption.

Private consumption is modelled as follows. WEGDYN_AT assumes a fixed savings rate and nested CES consumption functions with substitution possibilities. All income is spent either on consumption or savings (=investment). In DYNK, by contrast, private consumption is mostly driven by own-price elasticities and by income elasticities (with substitution possibilities for non-durable non-energy goods and services). The savings rate is thus endogenously determined by changes in income and total consumption. These differences, especially with regard to how income changes affect consumption, may play an important role in the effects of carbon pricing.

4 Model harmonization

4.1.1 Input data

First, the underlying emission databases have been harmonized so that all models use the same dataset. This means that in all models sectoral CO_2 emissions (by type of fossil fuel) are the same in the base year, which is one important prerequisite for meaningful model comparison in the context of CO_2 pricing. Second, the baseline scenarios of the models have been harmonized. For that, we used (i) the Impact Assessment of the 'Fit for 55' Package to assume an EU-ETS price development up to 2030 (European Commission, 2021) that increase from €50/tCO_2 in 2022 to €102/tCO_2 in 2030, as well as (ii) the "With Existing Measures" (WEM, (Environment Agency Austria, 2019)) scenario and its underlying assumption with respect to gross domestic product (GDP) and labor growth. Thus, the harmonization leaves some flexibility for assumptions on the structure of the energy and transport sectors (such as autonomous energy efficiency improvements or changes in the transport or energy mix).

4.1.2 Scenarios for non-ETS carbon pricing and revenue recycling

Based on the current eco-social tax reform by the Austrian government and in consultation with stakeholders, the following non-ETS carbon pricing scenario until 2030 is used: The non-ETS CO_2 price starts at the level of €30/tCO_2 in 2022 and reaches €90/tCO_2 in 2030 (nominal values). The carbon price scenario thereby represents the currently implemented CO_2 price pathway by the Austrian government (see the companion paper Kettner et al. (2024) for details).

We further model four options for recycling the revenues from carbon pricing (see also the companion paper Kettner et al. (2024) for details) and assess how these options play out in the different models:

1. Non-Targeted Recycling (NTR)
    - Use of revenues to increase the provision of public goods. Public consumption scale without specific earmarking of revenues.
2. Climate Bonus Recycling (CBR):
    - Revenue recycling via lump-sum transfers (a "climate bonus") to all private households. We assume equal per-capita payments for all residents.
3. Non-wage Labor Cost Reductions (LCR):
    - Use of revenues to reduce employers' non-wage labour costs. We thereby assume that labour costs are being reduced for employers, but wages remain the same for employees (*ceteris paribus – c.p.*).
4. Value Added Tax Reductions (VTR):
    - Use of revenues to decrease the value added tax (VAT) on goods for basic needs (see Table 4 in the appendix).

5 Quantitative model comparison assessment

We provide a quantitative assessment of impact chains for each of the four carbon-pricing and revenue recycling scenarios. All four carbon policy scenarios are compared to the harmonized baseline run. Results are provided for the last year of the model simulations, i.e. 2030. Detailed model results are provided in the appendix (see Figure 9 to Figure 12 in appendix 9.3 and Table 5 to Table 8 in appendix 9.4). We focus on highlighting impact chains and not the model results *per se*, which are addressed in section 5.3. and specifically in the companion paper (Kettner et al., 2024).

Before presenting the quantitative results, we first provide a general description of the hypothetical "first round" isolated carbon pricing effect, as the impact chains underlying this price shock are present in all scenarios (section 5.2).[7] It is important to note that we describe individual impact chains under *ceteris paribus* (*c.p.*) assumptions to highlight a specific mechanism, which might be masked or amplified by additional effects in the models. This helps to disentangle a specific effect from the multitude of feedback between impact chains in the models. Having established an understanding of the basic carbon pricing impact chains in the models, we will go through each

[7] However, this isolated effect has not been modelled explicitly due to the difficulty of subtracting revenues from the economy in a CGE framework. This is because from the theory of general equilibrium, it follows that any kind of income or revenue raised must be allocated (i.e. spent or transferred to some other agent) in the system. In other words, it is impossible to not use carbon pricing revenues in a productive way in the CGE model WEGDYN_AT, implying that different impact chains will always be triggered.

revenue recycling scenario individually, as the tax recycling options affect the impacts chains differently or trigger additional ones (see section 5.3).

5.1 Indicators

The following indicators are used to capture and quantify the three qualitatively identified impact chain dimensions and to trace their manifestations in model variables and structures:

- Consumer price indices (CPIs) → Prices / Markets
- Nominal income → Income
- Welfare / real consumption → Consumption

In WEGDYN_AT the welfare effects emerge from the combination of the income effect and the effect on CPI. The welfare effect thus shows which effect dominates. In DYNK welfare effects do not follow income and CPI effects as closely as in WEGDYN_AT as the model does not assume a fixed savings rate, hence private consumption reactions may differ from income effects. Generally, in DYNK income changes can affect consumption levels directly via income elasticities (differentiated for household income groups), whereas in WEDGYN_AT an exogenous savings rate determines how much of household income is saved and how much consumed (see section 3.3.3). This results in much more sensitive reactions by households to income changes in DYNK compared to WEGDYN_AT.

These three indicators are each considered separately as private, public, and total effects. CPIs are derived for household-specific and public baskets of goods. Income is measured as nominal private household disposable income and public revenue. Welfare is approximated through real consumption possibilities[8]. Since the provision of public goods and services (i.e. public consumption) also contributes to economy-wide welfare, welfare is the sum of private and public real consumption possibilities (see Mayer et al., 2021, for a discussion on this issue)[9]. In addition, we also provide information on other macroeconomic indicators, such as real GDP, real production output of economic sectors, unemployment rate, and price indices for labor, capital, and producers.

Note, that the definitions of real and nominal values differ across models. In DYNK nominal values are deflated by the (partly) exogenously driven price changes (inflation[10]) in order to express results in (real) constant EUR. In CGE models, changes in prices and quantities are determined at market equilibrium. The respective quantity effects in the CGE model are the equivalent to effects in real values in DYNK, while quantities multiplied by changes in prices (with respect to a numéraire) resemble nominal values in DYNK (which are expressed in current EUR in DYNK).

5.2 Impact chains of carbon pricing

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, which is

[8] In WEGDYN_AT welfare is measured using Hicksian Equivalent Variation, but it is approximated by real consumption possibilities in DYNK (i.e. consumption levels in constant Euros). The consumption structure of DYNK does not allow to calculate a Hicksian Equivalent Variation in income by calculus as it comprises separate consumption modules that are not connected via substitution elasticities (i.e. durables, non-durables, energy goods & services, non-durable non-energy goods & services), but are mostly determined by income and price elasticities as well as specific factors for energy goods & services (e.g. vehicle stocks or heating days).

[9] 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 investigate household-specific welfare effects.

[10] Inflation in DYNK does cover price pressure from import commodities and scarcity signals on the labour market. Monetary supply, which plays a central role in actual inflation, is not covered.

ultimately shown in terms of model results, is determined by the interaction of all six (and further minor impact chains as well). However, for the qualitative description of the individual impact chains we take a *c.p.* perspective and describe them without any potential indirect effect. For example, a lower value added tax would – *c.p.* – lead to higher consumption and higher GDP, however, this neglects (on purpose) the effect from lower tax income for the public agent.

Figure 1 illustrates the two primary impact chains that are similar across all model variants: (1) price increases with the associated higher production costs and lower productivity[11] and (2) the shift towards labor intensive sectors (which might not be the case for CO_2 pricing in ETS-sectors). Figure 2 highlights differences in impact chains for the labor market and Figure 3 identifies differences in impact chains for the capital market, the goods and service market, and the public budget. The following subsections will provide a detailed description of these impact chains.

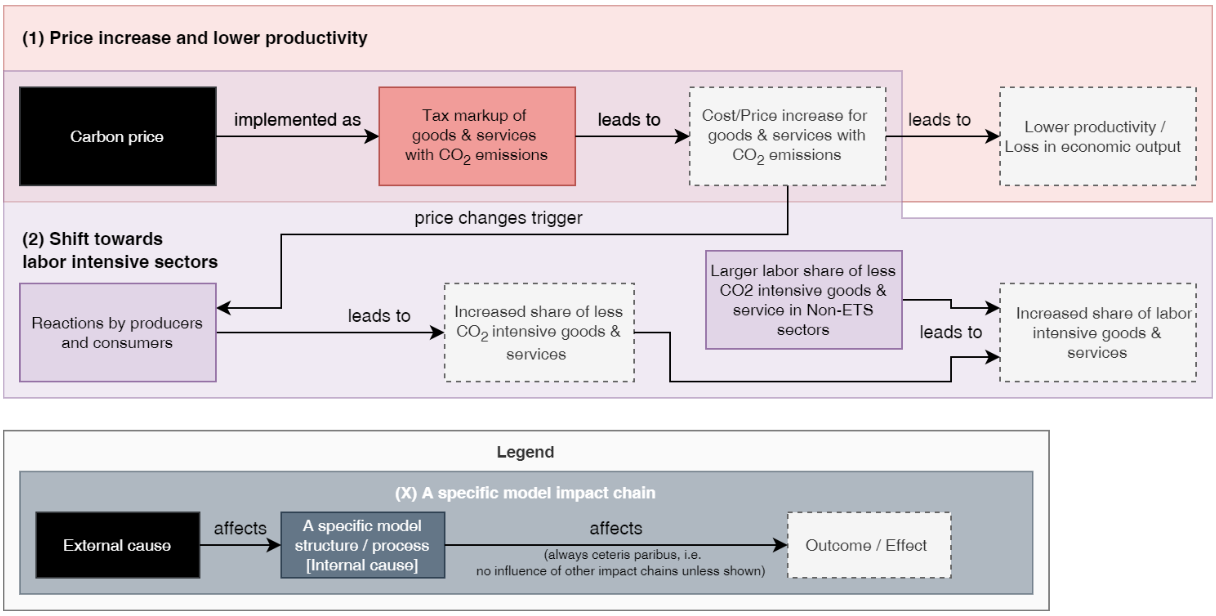

Figure 1: The two primary impact chains of carbon pricing that are similar across the models

[11] The term “productivity” used here refers primarily to loss in real economic output due to higher prices and not to changes in total factor productivity.

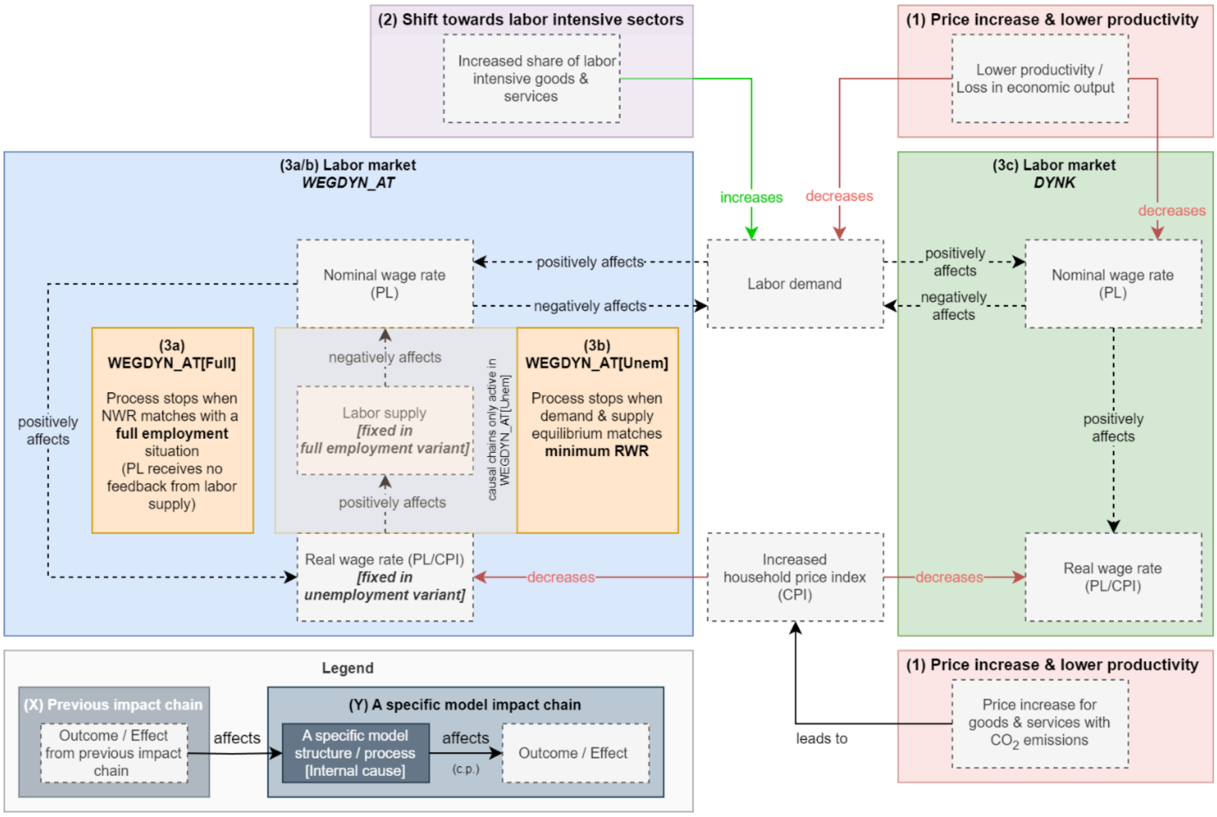

Figure 2: Labor market impact chains in the model variants and how they are affected by the first two impact chains. Note: In cases where the impact/effect is certain, we labelled it as such (e.g. "increases"). In all other cases we refer to the general causal relationship (e.g. labor demand "positively affects" nominal wage rate → if labor demand increases/decreases so will the nominal wage rate)

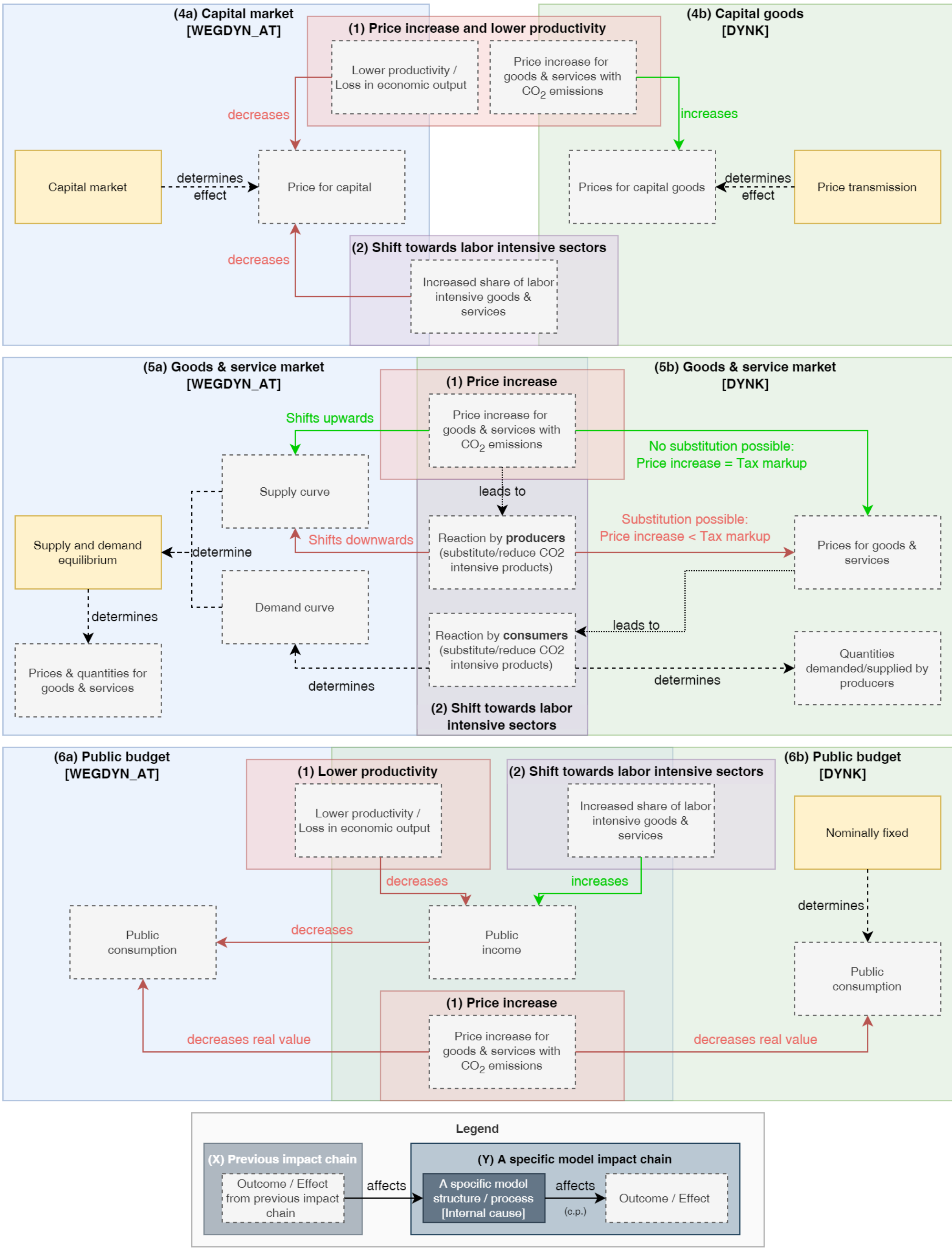

Figure 3: Model impact chains of carbon pricing for the capital market, goods and service market and the public budget.

5.2.1 Price increase and lower productivity (1)

In both models carbon pricing in Non-ETS sectors is implemented as a tax markup (see Figure 1). This induces, at first, higher costs that increase prices of fossil fuel inputs for producers in these sectors and thus a markup price accounting for CO_2 emissions. This tax and price distortion has, *c.p.*, negative impacts on macroeconomic performance as current economic flows do not account for the social cost of carbon. Production is thus getting more expensive. The isolated effect of this would be reflected in a decrease in sector output and GDP. Relaxing the *c.p.* assumption, one would have to account for the mediating effects of market adjustments in WEGDYN_AT (final price increases will thus be lower than the tax markup) as well as adjustments in DYNK (lower than in WEGDYN_AT, but still below the tax markup, see also section 5.2.5) via consumer and producer reactions to price changes.

5.2.2 Shift towards labor intensive sectors (2)

In both models, producers and consumers react to the price changes 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 (see Figure 1). This, of course, is the intended effect of carbon pricing, as it decreases CO_2 emissions. Thereby, another important "side-effect" occurs: In the non-ETS domain less CO_2 intensive inputs/goods and services are relatively more labor intensive. Mayer et al. (2021) show a negative correlation of -0.14 between labor intensity (EUR factor input per EUR gross output) and non-ETS CO_2 intensity (tCO_2 input per EUR gross output), and a positive correlation of 0.01 between capital intensity and non-ETS CO_2 intensity for the Austrian economy. Therefore, we expect – *c.p.* – a shift towards more labor-intensive sectors in both models.

5.2.3 Labor market effects (3)

The aforementioned impact chains affect labor demand in two opposing ways: Lower productivity and loss in output (an effect from impact chain 1) pushes labor demand down, and the shift towards labor intensive sectors (an effect from impact chain 2) pushes labor demand up. How the combination of these effects ultimately impacts wage rates differs between models and is not clear à priori[12] (see Figure 2):

- 3a: In WEGDYN_AT[Full] the real wage rate is flexible. Labor is scarce and fully employed. If labor demand increases (e.g. impact chain 2), scarcity is increased, leading to a higher nominal wage rate (PL). Contrary, PL will decrease due to a loss in economic output (e.g. impact chain 1) and an increase in the household CPI (e.g. impact chain 1) will lower the real wage rate (PL/CPI).
- 3b: In WEGDYN_AT[Unem] the real wage rate is fixed (minimum wage assumption). So, if the household CPI increases (e.g. impact chain 1), real wages (PL/CPI) would decrease, leading to lower labour supply (people voluntarily leave the labour market, since their remuneration is not high enough) and thereby to scarcity, which in turn increases PL. Ultimately, this process reaches equilibrium where the real minimum wage is met, at lower labor supply. An increase in labor demand (e.g. impact chain 2) increases PL, which in turn increases the real wage rate (PL/CPI; assuming *c.p.* that CPI does not change). This increases labor supply and lowers PL. Ultimately, also this process reaches equilibrium where the real minimum wage is met, at higher labor supply.
- 3c: In DYNK both labor demand and a loss in economic output directly affect the nominal wage rate (PL). Higher labor demand increases the nominal wage rate while a loss in economic output decreases it. A higher household (CPI) decreases the real wage rate (PL/CPI).

[12] For DYNK we know that lower productivity will outweigh labor demand, as DYNK can simulate a "pure" price effect by simply not recycling carbon tax revenues. In WEGDYN_AT tax revenues need to be recycled; hence we can only speculate about the effect. We assume that changes in the WEGDYN_AT variants will be quite similar, although with significant differences between the two variants.

Changes in the nominal wage rate in turn affect public and household 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.

5.2.4 Capital market (4)

Regarding prices for capital (WEGDYN_AT) or capital goods (DYNK), we identify opposing effects (see Figure 3). In WEGDYN_AT we expect decreases in the price of capital: Both the loss in economic output (impact chain 1) and the shift towards labor intensive sectors (impact chain 2; see also section 5.2.2) lower demand for capital (or at least do not increase demand stronger than for labor) which leads to price decreases in the capital market. DYNK does not account for a capital market. It assumes that capital is supplied where demanded without restrictions/scarcity and thus there is no price of capital. In DYNK we thus use the price of investment goods as a proxy for capital prices. 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. Consequently, the price transmission impact chains in DYNK likely lead to an increase in the price for capital goods even though the demand for capital shrinks. A price increase makes investments more expensive and increases nominal gross investment expenditure. Depreciation costs and interest revenues increase nominally.

5.2.5 Goods and service market (5)

We expect that consumer prices for goods and services will generally increase due to carbon pricing in both models, but substantially less in WEGDYN_AT than in DYNK (see Figure 3 and Figure 8 in the appendix for a schematic illustration of these effects).

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 dampen the upward shift). Considering the reaction by consumers (i.e. the demand curve) will then determine the new market equilibrium. *C.p.*, 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.

5.2.6 Public budget (6)

A very straightforward, yet quite important, difference between the models lies in their assumptions regarding the public budget. In WEGDYN_AT the public budget is endogenous, i.e. public consumption is determined by public income (which is turn is determined by fixed tax rates and an endogenous tax base). 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.

5.3 Results of carbon pricing policy scenarios and their impact chains

In the following sub-sections, we show the quantitative results for our four scenarios and highlight how the revenue recycling options interact with the carbon pricing impact chains as described in section 5.2. Some of the discussed impact chains and model structures in the previous section are very similar across models (price increase & loss in economic output, producer and consumer behavior), 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.

5.3.1 Non-Targeted Recycling (NTR)

Impact chains affected by the recycling option

The NTR scenario assumes that public provisions are expanded. This means that public consumption is increased by the amount of revenues generated, which has, *c.p.*, a positive effect on real economic output in both models. More public consumption specifically affects two primary carbon pricing impact chains:

- It mitigates the loss in economic output (impact chain 1).
- It amplifies the shift towards labor intensive sectors (impact chain 2) as public consumption is more labor intensive than private consumption[13].

Results for our main indicators are shown in Figure 4. Results for other macroeconomic indicators are provided in Figure 9 in the appendix.

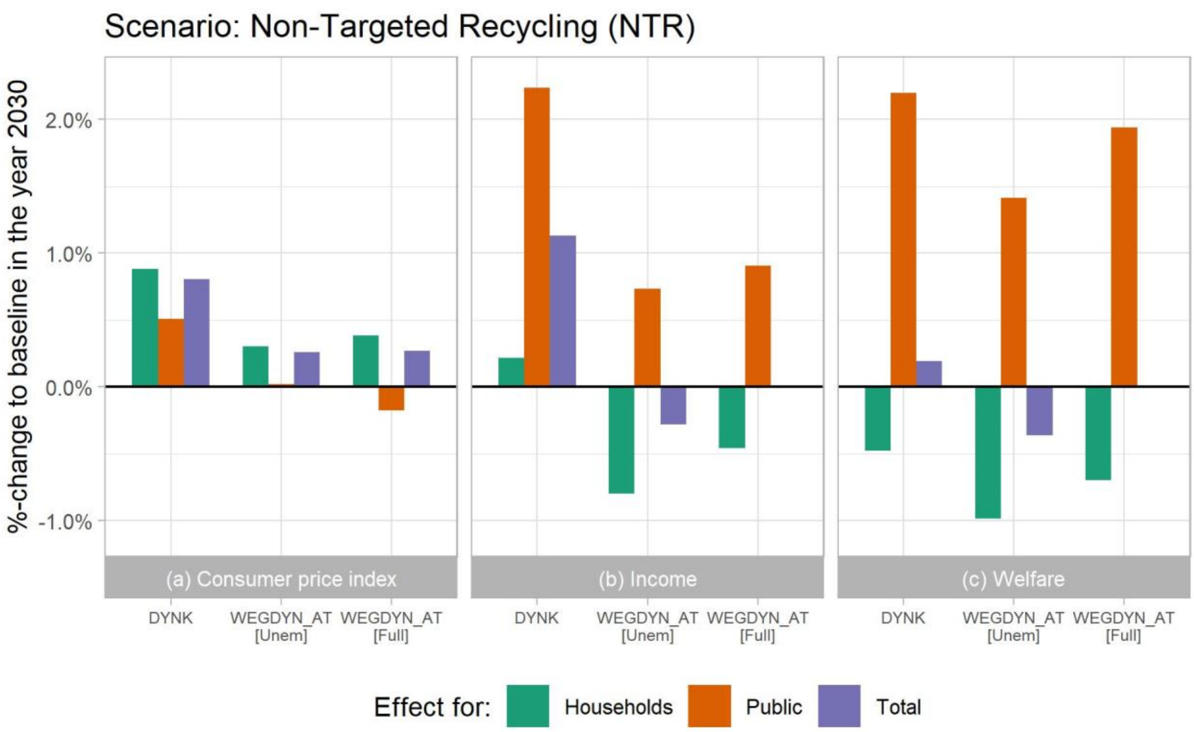

Figure 4: Main indicators – NTR scenario.

[13] In the WEGDYN_AT base year data private consumption has a labor share of 14% compared to 28% for public consumption (capital share is 24% and 14%, respectively). In the DYNK base year data private consumption has a labor share of 20% compared to 34% for public consumption (capital share is 31% and 15%, respectively).

Consumer price indices (CPIs)

Changes in the CPIs (see Figure 4a) reflect differences in price formation on markets (see impact chains 3 to 5 in sections 5.2.3 to 5.2.5). As expected, the WEGDYN_AT variants show weaker consumer price effects than DYNK due to flexible adjustments like demand reactions in markets. In WEGDYN_AT public consumption is in fact stimulated by higher revenues, which puts an upward pressure on the public CPI due to higher demand. Additionally, public consumption is relatively labor intensive, and thus affects wages as well via public demand. There are differences between the two WEGDYN_AT variants, though. In WEGDYN_AT[Full] the higher price level due to CO_2 pricing leads to a somewhat lower economic activity (output, see Figure 9 and Table 5 in the appendix), with lower factor demand and respective lower factor prices (relative to the numéraire). Note that as the nominal wage rate clears the labor market in the full employment variant, nominal wages decline; however not as strong as capital prices. This is because of two channels that put an upward pressure on wages: i) CO_2 pricing in the non-ETS sectors induces a relative shift from capital to labor intensive structures, and ii) there is higher demand for labor intensive public consumption due to higher tax revenues. However, these pressures are not strong enough to turn the effect on the nominal wage rate to the positive, leaving the nominal wage rate and thus public CPI with a negative effect. In contrast, nominal wages in WEGDYN_AT[Unem] are slightly higher, because the higher private CPI puts a downward pressure on real wages (PL/CPI), which leads to lower labor supply and thus higher nominal wages in equilibrium (put differently, wages are bound to the private CPI (minimum wage requirement)). This leads to an upward pressure on the public CPI, however, the loss in economic output and respective lower tax income and public demand set off these upward pressures on the public CPI leaving a neutral effect in WEGDYN_AT[Unem].

Income

Changes in nominal household income (see Figure 4b) are quite similar across models for public income but differ with respect to household income and the underlying impact chains:

- In DYNK most of the increase in household income can be attributed to increases in nominal wage rates (see Figure 9d in the appendix) and the price of capital goods (see Figure 9e) while the unemployment rate remains unchanged (see Figure 9c).
- In WEGDYN_AT[Full] we see a lower income for private households, originating from decreases in the nominal wage rate and the rental rate of capital. The public income, though, increases due to revenues from carbon pricing. We thus see a redistribution of the economy-wide (limited) income from private households to the public with a neutral overall effect.
- In WEGDYN_AT[Unem] we see increases in unemployment and the nominal wage because higher consumer prices put a downward pressure on real wages, reducing labor supply (at higher nominal wages in the new equilibrium). Together with decreases in capital income this leads to lower household income. Higher unemployment means also less tax revenue and thus less public income. The overall income effect is thus slightly negative.

Note that in DYNK a much smaller proportion of capital rent is transferred to private household income (see section 3.3.2) and nominal capital income increases due to the price transmission channels that affect the price of capital goods (see section 5.2.1).

The change in public income is also similar across the models, but magnitudes differ a bit more (see Figure 4b). Most of the increase is due to the carbon pricing revenues, but differences occur due to changes in the nominal wage rate (see Figure 9d), which affects labor tax income, and changes in production (see Figure 9a), which affects production tax revenues. Increases in DYNK are highest, as this model shows the strongest increase in the nominal wage rate and only small losses in GDP.

WEGDYN_AT[Unem] shows similar increases in the nominal wage rate as DYNK, but GDP losses are much higher. Labor tax income decreases in WEGDYN_AT[Full] with weaker changes in GDP, which puts this scenario between the other two model variants.

Welfare

The direction of private and public welfare effects is similar across models, but magnitudes differ (see Figure 4c). Negative private welfare effects are more pronounced in WEGDYN_AT than in DYNK. On the other hand, positive public welfare effects are more pronounced in DYNK than in WEGDYN_AT. This is mostly related to how public consumption is modelled: endogenously in WEGDYN_AT and exogenously determined in DYNK. The net nominal increase in public income in both WEGDYN_AT variants is lower than the carbon pricing revenues, which means that nominal public consumption in the WEGDYN_AT variants will also be lower, while the increase in nominal public consumption in DYNK will equal exactly the amount of carbon pricing revenues.

The net public welfare effect is somewhat mitigated as the public CPI remains almost unchanged in WEGDYN_AT[Unem] and decreases in WEGDYN_AT[Full], but this cannot outweigh the nominal consumption effect. Overall, this leads to positive total welfare effects in DYNK, neutral total welfare effects in WEGDYN_AT[Full], and slightly negative total welfare effects in WEGDYN_AT[Unem].

5.3.2 Climate Bonus Recycling (CBR)

Impact chains affected by the recycling option

The CBR scenario assumes that carbon pricing revenues are fully transferred back to households via equal per capita lump-sum payments. Higher income increases households' consumption opportunities, which has, *c.p.*, a positive impact on real economic output in both models. More private consumption specifically affects the two primary carbon pricing impact chains:

- It mitigates the loss in economic output (impact chain 1).
- It mitigates the shift towards labor intensive sectors (impact chain 2) as private consumption is more capital intensive than public consumption.

Results for our main indicators are shown in Figure 5 and for other macroeconomic indicators in Figure 10 in the appendix.

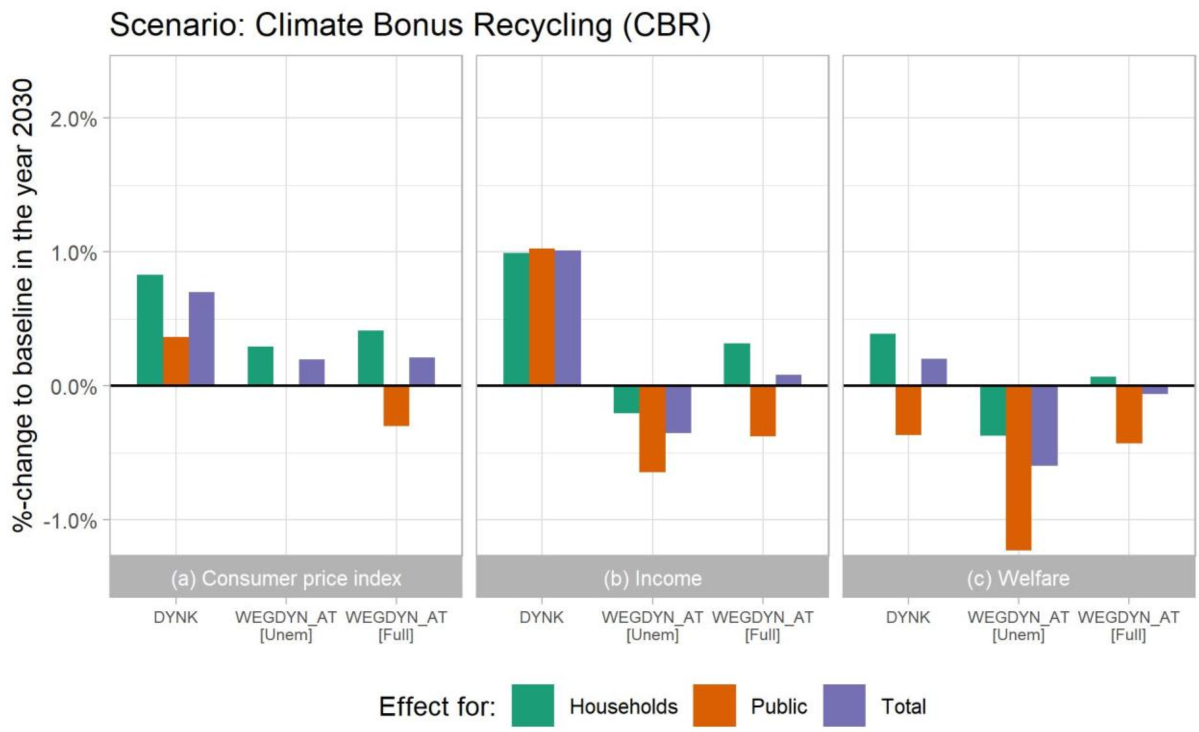

Figure 5: Main indicators – CBR scenario

Consumer price indices (CPIs)

Changes in the CPIs (see Figure 5a) and associated model impact chains are almost identical to the NTR scenarios (see section 5.3.1).

Income

Household income (see Figure 5b) generally increases due to lump-sum payments assumed in this scenario, except for WEGDYN_AT[Unem]. Differences in household income between the models accrue also due to overall macroeconomic effects (see Figure 10). Highest increases in household income are found in DYNK, where increases in the nominal wage rate (see Figure 10d) and the rate of capital (see Figure 10e) together with the climate bonus payments outweigh slight increases in the unemployment rate (see Figure 10c). In WEGDYN_AT[Full] decreases in the nominal wage rate are fully compensated by the climate bonus payments, which leads to higher household incomes. In WEDGDYN_AT[Unem] higher nominal wage rates and the climate bonus payments are not sufficient to compensate for a lower rental rate of capital and the substantial increases in unemployment (see Figure 10c), hence household income decreases.

The loss in public income (see Figure 5b) is highest in WEGDYN_AT[Unem] as tax revenues go down due to higher unemployment rates and the associated lower tax income (see Figure 10c) as well as lower sector output (see Figure 10b). In WEGDYN_AT[Full] the effect on public income is weaker since there is no effect via higher unemployment. In DYNK positive public income effects are driven solely by a larger tax revenue from labor, as the nominal wage rate increases, and the unemployment rate remains rather unaffected. However, changes in public income do not affect public consumption in DYNK.

Welfare

Private welfare (see Figure 5c) mostly follows the income effects for all models. In DYNK and WEGDYN_AT[Full] the positive household income effects dominate the higher CPI, leading to higher welfare. Since household income is already negatively affected in WEGDYN_AT[Unem] a higher CPI amplifies the negative welfare effect.

Public welfare effects (see Figure 5c) are quite similar across the models, but there are differences in impact chains. In DYNK public welfare decreases simply due to increases in the public CPI as public consumption is nominally fixed. In WEGDYN_AT[Unem] we see the highest losses in public welfare, caused by decreases in public income (particularly due to higher unemployment). Since the income effect is less strong in WEGDYN_AT[Full] we also see a weaker effect on public welfare.

Total welfare effects are positive in DYNK, as increases in household welfare outweigh decreases in public welfare. In WEGDYN_AT[Full] total welfare decreases slightly, as the loss in public welfare cannot be compensated by gains in household welfare. In WEGDYN_AT[Unemp] total welfare clearly decreases, due to losses in both household and public welfare.

5.3.3 Non-wage Labor Cost Reductions (LCR)

Impact chains affected by the recycling option

The LCR scenario assumes that non-wage labor costs are reduced by an amount that equals carbon pricing revenues. This means that labor costs are reduced for producers (via a reduced tax rate on the use of the factor labor), but nominal wage rates for employees remain unchanged (*c.p.*). Lower labor costs mean (i) that prices are reduced which would – in isolation – induce an increase in consumption and (ii) that demand for labor increases, leading to higher employment or higher wages. These basic effects specifically affect two carbon pricing impact chains:

- It mitigates the loss in economic output (impact chain 1).
- It amplifies the shift towards labor intensive sectors (impact chain 2) as labor costs are reduced.

Results for our main indicators are shown in Figure 6 and for other macroeconomic indicators in Figure 11 in the appendix.

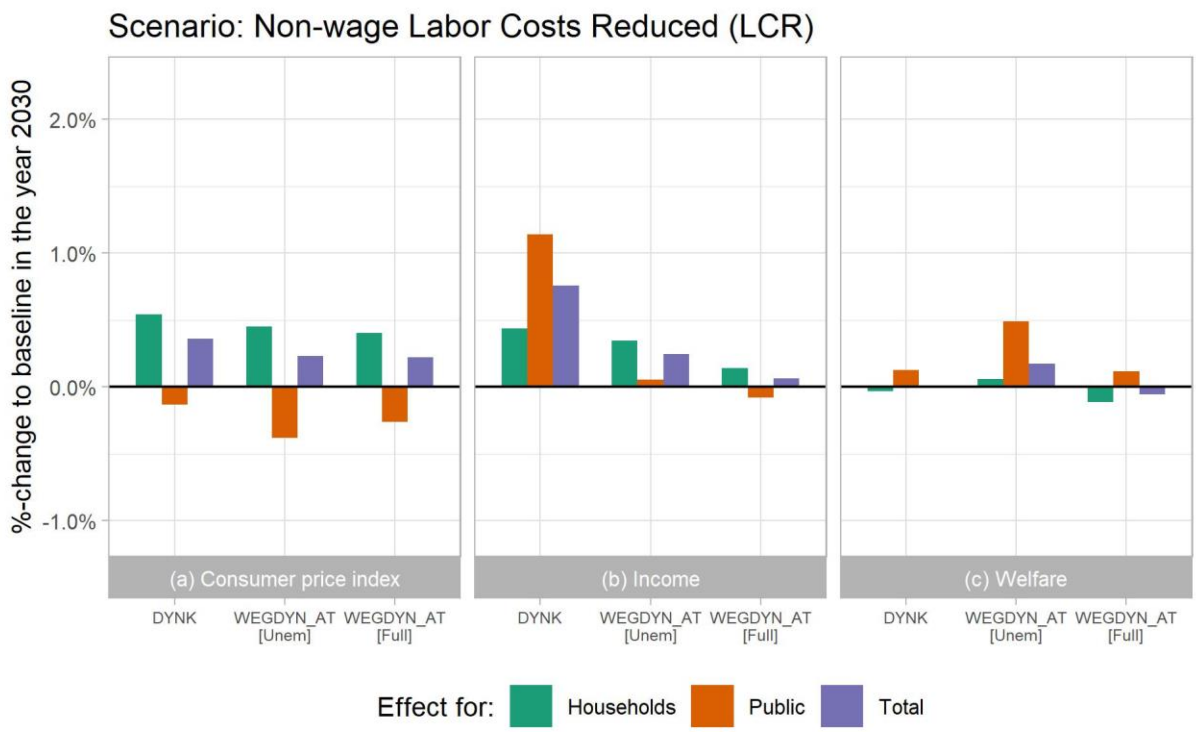

Figure 6: Main indicators – LCR scenario

Consumer price indices (CPIs)

Changes in CPIs (see Figure 6a) are very similar across the models in this scenario. Private and total CPIs increase due to CO_2 pricing (but less than in the NTR and CBR scenarios), while the public CPI decreases slightly, due to its high share of labor-intensive goods and services, which are now cheaper due to lower non-wage labor costs.

Income

Household income (see Figure 6b) increases in DYNK because of increases in nominal wage rates (see Figure 11d) and lower unemployment rates (see Figure 11c). Likewise, household income increases in the WEGDYN-AT variants. In WEGDYN_AT[Full] the nominal wage rates increase due to higher demand (see Figure 11d), which outweighs the somewhat lower rental rate of capital due to its relative abundance (see Figure 11e). In WEGDYN_AT[Unem] income is higher due to increases in the nominal wager rate, lower unemployment (see Figure 11c) and the associated stimulating economic effect with a higher rental rate of capital (see Figure 11e).

Public income (see Figure 6b) remains stagnant in the WEGDYN_AT variants. Increases in tax revenue due to higher nominal wage rates (WEDGYN_AT[Full]; see Figure 11d) or employment (WEGDYN_AT[Unem]; see Figure 11c) are counterbalanced by reductions in tax income from the lower tax rate that is levied on labor. In DYNK, we only see marginal losses in sector output and higher employment rates, hence also substantial increases in public income.

Welfare

Private welfare changes only slightly in all models, as increases in household income are almost fully compensated by increases in household CPI in all models. In DYNK and WEGDYN_AT[Full] income effects are not sufficient to compensate increases in the household CPI, leading to small decreases. In WEGDYN_AT[Unem] private welfare increases slightly.

Public welfare increases in all models. The differences in magnitude are almost solely caused by the differences in public CPI since public income remains rather unaffected in the WEGDYN_AT variants and nominal public consumption is fixed in DYNK.

The sum of private and public welfare leads to some increases in total welfare in WEGDYN_AT[Unem] and small decreases in WEGDYN_AT[Full]. In DYNK small negative private welfare effects cancel out the small positive public welfare effects.

5.3.4 Value Added Tax Reductions (VTR)

Impact chains affected by the recycling option

The VTR scenario assumes that value added taxes (VAT) for necessities (e.g. food, books) are reduced. This reduction equals the carbon pricing revenues. The basic *c.p.* effect thereby is that prices for these goods and services are reduced which induces an increase in demand for them and also lower CPIs. This specifically affects two carbon pricing impact chains:

- It mitigates the loss in economic output (impact chain 1).
- It mitigates the shift towards labor intensive sectors (impact chain 2) as goods and services affected by the VAT reduction are more capital intensive than the average.

Results for our main indicators are shown in Figure 7 and for other macroeconomic indicators in Figure 12 in the appendix.

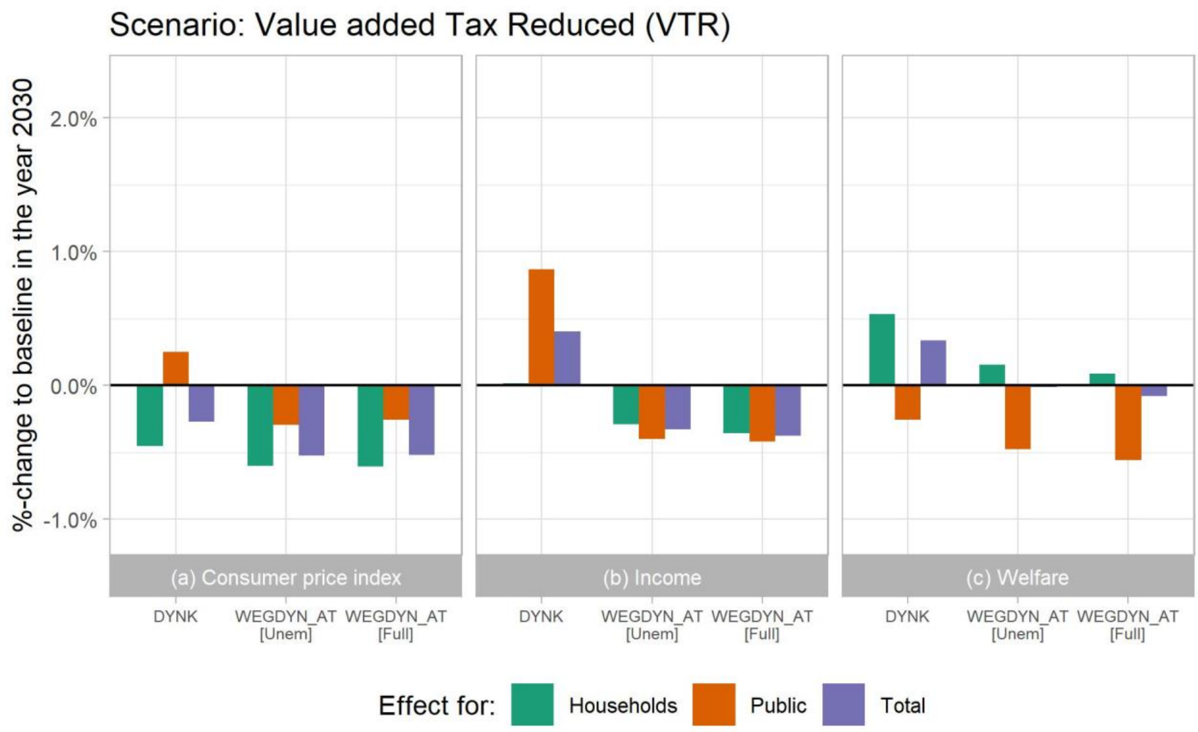

Figure 7: Main indicators – VTR scenario

Consumer price indices (CPIs)

In DYNK, we see decreases in all CPIs except the public one (see Figure 7a). In the WEGDYN_AT variants the household CPI decreases more than the public CPI since the VAT reductions focus on goods and services primarily consumed by households. The price effects are more pronounced in the WEGDYN_AT variants than in DYNK.

The public CPI in DYNK increases because public consumption focuses on labor intensive products – which become more expensive due to the CO_2 price-induced shift towards labor-intensive goods and the accompanying nominal wage rate increase in the respective sectors – and the general price increase of goods due to carbon pricing. In contrast to WEGDYN_AT, nominal wage rates in DYNK do not change (see Figure 12d in the appendix), which leads to a net increase in the public CPI. In WEGDYN_AT there is both, lower nominal wage rates as well as lower public demand due to lower tax income, lowering the public CPI. Regarding the household CPI, the lower VAT rates combined with lower labor costs in production (wages) are strong enough to outweigh the increase in the carbon price markup.

Income

We see opposing effects for income between DYNK and WEGDYN_AT (see Figure 7b). In WEGDYN_AT both household and public income decrease, with similar magnitude in the two variants. In WEDGYN_AT there is a general negative economy-wide productivity effect (although real GDP increases due to the much lower CPI, real sector output is lower) and thus, relative to the numéraire, factor prices are lower. We clearly see decreases in the rental rate of capital (see Figure 12e) and the nominal wage rate (Figure 12d) in both variants. In WEGDYN_AT[Full] there is lower factor demand, and as prices are clearing markets, factor remuneration is lower. The effect on factor prices is even stronger in WEGDYN[Unem] since the lower private CPI leads to more labor supply and thus another downward pressure on the nominal wage rate (next to the overall negative demand effect). Thus, we see decreases in both household income (lower labor and capital income) and public income (lower tax base).

In DYNK, household income remains almost stagnant and public income increases (see Figure 7b). Minimal increases in household income are due to reduced unemployment (see Figure 12c) but stagnant nominal wage rates (see Figure 12d). Public income increases mainly due to higher labor taxes.

Welfare

Private welfare increases in all models, but much stronger in DYNK than in the WEGDYN_AT variants. In both DYNK and WEGDYN_AT, the lower household CPI is a major driving force for these positive welfare effects. The weaker effects in WEGDYN_AT are due to negative household income effects, whereas there are positive effects in DYNK. This is further amplified due to consumption in DYNK being more sensitive to income changes (see section 3.3.3).

Public welfare effects are negative in all models, but much stronger in the WEGDYN_AT variants than in DYNK. As public consumption is unaffected by income changes in DYNK, we only see the effect of a higher public CPI. In WEGDYN_AT a lower public CPI is not enough to outweigh the decreases in public income to yield a positive public welfare effect.

Given the strong positive effect in private welfare in DYNK we see a positive total welfare effect. In WEGDYN_AT[Unem] positive private welfare effects and negative public welfare effects cancel each other out, leading to no changes in total welfare. Negative public welfare effects dominate in WEGDYN_AT[Full], leading to small negative total welfare effects.

6 Discussion

6.1 Impact chains and results

The common starting point across all model variants is the assumption that isolated carbon pricing (i.e. only assuming its cost increasing-effect) leads to lower productivity and a loss in economic output due to higher production costs and distortionary effects. Further, from the underlying database (the input output-table for Austria) we would expect a shift in relative factor demand towards a higher share of labor as a result for non-ETS CO_2 pricing, as for non-ETS sectors there is a lower (even negative) correlation between labor- and CO_2-intensity than for capita (see also section 5.2.2)[14].

Our results show that all model variants agree that the tax recycling options considered can significantly mitigate, if not outweigh, the isolated pricing effect. The general *a priori* mechanisms for these mitigating effects of tax recycling are also the same across the model variants, but differences arise due to significant differences in impact chains, specifically regarding:

- the labor market,
    - WEGDYN_AT[Unem]: market equilibrium with fixed real minimum wage
    - WEGDYN_AT[Full]: market equilibrium with full employment
    - DYNK: institutional rigidities (sticky)
- capital market,
    - WEGDYN_AT: market equilibrium
    - DYNK: price transmission (sticky)

[14] A critical remark on the shift towards more labor-intensive sectors is made in the next sections (caveats).

- goods & services market,
  - WEGDYN_AT: market equilibrium / endogenous consumption quantity effect / nested consumption
  - DYNK: demand-led unit cost approach / different income elasticities / separate consumption blocks
- and the public budget (WEGDYN_AT: endogenous / DYNK: exogenous.

Most of these differences accrue due to the different theoretical macroeconomic backgrounds of WEGDYN_AT and DYNK, but not all. Especially assumptions regarding income elasticities and the public budget have arisen from the history of the development of the models and cannot be attributed fully to the respective theoretical backgrounds. Furthermore, the flows of capital revenues are handled differently. While in WEGDYN_AT the revenues are fully transferred to the private sector (households, ultimately) where they are used for consumption and investments, DYNK is less dynamic in this respect as the change in capital revenues merely triggers sectoral investments (via constant relation between gross capital revenues and gross investments).

From the point of macroeconomic background, a large difference between the WEGDYN_AT variants and DYNK is the assumption of market equilibria and sticky prices (and price transmissions) in DYNK. This results in markedly different impact chains regarding the labor, capital, and goods & services market (see sections 5.2.3 to 5.2.5). Across our four revenue recycling options this leads to significant differences in CPIs, showing that price effects of carbon pricing are much weaker in the WEGDYN_AT variants, due to more flexible markets. However, flexible markets do not necessarily lead to lower price effects, as can be seen in the VTR scenario, where decreases in household CPI are larger in the WEGDYN_AT variants than in DYNK. Differences in sign only occur for the public CPI where the differences between models are strongly affected by the assumptions regarding the public budget.

Concerning the analyzed revenue recycling options we find the following. First, we can highlight that even when results are the same at the macroeconomic level, the underlying impact chains differ between the models. This can be illustrated for private welfare effects in NTR which are quite similar across the model variants, although the affected impact chains differ. Losses in DYNK result from increases in the household CPI that outweigh household income gains. In WEGDYN_AT[Unem] household CPI increases are smaller, but household income generally decreases as (a) the increase in unemployment outweighs the increase in the nominal wage rate and (b) the rental rate of capital decreases (see section 5.3.1). In WEGDYN_AT[Full] the effect is similar, only that full employment leads to lower nominal wage rates. Most of these effects can again be attributed to the economic background of the models (i.e. flexible vs. sticky markets; or long- versus short-term perspective). Hence, while there is high agreement between model variants regarding household welfare in NTR, our analysis highlights substantial differences in how these effects come about (i.e. the underlying impact chains). Looking at more disaggregated results reveals larger differences, such as distributional effects (see companion paper Kettner et al., 2024).

Second, the LCR scenario indicates that a different form of recycling may trigger the impact chains in a way that indeed leads to different results for household welfare. This scenario nicely illustrates the effect of sticky prices vs. flexible markets. In DYNK, the sticky price assumption results in a more rigid reaction in both the commodity and the labor market compared to the WEGDYN_AT variants. This results in both a higher carbon price transmission and a lower effect of reducing labor costs compared to the WEGDYN_AT variants. Although changes in household welfare are very small in all models, these differences in impact chains remain decisive for the sign of the net effect.

Third, the CBR scenario highlights how assumptions about the labor market in a CGE model can result in substantially different outcomes. In WEGDYN_AT[Unem] the labor market is cleared via changes in labor supply, resulting in an equilibrium where the real wage rate matches the minimum wage. This leads to large increases in unemployment and thus lower labor income, amplified by losses in capital income. Together with a higher household CPI, this results in significant welfare losses. In contrast, the adjustment of the nominal wage rate to meet full employment in WEGDYN_AT[Full] leads to increases in household income. The climate bonus more than compensates both the decrease in the (market clearing) nominal wage rate and the relatively small decrease in the rental rate of capital.

Finally, differences in the VAT scenario between DYNK and the WEGDYN_AT variants are most likely attributed to initial differences in consumer reactions (followed by the interaction of all other impact chains). DYNK allows for stronger reactions to price changes, inducing more consumption, while the flexible markets of WEGDYN_AT smooth such a reaction.

6.2 Caveats

Our analysis could be improved in several ways, and we identify the following caveats.

In our specific context, it needs to be emphasized that neither GDP nor our welfare indicators fully account for the social and ecological costs of economic processes. In all scenarios differences remain quite small in relative terms and none of these results would lead to the conclusion that implementing carbon pricing has negative welfare effects when taking into account available bandwidths of the social cost of carbon (Ricke et al., 2018), especially assuming low discount rates (Tol, 2023).

As we conducted a model structure uncertainty analysis, we cannot make any claims on which impact chain is more likely than the other. All models and their inferred causal relationships (= model impact chains) are simplified representations of reality. Depending on the current state and structure of the economy, one model might be closer to reality than the other. Structural aspects of the economy, such as the share of capital and labor income, affect the model impact chains and determine the extent to which our results may be generalized to similar models. Overall, econometrically expanded input-output models such as DYNK might better represent short- to mid-term impacts, while CGE models such as WEGDYN_AT might be a better tool for analyzing mid- to long-term market adjustments.

Our results may be generalized to similar models, but some aspects of the impact chains crucially depend on the type of economic shock in combination with the structure of the economy to be studied, such as a potential shift towards labor intensive sectors or the share of capital and labor income.

Finally, we might under- or overestimate the requirement of labor and capital for a transition towards a carbon neutral economy, as we only consider currently available abatement options at a very aggregate level. If the transition is very capital intensive, the relative increase in labor demand could be mitigated or even overcompensated by more capital demand. In this analysis, we focus on the effects of CO_2 pricing and revenue recycling options, without taking into account strong infrastructural changes and novel abatement options that might be triggered by such a policy. Put differently, we assume myopic agents in all models (no forward-looking expectations) and reactions will thus take place only in the domain of existing (and depicted) mitigation options. For these reasons we explicitly excluded green spending as a revenue recycling option. This could be investigated by coupling top-down macroeconomic models with bottom-up process models.

7 Conclusions

Our assessment highlights both similarities and differences between impact chains and results in the default model applications of WEGDYN_AT and DYNK. This can help policy analysis by (1) identifying impact chains and results where all model variants agree (thus indicating a higher degree of certainty), (2) considering uncertainty where both models disagree and (3) increase research efforts in case of impact chains with strong disagreement and substantially different results. Keeping the caveats in mind, our analysis suggests the following implications for policy analysis in macroeconomic modelling:

1. The general macroeconomic effects are quite similar across our model variants, i.e.
   - Depending on the chosen tax revenue recycling option, potential negative effects of carbon pricing on macroeconomic indicators can be mitigated or even outweighed, for example via an increase in employment or reduced consumer prices.
   - Carbon pricing of non-ETS sectors in Austria increases the share of labor-intensive goods & services due to the inherent structures of production sectors as well as consumption. To harvest these potential positive employment effects, capacities on factor market could be increased.
2. Short-term oriented Keynesian models show stronger effects to external price shocks, but smoother effects in the labor market (with the opposite effect for CGEs). Thus, to avoid strong consumer price effects in the short term, flexibility in terms of quick reaction possibilities of consumers and markets could be increased. This requires the establishment of alternatives, such as the possibility of switching effortlessly to public transport or low emission heating systems.
3. Different assumptions regarding the public budget and consumption behavior, such as the type of consumption function and respective nesting and elasticities, can significantly influence the overall effect of tax recycling options that directly (climate bonus) or indirectly (non-wage labor cost reductions) address household income. The question of re-distribution of tax revenues thus becomes important, as low-income households have different consumption structures and savings rates as high-income households.
4. Similar overall macroeconomic effects in carbon pricing policy scenarios may conceal differences in impact chains between the models. Thus,
   - highlighting impact chains remains important in understanding the causal mechanisms behind the results.
   - differences in effects likely increase with more disaggregated results (e.g. household income groups, sectoral analysis).

As the companion paper to this analysis (Kettner et al., 2024) shows, highlighting structural differences and impact chains can shed light on the bandwidth of potential impacts of carbon pricing across different macroeconomic disciplines and assumptions and allows policymakers to select carbon pricing policies that are likely to return more robust outcomes, considering the current state and structure of the economy. Hence, rather than relying solely on the net effects of macroeconomic simulations, carbon pricing policies can be guided by detailed knowledge of impact chains. We recommend expanding such analyses and including more macroeconomic disciplines and modelling approaches, such as agent-based or system dynamics modelling.

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9 Appendix

9.1 Structural differences

Table 3: Structural differences (selection) between macroeconomic models

Difference	Category	Structure	WEGDYN_AT	DYNK
Small	Production	Sectoral detail	81	74
		Special sectoral coverage	Electricity generation by source; motorized individual transport and land transport sectors are disaggregated	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) - other variants available; 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 ETS and non-ETS CO_2 emissions, including industrial process emissions	CO_2 coefficients of 26 energy carriers and 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	20 differentiated by income (quintiles) and residence location (Vienna, other 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 Modules	CES consumption functions by household	Explicit representation of durable, non-durable and energy commodities and services
Large		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 and represents self-employed income
	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 Sectoral investment is linked to the historic relation between a sector's gross surplus and investment; Capital stocks are not explicitly modelled; Price transmission from changes in the cost of investment goods affects prices for capital goods and thereby increase production costs of sectors

		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 public budget → public consumption reacts to changes in public taxes	Exogenous public consumption (nominal) → public consumption will not react to changes in the public taxes, but it will change in real terms due to price changes

Table 3 provides a detailed overview of structural differences. Many structural differences are rather small, especially those regarding the production structure such as coverage of production sectors and technologies, sectoral production functions or elasticities of substitution. Furthermore, there is quite some overlap in how taxes, carbon pricing and CO_2 emissions are modelled and considered in the household types (both models differentiate across income and location of residence). Similarities not included in Table 3 encompass assumptions on exogenous growth parameters for population, labor and GDP (e.g., labor force development, export demand, marginal propensity of consumption, capital stock development), sources and structure of household income, dynamics (1-year-recursive time steps). Both models assume fixed tax rates (except for the scenarios where they are changed) and fixed growth of generic transfers from the government to private households (leaving room for public consumption to vary with changes in the public budget).

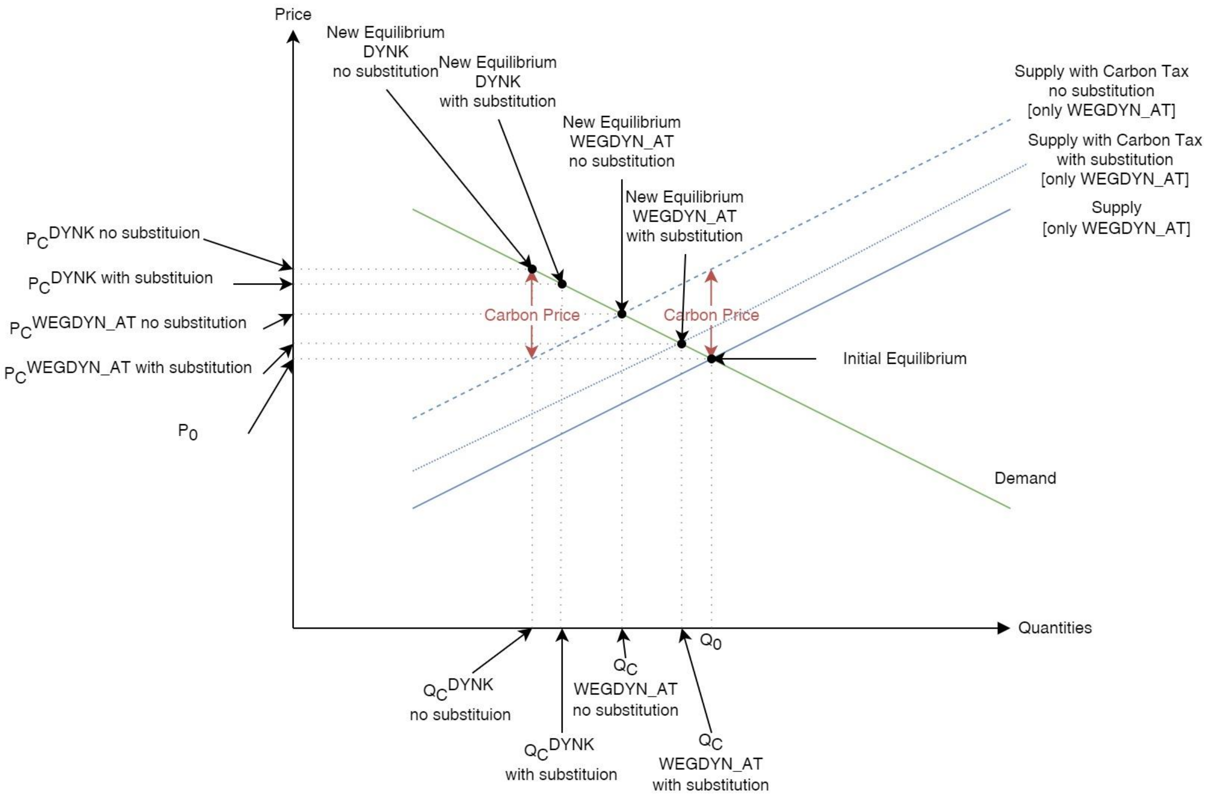

Figure 8: Schematic illustration of the difference in goods and service markets between DYNK and WEGDYN_AT (optimized for readability not likelihood of differences). Note: The demand curve will most likely differ between the models. Therefore, while prices are most likely always higher in DYNK, changes in quantity may be less if demand elasticities in DYNK are much smaller (and the demand curve thus much steeper) than in WEGDYN_AT.

9.2 Scenario data

Table 4: List of products affected by the VAT reduction in the VTR scenario (= not in WEGDYN_AT)*

CPA	Name
01	Products of agriculture, hunting and related services
02	Products of forestry, logging and related services
03	Fish and fishing products
10	Food products
18	Printing and recording services
21	Basic pharmaceutical products and preparations
36	Natural water; water treatment and supply services
37-39	Sewerage, waste management a. remediation services
49*	Land transport services a. transport services via pipelines
50*	Water transport services
51*	Air transport services
55-56	Accommod. services; food a.beverage serving services
58	Publishing activities
59	Audiovisual services
60	Programming and broadcasting services
64	Financial services
65	Insurance, reinsurance and pension funding services
66*	Services auxiliary to financial a. insurance services

72	Scientific research and development services
84	Public administration, defence, social security services
85	Education services
86	Human health services
87-88	Residential care services, social work services
90	Creative, arts and entertainment services
91	Library, archive, museum and other cultural services
93	Sporting services, amusement and recreation services
94	Services furnished by membership organisations

9.3 Other macroeconomic indicators

Figure 9: Main macroeconomic indicators – NTR scenario

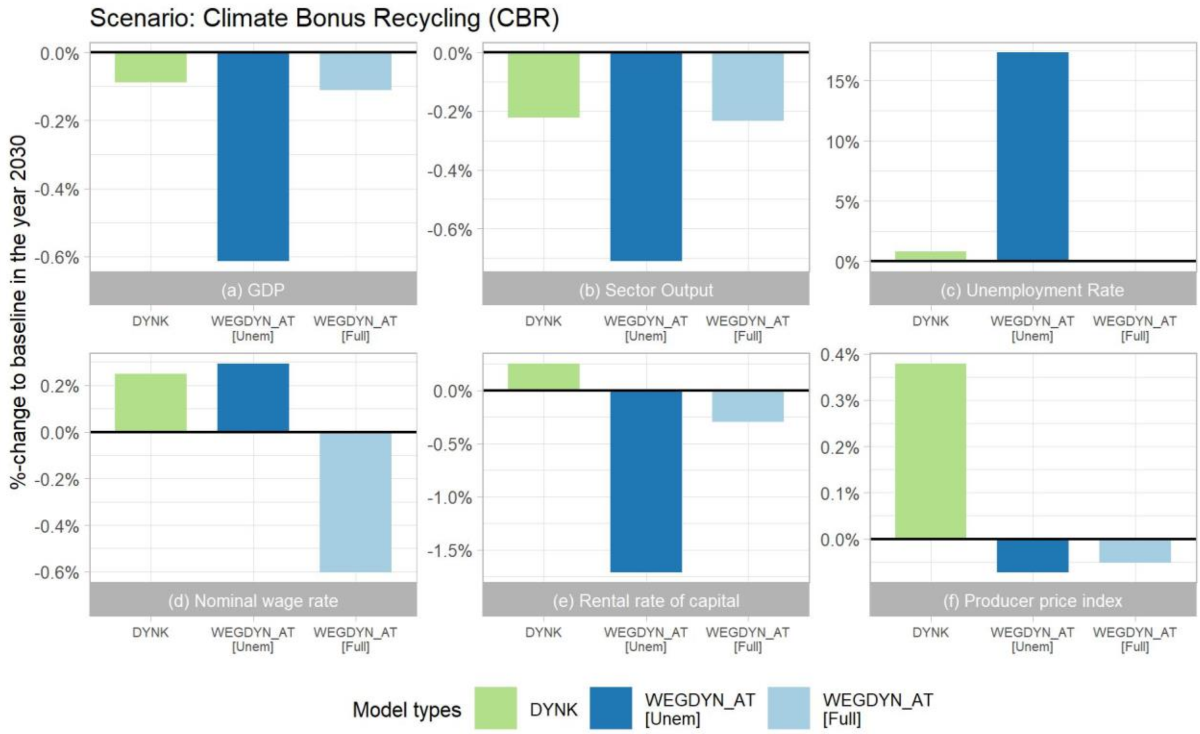

Figure 10: Main macroeconomic indicators – CBR scenario

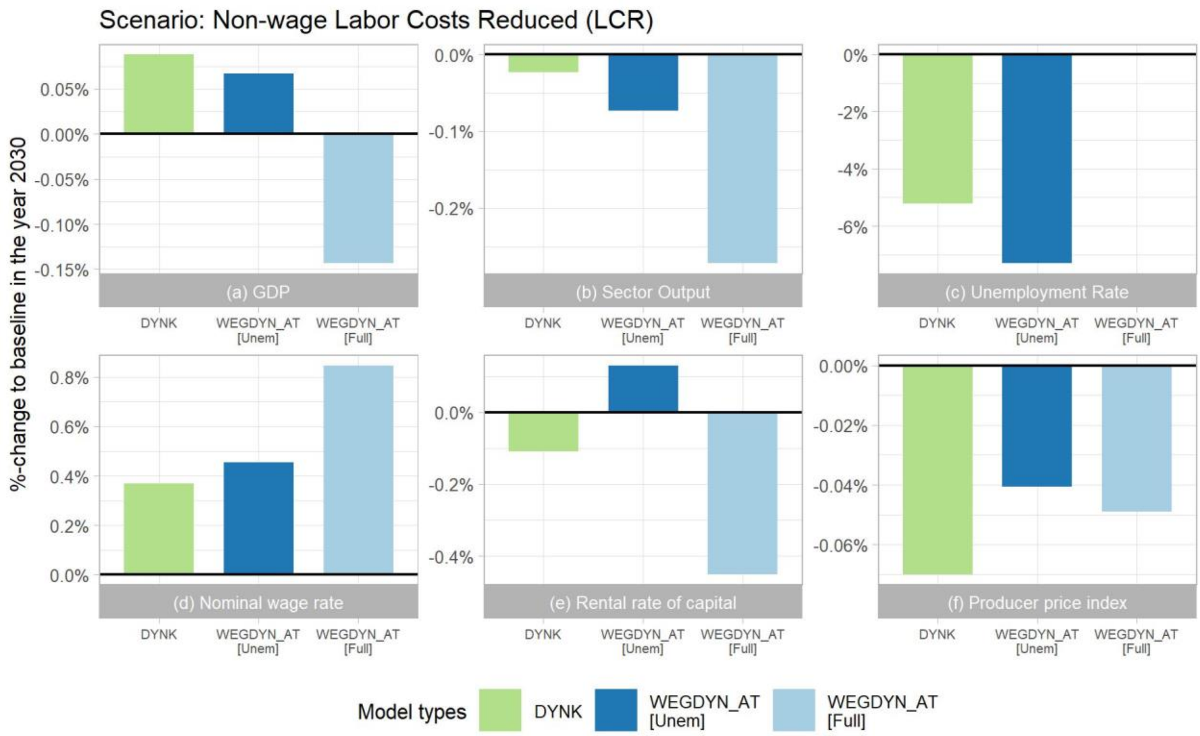

Figure 11: Main macroeconomic indicators – LCR scenario

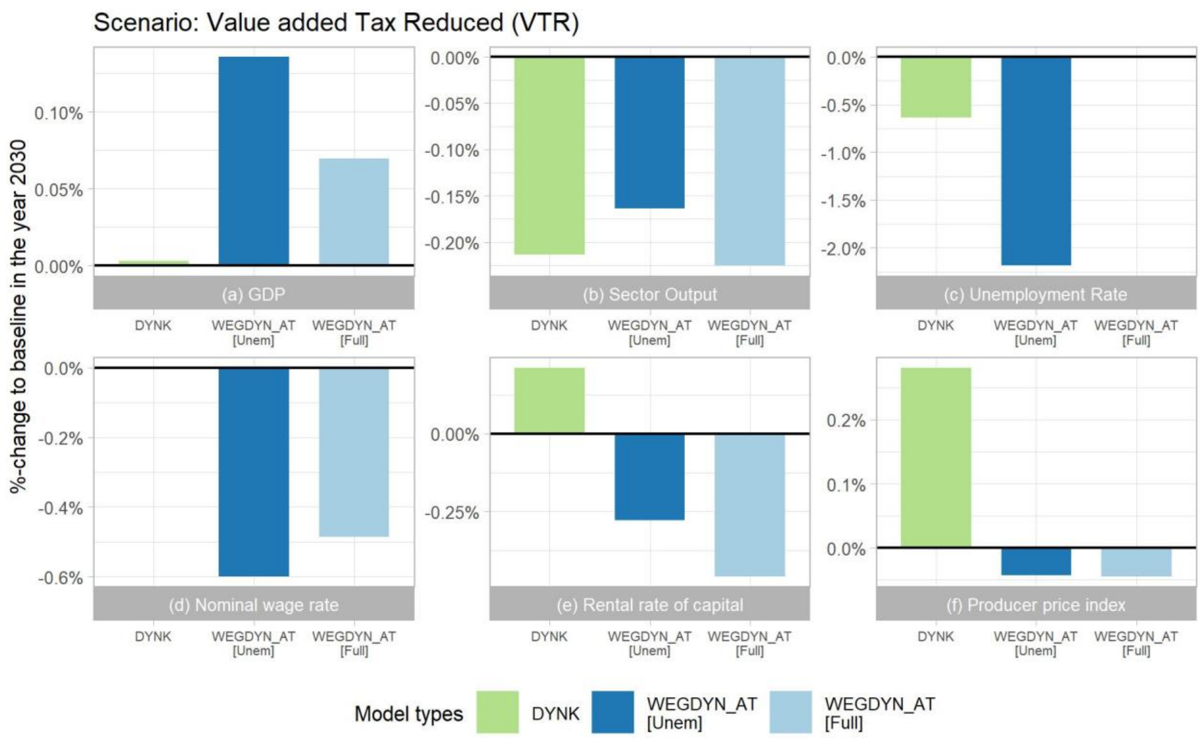

Figure 12: Main macroeconomic indicators – VTR scenario

9.4 Model output data

Table 5: Model results for the Non-Targeted Recycling (NTR) scenario – Values show percentage difference to the baseline run in the year 2030

Indicator	Level	DYNK	WEGDYN_AT	
			[Unem]	[Full]
Consumer price index	Total	0.81%	0.26%	0.27%
Consumer price index	Households	0.88%	0.30%	0.38%
Consumer price index	Public	0.51%	0.02%	-0.18%
Income (nominal)	Total	1.13%	-0.28%	0.00%
Income (nominal)	Households	0.22%	-0.80%	-0.46%
Income (nominal)	Public	2.24%	0.74%	0.91%
Welfare	Total	0.19%	-0.36%	-0.01%
Welfare	Households	-0.48%	-0.98%	-0.70%
Welfare	Public	2.20%	1.41%	1.94%
GDP (real)	Total	-0.07%	-0.59%	-0.26%
Sector Output (real)	Total	-0.22%	-0.73%	-0.42%
Unemployment Rate	Total	0.14%	11.48%	0.00%
Nominal wage rate	Total	0.43%	0.30%	-0.31%
Rental rate of capital	Total	0.30%	-1.70%	-0.74%
Producer price index	Total	0.45%	-0.05%	-0.03%

Table 6: Model results for the Climate Bonus Recycling (CBR) scenario – Values show percentage difference to the baseline run in the year 2030

Indicator	Level	DYNK	WEGDYN_AT	
			[Unem]	[Full]
Consumer price index	Total	0.70%	0.20%	0.21%
Consumer price index	Households	0.83%	0.29%	0.41%
Consumer price index	Public	0.37%	-0.01%	-0.30%
Income (nominal)	Total	1.01%	-0.35%	0.08%
Income (nominal)	Households	0.99%	-0.20%	0.32%
Income (nominal)	Public	1.03%	-0.64%	-0.38%
Welfare	Total	0.20%	-0.60%	-0.06%
Welfare	Households	0.39%	-0.37%	0.07%
Welfare	Public	-0.37%	-1.23%	-0.43%
GDP (real)	Total	-0.09%	-0.61%	-0.11%
Sector Output (real)	Total	-0.22%	-0.71%	-0.23%
Unemployment Rate	Total	0.85%	17.36%	0.00%
Nominal wage rate	Total	0.25%	0.29%	-0.60%
Rental rate of capital	Total	0.25%	-1.71%	-0.29%
Producer price index	Total	0.38%	-0.07%	-0.05%

Table 7: Model results for the non-wage Labor Costs Reduced (LCR) scenario– Values show percentage difference to the baseline run in the year 2030

Indicator	**Level**	**DYNK**	**WEGDYN_AT**	
			[Unem]	**[Full]**
Consumer price index	Total	0.36%	0.23%	0.22%
Consumer price index	Households	0.54%	0.45%	0.40%
Consumer price index	Public	-0.13%	-0.38%	-0.26%
Income (nominal)	Total	0.76%	0.25%	0.07%
Income (nominal)	Households	0.44%	0.35%	0.14%
Income (nominal)	Public	1.14%	0.05%	-0.08%
Welfare	Total	0.01%	0.17%	-0.05%
Welfare	Households	-0.03%	0.06%	-0.11%
Welfare	Public	0.13%	0.49%	0.12%
GDP (real)	Total	0.09%	0.07%	-0.14%
Sector Output (real)	Total	-0.02%	-0.07%	-0.27%
Unemployment Rate	Total	-5.22%	-7.31%	0.00%
Nominal wage rate	Total	0.37%	0.45%	0.85%
Rental rate of capital	Total	-0.11%	0.13%	-0.45%
Producer price index	Total	-0.07%	-0.04%	-0.05%

Table 8: Model results for the Value added Tax Reduced (VTR) scenario– Values show percentage difference to the baseline run in the year 2030

Indicator	**Level**	**DYNK**	**WEGDYN_AT**	
			[Unem]	**[Full]**
Consumer price index	Total	-0.27%	-0.53%	-0.52%
Consumer price index	Households	-0.45%	-0.60%	-0.61%
Consumer price index	Public	0.25%	-0.29%	-0.26%
Income (nominal)	Total	0.40%	-0.33%	-0.38%
Income (nominal)	Households	0.02%	-0.29%	-0.36%
Income (nominal)	Public	0.87%	-0.40%	-0.42%
Welfare	Total	0.34%	-0.01%	-0.08%
Welfare	Households	0.53%	0.15%	0.09%
Welfare	Public	-0.26%	-0.48%	-0.56%
GDP (real)	Total	0.00%	0.14%	0.07%
Sector Output (real)	Total	-0.21%	-0.16%	-0.23%
Unemployment Rate	Total	-0.63%	-2.19%	0.00%
Nominal wage rate	Total	0.00%	-0.60%	-0.49%
Rental rate of capital	Total	0.21%	-0.28%	-0.46%
Producer price index	Total	0.28%	-0.04%	-0.04%

9.5 Model documentation

9.5.1 ETS vs- Non-ETS sectors

The following table provides information on ETS vs. Non-ETS taxation in the models:

Sector aggregate	Model sector	OeNACE code	ETS/non-ETS	Description of model sector
AGFO	AGRI	A 01	non-ETS	Crop and animal production, hunting and related service activities
	FORE	A 02	non-ETS	Forestry and logging
	FISC	A 03	non-ETS	Fishing and aquaculture
CONS	BUIL	F 41	non-ETS	Construction of buildings
	CIEN	F 42	non-ETS	Civil engineering
	CONT	F 43	non-ETS	Specialised construction activities
ELYs	ELYs	D 35.1	ETS/non-ETS	Electricity supply
FMRO	FEXT	B 05-07; C 19	ETS/non-ETS	Mining of coal and lignite; Extraction of crude petroleum and natural gas; Manufacture of coke and refined petroleum products
	MEXT	B 08-09	non-ETS	Other mining and quarrying
GASs	GAS_MDT	D 35.2-3	non-ETS	Gas manufacturing, distribution and trade
HEATs	HEATs		ETS	Heat supply
LTRA	RAILPT	H 49	non-ETS	Rail passenger transport
	RAILFT		non-ETS	Rail freight transport
	ROADPT		non-ETS	Road passenger transport
	CITYPT		non-ETS	City passenger transport
	ROADFT		non-ETS	Road freight transport
	LTrest		non-ETS	Land transport rest
MANU	FOOD	C 10	ETS/non-ETS	Manufacture of food products
	BEVE	C 11-12	non-ETS	Manufacture of beverages
	TEXT	C 13	non-ETS	Manufacture of textiles
	CLOT	C 14	non-ETS	Manufacture of wearing apparel
	LEAT	C 15	non-ETS	Manufacture of leather and related products
	WOOD	C 16	non-ETS	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
	PAPE	C 17	ETS/non-ETS	Manufacture of paper and paper products
	PRNT	C 18	non-ETS	Printing and reproduction of recorded media
	CHEM	C 20	ETS/non-ETS	Manufacture of chemicals and chemical products
	PHAM	C 21	non-ETS	Manufacture of basic pharmaceutical products and pharmaceutical preparations
	PLAS	C 22	non-ETS	Manufacture of rubber and plastic products
	GLAS	C 23	ETS/non-ETS	Manufacture of other non-metallic mineral products
	META	C 24	ETS/non-ETS	Manufacture of basic metals
	MAME	C 25	non-ETS	Manufacture of fabricated metal products, except machinery and equipment
	MAED	C 26	non-ETS	Manufacture of computer, electronic and optical products
	MAEL	C 27	non-ETS	Manufacture of electrical equipment
	MACA	C 28	non-ETS	Manufacture of machinery and equipment n.e.c.
	MAVE	C 29	non-ETS	Manufacture of motor vehicles, trailers and semi-trailers
	MAVO	C 30	non-ETS	Manufacture of other transport equipment
	MAFU	C 31	non-ETS	Manufacture of furniture
	MAOT	C 32	non-ETS	Other manufacturing
	MARE	C 33	non-ETS	Repair and installation of machinery and equipment
SERV	STRAIL	H 52	non-ETS	Warehousing and support activities for rail transportation
	STROAD		non-ETS	Warehousing and support activities for road transportation
	STREST		non-ETS	Warehousing and support activities for other transportation
	POST	H 53	non-ETS	Postal and courier activities
	ACCO	I 55-56	non-ETS	Accomodation and food service activities
	SPUB	J 58	non-ETS	Publishing activities

Sector aggregate	Model sector	OeNACE code	ETS/non-ETS	Description of model sector
	CINE	J 59	non-ETS	Motion picture, video and television programme production, sound recording and music publishing activities
	BRDC	J 60	non-ETS	Programming and broadcasting activities
	TELE	J 61	non-ETS	Telecommunications
	SITC	J 62-63	non-ETS	Computer programming, consultancy and related activities; Information service activities
	SFIN	K 64	non-ETS	Financial service activities, except insurance and pension funding
	INPE	K 65	non-ETS	Insurance, reinsurance and pension funding, except compulsory social security
	SFIO	K 66	non-ETS	Activities auxiliary to financial services and insurance activities
	REAL	L 68	non-ETS	Real estate activities
	LEGA	M 69	non-ETS	Legal and accounting activities
	CNSU	M 70	non-ETS	Activities of head offices; management consultancy activities
	ARCH	M 71	non-ETS	Architectural and engineering activities; technical testing and analysis
	RADE	M 72	non-ETS	Scientific research and development
	ADVT	M 73	non-ETS	Advertising and market research
	FREO	M 74-75	non-ETS	Other professional, scientific and technical activities; Veterinary activities
	SRNT	N 77	non-ETS	Rental and leasing activities
	SLAB	N 78	non-ETS	Employment activities
	TRAV	N 79	non-ETS	Travel agency, tour operator and other reservation service and related activities
	SECO	N 80-82	non-ETS	Rest of N
	PUBL	O 84	non-ETS	Public administration and defence; compulsory social security
	EDUC	P 85	non-ETS	Education
	HEAL	Q 86	non-ETS	Human health activities
	NURS	Q 87-88	non-ETS	Residential care activities; Social work activities without accommodation
	ARTS	R 90	non-ETS	Creative, arts and entertainment activities
	CULT	R 91	non-ETS	Libraries, archives, museums and other cultural activities
	GMBL	R 92	non-ETS	Gambling and betting activities
	SPOR	R 93	non-ETS	Sports activities and amusement and recreation activities
	ASSO	S 94	non-ETS	Activities of membership organisations
	UREP	S 95	non-ETS	Repair of computers and personal and household goods
	SOTH	S 96	non-ETS	Other personal service activities
TRADE	TRCA	G 45	non-ETS	Wholesale and retail trade and repair of motor vehicles and motorcycles
	TRWH	G 46	non-ETS	Wholesale trade, except of motor vehicles and motorcycles
	TRRE	G 47	non-ETS	Retail trade, except of motor vehicles and motorcycles
WATR	WTRA	H 50	non-ETS	Water transport
	ATRA	H 51	ETS/non-ETS	Air transport
WAWA	WATE	E 36	non-ETS	Water collection, treatment and supply
	WAST	E 37-39	non-ETS	Rest of E

9.5.2 Model version differences

Here, we briefly highlight the most significant changes in model versions compared to the latest detailed technical documentation of the models (see Mayer et al. (2021)[15] for WEGDYN_AT and Kirchner et al. (2019)[16] for DYNK).

[15] See appendix B – supplementary data, downloadable from here (open access): https://ars.els-cdn.com/content/image/1-s2.0-S0140988321005181-mmc1.pdf [accessed 2024-02-28]

9.5.2.1 WEGDYN_AT

The WEDGYN_AT version applied here is the same as applied in Mayer et al. (2021).

9.5.2.2 DYNK

The main difference to the model documentation in Kirchner et al. (2019) is the update of the database. This comprises the Input-Output-Tables as well as estimations.

The update to base year 2017 comprised a special evaluation of the statistical institute who provide the original Input-Output-Tables. This special evaluation results in the disaggregation of the energy sector (D35) into D35A (Generation and supply of electricity), 35B (Manufacturing of Gases and Gas Supply) and 35C (Generation and supply of district heating and cooling). The production function of these three sub-sectors comprises the very same coefficients as the original sector D35. I.e. no new estimations were implemented due to lack of time series data at this level.

The econometric estimations regarding production (Translog production function) and consumption (AIDS model and various commodity demand equations) were updated using a respective longer time series.

[16] See technical supplementary material in appendix B, downloadable from here (only with access): https://ars.els-cdn.com/content/image/1-s2.0-S0301421518307535-mmc2.pdf [accessed 2024-02-28]