Macroeconomic Effects of Carbon Transition Policies: An Assessment Based on the ECB's New Area-Wide Model with a Disaggregated Energy Sector

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Motivation

- The transition to a "net-zero" economy constitutes a structural force which is expected to affect euro area macroeconomic dynamics (Lane, 2022; Schnabel, 2022).
- In the short to medium term, due to:
  - pathway for the price of carbon emissions, and hence of energy
  - changing mix of fossil and renewable resources in energy production
  - structural shifts in aggregate supply, and changing composition of aggregate demand
- In the longer term, due to efficiency gains in production and use of renewable energy.

What we do

- Augment ECB's New Area-Wide Model (cf. Coenen, McAdam, and Straub, 2008) with a disaggregated energy sector.
- Use scenario analysis to assess the macroeconomic effects of transition policies aimed at reducing carbon emissions in the euro area.
- Consider a carbon tax scenario anchored on the OECD's Effective Carbon Rates (ECRs): increase to EUR 140/tCO2 over 2022-2030.
- Examine sensitivity to conduct of monetary policy, fiscal policy, tax path, policy credibility, supply of renewable energy.

Preview of results

- Assumed increase in carbon taxes has overall limited macro impacts:
    - modestly higher inflation in the short to medium run (0.2 pp in 2023); moderate, but lasting decline in real GDP (-1.2% by 2030); and fall in emissions (about 7% by 2030)
- Additional findings:
    - specification of the monetary authority's reaction function shapes the carbon tax-induced inflation-output trade-off
    - redistributing carbon revenues to low-income households reduces consumption inequality
    - subsidising clean energy production primarily raises profits and, to a lesser extent, production
    - imperfectly credible tax increase leads to initially contained but more persistent impacts
    - enhancing supply of renewable energy reduces impacts

Related literature

- Earlier contributions of macroeconomic models with emission externalities: Angelopoulos et al. (2010), Fischer and Springborn (2011), Heutel (2012), Annicchiarico and Di Dio (2015)
- Medium-scale DSGE models with a role for energy: Känzig (2021), Ferrari and Nispi Landi (2022), Airaudo et al. (2022), Dupraz et al. (2022), Del Negro et al. (2023), Priftis and Schoenle (2023)
- Larger-scale, quantitative DSGE models investigating macroeconomic effects of carbon taxation: Varga et al. (2021), Bartocci et al. (2022), Carton et al. (2022), Ernst et al. (2022)
- Complementary IAM/CGE frameworks focusing on long-term effects: DICE (Nordhaus, 2017), GCAM (Calvin et al., 2019), REMIND-MagPIE (Dietrich et al., 2019), IMF-ENV model (Rojas-Romagosa et al., 2022), McKibbin et al. (2021)

Outline

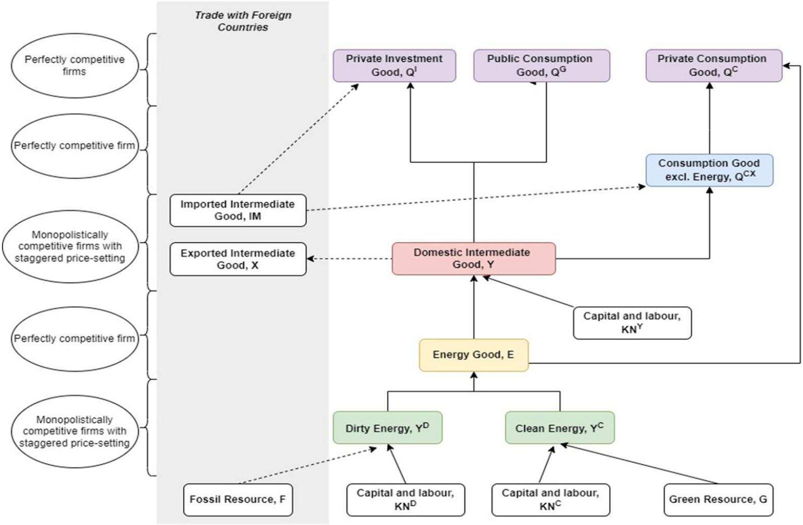
1. The model
2. The effects of carbon transition policies
   - The carbon transition scenario
   - The effects of the carbon transition scenario
3. Sensitivity analyses
4. Summary and conclusion

Main features of NAWM-E

- Large-scale 2-country New-Keynesian DSGE model of the euro area and the rest of the world, augmented with a (small) fossil resource-exporting country.
- Disaggregate energy production and use:
  - 2 separate energy-producing sectors: "clean" (solar/wind, etc.) and "dirty" (oil/coal, etc.)
  - households consume a consumption bundle, incl. an energy composite
  - intermediate-good firms use the energy composite as an input factor
- Carbon emissions primarily arise from the use of dirty energy.
- Household heterogeneity and rich specification of fiscal policy.

▸ Original NAWM

Production structure of NAWM-E



Note: This figure depicts the input and output flows across production sectors in the extended version of the NAWM with a disaggregated energy sector.

Use of the energy bundle

- Production of the final consumption good:

$$Q_t^C = \left[\nu_C^{\frac{1}{\mu_C}} \left((1 - \Gamma_{E^C,t}) E_t^C \right)^{\frac{\mu_C - 1}{\mu_C}} + (1 - \nu_C)^{\frac{1}{\mu_C}} \left(Q_t^{CX} \right)^{\frac{\mu_C - 1}{\mu_C}} \right]^{\frac{\mu_C}{\mu_C - 1}},$$

  where E_t^C denotes energy used for consumption purposes, which is subject to adjustment costs, $\Gamma_{E^C,t} = \Gamma_{E^C}(E_t^C / Q_t^C; \gamma_{E^C})$, and Q_t^{CX} is the consumption good excluding energy.

- Production of intermediate goods:

$$Y_{f,t} = z_t^Y \left[\nu_Y^{\frac{1}{\mu_Y}} \left(E_{f,t}^Y \right)^{\frac{\mu_Y - 1}{\mu_Y}} + (1 - \nu_Y)^{\frac{1}{\mu_Y}} \left(KN_{f,t}^Y \right)^{\frac{\mu_Y - 1}{\mu_Y}} \right]^{\frac{\mu_Y}{\mu_Y - 1}} - \psi^Y,$$

  where $E_{f,t}^Y$ denotes energy used for the production of intermediate-good variety f and $KN_{f,t}^Y$ is the capital-labour bundle used.

Calibration

Parameter	Value		Description
	Euro area	RoW	
A. Final-consumption-good production			
ν_C	0.061^*	0.037^*	Energy share in final consumption
μ_C	0.4	0.4	EoS: energy and consumption ex energy
γ_{E^C}	5	5	Elasticity of adjustment costs
B. Intermediate-goods production			
ν_Y	0.072^*	0.071^*	Energy share in intermediate goods
μ_Y	0.4	0.4	EoS: energy and capital-labour bundle
ψ^Y	$0.725^\dagger$	$0.749^\dagger$	Fixed costs of production

Note: The superscript "$*$" ("$\dagger$") indicates that the parameter value is implicitly calibrated by matching the empirical energy shares computed using data from the OECD (zero steady-state profits).

▸ Empirical shares ▸ Elasticities ▸ Fossil supply shock

Production and price of the energy bundle

- Production of the energy bundle:

$$E_t = z_t^E \left[\nu_E^{\frac{1}{\mu_E}} \left((1-\Gamma_{\mathcal{D},t})\mathcal{D}_t \right)^{\frac{\mu_E-1}{\mu_E}} + (1-\nu_E)^{\frac{1}{\mu_E}} \left(\mathcal{C}_t \right)^{\frac{\mu_E-1}{\mu_E}} \right]^{\frac{\mu_E}{\mu_E-1}},$$

  where $\mathcal{D}_t$ and $\mathcal{C}_t$ denote bundles of "dirty" and "clean" energy varieties, with the dirty energy bundle being subject to adjustment costs, $\Gamma_{\mathcal{D},t} = \Gamma_{\mathcal{D}}(\mathcal{D}_t/E_t; \gamma_{\mathcal{D}})$.

- Price of the energy bundle:

$$P_{E,t} = \frac{1}{z_t^E} \left[\nu_E \left(\frac{(1+\tau_t^{M_{\mathcal{D}}})P_{\mathcal{D},t}}{\Gamma_{\mathcal{D},t}^{\dagger}} \right)^{1-\mu_E} + (1-\nu_E)\left(P_{\mathcal{C},t}\right)^{1-\mu_E} \right]^{\frac{1}{1-\mu_E}},$$

  where $\tau_t^{M_{\mathcal{D}}}$ denotes the carbon tax and $\Gamma_{\mathcal{D},t}^{\dagger}$ is an expression derived from $\Gamma_{\mathcal{D},t}$.

Production and prices of dirty and clean energy

- Production of dirty energy varieties:

$$Y^{\mathcal{D}}_{d,t} = z^{\mathcal{D}}_t \left[\nu_{\mathcal{D}}^{\frac{1}{\mu_{\mathcal{D}}}} \left(\mathcal{F}_{d,t}\right)^{\frac{\mu_{\mathcal{D}}-1}{\mu_{\mathcal{D}}}} + (1-\nu_{\mathcal{D}})^{\frac{1}{\mu_{\mathcal{D}}}} \left(KN^{\mathcal{D}}_{d,t}\right)^{\frac{\mu_{\mathcal{D}}-1}{\mu_{\mathcal{D}}}} \right]^{\frac{\mu_{\mathcal{D}}}{\mu_{\mathcal{D}}-1}} - \psi^{\mathcal{D}},$$

  where $\mathcal{F}_{d,t}$ denotes the fossil resources and $KN^{\mathcal{D}}_{d,t}$ is the capital-labour bundle for the production of dirty energy variety d.

- Production of clean energy varieties:

$$Y^{\mathcal{C}}_{c,t} = z^{\mathcal{C}}_t \left[\nu_{\mathcal{C}}^{\frac{1}{\mu_{\mathcal{C}}}} \left(\mathcal{G}_{c,t}\right)^{\frac{\mu_{\mathcal{C}}-1}{\mu_{\mathcal{C}}}} + (1-\nu_{\mathcal{C}})^{\frac{1}{\mu_{\mathcal{C}}}} \left(KN^{\mathcal{C}}_{c,t}\right)^{\frac{\mu_{\mathcal{C}}-1}{\mu_{\mathcal{C}}}} \right]^{\frac{\mu_{\mathcal{C}}}{\mu_{\mathcal{C}}-1}} - \psi^{\mathcal{C}},$$

  where $\mathcal{G}_{c,t}$ denotes the green resources and $KN^{\mathcal{C}}_{c,t}$ is the capital-labour bundle for the production of clean energy variety c.

- The prices of the dirty and clean energy varieties are set in a staggered Calvo-style fashion.

Calibration

Parameter	Value				Description
	Euro area		RoW		
A. Production of energy bundle					
ν_E	0.717*		0.717*		Dirty energy share in energy bundle
μ_E	1.8		1.8		EoS: dirty and clean energy
$\gamma_{\mathcal{D}}$	5		5		Elasticity of adjustment costs
B. Production of dirty and clean energy					
$\nu_{\mathcal{D}}, \nu_{\mathcal{C}}$	0.732*	0.730*	0.528*	0.528*	Resource share in energy production
$\mu_{\mathcal{D}}, \mu_{\mathcal{C}}$	0.25	0.25	0.25	0.25	EoS: resources and cap.-lab. bundle
$\psi^{\mathcal{D}}, \psi^{\mathcal{C}}$	0.249†	0.098†	0.232†	0.092†	Fixed costs of production
$\alpha_{\mathcal{D}}, \alpha_{\mathcal{C}}$	0.707	0.707	0.716	0.716	Capital share in cap.-lab. bundle

Note: The superscript "*" ("†") indicates that the parameter value is implicitly calibrated by matching the empirical energy shares computed using data from Eurostat and KLEMS (zero steady-state profits).

▸ Empirical shares ▸ Elasticities ▸ Fossil supply shock

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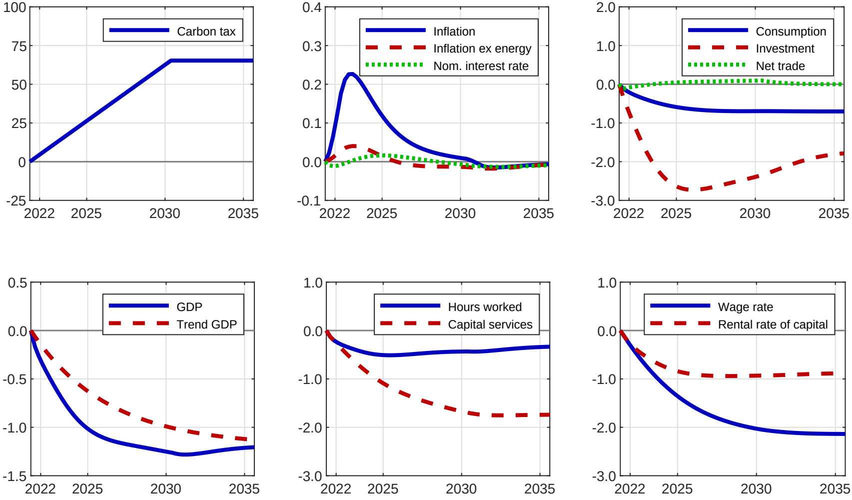
The carbon transition scenario

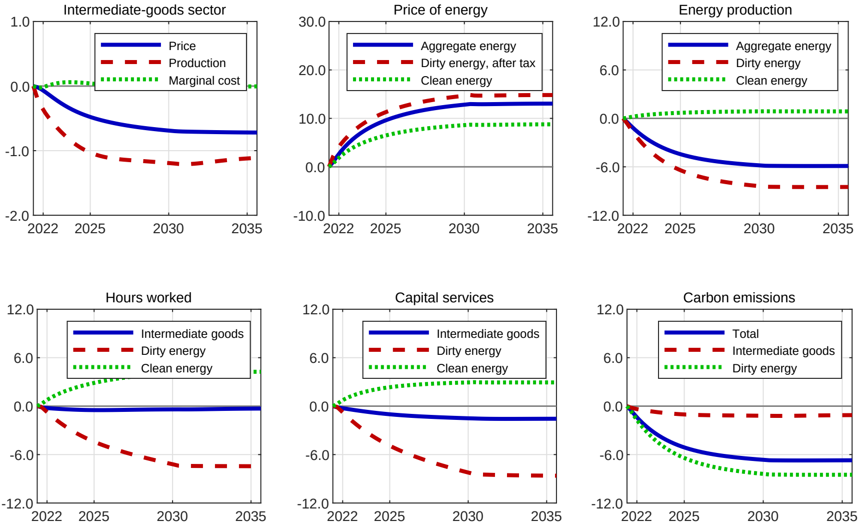
- Anchored on OECD's Effective Carbon Rates (ECRs) in 2021:
  - ECRs comprise fuel and energy excise taxes, carbon taxes and emission trading schemes
  - aggregated across 6 sectors (industry, electricity, agriculture and fisheries, residential and commercial services, off-road transport and road transport) and available at the country level
- Linear increase until 2030, and constant thereafter:
  - in the euro area, from EUR 85/tCO2 in 2021 to EUR 140/tCO2 by 2030 in line with net-zero scenario of the IEA
  - same relative increase for the rest of the world, starting from a lower level

Aggregate effects of the carbon transition scenario



Note: Inflation is measured as the annual rate of change in consumer prices, and the nominal interest rate is annualised. Net trade is reported as a share of GDP, and the wage rate and the rental rate of capital are expressed relative to consumer prices. All dynamic responses are reported as percentage deviations from baseline values, except for the dynamic responses of inflation, the interest rate and net trade, which are reported as percentage-point deviations.

Sectoral effects of the carbon transition scenario



Note: Prices are expressed relative to consumer prices, while the marginal cost of intermediate-good production is expressed relative to intermediate-good prices. All dynamic responses are reported as percentage deviations from baseline values.

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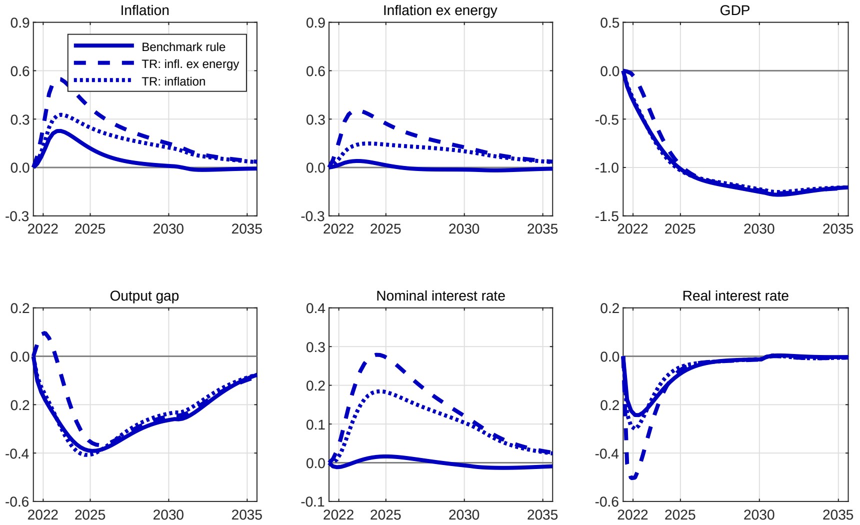
Sensitivity analyses

- Monetary policy: alternative reaction functions responding to "core" vs. "headline" inflation and the output gap
- Fiscal policy: redistribution of revenues to low-income households, and payment of subsidies to clean energy producers
- Tax pathway: front-loaded vs. back-loaded carbon tax
- Policy credibility: imperfect credibility of tax implementation
- Increases in efficiency of clean energy production and in supply of green resources
- Other robustness checks: share of energy in consumption, elasticity of substitution between clean and dirty energy

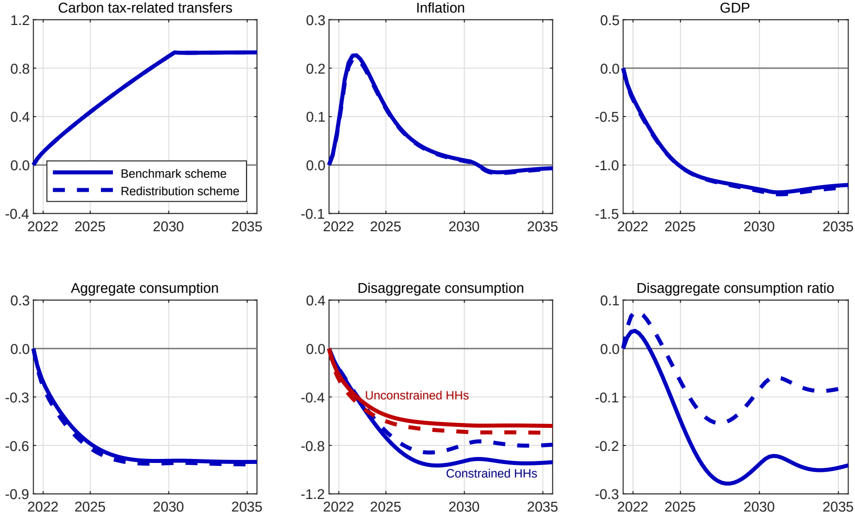
Monetary policy and the inflation-output trade-off

Rules



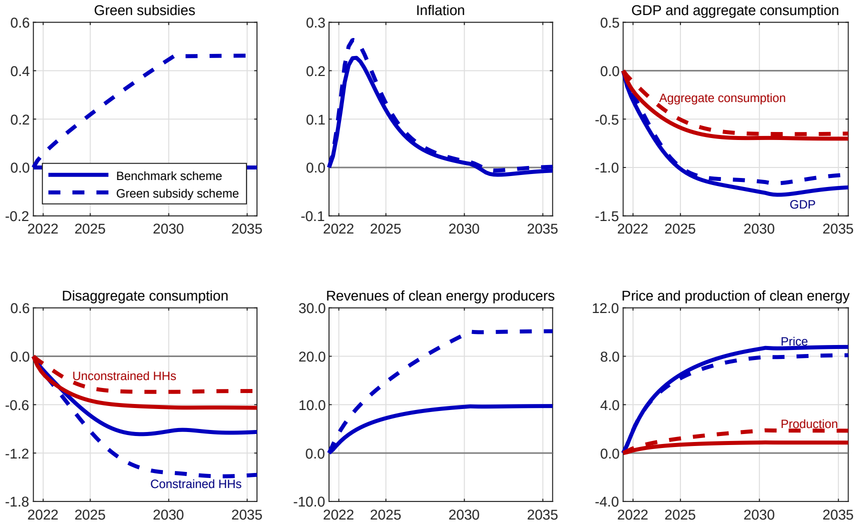
Note: Inflation is measured as the annual rate of change in consumer prices, and the nominal and real interest rates are annualised. The output gap is measured as the deviation of GDP from trend GDP and expressed as a percentage of trend GDP. All dynamic responses are reported as percentage deviations from baseline values, except for the dynamic responses of inflation and interest rates, which are reported as percentage-point deviations.

Distributional effects of transfers to households



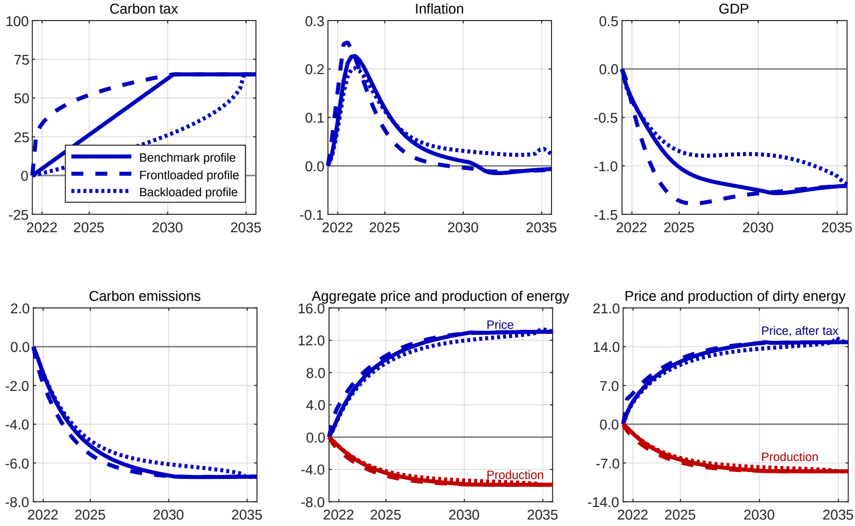
Note: Inflation is measured as the annual rate of change in consumer prices, and the carbon tax-related transfers are expressed as a share of GDP. The disaggregate consumption ratio is measured as the consumption level of constrained households over the consumption level of unconstrained households. All dynamic responses are reported as percentage deviations from baseline values, except for the dynamic responses of inflation, the transfer-to-GDP ratio and the consumption ratio, which are reported as percentage-point deviations.

Effects of subsidies to clean energy producers



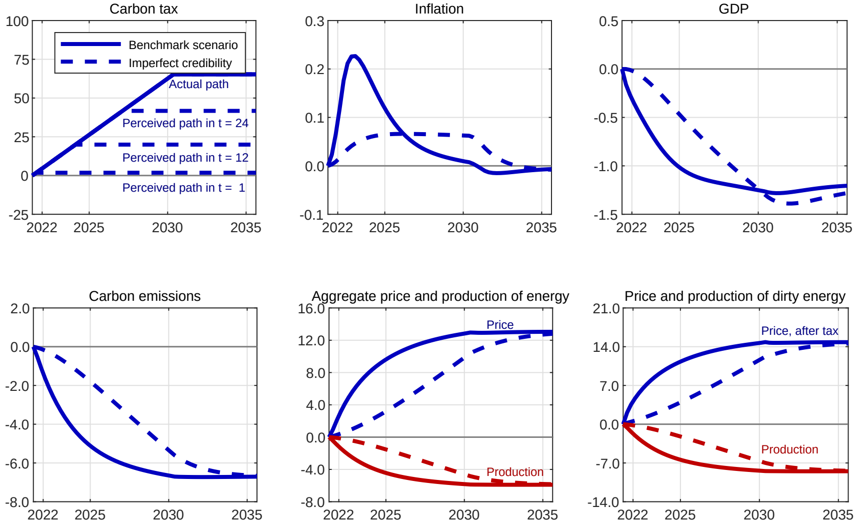
Note: Inflation is measured as the annual rate of change in consumer prices. The subsidies are expressed as a share of GDP, and the price of clean energy is expressed to consumer prices. All dynamic responses are reported as percentage deviations from baseline values, except for the dynamic responses of inflation and the subsidy-to-GDP which are reported as percentage-point deviations.

Implications of alternative carbon tax paths



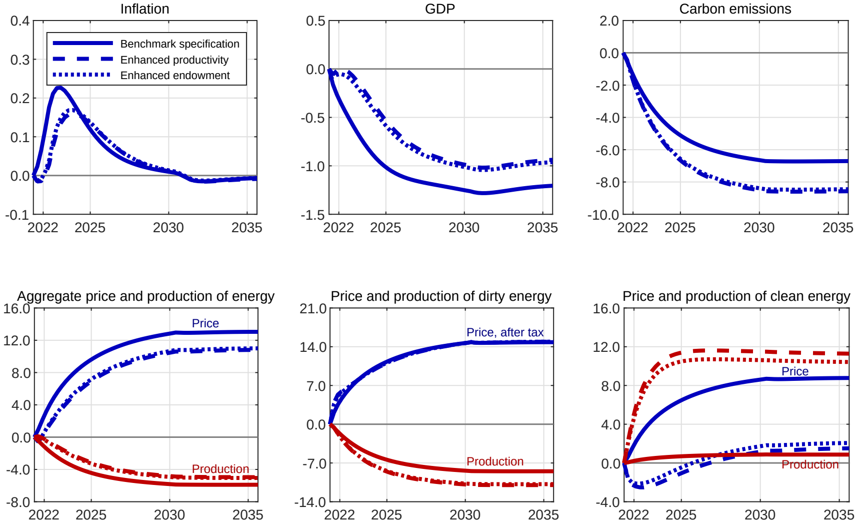
Note: Inflation is measured as the annual rate of change in consumer prices, and aggregate and dirty energy prices are expressed relative to consumer prices. All dynamic responses are reported as percentage deviations from baseline values, except for the dynamic responses of inflation, which are reported as percentage-point deviations.

Implications of imperfect credibility



Note: Inflation is measured as the annual rate of change in consumer prices, and aggregate and dirty energy prices are expressed relative to consumer prices. All dynamic responses are reported as percentage deviations from baseline values, except for the dynamic responses of inflation, which are reported as percentage-point deviations.

Enhancing the supply of clean energy



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Summary and conclusion

- Scenario of raising euro area carbon price to EUR 140/tCO2 by 2030 leads to a transitory increase in inflation (0.2 p.p. in 2023) and a moderate, but lasting decline in GDP (-1.2% by 2030).
- Given the size of the carbon tax increase, and absent other policies or technological change, euro area carbon emissions decline by about 7% by 2030.
- The monetary policy reaction function, and fiscal policy configuration influence aggregate and distributional effects.
- The tax path and the credibility of its implementation affect the persistence of macro impacts.
- Incentivising "green technological change" and/or "green investments" is key.

Background slides

The NAWM: Country coverage

Back

- The NAWM consists of two symmetric countries of normalised population size:
  - the euro area (denoted as home country)
  - the United States (representing the rest of the industrialised world and denoted as foreign country)
- International linkages arise from the trade of goods and international assets, allowing for imperfect exchange-rate pass-through and imperfect risk sharing.

The NAWM: Agents

Back

- In each country, there are four types of agents:
  - households (differing with respect to their ability to participate in asset markets)
  - firms (producing either tradable differentiated intermediate goods or nontradable final goods)
  - the fiscal authority (financing expenditure and transfers by issuing bonds, earning seignorage and levying distortionary as well as lump-sum taxes, with a suitable instrument feeding back to government debt)
  - the monetary authority (setting the nominal interest rate by following a Taylor-type interest-rate rule)
- The existence of liquidity-constrained households allows to depart from "Ricardian equivalence" and, thus, to establish a meaningful role for fiscal policy.

The NAWM: Households

▸ Back

- There are two types of households of normalised size:
  - household I (consuming, accumulating physical capital, trading in domestic and international bonds, holding money)
  - household J (consuming, holding money)
- Fiscal policies other than government spending – notably transfers – have real effects even though both households are optimising subject to intertemporal budget constraints.
- The size of household J is set equal to 0.25 and the dispersion of consumption is limited by distributing transfers unevenly in the proportion of roughly 3 to 1 in favour of household J.
- Both households supply differentiated labour services and act as wage setters in monopolistically competitive markets

The NAWM: Firms

Back

- There are two types of firms:
  - intermediate-good firms (using labour and capital services as inputs, producing tradable differentiated goods, setting prices in local currency in monopolistically competitive markets at home and abroad)
  - final-good firms (combining home and foreign intermediate goods into three non-tradable goods: a private consumption good, a private investment good and a public consumption good)
- The assumption of local-currency pricing allows introducing imperfect exchange-rate pass through in the short to medium run.
- The profits accruing to the intermediate-good firms are distributed as dividends to household I.

The NAWM: Frictions

Back

- The model contains a relatively large number of real and nominal frictions:
  - external habit formation in consumption; generalised adjustment cost in investment; variable capital utilisation; fixed cost in intermediate-good production
  - monopolistic competition in goods and labour markets with sticky prices and wages à la Calvo, and indexation of prices and wages
- In addition, the model includes:
  - transaction cost in consumption purchases
  - generalised adjustment cost in the import content of final-good production
  - intermediation cost for trading international bonds

Monetary policy rules

Back

- Benchmark rule with response to "growth rate gap":

$$R_t^4 = 0.9 \cdot R_{t-1}^4 + (1-0.9) \cdot \left[R^4 + 1.5 \cdot \left(\frac{P_{CX,t}}{P_{CX,t-4}} - \Pi \right) \right]$$
$$+ 0.1 \cdot \left(\frac{GDP_t}{GDP_{t-1}} - \frac{\overline{GDP}_t}{\overline{GDP}_{t-1}} \right)$$

- Taylor rule with response to "output gap":

$$R_t^4 = 0.9 \cdot R_{t-1}^4 + (1-0.9) \cdot \left[R^4 + 1.5 \cdot \left(\tilde{\pi}_t^{(4)} - \Pi \right) \right.$$
$$\left. + 0.5 \cdot \left(\frac{GDP_t}{\overline{GDP}_t} - 1 \right) \right],$$

where $\tilde{\pi}_t^{(4)} = P_{CX,t}/P_{CX,t-4}$ or $\tilde{\pi}_t^{(4)} = P_{C,t}/P_{C,t-4}$

Empirical shares

Back

Empirical share	Value		Source
	EA	RoW	
Energy share in final consumption	5.5%	3.3%	OECD TiVA
Energy share in intermediate goods	7.2%	7.1%	OECD TiVA
Dirty energy share in energy bundle	71.7%	71.7%	Eurostat, energy balances
Fossil resource in dirty energy production	73%	52.8%	KLEMS
Green resource in dirty energy production	73%	52.8%	KLEMS

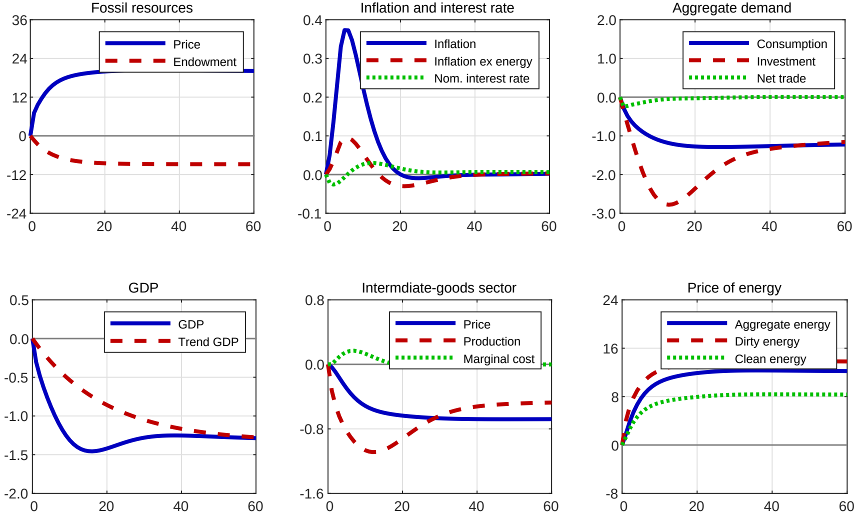
Elasticities of substitution

Back

Param.	Value		EoS:	Source
	EA	RoW		
μ_C	0.4	0.4	Energy and consumption ex energy	Bodenstein et al. (2011)
μ_Y	0.4	0.4	Energy and capital-labour bundle	Bodenstein et al. (2011)
μ_E	1.8	1.8	Dirty and clean energy	Papageorghiou et al. (2017)
$\mu_{\mathcal{D}}$	0.25	0.25	Fossil resource and cap.-lab. bundle	Sensitivity
$\mu_{\mathcal{C}}$	0.25	0.25	Green resource and cap.-lab. bundle	Sensitivity

Effects of a shock to the supply of fossil resources

Back



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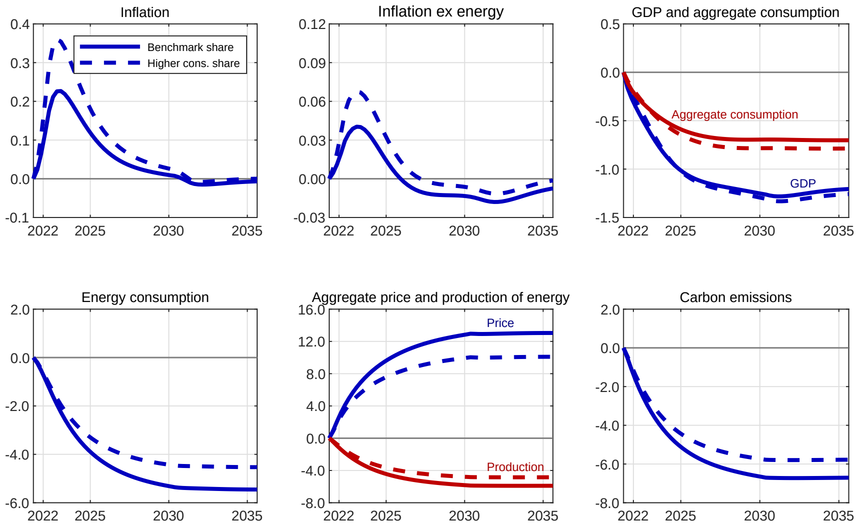
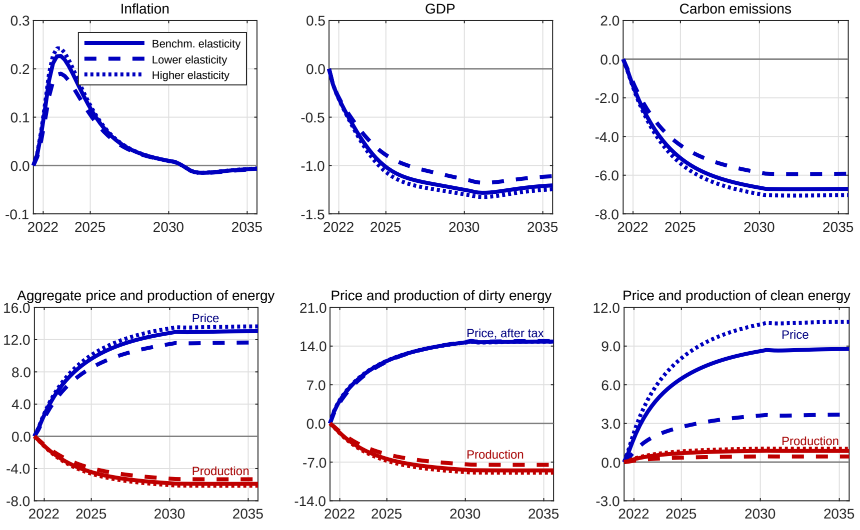
The share of energy in final consumption



Note: Inflation is measured as the annual rate of change in consumer prices, and the nominal interest rate is annualised. The aggregate energy price is expressed relative to consumer prices. All dynamic responses are reported as percentage deviations from baseline values, except for the dynamic responses of inflation and the interest rate, which are reported as percentage-point deviations.

Substitutability of energy inputs: fixed green resources



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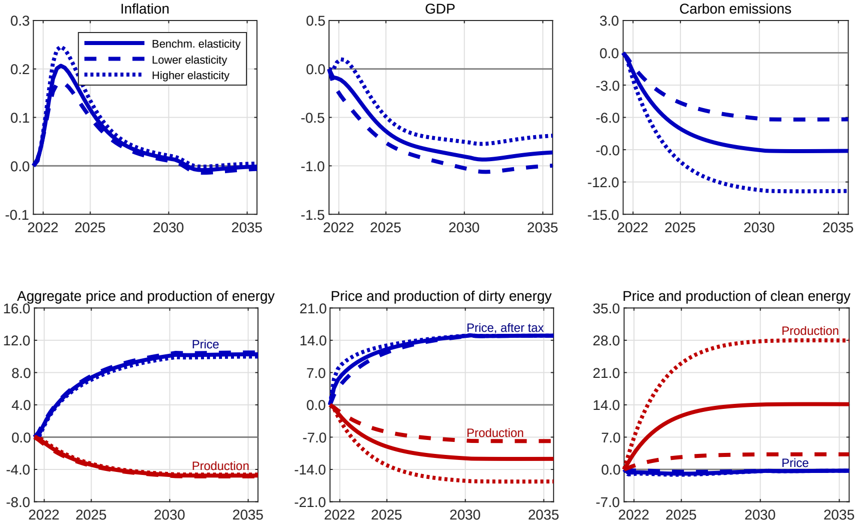
Substitutability of energy inputs: adjustable green resources



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