BBVA Research

Transitioning to Net Zero: Macroeconomic Implications and Welfare Assessment

J. Andrés, J.E Boscá, R. Doménech and J. Ferri

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Creating Opportunities

Introduction

- Paris Agreement (UNFCCC, 2015), International Energy Agency (IEA, 2020) $\rightarrow$ normative scenario aimed at achieving Net Zero Emissions (NZE) by 2050
- COP28 agreed to begin reducing global consumption of fossil fuels
- The effective implementation of policies to facilitate energy transition will significantly shape the economic dynamics of these economies
- Decisions on which strategy/ies to employ should be based on expected: (a) impact on emissions; (b) macroeconomic effects and population well-being

What we do

- Assess the transition to a low-emissions economy in an eDGE (environmental DGE) model
- Allow emissions reductions to be achieved by changing inputs: green vs brown energy production (Marron and Toder (2014),IMF (2019), Semmler et al. (2021), Delgado-Téllez, Ferdinandusse and Nerlich (2022))
- Consider three types of technological progress: (a) improvement in the efficiency of green production; (b) reduction in emissions per unit of production of brown energy (Fried, 2018; Nakicenovic and Swart, 2000); (c) enhancement in efficiency in aggregate goods production
- Analyze the welfare and macroeconomic effects of different carbon mitigation strategies:
  - increase the domestic price of fossil fuels
  - implement a subsidy on green investment financed by lump-sum taxes
  - levy taxes on emissions rebated to households
  - use emissions taxes to finance green investment.

Model: Households

- Households make decisions on consumption, working hours (leisure), investment. Pay taxes and receive transfers from the government.

- Invest in three types of capital
  - Capital for green energy production
  - Capital for brown energy production
  - Capital for production of goods and services

Model: Green and brown energy

- Production of goods and services requires consumption of energy, which can be obtained using green (carbon clean) technologies or brown (dirty) energy which uses fossil fuels that produce CO2 emissions
- Green and brown energies (v) are produced with specific capital (k)

$$v_t^g = \varsigma_t^g \left(k_{t-1}^g\right)^{\alpha^g} \tag{1}$$

$$\varsigma_t^g = \varsigma_0^g \left(1 + g_{\varsigma^g}\right)^t$$

$$v_t^b = \left(k_{t-1}^b\right)^{\alpha^b} \left(m_t^b\right)^{(1-\alpha^b)} \tag{2}$$

The model: Energy II

- Carbon emissions are an increasing function of the amount of brown energy produced

$$e_t^b = \left(1 - \mu_t^b\right) \gamma_{1t}^b \left(v_t^b\right)^{1-\gamma_2^b} \tag{3}$$

$$\gamma_{1t}^b = \gamma_{10}^b \left(1 - g_{\gamma_1^b}\right)^{t}$$

- Abatement costs z_b are proportional to brown energy production,

$$z_t^b = \theta_1^b \left(\mu_t^b\right)^{\theta_2^b} v_t^b \tag{4}$$

- Energy distributors package a mix of green and brown energy that they sell to intermediate goods producers

$$v_t^y = A_t^x \left[\theta^g \left(\varsigma_t^g f(k_t^g)\right)^{\frac{\sigma^x-1}{\sigma^x}} + (1-\theta^g)\left(g(k_t^b, m_t^b)\right)^{\frac{\sigma^x-1}{\sigma^x}}\right]^{\frac{\sigma^x}{\sigma^x-1}} \tag{5}$$

The model: Production, atmospheric carbon and economic damage

- Production technology uses capital, labor and energy

$$y_t(i) = A_t^y(i) k_{t-1}^y(i)^{\alpha^y} h_t(i)^{\beta^y} v_t^y(i)^{1-\alpha^y-\beta^y} \tag{6}$$

- Carbon accumulation: emissions feed the atmospheric carbon stock

$$x_t = \eta_t x_{t-1} + e_t + e_t^{row} \tag{7}$$

- Damage function. Atmospheric carbon stock damages total factor productivity

$$A_t^y = [1 - d_0 x_t^{d_1}] \widetilde{A}_t^y \tag{8}$$

where $\widetilde{A}_t^y$ is the zero-carbon TFP that evolves exogenously

$$\widetilde{A}_t^y = \widetilde{A}_0^y \left(1 + g_{\widetilde{A}}\right)^t \tag{9}$$

The model: Decarbonization and mitigation

- Subsidies for green investments, carbon taxes, and import tariffs on fuel commodities are included in the government's fiscal constraints:

$$g_t + t_t^{i^g} i_t^g = t_t + t_t^m p_t^{*m^b} m_t^b + \tau_t e_t \tag{10}$$

- Factors contributing to reducing carbon emissions can be divided into two blocks
  - **Decarbonization technological progress**: technological progress biased towards green energy production (changes in g_{ς^g}) or technical progress reducing dirty energy emissions (changes in $g_{\gamma_1^b}$)
  - **Mitigation policies**: tariff/taxes on fuel commodities; green energy investment subsidies; tax on carbon emissions

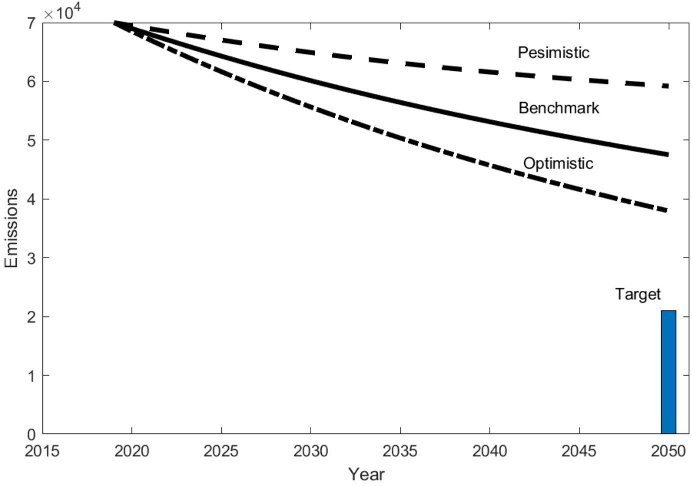
Calibration

- Calibration on an annual basis to replicate energy and environmental ratios of the Spanish economy in 2010
- Parameters from the literature and equations of the model + empirical evidence
- We target three rates of growth between 2010 and 2019
    - Spain's real GDP grew by 10.6%
    - Carbon emissions decreased by 11.8%
    - The ratio of green to brown energy production increased by 14.5%
- Find the value of $g_{\widetilde{A}}$, g_{ς^g}, $g_{\gamma_1^b}$ that, when included in the model, it produces the observed changes in GDP, carbon emissions and the ratio of green to brown energy production

Baseline scenario 2019-2200 without mitigation policies

- We feed the model with the calibrated growth rates of different types of technology progress to obtain a baseline scenario from 2019 to 2200
- From this baseline scenario, we define an *optimistic scenario*, where technological progress toward decarbonization accelerates 1/3, and a *pessimistic scenario*, where it slows down 1/3
- To establish the emissions target for 2050, we take into account that natural carbon sinks capture approximately 30% of global emissions (Brienen et al., 2020). Consequently, we align the Net Zero Emissions (NZE) objective with 30% of Spain's emissions in 2019

Baseline scenario 2019-2200 without mitigation policies



Projected carbon emissions

Baseline scenario 2019-2200 without mitigation policies

	Pesssimistic	Baseline	Optimistic
Reduction due to technology	-15.4	-32.1	-45.8
Additional effort	-54.6	-37.9	-24.2

Required emissions reduction in 2050 to achieve the emissions target (percentage decrease with respect to 2019)

Mitigation policies

- We investigate the economic impacts of various mitigation plans designed to bridge the emissions gap in 2050 between projected levels and the maximum allowed under the Paris Agreement
  - Increase in the energy commodity price (international markets + tariff + subsidies)
  - Subsidies to green investment
  - Emissions taxes
  - Emissions taxes to finance subsidies to green investment

- Two mitigation exercises:
  1. A non-anticipated change in policies to reach net zero emissions in the new steady state, assuming that the rest of the world's emissions are considered exogenous and constant (the uncoordinated scenario)
  2. An anticipated increase in the carbon tax to reach net zero emission in 2050, assuming that the rest of the world's emissions follows the same patht (the coordinated scenario)

1. Mitigation policies: uncoordinated scenario

- All the plans compared are initially unanticipated, but once implemented, they are perceived by agents as being in place indefinitely (front loaded policies)

- The rest of the world's emissions are considered exogenous and constant

- To ensure a fair comparison of different plans, we maintain consistency in the following manner: all plans, regardless of technological developments, strive for a long-term emissions reduction equal to the additional effort detailed in Table 1

- By comparing the expected evolution of macro variables when we add mitigation plans to technological progress with the baseline scenario, we assess the transitional effects of the policy from 2019 to 2050

1. Macro effects of mitigation policies: uncoordinated scenario

	Commodity price	Green investment	Emissions taxes	Taxes + Subsidies
Emissions	-29.13	-13.36	-24.13	-22.21
GDP	-0.95	1.65	-0.43	0.06
Consumption	-1.05	-0.43	-0.20	-0.08
Green energy production	4.42	43.11	3.12	13.51
Brown energy production	-29.96	-15.17	-17.34	-17.02
Energy mix distribution	-12.11	14.28	-6.63	-1.20
Green energy price	7.84	-13.19	3.75	-1.89
Brown energy price	19.28	-3.22	9.71	5.75
Energy mix price	12.51	-9.66	6.28	1.20
Abatement	0.00	0.00	9.42	7.71
Year for reaching the target	2076	2072	2091	2086
% reduction target by 2050	82	79	76	77
% Green Deal target by 2030	96	92	88	89

Macro effects of various mitigation plans (2019-2050). Average percentage deviations from accumulated baseline paths, except for abatement which is represented as the percentage reduction of accumulated emissions

1. Macro effects of mitigation policies: uncoordinated scenario

- Policies heavily front loaded, suitable for achieving the intermediate 2030 Green Deal target, would prove insufficient to meet the 2050 Net Zero Emissions (NZE) target
- Green investment subsidies require more time to accumulate a significant reduction in emissions compared to other policies
- In contrast to other mitigation policies, subsidizing green investment would lead to an increase in energy intensity per unit of output, due to the upsurge in green energy production
- A policy centered on raising the price of imported fuels results in the most significant reduction in brown energy production
- The price of the energy mix would decrease under a green investment subsidy plan, but it would see the most significant increase when the policy aims to raise the price of fuels

1. Annual average effects of welfare effects: uncoordinated scenario

	Oil price		Green investment		Emissions taxes		Taxes + subsidies	
	Price (% growth)	Welfare (% growth)	Subsidy (%)	Welfare (% growth)	Tax € per tn carbon	Welfare (% growth)	Tax/Subsidy € per tn carbon/(%)	Welfare (% growth)
2019-2050								
Baseline	58	-1.59	62	-1.11	83	-0.21	58/20	-0.08
Optimistic	31	-0.95	46	-0.08	44	-0.05	29/12	0.08
Pessimistic	107	-2.66	76	-3.87	152	-0.81	112/29	-0.73
2019-2200								
Baseline	58	-13.94	62	23.80	83	-7.88	58/20	1.81
Optimistic	31	-9.28	46	16.92	44	-4.99	29/12	2.00
Pessimistic	107	-24.42	76	22.62	152	-16.42	112/29	-4.72

Welfare effects of mitigation plans from 2019-2050 and 2019-2200, expressed as average percentage changes in equivalent consumption (negative values = loss, positive values = gain)

1. Annual average effects of welfare effects: uncoordinated scenario

- A 58% increase in the price of fossil fuels would achieve 82% of the 2050 Net Zero Emissions (NZE) target in the baseline scenario. However, in the pessimistic scenario regarding technological progress, the relative price increase would nearly double to 107%
- Disincentivizing fossil fuels through higher pricing incurs the highest welfare costs both in the transition towards 2050 and in the long run
- Emissions taxes would be preferable in terms of welfare during the transition period to 2050. However, in the very long run, green investment subsidies emerge as the only plan that yields a substantial welfare gain
- Reallocating revenues from carbon taxes towards green investment subsidies leads to the most balanced welfare effect between the short and long run

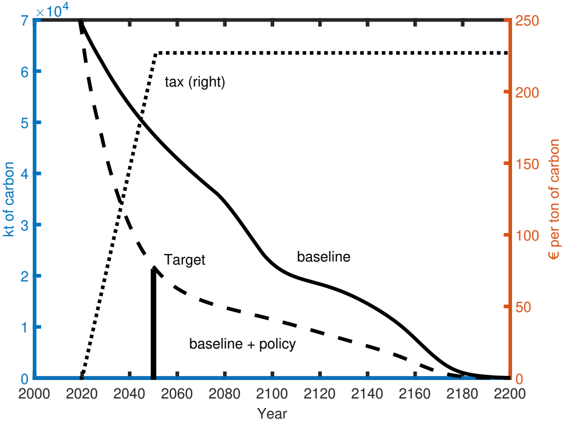
2. A gradual increase in the carbon tax to reach net zero in 2050: the coordinated scenario

- What level of emissions tax would be required to *effectively* reach the NZE target by 2050?
- We adopt a more realistic emissions tax scheme that increases linearly until 2050 and remains constant thereafter
- In addition to the scenario where Spain acts alone, we consider a 'coordinated' scenario where the rest of the world reduces emissions at the same rate as Spain does endogenously
- We establish a mapping between the evolution of CO2 atmospheric stock and temperature using the following expression

$$T_t = \lambda \frac{\log\left(\frac{x_t}{\bar{x}}\right)}{\log(2)} \tag{11}$$

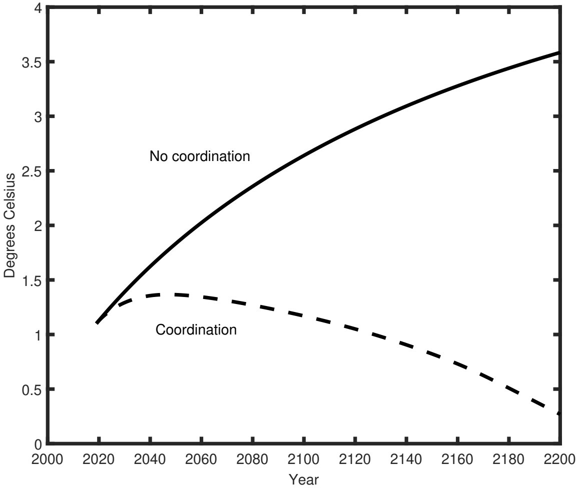
where $\lambda = 2.3$

2. A gradual increase in the carbon tax to reach net zero in 2050: the coordinated scenario



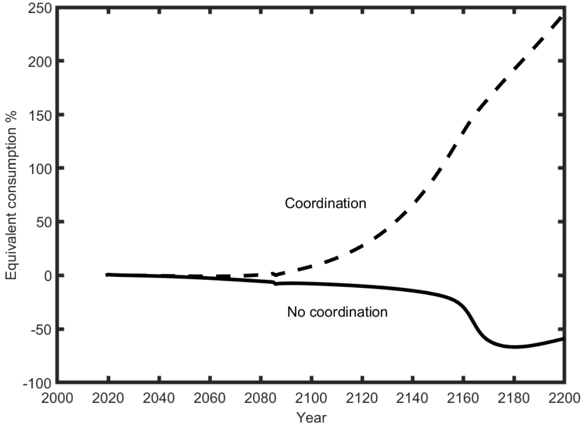
Dynamic trajectory of emissions after an increase in emissions taxes. Baseline and baseline + policy scenarios (left scale). Taxes (right scale)

Full emissions target by 2050: coordinated scenario



Temperature evolution (above pre-industrial levels) between non-coordinated and coordinated scenarios

2. A gradual increase in the carbon tax to reach net zero in 2050: the coordinated scenario



Welfare evolution between non-coordinated and coordinated scenarios

F2. A gradual increase in the carbon tax to reach net zero in 2050: the coordinated scenario

Welfare			
2019-2050		2019-2200	
No coordination	Coordination	No coordination	Coordination
-0.44	-0.18	-19.11	60.28

Temperature			
2050		2200	
No coordination	Coordination	No coordination	Coordination
1.83	1.36	3.58	0.27

Average welfare effects and temperature comparison (above pre-industrial levels) between non-coordinated and coordinated scenarios.

2. A gradual increase in the carbon tax to reach net zero in 2050: the coordinated scenario

- Emissions taxes increase lineraly to a level of €227 per ton of carbon in 2050
- In a non-coordinated strategy, the temperature is projected to increase by 1.8 degrees Celsius above pre-industrial levels by 2050, and by over 3.5 degrees Celsius by 2200
- The average welfare loss relative to the technology baseline is estimated at -0.44% in terms of equivalent consumption during the period 2019-2050, and -19.11% between 2019 and 2200
- In a coordinated scenario, temperature remains below 1.5 degrees Celsius by 2050 and reverts to almost pre-industrial levels by 2200.
- The beneficial impact on welfare is apparent, although it takes several decades to materialize. In the very long run, there is an average welfare increase of 60% between 2019 and 2200

Conclusions

- We have proposed an environmental dynamic general equilibrium (eDGE) model to assess the welfare effects of energy transition policies
- Our paper shows the utility of eDGE models for assessing the welfare and macroeconomic consequences of various mitigation policies across different scenarios and assumptions
- Carbon taxes + green investment subsidies lead to a more balanced welfare effects in the transition to net zero.
- We demonstrate that a coordinated policy has the potential to completely reverse the long-term adverse effects of emission taxes, transforming them from negative to largely positive impacts., as the increase of the global temperature is avoided.