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## SPOKE 4

# D4.3.1 - Scenario analysis under uncertainty and controllability: an online tool

November 2024

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| Contributors | Régis Gourdel,<br>Andrea Mazzocchetti,<br>Stefano Battiston,<br>Monica Billio |
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# Executive summary

As a member of the European Union, **Italy has committed to reducing its net greenhouse gas emissions by at least 55% by 2030**, compared to 1990 levels (European Climate Law, Fit-for-55). However, achieving this ambitious target may involve transition risk, i.e. the risk associated with changes in the values of assets that cannot be fully anticipated or hedged, as a result of a late-and-sudden alignment to climate targets. This document reports the results of the Work Package 3 of Spoke 4 to understand the **effects of climate transition scenarios** on the **Italian economy and financial systems**, both in terms of their intrinsic uncertainty and potential possibility to be controlled.

The contribution is the **development of an online tool** that consists of a **complete set of detailed economic and financial trajectories conditioned to climate scenarios and parameters**. The online tool allows users to obtain **aggregate and sector-level outcomes** that can be visualized and exported, supporting a **comprehensive analysis of the evolution of the Italian economy**.

The simulations have been conducted using the **EIRIN Stock-Flow Consistent macro-financial model**, calibrated on the Italian economy and enhanced to capture key aspects

in the context of the low-carbon transition, such as the role of green subsidies and carbon cost pass-through.

The results focus on two critical aspects of the potential economic and financial impacts of climate change.

First, they shed light on the **effects of climate transition scenarios** on the **Italian economy and financial systems**.

Second, they assess the **impacts of acute physical risk on Italy**, with a specific focus on the **direct and indirect effects of extreme natural hazards hitting the economy through capital stock destruction**.

This analysis is particularly relevant as Italy is highly exposed to climate acute physical risks (in particular floods, droughts, and heatwaves), which have already caused major economic losses in key productive areas of the country and are expected to increase in frequency and intensity.

The results contribute to the **understanding on how climate transition policies can shape the trajectory of the low-carbon transition, also providing insight into the key role of public green subsidies in counteracting the economic impacts of carbon taxation**.

Furthermore, **the outcomes highlight that severe impacts on capital stock potentially caused by extreme natural hazard can lead to sustained economic setbacks in the absence of adequate adaptation strategies**. The role of financial and prudential policies in times of crisis is crucial to providing support to economies reeling from natural disasters. This underscores the **importance of developing adaptive strategies and forward-looking financial policies that not only address immediate recovery needs, but also build resilience against future risks.**

The report is organized as follows. The first part includes the description of the EIRIN Stock-Flow consistent macro-financial model. The second part includes the description of the online tool developed. The third part shows results of the impact of climate risks in Italy and discusses policy implications.

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## 1 Introduction

There is an increasing need to understand how climate risks will unfold in the future (NGFS, 2019; NGFS, 2023). This requires a focus on two critical dimensions: (i) the consequences of transition risks triggered by the sudden and delayed implementation of climate policies which are not anticipated, and (ii) the impacts of physical risks arising from unmitigated climate change.

In the last decade, the European Union (EU) has already experienced a large increase in a range of adverse effects of climate change, including heat waves, changing precipitation patterns, sea-level rise, and increased frequency and intensity of extreme weather events, which are expected to increase in the future (Seneviratne et al., 2021). In the EU, from 1980 to 2022, natural hazards affected millions of people and have cost the European Union's Member States 650 billion EUR in total, of which 59 EUR billion in 2021 and 52 EUR billion in 2022 (EEA, 2023).
Moreover, future climate conditions may deviate significantly from historical trends (IPCC, 2022). Thus, past observations on the distribution of losses from natural hazards may become less reliable for risk assessment and to inform fiscal and financial policy design.

In Italy, climate-related natural disasters such flooding, droughts and heatwaves are particularly highly relevant, and caused major economic losses in key productive areas of the country (e.g., the agri-food district of the Emilia-Romagna region in the North-Center of Italy). Against this evidence, Italy has also one of the lowest disaster insurance protection coverages in the EU, around 3% of the total insured assets), and one of the largest disaster risk insurance protection gaps in the EU (ECB-EIOPA, 2023). In addition, Italy exited the COVID-19 crisis and the energy price crisis with low fiscal space. Italy has one of the highest public debts in the EU (Eurostat, 2024), leaving the country with limited spending capacity for adaptation investments aimed at building resilience to natural disasters (e.g., water management to prevent floods, water reservoirs to dampen the impact of droughts, coastline defense against sea level rise, etc.).

On the policy front, the European Union has placed climate change mitigation and adaptation at the core of its recent policy initiatives. In terms of climate change mitigation, this includes the European Green Deal and Fit-for-55, focused on achieving policy targets set by the Paris Agreement. As part of the EU, Italy committed to reduce its net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. This will require the uptake of renewable energies and an unprecedented pace in the electrification of final energy uses (in buildings, transport, etc.). Regarding climate change adaptation, the Ministry of Environment has approved in December 2023 the National Climate Change Adaptation Plan[1], which aims to guide the country in managing the impacts of climate change. Finally, the Italian government has recently launched the proposal to introduce compulsory firm insurance against natural disasters (Legge di bilancio 2024, Articolo 1, commi 101-111 'Misure in materia di rischi catastrofali').

[1] For more details see https://www.mase.gov.it/notizie/clima-approvato-il-piano-nazionale-di-adattamento-ai-cambiamenti-climatici

In this context, it is crucial to understand the extent to which transition and physical climate risks may impact the economy and financial system. To this end, we investigate the macroeconomic and financial effects of climate transition scenarios and physical risk, with particular focus on the Italian economy.

We do so by tailoring and extending the EIRIN Stock-Flow Consistent (SFC) macro-financial model (Dunz, Hrast Essenfelder, et al., 2023), and we calibrate it to the Italian economy. EIRIN is a Stock-Flow Consistent behavioral model populated by a limited number of heterogeneous, interacting agents of the economy and finance, which are modelled as a network of interconnected balance-sheet items. In the SFC tradition, accounting criteria hold irrespective of behavioural characteristics and assumptions, thus allowing us to capture the entry point of a shock in the economy, its transmission channels to agents and sectors, and its indirect impacts. EIRIN agents and sectors are modeled with adaptive expectations. Thus, in response to a shock, they adapt their behaviour based on past information, and on the present state of the economy. These features enable us to: capture the shock persistency on the levels of macroeconomic variables in the short to mid- term; understand the dynamics of the shock recovery given the characteristics of the economy (e.g. distribution of wealth and income, fiscal policies and monetary regimes); analyse the role of fiscal, monetary and prudential policies in the climate shock recovery.

We use the model to analyse (i) the macro-financial impacts of climate transision scenarios, aligned with the framework developed by the NGFS, and (ii) under which conditions climate tail risk scenarios could lead to a persistent shock on macroeconomic variables, and the transmission channels thorugh which the shock propagates.

Key findings reveal that that an orderly transition can lead to co-benefits in Italy (in terms of GDP and GHG emissions) in the mid-term. In contrast, a disorderly transition worsens the economic performance and financial stability. Within the context of the low-carbon transition, increased government green subsidies can help couteracting the negative economic impacts of carbon taxation.

Furthermore, the results indicate that severe impact on capital stock potentially caused by climate tail risks can lead to sustained economic setbacks in the absence of adequate adaptation and financial strategies. In this context the role of financial policy in times of crisis is crucial to avoid persistent negative effects on the economy, highlighting the importance of forward-looking financial policies that not only address immediate recovery needs but also build resilience against future risks.

The model documentation and results are integrated into an online tool that allows users to select climate scenarios and access aggregate and sector-level outcomes, which can be visualized and exported. This tool serves as a valuable resource for analyzing climate transition and physical risks in Italy, and for guiding transition policies in Italy, enabling more informed decision-making in the context of the low-carbon transition.

## 2 The EIRIN model

EIRIN is a Stock Flow Consistent (SFC) model of an open economy populated by a limited number of heterogeneous agents and sectors of the real economy and financial system, endowed with behavioral characteristics. In the model, accounting criteria hold irrespective of behavioral characteristics and assumptions, thus allowing us to capture the dynamics of stocks and their transmission channels, and to increase the transparency and accountability of results.

SFC models gained relevance in macroeconomics in the last decades (Godley and Lavoie, 2006; Caverzasi and Godin, 2015; Caiani et al., 2016; Nikiforos and Zezza, 2017; Mazzocchetti et al., 2020). In the context of climate economics and finance (Dunz, Essenfelder, et al., 2023; Ponta et al., 2018; Monasterolo and Raberto, 2019a; Naqvi and Stockhammer, 2018; Carnevali et al., 2021; Dafermos, Nikolaidi, and Galanis, 2017) SFC models have been recently implemented to study the macro-financial effects of green financial policies and climate risks (Dafermos and Nikolaidi, 2021) and of the transition in energy production systems (A. Jackson and T. Jackson, 2021).

EIRIN's agents and sectors are modelled as a network of interconnected balance-sheet items, allowing us to identify climate risks' transmission channels in the economy and finance. Indeed, a clear understanding of the risk transmission channels is fundamental for the quantitative assessment of the direct and indirect impacts of climate risks on the economy and financial sector. In particular, EIRIN agents are heterogeneous (e.g. in terms of skills, wealth and income) and are endowed with adaptive expectations about the future of the economy, i.e. they make projections based on past information and internalizing policy changes. Agents do not have priors on whether a policy of other types of shocks are temporary or not. In response to a shock they adapt to the new situation, and this leads to long lasting effects on the *levels* of variables, such as GDP and prices, but not on the *growth rates*, which return to the baseline value in the mid-long run. Adaptive expectations allow us to capture decision-making under uncertainty (climate policies and impacts). In particular, sgents do not fully anticipate the future impacts of the shock (e.g. carbon price trajectory). This implies that economic shocks (e.g. inflation, GDP) are larger than in presence of rationale expectations, it can be persistent in the mid-term and trigger monetary policy response.

### 2.1 EIRIN agents and markets

EIRIN is composed by heterogenous agents and sectors of the real economy and finance (figure 1), which interact in a number of markets (figure 2). In particular, EIRIN's agents and sectors include:

- a wage-earning household $(H_W)$ and a capital income-earning household $(H_K)$
- a consumption goods $(F_K)$ and a services sector $(F_L)$ that produce for final consumption
- a high-carbon capital goods producer $(K_B)$ and a low-carbon capital goods producer $(K_G)$
- a utility company that produces energy from fossil fuels (high-carbon, $(EN_B)$) and one that produces energy from renewables (low-carbon, $(EN_G)$)
- a mining and fossil fuel extraction company (MO)

- a commercial banking sector $(BA)$
- a government (G) in charge of fiscal policy and regulation (e.g. carbon tax), public debt issuance and management
- a central bank (CB) that sets the policy rate according to a Taylor-like rule
- the rest of the world (ROW) which provides import and export of commodities

The accounting framework of EIRIN is composed of three main matrices: i) a balance sheet matrix that accounts for all the stocks held by agents and sectors; ii) a transaction flow matrix that describes all the flows between agents and sectors at each period ; iii) a net worth change matrix that shows how sectors' net worth changes due to both net cash flows and the price changes of financial assets. EIRIN's accounting identities represent structural specifications that have to be fulfilled at any time step in the model simulation, thus providing relevant binding constraints for the model dynamics. Therefore, the SFC constraints contribute to strengthen both the model and code validation, and the transparency and accountability of results, overcoming a main limitation of simulation models. Moreover, the rigorous SFC accounting framework allows us to display the dynamic relations between agents and sectors' balance sheets, and to analyse in a consistent way the chains of causation and transmission channels throughout the economy.

The capital and current account flows of the model are presented in figure 1. The energy firms, the service sector and consumption good producer require capital as an input factor for production. To build-up their capital stock, they invest in capital goods (grey dashed line), which are produced either by the low- or the high-carbon capital goods producer. To finance investment expenditures, firms can use held liquidity or borrow from the commercial bank (red dotted line), which applies an interest rate to their loans (red solid line). Households, firms and the government hold deposits with the commercial bank (dark green dashed line). The commercial bank also holds reserves at the central bank, that could provide refinancing lines (red dotted line).

The government pays public employees (pink dashed line) and provides emergency relief and subsidies to firms in the real economy (blue solid line). The government collects tax revenues from households and firms (orange solid line) and finances its current spending by issuing sovereign bonds (dark blue dotted line). Sovereign bonds can be bought by the capitalist household, the commercial bank and the central bank. The government pays coupons on sovereign bonds (dark blue solid line).

Households are divided into workers and capitalists, based on their functional source of income: workers receive wage income (pink dashed line); capitalists own domestic firms from which they receive dividend income (purple solid line) and coupon payments for their sovereign bond holdings (dark blue solid line). The rest of the world receives remittances (grey dotted line), exports consumption goods to households (black solid line), and primary resources to firms as inputs for the production process (grey solid line). The rest of the world generates tourism flows and spending in the country, and exports of service sector and industry goods (grey solid line).

In figure 2 we display the main agents and sectors of the EIRIN economy (grey boxes), and the markets through which they interact. In particular, financial markets (light blue box)

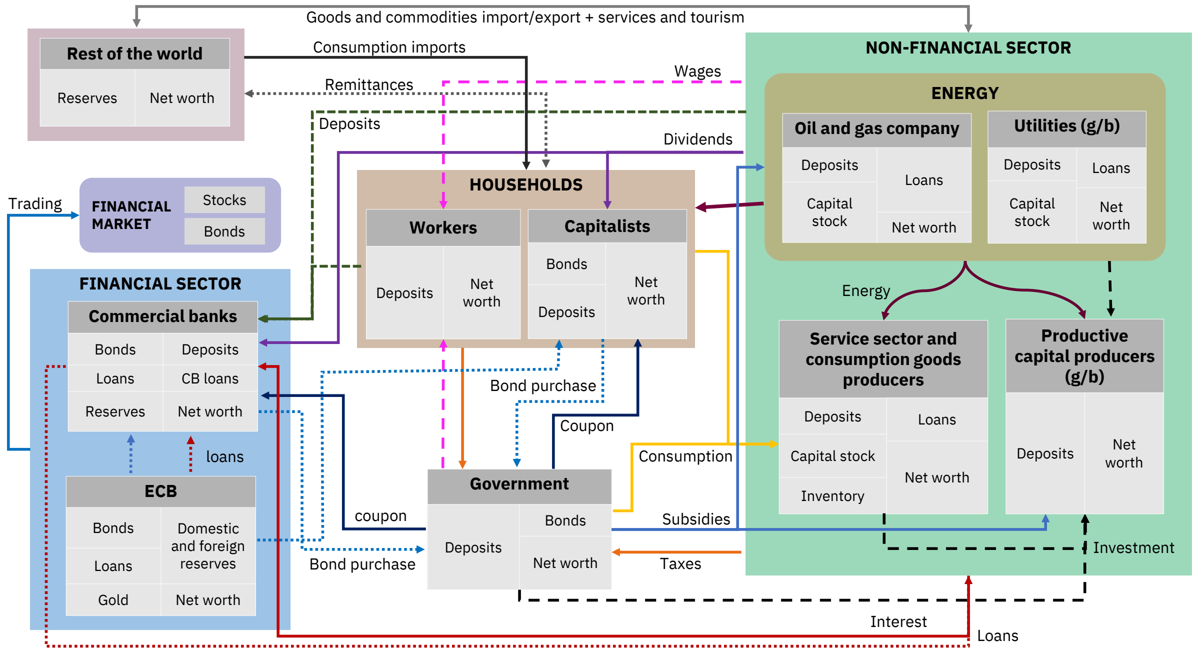



**Figure 1:** The EIRIN model framework: capital and current account flows of the EIRIN economy. For each sector and agent of the economy and finance, a representation in terms of their balance sheet entries (i.e. assets and liabilities) and their connections, is provided. The dotted lines represent the capital account flows, while the solid lines represent the current account flows.
Source: Authors' own elaboration.

include the markets for government bonds and stock shares (see Monasterolo, Dunz, et al., 2022 for details), and the credit market. The real markets (wheat box) include consumption goods and service markets, the labor market, the energy market, the capital goods markets, and the raw material market (oval boxes).

In the model, households (HH)' consumption/saving decisions is based on the Buffer Stock theory of saving (Deaton, 1991), while firms' investment decisions are based on expected production plan and the NPV (observation of current and past levels of interest rates and demand). On the financial side, banks' investment and lending depend on credit risk assessment and prudential requirements, potentially leading to credit rationing for firms, affecting GDP recovery.

The EIRIN model is initialised with calibrated quantities for each balance sheet entry and each parameter which determines the functional form of the behavioural equations. Consequently, the model is simulated for a predetermined number of periods within which it converges to stability. In the current setting each period represents a quarter. The next section describes the sequence of events that take place at each simulation period.

### 2.2 Sequence of events

At each simulation step, some transactions are performed in all markets. The sequence of events in the EIRIN economy is the following:

1. *Policy makers take their policy decisions.* The central bank sets a new baseline interest rate according to a Taylor-like rule depending on inflation and unemployment rates.

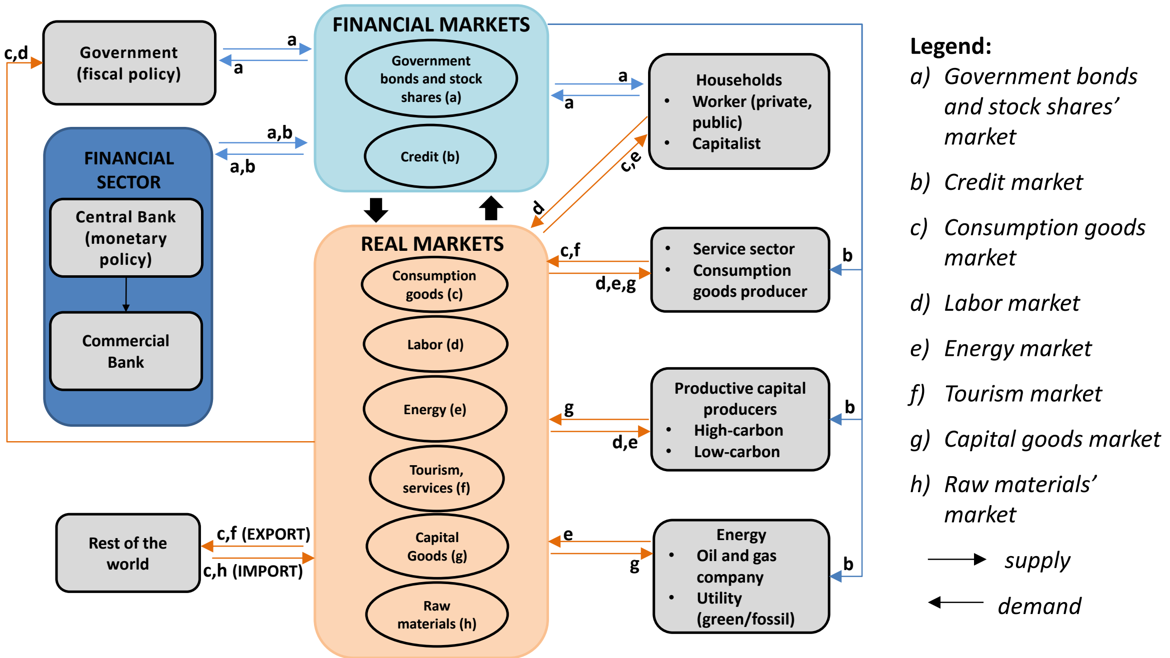



**Figure 2:** Agents, sectors and markets of the EIRIN economy.
Black boxes include agents and sectors, the light blue box contains financial markets and the light orange box includes the real markets. The agents and sectors interact through real and financial markets; outgoing arrows represent supply, while incoming arrows represent demand.
Source: Authors' own elaboration.

The government calculates its budget to GDP and adjusts tax rates accordingly. It also decides how much to refinance debt through the emission of bonds.

2. *Wage bargaining and capital goods pricing.* The new level of wages is set via the use of a Phillips curve à la Keen (2013)[2]. The price of raw materials, oil and energy are calculated. The price of capital is set by capital producers, given that the inputs for capital goods production are only labour, energy and raw materials.
3. *Goods and services market.* The worker and capitalist households set their nominal demand for consumption goods and services. The manufacturing and services sectors provide supply based on the available inputs and set unit costs at a fixed markup on production costs. $F_K$ and $F_L$ set their production plans for the next period, setting their investment targets. The quantity of low-carbon and high-carbon capital that will be purchased depends on the net present value (NPV) of investing in either of them.
4. *Credit market.* New investment plans for all sectors are financed partly through retained liquidity and partly through credit, determining its demand. The supply for credit depends on the commercial bank's Capital Adequacy Ratio (CAR) and thus the Probability of Default (PD) of the firms. The price of credit – the interest rate – depends on the baseline rate set by the central bank and on the PD of each firm.
5. *Capital goods, labour and energy markets.* After having received credit the $F_K$ and $F_L$ firms purchase capital in the desired combination. Capital is supplied by capital pro-

[2]For a detailed description of the wage setting in EIRIN see Gourdel et al. (2022)

ducers based on the demand and the inputs available. Given that the level of available capital is determined, the $F_K$ and $F_L$ sector determine their energy and labour demand to satisfy expected demand in the next period.

6. *Financial market.* The government issues new bonds to finance its debts, while the CB can enter the bonds market to perform quantitative easing via open market operations. Dividends are distributed to the capitalist households and the commercial bank based on profit rates. Consequently, $H_K$ and BA set their desired portfolio allocation of financial wealth on securities and trade shares at their new prices.
7. *Accounting.* All transactions and financial flows are recorded, taxes are paid and all the balance sheet entries are updated. Variables that have an exogenous growth rate (e.g. labour productivity) are updated.

The determination of demand, supply and prices are independent in all market except for the credit market. In the credit market, demand depends on the demand for capital goods and their prices. There can be temporary imbalances between demand and supply in each market, which are solved by demand rationing. The capital goods market can be an example of this. A detailed explanation of the model's behavioral equations is provided in the Appendix A.

### 2.3 Modelling advancements

During the project the model has been updated to streamline its operations and output. On one hand, checks and comparisons between versions have been conducted in order to stabilize and refine its dynamics. On the other hand, some mechanisms have been updated in order to reinforce the model on its strong points, namely the interaction of the real economy with the financial system and the monetary policy.

#### 2.3.1 Progress in the modelization of defaults

In addition to the general streamlining of the model, the first key extension conducted during the project is the modeling of the defaults of non-financial firms. Indeed, the possibility of defaults is essential to financial stability considerations, and their materialization has been absent from SFC models so far.

The work conducted on the development of a SFC default mechanism is based on the idea that a fraction of the firms in a given sector of the real economy default. These defaults lead to a loss on the credit portfolio of the bank. This ultimately enables for a better integration of financial stability considerations.

#### 2.3.2 Transmission of monetary policy

Historically, the modeling of monetary policy and its transmission has been incomplete for many SFC models. For instance, no central bank was explicitly represented, and models operate with a sole commercial bank. The integration of such aspects was already a key feature of the first version of the EIRIN model (Monasterolo and Raberto, 2018), and changes in policy rate by the central bank are transmitted to changes in rates charged to firms when borrowing money.

However, the effect on the volume of credit and household consumption had not been clearly defined. The first innovation brought is the improvement in the channel from policy rate to investment decisions, i.e. on the investment from firms' own equity and the volume of credit granted by the bank. Consistently with the pre-existing framework of calculating the Net Present Value (NPV) of prospective investments, firms now calculate the Internal Rate of Return (IRR). The comparison of the IRR to the interest rate that is charged by the bank then conditions the obtention of credit.

The second innovation being developed is the interaction of the policy rate with consumption. Building on the buffer-stock theory, the behavior of households is rendered more dynamic, whereas previously their volume of consumption was not dependent on the level of interest rates. The importance of interest rates in this setting comes from the fact that households receive interest on their deposits, which influences the inter-temporal wealth dynamics.

### 2.3.3 Changes in the pass-through rate

A new structural feature introduced and tested in the model is to make the carbon price pass-through only partial. This matters for all sectors but has even more effect in the energy sector due to the high carbon intensity of the brown energy producer. This sector is generally the one setting the price of energy as the marginal producer since it has higher variable costs.

Thus, higher carbon prices lead to an increase in energy prices, for the fossil fuel utility to remain profitable. If the firm was forced to internalize more of the tax increase, then this profitability would be limited, and its investment could be forcibly reduced. The evidence from Ganapati et al. (2020) in the case of the energy industry suggests that a full pass-through would be an overestimation.

Moreover, this should be designed cautiously so that the brown utility does not go bust directly. When using a pass-through of zero, we obtain the result shown in figure 3, whereby increases in carbon prices make the investments by the fossil fuel energy sector rapidly unprofitable. Thus, the share of renewable in the energy mix increases much faster but primarily as a result of this absence of investment by its high-carbon competitor. Results for a broader range of values are presented in the case of Italian simulations in section 4.2.

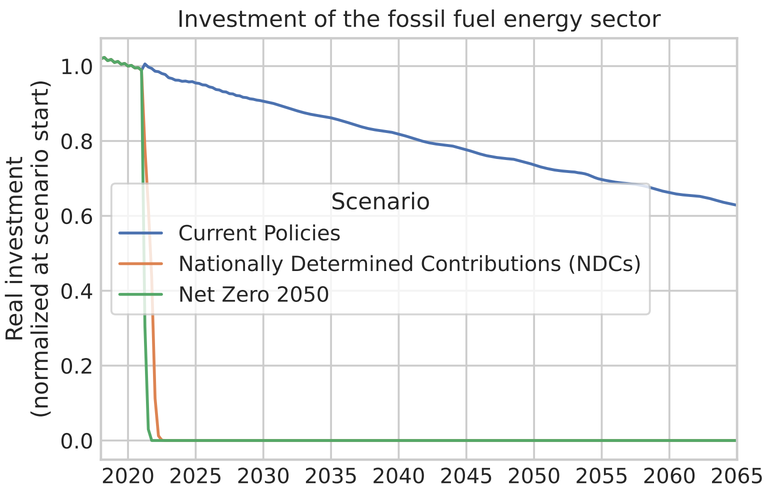



**FIGURE 3:** Normalized level of capital investment of the fossil fuel energy sector in the absence of pass-through, for the application to Italy.

## 3 Online tool

As part of this project, we have been developing an online tool that includes climate risk scenarios simulated with the EIRIN Stock-Flow Consistent macro-financial model. The online tool allows users to obtain sector-level and aggregate outcomes (including GDP, unemployment, CAR, and PD) that can be visualized and exported. For this purpose, a streamlined version of the EIRIN model has been developed. At this stage, it is calibrated on national economic and financial data of Italy. Climate scenarios used are taken from the Network for Greening the Financial System (NGFS). Variables of interest relate to both climate physical risk and transition risk, with a focus on the latter.

The workflow underpinning this work is represented in figure 4. The core of the work has been to develop the model, coded in Matlab, and the website, coded in Quarto. The generation of the HTML content from the output of the model has been automatized. Overall, the output of this project contributes to advancements, applications, and visualizations of Stock-Flow Consistent models, and to the EIRIN model in particular (Monasterolo and Raberto, 2018; Monasterolo and Raberto, 2019b; Gourdel et al., 2024).

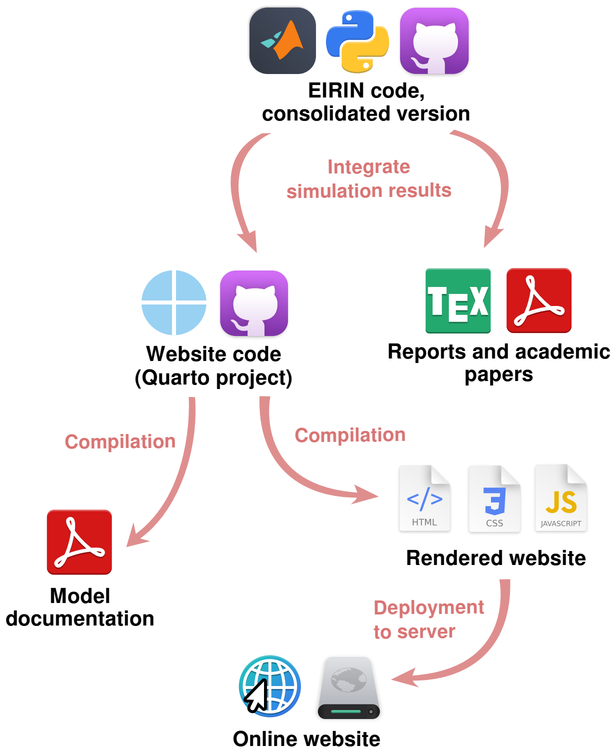



**Figure 4:** Schematic functioning of the project.

The website includes a set of simulation outcomes, using selected climate scenarios and key parameters for each calibrated country. Several variables can be selected, visualized, and exported by the users in a format that is similar to the one used by the NGFS Scenario website.

The website is built using Quarto, which is an open-source software. Thus, the core parts of the website are represented as Quarto files (with a `.qmd` extension). It also contains Excel files that store results from runs of the model. These Excel files are read by a Python code embedded in the Quarto files, and using the Python Plotly package they output figures with interactive features.

The output contains HTML and Javascript files, as well as Excel files, which can be downloaded following links in the pages. The Quarto code and data are synchronized with a GitHub repository.

The documentation builds on the model description written in LaTeX across several of the papers that introduced the EIRIN model (see section 3.4). The writing of equations in Quarto is virtually identical to that of LaTeX, so that any researcher with knowledge of it can contribute to updates and extensions of the documentation on the website. Therefore, there is a low entry cost for future contributors and maintainers of the website.

### 3.1 Overview of the structure

The current version of the website includes a landing page with a general description and a top bar menu with the following elements:

- *Home*, which links to the landing page, a screenshot of which is provided in figure 5;
- *Publications*: link to a page offering a summary of papers based on EIRIN;
- *Projects*: link to a page that describes projects that funded and used the model;
- *Results*: a page with an interactive dashboard that allows the user to visualize all outputs;
- *Applications*: a drop-down menu with links to results for different countries/regions;
- *Documentation*: a drop-down menu with links to the different sections of the documentation.

The outcomes from each application (with its separate calibration) are accessible from the *Results* page and it has in addition its dedicated page under *Applications*, where extra information is provided. First, it contains information on the calibration data and climate scenarios that are used. This includes the plots for the time series used in the calibration (GDP growth, sector-level value-added, employment, etc), which can also serve to establish the main stylized facts of the economy under study. Variables displayed for the scenarios include carbon price paths, physical damages, etc.

Second, it contains the main outcomes that reflect the way we addressed a research question for the country/region under examination. The variables represented are in line with what has been done in the EIRIN-based papers thus far. A minimal set of variables are GDP, inflation, GHG emissions, (un)employment, public debt, deficit, trade balance, sector-level PDs, credit to GDP, share of renewable energy, and composition of GDP. Other sectoral and aggregate variables are added when necessary. Pages with successive plots allow for a description and discussion of all graphs, in the same manner as done in the papers, in order to build a narrative and explain how the applications address different research questions.

For every application, a first webpage is accessible from the drop-down menu *Applications*. Additional pages are accessible from the first. They present the coding notebook used to download and bring together the data, in order to show what the data sources are and what treatments are applied to it. Optionally, more pages could be added to display results for more advanced simulations, such as sensitivity analysis and robustness checks.

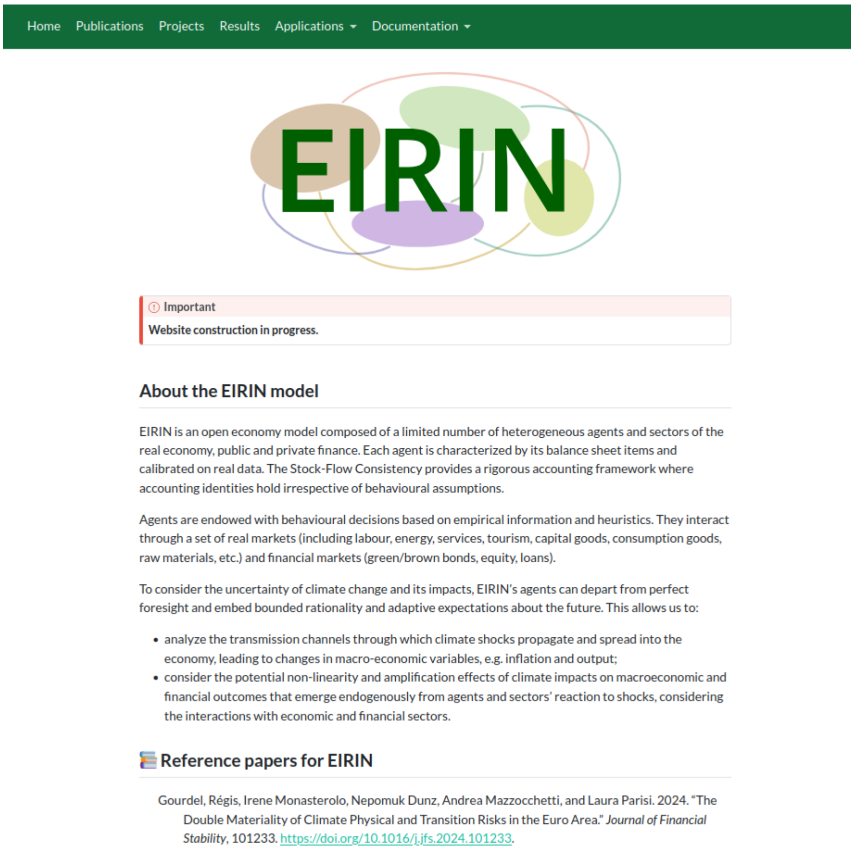



**Figure 5:** Screenshot of the website homepage.

### 3.2 Visualisation of results

An aspect of the website that imposes particular requirements is the visualization of results coming from the simulations conducted with EIRIN.[3]

The first core component used to render outputs from EIRIN is the Plotly package for Python (see appendix B for additional technical information). Plotly is a popular package, commonly used for data visualization on web pages. It allows all sorts of standard plots, and its output is in Javascript format, which allows the user to get information about components of the plots by hovering over them, such as displaying path labels and values. The generation of these figures is done once when compiling the Quarto code to produce the website. Such an example is provided in figure 6. This is the solution used in all country-specific pages that are accessible under the *Applications* menu.

However, for the *Results* page, a more advanced solution is required in order to embed more interactive features, in the sense that the underlying data used in the plot can be changed by the user. To do so, a dashboard hosted by an external service has been created. This has been done using a second Python package called Shiny, which allows for a wide range of user-interface interactions (see appendix B). In particular, the user can choose the country/region and variable that is displayed, restrict the set of scenarios presented by ticking their respective boxes, and restrict the time range on display through a slider.

[3] For example, relying on the Content Management System of the Unive website would have been difficult due to this visualisation need, as well as for the display and editing of equations.

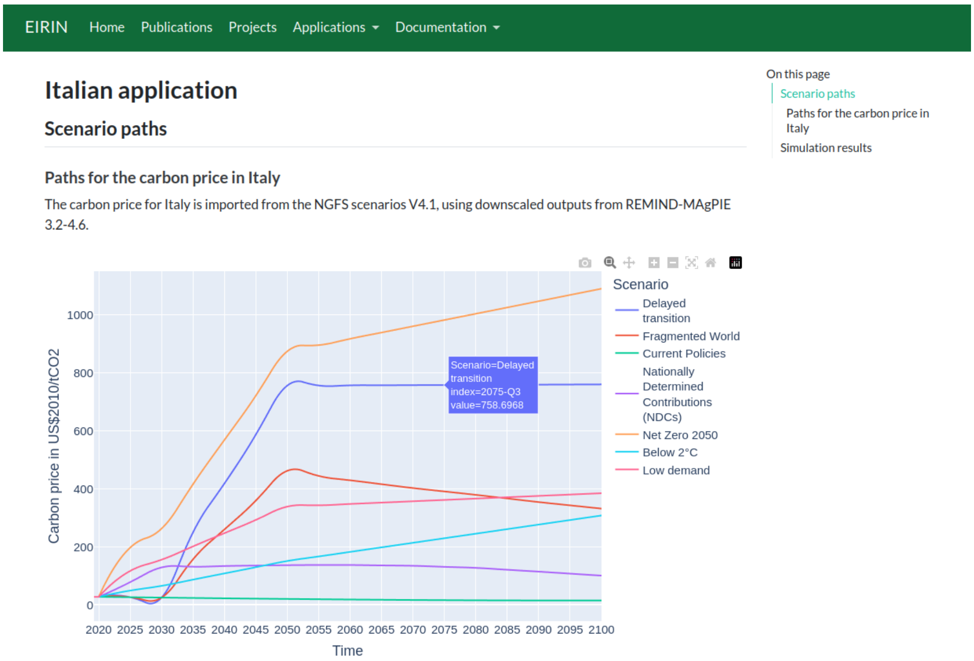



**FIGURE 6:** Screenshot of an example plot on the website, using Plotly.

The dashboard is then embedded in the website using an HTML snippet (an *iframe*), which points to the external dashboard. The outcome is presented in figure 7.

## 3.3 Deployment and updates

The process of deploying the website produced is also integrated to a large extent with the Quarto software. In particular, using the `publish` command of Quarto, one can push the compiled website to a specific target location. This target location can be an external server or another branch of the GitHub repository.

The website can be hosted by a third-party service, but the publication can be deployed via the service GitHub Pages (see further information in appendix B). This publication flow has been tested using my personal account, whereby the website could be accessed online with all its functions, though only as a subdomain of my personal page. In the future, the deployment can be extended using a different GitHub account or a paid hosting service that is compatible with a GitHub workflow. This would give more choice in the selection of the address used to host the website.

The advantage of the framework adopted is that the same Quarto code can be used and expanded by any person who becomes a contributor to the GitHub repository later on. In particular, results for other countries can be added by anyone working on the model later. Moreover, this configuration removes the need for a dedicated developer who would need to remain as a referent and take care of updates. Lastly, as repositories can be transferred and forked, the ownership of the website code is flexible.

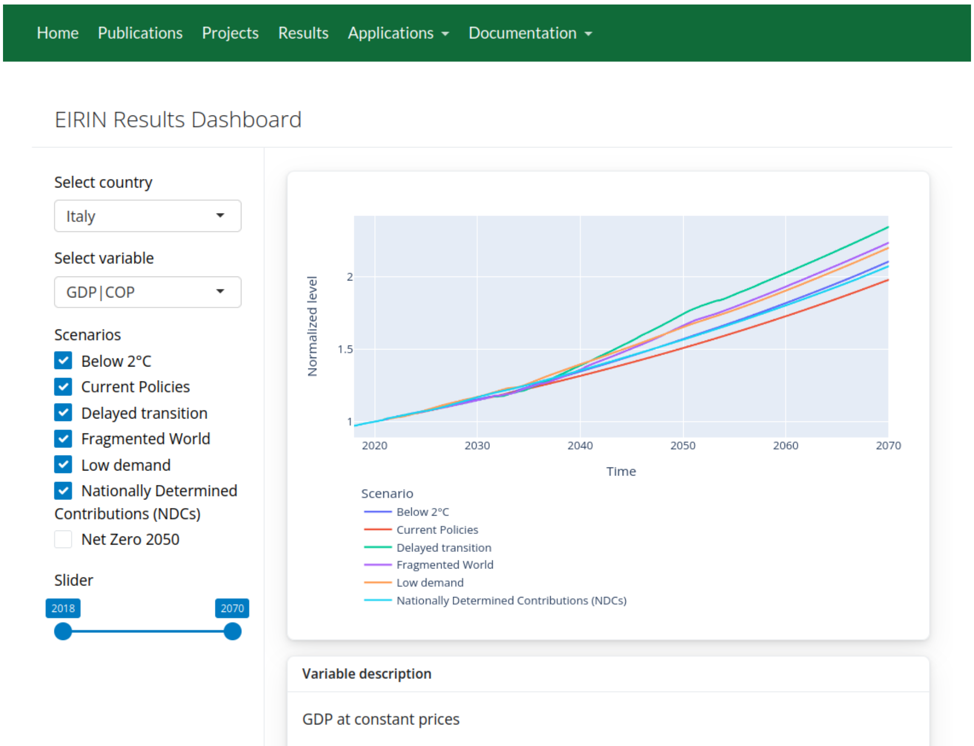
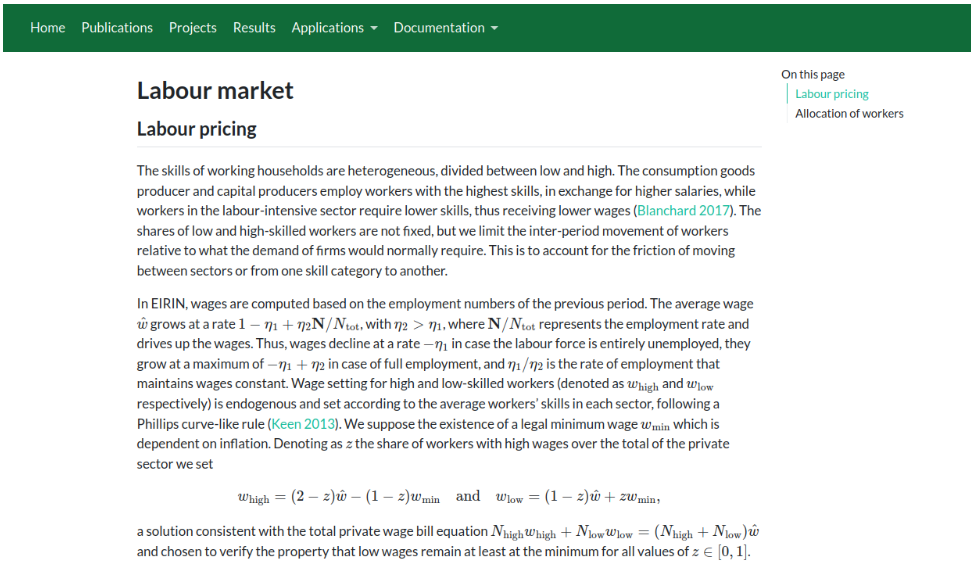



**Figure 7:** Rendering of the overall dashboard on the website.

### 3.4 Model documentation

In order to render mathematical equations in a text document, Quarto uses MathJax, which is the dominant technology for this purpose.[4] Moreover, a file that is part of the repository is used to generate a PDF version of the documentation, which can serve as a reference for the functioning of the model. It uses the same files that are used to generate the HTML pages created for the website. Thus, the content of the website and the PDF version are the same. The documentation builds on what has been produced in the various papers that documented progress on the model. An example of the rendering on the website is provided in figure 8.

[4]Information on MathJax is is accessible at `https://www.mathjax.org/`.



Home Publications Projects Results Applications Documentation

On this page
Labour pricing
Allocation of workers

# Labour market

## Labour pricing

The skills of working households are heterogeneous, divided between low and high. The consumption goods producer and capital producers employ workers with the highest skills, in exchange for higher salaries, while workers in the labour-intensive sector require lower skills, thus receiving lower wages (Blanchard 2017). The shares of low and high-skilled workers are not fixed, but we limit the inter-period movement of workers relative to what the demand of firms would normally require. This is to account for the friction of moving between sectors or from one skill category to another.

In EIRIN, wages are computed based on the employment numbers of the previous period. The average wage $\hat{w}$ grows at a rate $1 - \eta_1 + \eta_2 \mathbf{N}/N_{\text{tot}}$, with $\eta_2 > \eta_1$, where $\mathbf{N}/N_{\text{tot}}$ represents the employment rate and drives up the wages. Thus, wages decline at a rate $-\eta_1$ in case the labour force is entirely unemployed, they grow at a maximum of $-\eta_1 + \eta_2$ in case of full employment, and $\eta_1/\eta_2$ is the rate of employment that maintains wages constant. Wage setting for high and low-skilled workers (denoted as $w_{\text{high}}$ and $w_{\text{low}}$ respectively) is endogenous and set according to the average workers' skills in each sector, following a Phillips curve-like rule (Keen 2013). We suppose the existence of a legal minimum wage $w_{\text{min}}$ which is dependent on inflation. Denoting as $z$ the share of workers with high wages over the total of the private sector we set

$$w_{\text{high}} = (2 - z)\hat{w} - (1 - z)w_{\text{min}} \quad \text{and} \quad w_{\text{low}} = (1 - z)\hat{w} + z w_{\text{min}},$$

a solution consistent with the total private wage bill equation $N_{\text{high}} w_{\text{high}} + N_{\text{low}} w_{\text{low}} = (N_{\text{high}} + N_{\text{low}})\hat{w}$ and chosen to verify the property that low wages remain at least at the minimum for all values of $z \in [0, 1]$.

**Figure 8:** Screenshot of the section of the documentation dedicated to the labour market.

# 4 Climate transition policies and transition risk

We use EIRIN to explore the impacts of low-carbon transition policies across the Italian economy and financial system. We use seven scenarios from the NGFS, more specifically from the fourth vintage, released at the end of 2023 (Figure 9).

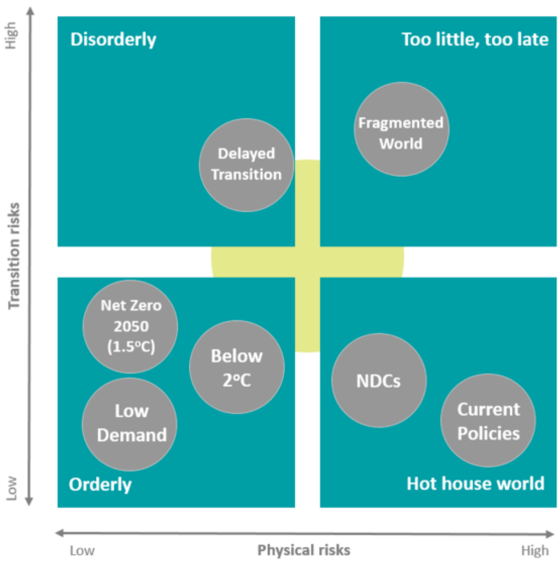



**Figure 9:** NGFS scenarios framework in Phase IV, four quadrants.

The results are accessible from the general dashboard and are presented on the dedicated page as well. The particularity of this application is that we focused on the sole effect of carbon taxes, while previous ones used complementary policies consistent with the scenarios. In turn, this allows us to identify what changes comes from carbon prices alone, and thus the gap that remains to be filled by other policies.

## 4.1 Results

Simulations were conducted with the seven scenarios produced by the NGFS in its fourth version. We compare below the results to that of the "Current Policies" scenario, which is a low-ambition pathway that is close to a "buisness-as-usual" situation with a very limited increase in carbon prices and is far from achieving climate targets.

We can first notice from figure 10 that changes in the economic output are generally contained. This is in a context where baseline growth is calibrated at a relatively low level to match recent macroeconomic data. In line with Gourdel et al. (2024), we can notice an initial dip in the relative real GDP level, when the increase in the carbon price is fastest. In scenarios where transition policies are moderate, the economic output eventually reaches levels higher than in the Current Policies scenario. The biggest relative losses are observed in the case of a delayed transition, where a sudden and late increase in the carbon price is most detrimental to the economy. Nevertheless, given the absence of additional policies, this change is limited to a relative difference of about 2%. Recessions occur in some periods for the Net Zero 2050 and the Delayed Transition scenarios, but with a lower bound on growth of -0.2%.

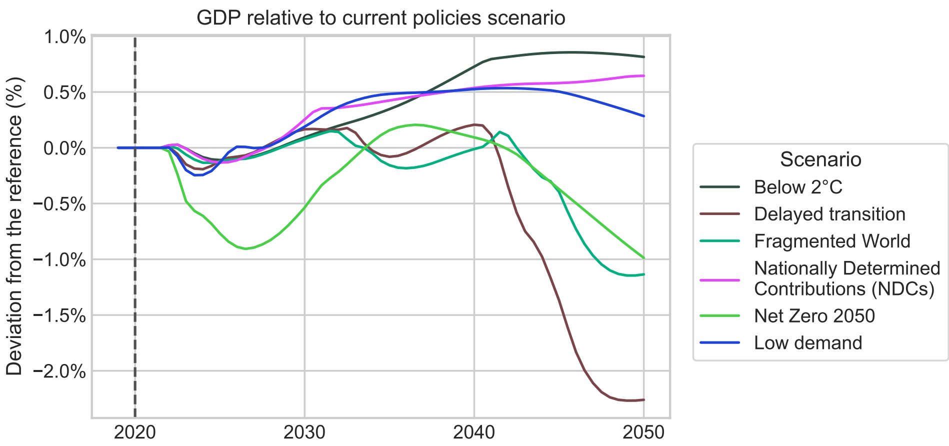



**Figure 10:** Deviation in economic output (annualized GDP) in the simulations for Italy relative to the Current Policies scenario.

Second, we observe from figure 11 that these policies are efficient at reducing the level of GHG emissions from the domestic economy. In the absence of any policy add-on, the decrease in emissions is not sufficient to reach policy targets though. For example, we observe changes in the share of renewable energy in the country (see figure 12), but this shift is lesser than what would be needed. Nonetheless, we find that carbon emissions are much more sensitive to carbon prices than GDP, meaning that the trade-off when implementing such climate policies is minor.

In particular, Net-Zero scenario leads to higher GHG emission reduction and slight decrease in GDP compared to Current Policies. On constrast, delayed transition scenario is characterized by a sudden increase in the carbon price, which leads to a late decrease in emission and sudden decrease in GDP (higher transition risk).

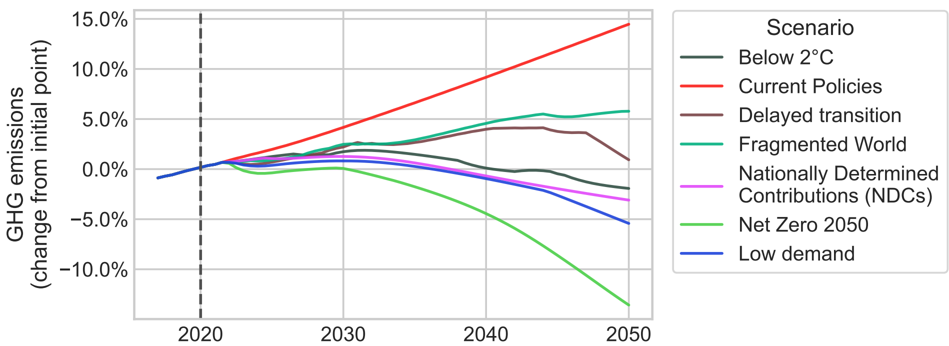



**Figure 11:** Changes in total Green House Gas emissions in the simulations for Italy, from the start of the scenarios.

Lastly, to assess the role of the default mechanism presented in section 2.3.1, we plot in figure 13 the annualized losses from defaults in the real economy relative to the bank's capital. We see that transition policies generally tend to reduce defaults within the economy, although scenarios with more sudden episodes of carbon price increase can lead to values higher than in Current Policies for some periods of time. These dynamics are mostly influenced by changes

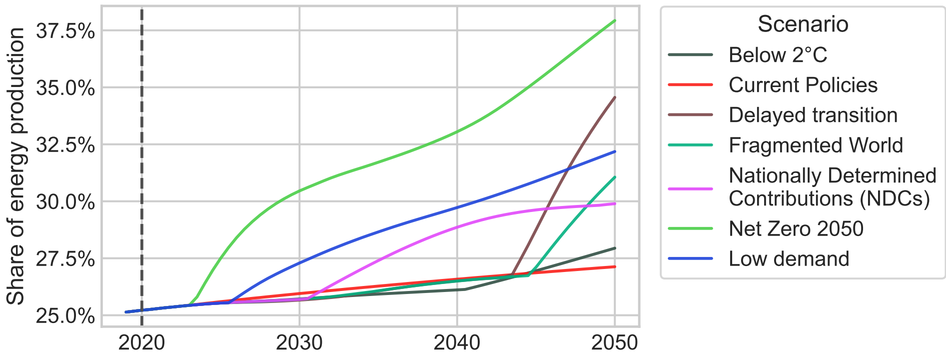



**FIGURE 12:** Changes in the share of renewable energy in the simulations for Italy, from the start of the scenarios.

in the ratio of defaults and the debt volumes, as the recovery rates vary typically less in the simulations.

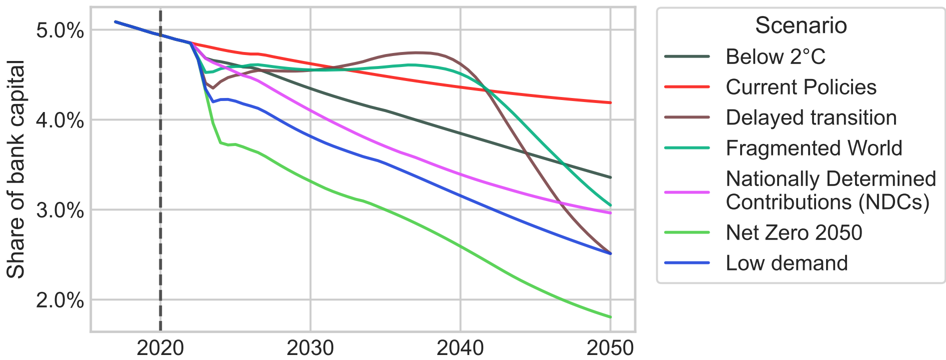


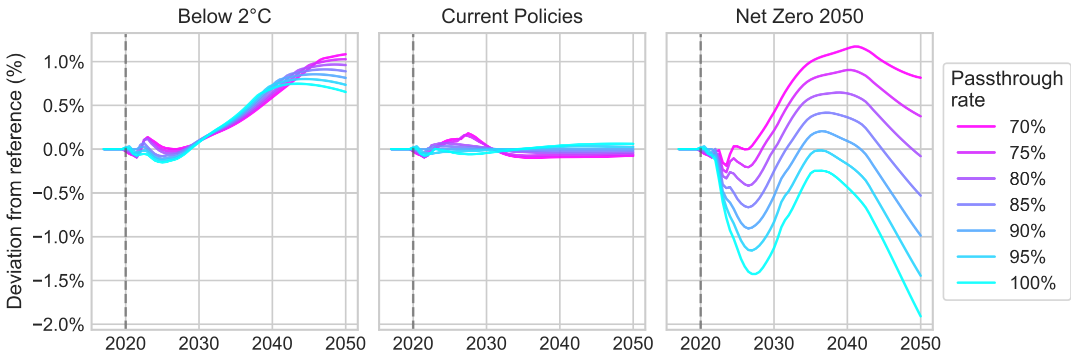

**FIGURE 13:** Default losses for the bank, after partial recovery, as a share of the bank's capital; annualized values.

### 4.2 Effect of a passthrough and green rebate

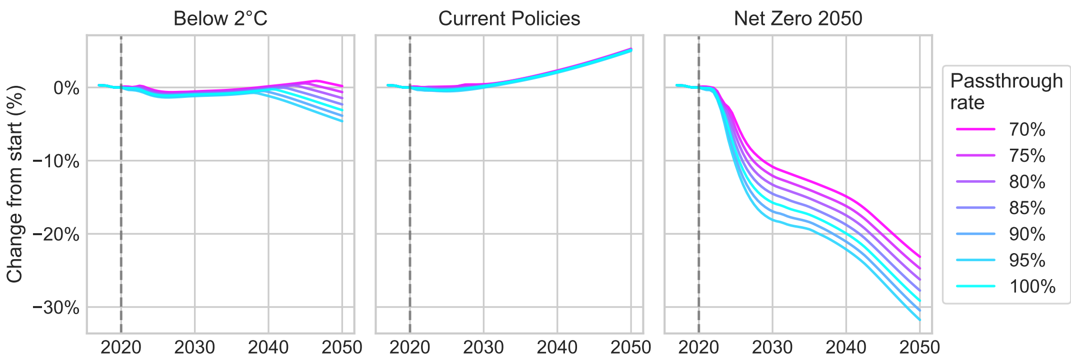
On top of the main results presented before, we can examine in the case of Italy the sensitivity of key results to the variation of some of the new parameters introduced. In particular, we consider the effect of the parameter governing the pass-through of carbon taxes, as described in section 2.3.3. Before the work conducted on the model in the context of this project, a unit pass-through was used, whereby firms would integrate carbon price in their cost, hence triggering inflationary dynamics and leading to a lesser volume of consumption given the same budget of consumers. In the new version of the model, the share of the carbon taxes that is absorbed by an increase in prices is variable. Therefore, firms internalize more of this cost.

I present the effect of this parameter on the annualized levels of GDP and GHG emissions in figure 16. We focus here on three of the scenarios tested: Below 2°C, Current Policies, and Net Zero 2050. We observe that the parameter matters mostly when the carbon price reaches high values, which is why the clearest differentiation happens in the Net Zero 2050 scenario. More specifically, we see from figure 14a that the pass-through has a monotonic effect on GDP, which is lower for higher values of the pass-through rate. The most important mechanism behind this is that higher prices lead to less consumption in units of goods, hence a lesser need for labour. The increased unemployment leads in turn to a less demand from working households. This appears to dominate the opposite effect, which is that a full passthrough leads to higher dividends for capitalist households. The fact that capitalist households have a lesser marginal propensity to consume explains in turn the effect observed.

The effect on GHG emissions is broadly in line with that of the economic output. The difference in GDP explains part of the lower level of emissions. However, the relation is not strictly monotonic in that case, which suggests that a passthrough rate too high allows brown activities to retain economic attractiveness, as they can pass on their cost, in turn impeding the green transition.




**(A)** Effect on GDP



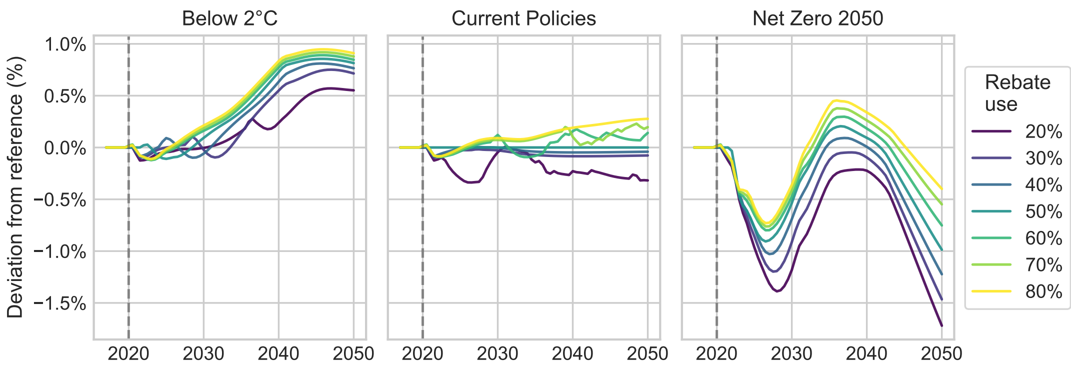

**(B)** Effect on GHG emissions

**FIGURE 14:** Sensitivity of simulations to the pass-through rate.

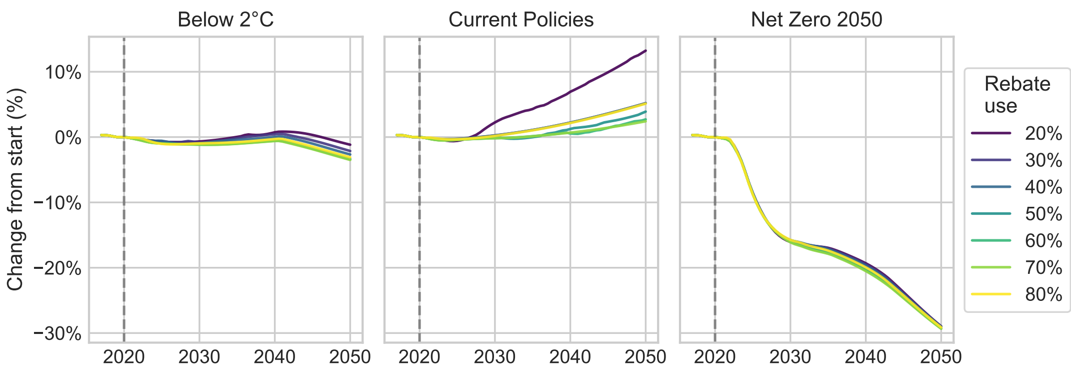
A second innovation of the model that is tested in the case of Italy is the effect of using part of carbon tax revenues to subsidize the purchase of green capital by corporations. In practice, a budget for the subsidies is determined as a share of the revenues from the carbon tax, and this share is the parameter that can be changed, henceafter the "rebate use". Then, based on the volume of green capital sold to corporations, a discount is applied to its price so as to use the dedicated budget. Revenues that are not invested in this rebate are assigned to the general budget of the state.

The results from this exercise are visible in figure 15. We can notice that the most striking effects are observed in the Current Policies scenario. There, even though the carbon price is low, the presence of this rebate for values above 20% allow the country not to increase significantly its emissions. However, when falling to 20%, emissions do increase by more than 10% over the simulation period. It is contemporaneous to a somewhat lower level of GDP, but this can be partly attributed to the setup of the exercise, whereby the value of the parameter is changed from one period to the next, which allows for comparison between simulations but may cause instability in the model.

For other scenarios with higher values of the carbon price reached quickly, the effect on emissions appears small. On the other hand, some effect is observed on GDP in the case of the Net Zero 2050 scenario, where a higher rebate use mitigates the decrease in growth incurred relative to the reference policy.




**(A)** Effect on GDP




**(B)** Effect on GHG emissions

**Figure 15:** Sensitivity of simulations to the share of carbon tax proceeds used to subsidize green capital.

Results for the euro area are also integrated to the website, reflecting an update of those from Gourdel et al. (2024), and using more recent NGFS scenarios. In the future, results from other applications of the model will be added, in particular those coming from previous projects, such as Indonesia, Barbados, and Mexico. Moreover, future applications of the model will be showcased as well on the website.

## 5 Climate physical risk

Significant uncertainty about the scale, timing, and regional distribution of the impacts of physical risk makes it challenging to anticipate and prepare for potential outcomes using traditional forecasting methods. To address these challenges, we explore the severity of acute physical risks that could prevent the recovery of the Italian economy.

To do so, we calibrated the EIRIN model on the Italian economy and considered the impact of a representative natural hazard that enters the economy by destroying productive capital, thus reducing production (direct impact), since the capital is an input factor for firms. Capital stock destruction represents a supply shock that limits firms' ability to serve demand in the aftermath of the impact, with cascading impacts on unemployment, debt to GDP and firms' financial conditions (indirect impact). We simulate a single event leading to a capital stock destruction of maximum 15% in four quarters.

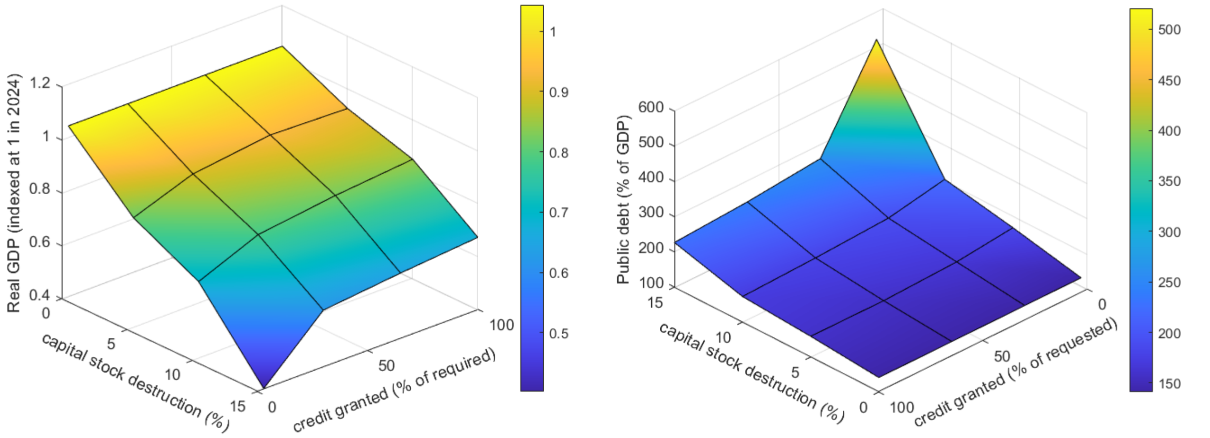
In addition to the natural hazard, we take into account also the financial conditions in the aftermath of the shocks. In particular, we consider scenarios in which the banking sector is not providing the required credit needed by the firms for reconstruction purposes. This is modeled as the banking sector constraining credit in the year following the shocks. We assume that the banking sector provides only a share of required credit by the firms, which need to borrow to invest and recover from the capital losses.

### 5.1 Results

We use EIRIN to analyse the direct and indirect impact of extreme natural hazards and the transmission channels through which they impact on the economy and finance. Further, we analyse the financial conditions which can lead to amplification of the shock and long-term non recovery paths.

Our analysis primarily concentrates on the destruction of capital stock, which is one of the most frequently observed immediate consequences of flooding and has demonstrated the most significant direct effects in our EIRIN simulations. We test the shocks in capital stock occurring for 4 consecutive quarters in 2025. Additionally, we evaluate macro-financial conditions by examining the impact of compounding financial constraints. This is quantified by the ratio of credit extended to credit requested, reflecting the reality that firms' ability to rebuild post-disaster - often a driver of robust GDP growth and recovery - is contingent upon their access to financing for such investments. It is worth mentioning that the baseline scenarios with no credit constraint represents the most optimistic scenario.

Our study delves into the scenarios under which an economy fails to return to a stable growth trajectory following a shock, a state we define as the economy "breaking". To do this, we examine the varied effects of different levels of capital stock destruction and financial constraints post-shock. Figure 16a illustrates the impact of these variables on real GDP, represented as the average over the five years following the shock. As expected, the figure reveals that greater destruction of capital stock correlates with more significant reductions in GDP. However, it also shows that the adverse effects on the economy escalate non-linearly with increased capital stock damage. This is due to a decrease in demand, which leads firms to downscale their capacity requirements, subsequently lowering their expectations for demand and investment. This dynamic is exacerbated and can lead to the economy "breaking", measured by permanently subdued GDP and unsustainable public debt amounts (figure 16b), when credit constraints become an insurmountable barrier for businesses.

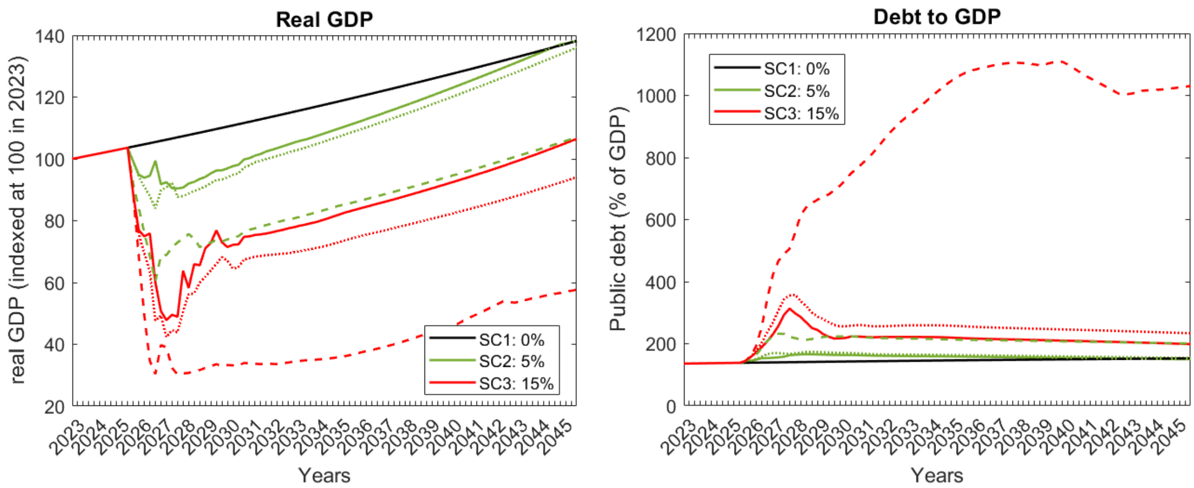



**(A)** Real GDP **(B)** Debt to GDP

**FIGURE 16:** Mean of real GDP (indexed at 1 in 2024) and public debt (% of GDP) over 5 years after the impact of natural hazard. The x-axis includes the percentage of destroyed capital stock over the total. The y-axis includes the share of credit granted by the banking sector in the year following the shock, as percentage of total demand of credit. The z-axis shows the real GDP (left panel) and the debt to GDP (right panel)

In the scenario where capital stock incurs 5% damage — a significant amount by historical standards for Italy post-natural disaster — the economy shows a robust ability to bounce back, realigning with the BAU path within roughly two decades, as illustrated in Figure 15a. This rebound is primarily propelled by substantial recovery investments (figure 19), which catalyze GDP growth and enable public debt (Figure 17b) and unemployment rates (Figure 18a) to recalibrate to BAU benchmarks. When credit constraints are introduced, particularly at the extreme of 100%, the economic outlook dims, with dampened GDP growth, elevated public debt, and higher unemployment rates. The probability of default (Figure 18b) for firms is subject to two opposing forces. On one hand, stringent credit constraints hinder firms' recovery capabilities, leading to reduced overall indebtedness. On the other hand, the weakened economic environment increases firms' default risk. In the 100% credit constraint scenario, the adverse impact of a sluggish economy on PDs overshadows the effect of reduced credit volume.

In the scenario where capital stock suffers 15% damage, the economic consequences escalate in a non-linear fashion. This significant damage to capital stock leads to a substantial and immediate impact on GDP, which is further exacerbated over time by a prolonged economic downturn. This downturn is driven by a decrease in aggregate demand, stemming from higher unemployment and lower labor income, which in turn causes investment behavior to become more erratic before recovery investments can stabilize GDP growth. Despite these efforts,



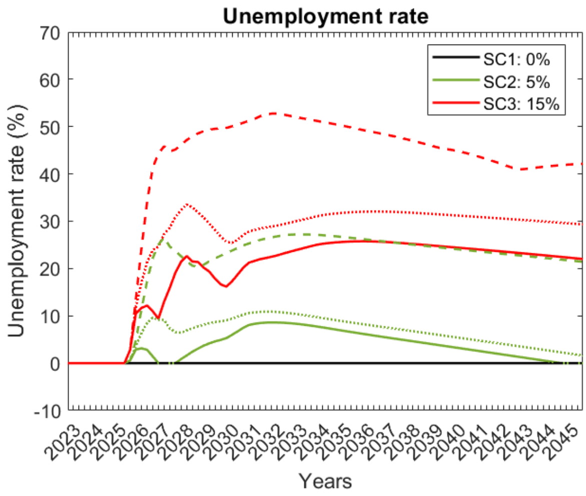

**(A)** Real GDP **(B)** Debt to GDP

**Figure 17:** Real GDP and debt to GDP ration including capital stock destruction and credit rationing. The solid lines represent the scenario without credit constraints. The dotted lines represent the scenarios including 50% of credit constraints, while dashed lines represent the scenarios including 100% of credit constraints.
Source: Authors' own elaboration.

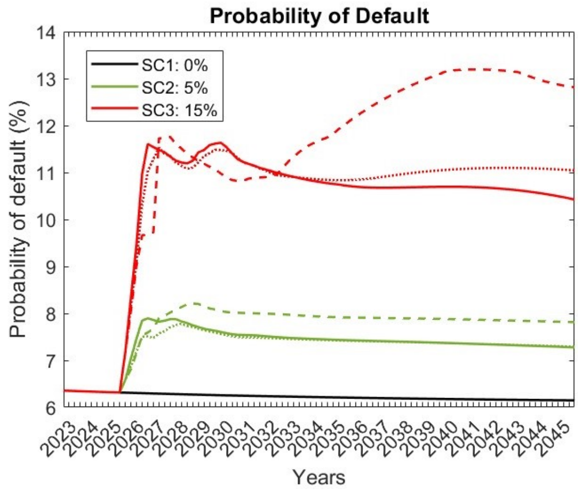
the overall GDP fails to catch up with the Business-As-Usual (BAU) scenario due to hysteresis effects that permanently dampen aggregate demand. As a result, unemployment levels (Figure 18a), public debt (Figure 17b), and the probability of default (Figure 18b) remain high. The situation worsens when firms are credit constrained, particularly if they face these constraints immediately after the disaster. Under such conditions, the negative economic impacts are long-lasting, preventing the economy from returning to its previous growth trajectory for decades. In this case, the economy's levels are permanently about 60% lower than in the BAU scenario, with public debt and unemployment levels surging, and an additional increase in the probability of default for firms materializing after a few years.

In light of the analysis presented, it becomes evident that banks play a crucial role in mitigating the aftermath of economic shocks, such as those caused by natural disasters. Acting countercyclically, banks can provide the necessary credit to firms seeking to rebuild and recover, thereby facilitating a return to stable economic growth. The ability of banks to perform this function is heavily dependent on their financial health; sound financial buffers are essential to absorb the increased risks during crises without compromising their operational stability.

For policymakers, the implication is that there is a need to support regulatory frameworks that encourage banks to maintain robust capital reserves during economic upturns, which can then be drawn upon in times of crisis. Additionally, policies that promote rapid and flexible credit extension to creditworthy firms after shocks can help sustain investment and consumption, thus shortening the duration of economic downturns. Furthermore, the timely introduction of climate mitigation policies and adaptation investment can play a key role to support countries' climate risk management under tail risk scenarios. This research highlights the im-




**(A)** Real GDP




**(B)** Debt to GDP

**FIGURE 18:** Unemployment rate and firms' probability of default (PD) including capital stock destruction and credit rationing. The solid lines represent the scenario without credit constraints. The dotted lines represent the scenarios including 50% of credit constraints, while dashed lines represent the scenarios including 100% of credit constraints.
Source: Authors' own elaboration.

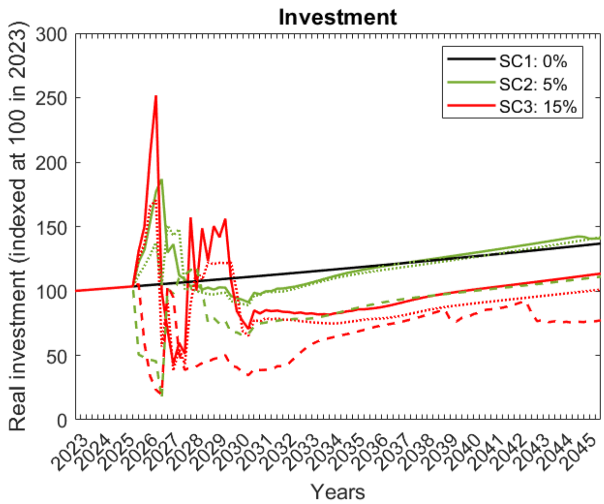



**FIGURE 19:** Firms' investment including capital stock destruction and credit rationing. The solid lines represent the scenario without credit constraints. The dotted lines represent the scenarios including 50% of credit constraints, while dashed lines represent the scenarios including 100% of credit constraints.
Source: Authors' own elaboration.

portance of timely adaptation actions to prevent economic breakdowns and public and private debt sustainability.

## 6 Conclusion

The project underscored the critical importance of understanding and addressing the multi-faceted impacts of climate risks on the Italian economy and financial system. By developing an online tool and employing the EIRIN stock-flow consistency model tailored to Italy's economic context, we have provided an analysis of how transition and physical risks could unfold conditioned to climate scenarios. This modeling framework allows for an in-depth exploration of the pathways through which these risks affect economic and financial stability in Italy, as well as the implications for policy making.

The report highlights that the dynamics of climate risks are complex and interdependent. For instance, transition risks arising from an unaticipated delayed and sudden transition can lead to stranded assets and economic downturn, thereby straining fiscal and financial systems. In addition, severe physical shocks, such as damage to capital stock driven by extreme natural hazards, can lead to prolonged economic setbacks if not addressed by adequate adaptation strategies.

Through simulation of various policy scenarios aligned with the NGFS framework, the results demonstrate the critical importance of an orderly transition. A well-managed transition not only mitigates risks but also generates co-benefits in terms of GDP and GHG emission reduction. In contrast, a disorderly transition exacerbates economic challenges, deepens financial vulnerabilities, and increases the risks of preventing decarbonization efforts.

The findings also emphasize the pivotal role of fiscal policy in promoting the low-carbon transition. In particular, effective use of fiscal tools, such as revenue recycling from carbon taxes to provide green subsidies, can help offset the economic costs of higher taxation in the climate transition scenarios.

In addition, the financial sector plays a crucial role in enabling recovery from physical risk impacts by providing credit to businesses. Ensuring the resilience of financial institutions is therefore essential to maintaining stability in the face of climate risks.

This project contributed not only to advance the understanding of climate risks but also to provide practical tools for policymakers and stakeholders. The development of an online platform as part of this project enables users to explore simulation results, visualize data, and make informed decisions. This tool serves as a bridge between complex modeling outcomes and actionable policy insights, making it a valuable resource for designing and implementing effective climate policies in Italy.

In conclusion, this project highlights the urgent need for integrated approaches that align climate goals with economic and financial stability. By leveraging the insights generated through the EIRIN model and the online tool, policymakers can adopt proactive measures that mitigate risks, drive decarbonization, and build resilience, ensuring that Italy remains on a sustainable path amidst the growing challenges of climate change.

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# A EIRIN agents and sectors' behaviour

We detail here the main model's behaviours. First, we introduce the notation used. Let $i$ and $j$ be two agents. Then, $p_i$ is the price of the output produced by $i$, while $p_i^\dagger$ is the price of the security issued by $i$. $D_{i,j}$ is the demand by $j$ of what $i$ produces, and $\mathbf{D}_i = \sum_j D_{i,j}$. Moreover, $\mathbf{q}_i$ is the total production of $i$ and $q_{i,j}$ is the part of it that is given to $j$. We also denote by $M_i$ the liquidity of $i$, akin to holdings of cash, and by $K_i$ its stock of productive capital where applicable.

By building on Goodwin (1982), households are divided in two classes.

The working class ($H_W$) lives on wages, with gross revenues

$$Y_{H_W}^{gross} = \sum_i N_i \cdot w_i \tag{1}$$

where $w_i$ is the wage paid by $i$ and $N_i$ the size of the workforce it employs (we omit the time dimension for simplicity as all variables are contemporaneous). The labour market mechanism[5], determines the final workforce $N_i$ of each agent based on the total $N_{tot}$ of workers available and the demand for labour of firms. It also determines the salary level $w_i(t)$ paid by $i$, based on the required skills of employing firms.

The capitalist class ($H_K$) earns its income out of financial markets through government bonds' coupons and firms' dividends:

$$Y_{H_K}^{gross} = c_G \cdot n_{H_K,G} + \sum_i d_i \cdot n_{H_K,i} \tag{2}$$

where $d_i$ are the dividends of $i$ and $c_G$ represents the coupon's rate, and $n_{H_K,G}$ and $n_{H_K,i}$ are the quantity of government bonds and firm's shares held by private households respectively.

Both households are then taxed, with $\tau_{H_W}$ being the rate of the income tax, and $\tau_{H_K}$ the rate of the tax on profits from capital. Furthermore, both household classes receive net remittances $\mathrm{RM}_i$ from abroad. All households pay their energy bill.

This leaves them with $Y_i^{\text{net}}$ as net disposable income:

$$\forall i \in \{H_W, H_K\}, \quad Y_i^{\text{net}} = \underbrace{(1-\tau_i) \cdot Y_i}_{\text{net income}} - p_{EN} q_{EN}^i + \mathrm{RM}_i \tag{3}$$

Households' consumption plans (eq. 4) are based on the Buffer-Stock Theory of savings (Deaton, 1991; Carroll, 2001), with consumers adjusting their consumption path considering a target liquid wealth to income ratio $\rho_i$ and the speed of adjustment of consumption $\phi_i$. In particular, consumers spend more (less) than their net income if their actual liquid wealth to income ratio is higher (lower) than the target level. This results in a quasi target wealth level that households pursue. Then, households split their consumption budget $C_i$ between consumption goods and services, also importing a share $\beta_0$ from the rest of the world.

[5]For details see Gourdel et al. (2022)

$$C_i = Y_i^{\text{disp}} + \rho_i \left( M_i - \phi_i \times Y_i^{\text{disp}} \right) \tag{4}$$

$$D_i^{F_L} = (1 - \beta_0) \times \beta_1 \times C_i \tag{5}$$

$$D_i^{F_K} = (1 - \beta_0) \times (1 - \beta_1) \times C_i \, . \tag{6}$$

The service firm $F_L$ (labour intensive) and consumption goods producer $F_K$ (capital intensive) produce their respective outputs by relying on a Leontief technology. This implies no substitution of input factors, meaning that if an input factor is constrained (e.g. due to limited access to credit to finance investments), the overall production is proportionately reduced:

$$\forall j \in \{F_L, F_K\}, \quad \mathbf{q}_j = \min \left\{ \gamma_j^N N_j, \ \gamma_j^K K_j \right\} \ . \tag{7}$$

In contrast, several macroeconomic models allow for substitution of input factors (elasticity of substitution equals 1) by using a Cobb-Douglas production technology. In our case, this would imply a substitution of constrained input factors such as capital stock with labour, while still generating the same level of output.

The two firms set their goods' price as a mark-up $\mu_j$ on their labour costs $w_j/\gamma_j^N$, capital costs $\kappa_j L_j$, energy $p_{EN} q_{EN,j}$ and resource costs $p_R q_{R,j}$, such that

$$\forall j \in \{F_L, F_K\}, \quad p_j = (1 + \mu_j) \times (1 + \tau_{\text{VAT}}) \left[ \frac{w_j}{\gamma_j^N} + \frac{\kappa_j L_j + p_{EN} q_{EN,j} + p_R q_{R,j}}{q_j} \right] \ . \tag{8}$$

In particular, final prices can be affected by firms' interest rates $\kappa_j$ on loans, more expensive imports ($p_R$), energy and/or wages. Higher prices of consumption goods and services constrain households' consumption budgets, which in turn lower aggregate demand. This represents a counterbalancing mechanism on aggregate demand.

The minimum between real demand of the two consumption goods and the real supply (eq. 9 and 10) determines the transaction amount $\tilde{q}_j$ that is traded in the goods and services market. The supply of capital intensive consumption goods also takes firm's inventories ($IN_{F_K}$) into account.

$$\tilde{q}_{F_K} = \min \left( \text{IN}_{F_K} + q_{F_K}, \ \frac{1}{p_{F_K}} \left( D_{H_W}^{F_K} + D_{H_K}^{F_K} + D_G^{F_K} + D_{RoW}^{F_K} \right) \right) \tag{9}$$

$$\tilde{q}_{F_L} = \min \left( q_{F_L}, \ \frac{1}{p_{F_L}} \left( D_{H_W}^{F_L} + D_{H_K}^{F_L} + D_G^{F_L} + D_{RoW}^{F_L} \right) \right) \tag{10}$$

In case that demand exceeds supply, both capitalist and worker households are rationed proportionally to their demand. The share of newly produced but unsold products add up to the inventory stock of $F_K$ ($IN_{F_K}$). Finally, both consumption goods producers make a production plan $\hat{q}_j$ for the next simulation step based on recent sales and inventory levels.

Both $F_L$ and $F_K$ make *endogenous investment decisions* based on the expected production plans $\hat{q}_j$, which determine a target capital stock level $\hat{K}_j$. The target investment amount $I_j^\dagger$ is set by the target capital level $\hat{K}_j$, considering the previous capital endowment $K_j(t-1)$ subject to depreciation $\delta_j \cdot K_j(t-1)$, hence

$$I_j^\dagger(t) = \max\left\{\hat{K}_j(t) - K_j(t-1) + \delta_j \cdot K_j(t-1), 0\right\} \tag{11}$$

Differently from supply-led models (Solow, 1956), in EIRIN, investment decisions are fully endogenous and they are based on firms' Net Present Value (NPV). This, in turn, is influenced by six factors:

(i) investment costs, (ii) expected future discounted revenue streams (e.g. endogenously generated demand), (iii) expected future discounted variable costs, (iv) the agent's specific interest rate set by the commercial bank, (v) the government's fiscal policy and (vi) government's subsidies.

More precisely, the planned investment is given by $I_j^\star(t) = \left(\varphi_j \cdot M_j(t-1) + \Delta^+ L_j(t)\right)/p_{K,j}(t)$, where $\varphi_j$ is the share of liquidity that $j$ uses to finance investment, $\Delta^+ L_j$ is the part that comes from new credit, and $p_{K,j}$ is the average price of capital, which depends on the ratio of low- and high-carbon capital, at unit prices $p_{K_G}$ and $p_{K_B}$ respectively. The NPV calculations allow us to compare the present cost of real investments in new capital goods to the present value of future expected (positive or negative) cash flows. We differentiate in that regard between low- and high-carbon capital ($K_G$ and $K_B$ respectively), that is, for a level $\iota$ of investment, the related NPVs are

$$NPV_j^{\mathsf{low}}(\iota, t) = -p_{K_G}(t) \cdot \iota + \sum_{s=t+1}^{+\infty} \frac{\mathrm{CF}_j^{\mathsf{low}}(\iota, t, s)}{(1+\kappa_i)^{s-t}} \tag{12}$$

$$NPV_j^{\mathsf{high}}(\iota, t) = -p_{K_B}(t) \cdot \iota + \sum_{s=t+1}^{+\infty} \frac{\mathrm{CF}_j^{\mathsf{high}}(\iota, t, s)}{(1+\kappa_i)^{s-t}} \tag{13}$$

where $\mathrm{CF}_j^{\cdot}(\iota, t, s)$ includes the total expected cash flows expected at time $s$ from the new investment[6]. Cash flows are discounted using the sector's interest rate $\kappa_j$ set by the commercial bank. The final realised investment $I_i(t)$ is divided into low- and high-carbon capital such that $I_i = I_i^{\mathsf{low}} + I_i^{\mathsf{high}}$. Then, it is potentially constrained by the supply capacity of the producers.

The energy sector ($EN$) is divided into low- and high-carbon energy producers ($EN_G$ and $EN_B$ respectively) and produces energy, demanded by households and firms for consumption and for production, respectively. We assume that all demand is met, even if $EN_B$ might have to buy energy from the foreign sector, such that $\mathbf{q}_{EN} = \mathbf{D}_{EN}$. Households' energy demand is given by a share of their consumption, while firms' energy requirements are proportional to their output. The high-carbon energy company requires capital stock and oil as input factors for production, and only productive capital for its low-carbon counterpart but in higher

[6]Details of the cash flows calculations are provided in Gourdel et al. (2024)

quantity. The energy price is common and endogenously set from the unit cost of both firms (see Gourdel et al. (2022) for a detailed description).

$H_W$ and $H_K$ subtract the energy bill from their wage bill as shown by their disposable income (eq. 4), while firms transfer the costs of energy via mark-ups on their unit costs to their customers (eq. 8). To be able to deliver the demanded energy, the energy sector requires capital stock and conducts investments to compensate capital depreciation and expand its capital stock to be able to satisfy energy demand (further details are provided in Gourdel et al. (2022)). The oil and mining company $MO$ supplies $EN_B$ with oil and exports to the rest of the world as well. It faces no restriction on extraction but requires a proportional amount of productive capital to operate.

In EIRIN we consider both price and wage stickiness. In particular, prices are set by the supply side and are based on a mark-up on unit production costs (see e.g. Blanchard, 2017). Each unit cost evolves endogenously in the model, based on agents and sectors' interactions. In this context, the price stickiness can arise due to endogenous adjustments in response to a shock or a policy and can be further amplified by supply-side constraints. Regarding the wages, they don't adjust immediately in response to a shock. In particular, the speed of adjustment accounts for the level of employment and inflation at the previous time step, and can be moderated by a parameter.

The capital goods producers ($K$, divided into low- and high-carbon capital producers, $K_G$ and $K_B$ respectively) supply productive capital to fulfill the production capacity of $F_L$, $F_K$, $MO$ and $EN$:

$$\mathbf{q}_{K_G} = I_{K_G}^{F_L} + I_{K_G}^{F_K} + I_{K_G}^{EN_G} \leq \mathbf{D}_{K_G}, \quad \mathbf{q}_{K_B} = I_{K_B}^{F_L} + I_{K_B}^{F_K} + I_{K_B}^{EN_B} + I_{K_B}^{MO} \leq \mathbf{D}_{K_B}\ . \tag{14}$$

Newly produced capital goods will be delivered to the consumption good producers and the energy firms at the next simulation step. The capital good producers rely on energy, raw materials and high-skilled labour as input factors. There are differences between the low- and high-carbon versions of capital goods in both their production and their use. In production, low-carbon capital requires more skilled labour than the high-carbon one, as well as more material imported from the rest of the world. The latter condition represents the more complex supply chain and international dependencies that can be involved in low-carbon capital production, such as rare metals for batteries. Therefore, a unit of low-carbon capital is more expensive than a unit of high-carbon capital (for the same productive capacity). In addition, in their use, low-carbon capital is the most interesting per unit for the service sector and the consumption goods producers (the ones with the choice as to which type of capital to use). This is due to a lower usage of raw material and energy, resulting in a lower bill per unit of capital used, and lower related GHG emissions. Capital good prices $p_{K_G}$ and $p_{K_B}$ are set as a fixed mark-up $\mu_K$ on unit costs:

$$\forall i \in \{K_G, K_B\}, \quad p_i = (1 + \mu_K) \times \frac{w_K N_i + D_i^{EN} p_{EN}}{\mathbf{q}_i} \tag{15}$$

In the financial sector, the commercial bank ($BA$) provides loans and keeps deposits. The commercial bank endogenously creates money (Jakab and Kumhof, 2015), meaning that it increases its balance sheet at every lending (i.e. the bank creates new deposits as it grants a new credit). This is consistent with most recent literature on endogenous money creation (McLeay et al., 2014).

The $BA$ gives out loans to finance firms' investment plans. The bank sets sector-specific interest rates that affect firms' capital costs and NPV calculations. The commercial bank can grant credit under the condition that it complies with regulatory capital requirements (eq. 16). When this does not happen, credit is rationed and firms have to scale down their investment plan. In this situation, the commercial bank reacts by retaining part of its earnings to increase the equity base and, thus, the Capital Adequacy Ratio (CAR) and the lending capacity. Thus, the lending activity in EIRIN can be endogenously affected by the performance of the borrowers, which pay interest on loans, thus impacting on bank's profits and equity. Within this framework, policies and/or shocks which influence firms' activity and investments may be sources of financial instability.

The credit market is characterised by the level of credit and the cost of credit. The *level of credit* is how much the bank lends to the sectors that demand credit at a time $t$. The maximum credit supply of the bank is set by its equity level $E_{BA}$ divided by the Capital Adequacy Ratio (CAR) parameter $\widetilde{\mathrm{CAR}}$, in order to comply with banking regulation. Another relevant information is the the demand for new credit $\mathbf{D}_{BA}(t)$ and the previous credit level $\mathbf{L}(t-1)$. The additional credit that the bank can provide at each time step is given by its maximum supply, minus the amount of loans already outstanding, so that the total amount of loans makes its realised capital adequacy ratio remain above $\widetilde{\mathrm{CAR}}$:

$$\Delta^+ \mathbf{L} = \min \left\{ \mathbf{D}_{BA}(t), E_{BA}(t-1)/\widetilde{\mathrm{CAR}} - \mathbf{L}(t-1) \right\} . \tag{16}$$

The *cost of credit* is the interest rates applied to the different sectors. The interest rate is sector-specific and based on macroeconomic indicators. In addition, credit can be constrained depending on the profitability of the investment and on bank's lending capacity.

Let $\nu$ be the risk free interest rate, which is the sum of the policy rate and the bank's Net Interest Margin (NIM). Given the annualised probability of default $PD_i$ of sector $i$, we seek to determine its objective loan interest rate $\hat{\kappa}_i$ granted by the bank.

We verify

$$\underbrace{\hat{\kappa}_i(t) - \nu(t)}_{\text{credit spread}} = PD_i(t) \times (1 - \mathcal{R}_i), \tag{17}$$

where $\mathcal{R}_i$ is the (constant) expected recovery rate[7] of $i$. The PDs themselves are computed following Alogoskoufis et al. (2021), that is $PD_i(t) = \beta_0 + \beta_1 * \Delta_{ROAi}(t) + \beta_2 * Lev_i(t) + \zeta_i$, where ROA stands for returns on assets, $Lev$ represents the leverage of sector $i$ and $\zeta_i$ is a sector specific constant.

Then, in order to determine the actual rate applied, we allow for bridging only part of the distance between the previous interest rate and the objective interest rate. That means, denoting as $\kappa_i(t)$ the realised interest rate at $t$ we have $\kappa_i(t) = \kappa_i(t-1) + \lambda \times (\hat{\kappa}_i(t) - \kappa_i(t-1))$, where $\lambda \in ]0, 1]$ is the interest adjustment speed.

Each indebted sector $i$ pays interests with rate $\kappa_i(t)$ at $t$ on its total loans $L_i(t-1)$ of the previous period. Thus, the total interests paid are:

$$\mathsf{ID}_i(t) = \kappa_i(t) \times L_i(t-1) \tag{18}$$

The interests paid on debt are subtracted from the operating earnings of $i$ and added to that of the banking sector. Similarly, the repayment of the debt is reduced:

$$\Delta^- L_i(t) = \chi_i \times L_i(t-1) \tag{19}$$

where $\chi_i$ is the (constant) repayment rate of $i$.

The central bank ($CB$) sets the risk free interest rate $\nu$ according to a Taylor-like rule (Taylor, 1993). The EIRIN's implementation of the Taylor rule differs from the traditional one because we do not define the potential output based on the Non-Accelerating Inflation Rate of Unemployment (NAIRU) (Ball and Mankiw, 2002). Indeed, NAIRU's theoretical underpinnings are rooted in general equilibrium theory, while EIRIN is not constrained to equilibrium solutions, focusing on the analysis of out of equilibrium dynamics. Thus, it would not be logically consistent to adopt a standard Taylor rule and NAIRU.

It is worth mentioning that, while the policy rate in EIRIN is set by the central bank following a Taylor rule, the speed and magnitude of policy rate adjustment can be tailored and calibrated to reproduce the characteristics of countries of interest.

The interest rate in EIRIN indirectly affects households' consumption via price increase, resulting from firms that adjust their prices based on the costs of credit.The policy interest rate depends on the inflation gap $\pi - \bar{\pi}$ and output gap (measured as unemployment gap $u - \bar{u}$, i.e. the distance to a target level of unemployment $\bar{u}$):

$$\nu(t) = \omega_\pi(\pi(t) - \bar{\pi}) - \omega_u(u(t) - \bar{u}) \tag{20}$$

where $\pi$ is the one-period inflation of the weighted basket of consumption goods and services (with a computation smoothed over a year, i.e. $m$ periods):

[7] See Hamilton and Cantor (2006) on the model itself, and Bruche and González-Aguado (2010) on the macroeconomic determinants of recovery rates.

$$\pi(t) = \frac{\mathbf{q}_{F_L}(t)}{\mathbf{q}_{F_K}(t) + \mathbf{q}_{F_L}(t)} \cdot \left(\frac{p_{F_L}(t)}{p_{F_L}(t-m)}\right)^{1/m} + \frac{\mathbf{q}_{F_K}(t)}{\mathbf{q}_{F_K}(t) + \mathbf{q}_{F_L}(t)} \cdot \left(\frac{p_{F_K}(t)}{p_{F_K}(t-m)}\right)^{1/m} - 1 \quad (21)$$

The inflation gap is computed as the distance of the actual inflation $\pi$ to the pre-defined target inflation rate $\bar{\pi}$. Moreover, the central bank can provide liquidity to banks in case of shortage of liquid assets.

The foreign sector ($RoW$) interacts with the domestic economy through tourism import, consumption good imports and exports, raw material supply, fossil fuels imports, and potential energy export to the domestic economy.

The foreign sector's exports to the domestic economy are provided in infinite supply and at a given price to meet the internal production needs. Tourists' inflows consist in the consumption of labour-intensive consumption goods. Raw material, consumption good and intermediate good exports are a calibrated share of the country's GDP and are sold at world prices.

The government ($G$) is in charge of implementing fiscal policy, via tax collection and public spending, including welfare expenditures, subsidies (e.g. for households' consumption of basic commodities), public service wages and consumption.

In order to cover its regular expenses, the government raises taxes and issues sovereign bonds, which are bought by the capitalist households, by the commercial bank and by the central bank. The government pays a coupon rate $c_G$ on its outstanding bonds $n_G$. Taxes are applied to labour income (wage), capital income (dividends and coupons), profits of firms, and GHG emissions. If the government's deposits are lower than a given positive threshold $\bar{M}$, i.e., $M_G < \bar{M}_G$, the government issues a new amount $\Delta\mathbf{n}_G = (\bar{M}_G - M_{Gov})/p_G^{\dagger}$ of bonds to cover the gap, where $p_G^{\dagger}$ is the endogenously determined government bond price. Government spending $C_G$ is a fixed percentage of revenues from taxes $R_G$.

For a detailed description of all sectors, market interactions and behavioural equations, refer to Gourdel et al. (2024) and Dunz, Hrast Essenfelder, et al. (2023).

## B Technical information on the website

Information on Plotly is accessible at `https://plotly.com/python/`. While the production of graphic elements for papers using EIRIN usually relies on Matplotlib and Seaborn, these two packages do not offer Javascript output and only render static charts. Thus, the use of Plotly is motivated by the will to have more of the interactions that are permitted by being embedded in a web page. The main alternative available in Python to produce interactive plots is Vega-Altair. It would also be usable within Quarto but is less popular than Plotly.

Information on GitHub Pages is available at `https://pages.github.com/`. Technical constraints apply to its use with a basic plan, such as total bandwidth used, and using an address that is a subdomain of GitHub.

The dashboard can be accessed at `https://regisg-eirin.hf.space`. Information on Shiny can be found at `https://shiny.posit.co/py/`. An alternative tested to achieve similar results is Tableau Public, which is also a cloud-based solution and can be similarly embedded in a webpage. Other Python packages that were tested as alternatives are Dash, which is a part of Plotly, and Shinylive, which allows part of the functions of Shiny while rendering the results in a static webpage and not requiring server-side calculations.

## C Theoretical exploration of a change in utility firms modelling

This section describe additional work that was carried in the search for improving the dynamics of the energy sector, and which constitutes an alternative that might be implemented in the model in the future. Currently, both utility firms are operating in the model, one green and one brown. Each firm has its separate balance-sheet and is bound to invest only in its corresponding type of capital.

The idea developed here is to merge the energy sector: with a single utility, the investment between fossil and renewable would follow the same principle as for the consumer goods sectors, i.e. comparing the rates of returns of the two options and shifting to the most profitable one. However, implementing an approach that simple might negate the differences between scenarios as the green capital would quickly become the most interesting (and in the baseline it already is), triggering a transition at the same rate in most scenarios.

### C.1 Modelling alternative

A nuanced modelling might require the introduction of a mechanism like decreasing marginal productivity from added capital. That is, instead of having a fixed productivity, there are positive increasing functions $\Gamma_G$ and $\Gamma_B$ such that the quantities produced by green and brown capital are given by $\Gamma_G(K_G)$ and $\Gamma_B(K_B)$ given capital stocks $K_G$ and $K_B$ respectively. Their first derivatives, denoted as $\gamma_G$ and $\gamma_B$, are both assumed positive and decreasing. The equilibrium defining the optimal mix of green and brown thus corresponds to the point where the return rates on new investments are the same for both. If we assume similar depreciation rates, it thus corresponds to equalizing the ratios of cash flows to capital prices.

Let us denote by $P$ the price of the output (the energy price in that case), and by $P_G, P_B$ the unit prices of both types of capital. Moreover, let $\mathrm{UE}_G, \mathrm{UE}_B$ denote the unit expenditure costs relative to the operation of each type of capital. In practice we have $\mathrm{UE}_G = 0$ as the renewable energy production does not require any other input, and $\mathrm{UE}_B > 0$ to represent the cost of fossil fuel purchased from the extracting sector and the carbon tax. For the applications below we will set

$$\mathrm{UE}_B = \chi_O \times P_O + \chi_{\mathrm{GHG}} \times \mathrm{CP},$$

where $\chi_O$ is the oil usage intensity, $P_O$ the price of oil, $\chi_{\mathrm{GHG}}$ the GHG emissions intensity, and CP the level of the carbon tax. Note that, so far, such costs could equivalently be defined as proportional to the total output, or proportional to the capital used in production. After merging the two previous utilities, these costs would instead necessarily be linked to the inputs of the sector.

The marginal cash flow of capital type $T$ is given by $\mathrm{CF} = \Gamma_T(K_T) \times (P - \mathrm{UE}_T)$. Thus, the optimal capital mix requires solving

$$\Gamma_G(K_G) \times \frac{P}{P_G} = \Gamma_B(K_B) \times \frac{P - \mathrm{UE}_B}{P_B} \, .$$

Let us consider a specification where $\Gamma_G(x) = \beta_G x^\alpha$, and $\Gamma_B(x) = \beta_B x^\alpha$, with $\beta_G, \beta_B > 0$ and $\alpha \in (0, 1)$. This is illustrated in 20, with the parameters specified in 1.

| Variable | Value |
|---|---|
| $\alpha$ | 0.8 |
| $\beta_G$ | 0.7 |
| $\beta_B$ | 1 |
| $P_G$ | 45 |
| $P_B$ | 30 |
| $\chi_O$ | 0.05 |
| $P_O$ | 1 |
| $\chi_{\mathrm{GHG}}$ | 0.05 |
| $\delta$ | 0.04 |
| $\mu$ | 0.25 |

**TABLE 1:** Calibration of variables and parameters

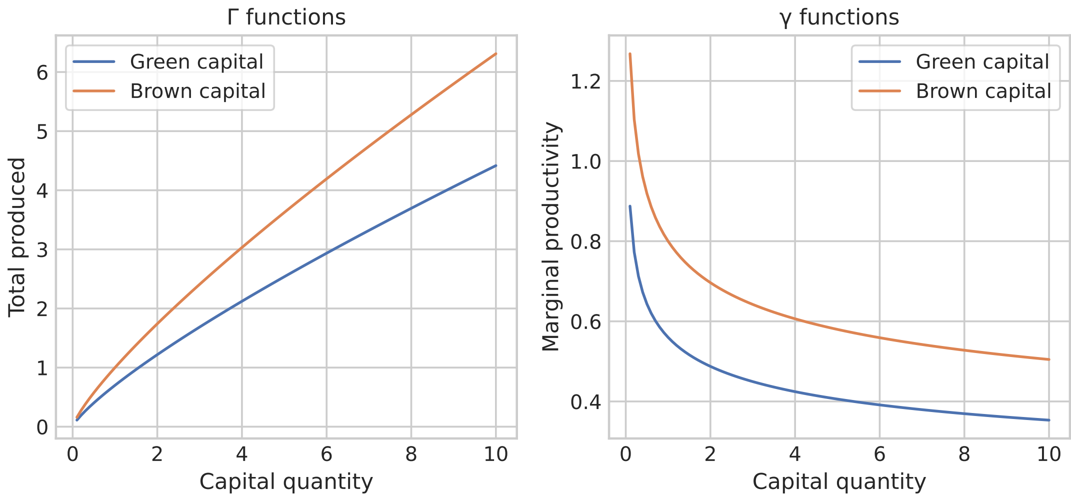


**FIGURE 20:** Illustration of functions corresponding to a decreasing marginal productivity of capital.

Then, we get the following optimal ratio of green to brown

$$\xi = \frac{K_G}{K_B} = \left(\frac{\beta_G}{\beta_B} \times \frac{P_B}{P_G} \times \frac{P}{P - \mathrm{UE}_B}\right)^{1/(1-\alpha)} . \tag{22}$$

It is a feature of the functions chosen that the ratio $\xi$ does not depend on the existing stock of capital or the production level when price $P$ is taken as fixed, but it is not true in general.

Given a production target $Q$, we also want to solve

$$\Gamma_G(K_G) + \Gamma_B(K_B) = Q,$$

in order to determine the amount of capital to buy. With the specification above, by plugging $K_G = \xi K_B$ into the second equation we get

$$K_B = \left(\frac{Q}{\beta_G \xi^\alpha + \beta_B}\right)^{1/\alpha} .$$

Note that this reasoning is used to determine the optimal composition of capital for a certain production level. However, when running the model, deviations from the optimal level can happen when too much capital of a certain type remains from the past. This is the case in particular when the changes in the carbon price is fast relative to the capital depreciation rate. In that case, the optimal allocation is not achieved: the firm will only buy green capital, and it does not seek to buy capital that would increase its production capacity beyond what is necessary.

### C.2 Calibration and comparison to the current code

Note that the existing production functions correspond to $\alpha = 1$, i.e. the case where the marginal productivity remains constant. Thus, $\beta_G$ and $\beta_B$ correspond to the parameters for capital productivity of the two utilities that are already in the model.

Parameter $\alpha$ is added, but in turn we would get rid of the parameter that governs the propensity of the green utility to invest to increase its market share. All other parameters introduced above already exist in the model. Moreover, the parameter that governs the maximum share of renewable that can be achieved would be removed. Therefore, the parameter space would be reduced by the change. Overall, the model would be further reduced in size from the merger of the two utilities, as they would now share a balance-sheet.

The calibration of variables $\alpha$, $\beta_G$ and $\beta_B$ cannot be done by direct reading from data, but they would depend on the matching of variables in the calibration period of the model, namely:

- the share of renewable being in line with the data given the baseline carbon price;
- the return rate of the utility being in a reasonable range in the baseline;
- the value added of the total energy sector being in line with the data.

### C.3 Dynamic analysis

The reasoning applied above, with equation (22) central in determining investment, is what can be applied in the model, where previous period prices $P$ can be used. However, for a long-run analysis of expected effects, we need to consider that $P$ is itself dependent on the cost. Let us assume that, even if we merge the two utilities, the pricing logic that applies is still to use the cost of the marginal producer. The green capital has no operating cost, and the only other expenditure taken into account in pricing energy is the cost of replacing depreciating capital (assuming a constant production level). In general we obtain

$$P = (1+\mu) \times \max\left\{\frac{\delta \times P_G}{\Gamma_G(K_G)}, \frac{\delta \times P_B}{\Gamma_B(K_B)} + \text{UE}_B\right\},$$

where $\mu$ is the markup and $\delta$ is the depreciation rate of capital. I do not consider here the fact that the pass-through of carbon taxes to consumers can be only partial, as this is equivalent to picking a lower value of $\chi_{\text{GHG}}$. Figure 21 shows the unit cost from the two types of capital as a function of its quantity. We can see that for values of the carbon price low enough, the marginal utility capital can change from being the brown one to the green.

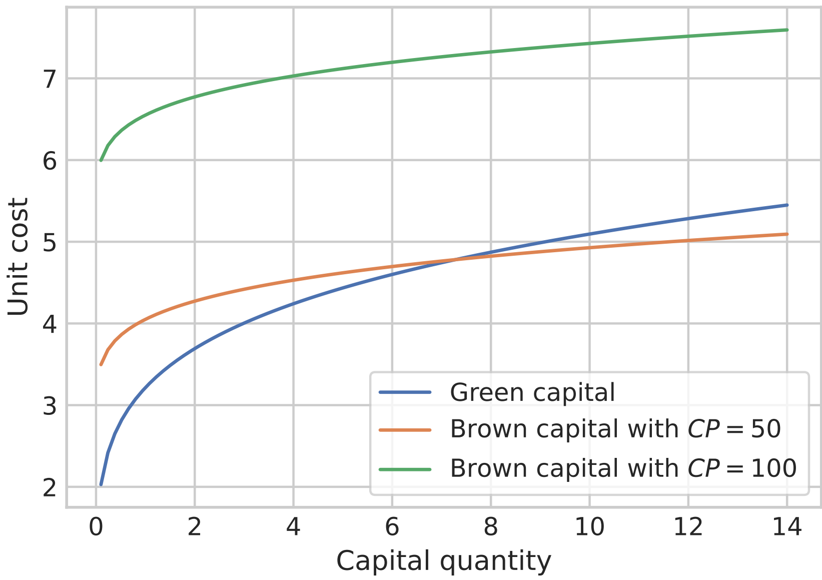


**Figure 21:** Illustration of the unit cost of the utility with different types of capital and different carbon price levels.

Given this additional constraint, we can solve the new system given variables $Q$ and CP and the parameters set above. A first example is provided in figure 22, where the quantity of each capital type is represented as a function of the production target $Q$. In figure 23, I represent the ratio of green capital in the capital mix, as a function of the carbon price. Moreover, figure 23 shows the dependence on the parameter $\alpha$, by displaying the green capital ratios for values other than the baseline parameter. We can see that a higher value of $\alpha$ leads to an earlier transition to green capital.

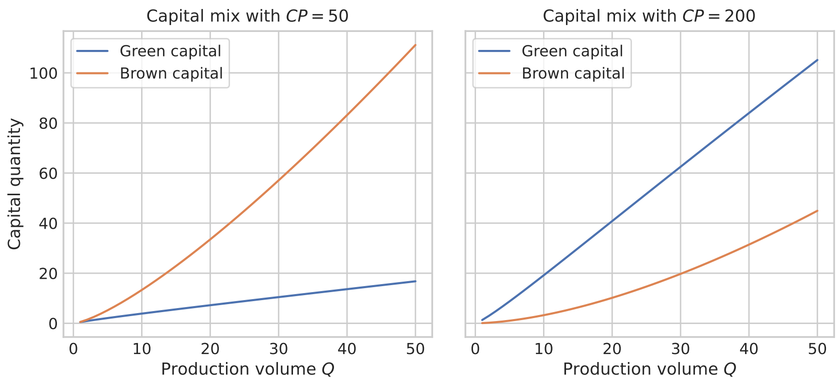


**Figure 22:** Capital mix by production level, given two carbon prices.

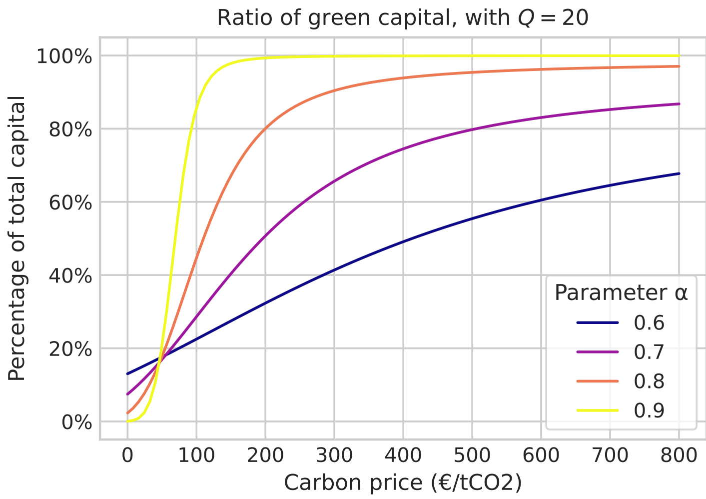


**Figure 23:** Ratio of green capital with a fixed production target, as a function of the carbon price.

# D Calibration of the carbon price

One part of the exercise that is not necessarily obvious is the choice of the tax base for the carbon tax. The level of the carbon tax crucially depends on where it is calibrated in the baseline. However, the baseline level is subject to some level of discretionary choices.

In principle, we want the taxes in the model to correspond to the real-life taxes that are susceptible to increase in line with scenario projections. A key difficulty is that European countries, and Italy in particular, do not have a unified carbon tax regime. Instead, the actual policy is composed of the Emission Trading Scheme (ETS) and a range of European- and national-level policies.

An upper bound of the carbon tax calibration value is provided by the total environmental taxes. Based on Eurostat data, these revenues amount to around 3% of GDP in Italy. These taxes contain taxes on energy, transport, and pollution. In particular, revenues from the ETS are a part of the energy category. Moreover, the carbon price provided by NGFS scenarios in 2020 (around 27€) corresponds to the observed price at ETS auctions, as shown in the top panel of figure 26. The subsequent increase in ETS auctioning prices corresponds to a level of transition policies that is close to the Net Zero scenario until 2022, with a stop in the trend bringing it closer to the NDCs scenario afterwards.

In the case of Italy in particular, emissions volume concerned by the ETS are represented in figure 24. It appears that the decrease in emissions was not fast enough relative to the decrease in allowances. Thus, based on current trends, Italy seems to become a net importer of emission permits.

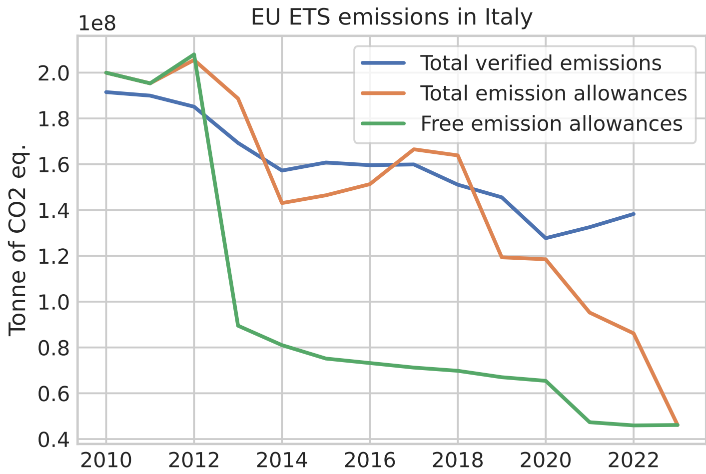


**FIGURE 24:** Carbon emissions for Italy in the ETS. Source: European Environment Agency.

However, the revenues from ETS auctions alone only amounted to 0.17% of GDP at most so far, as seen in figure 25. Note that the ETS covers only part of the economy and that part of the allowances are still given for free to companies. The EU plans to phase out the free allocation of allowances so that all will be attributed via auction in a few years. Therefore, this number is in turn too low to constitute an appropriate lower bound, as it does not include the national policies for non-ETS sectors and it corresponds to a case where the state would forego part of the revenues from the carbon tax.

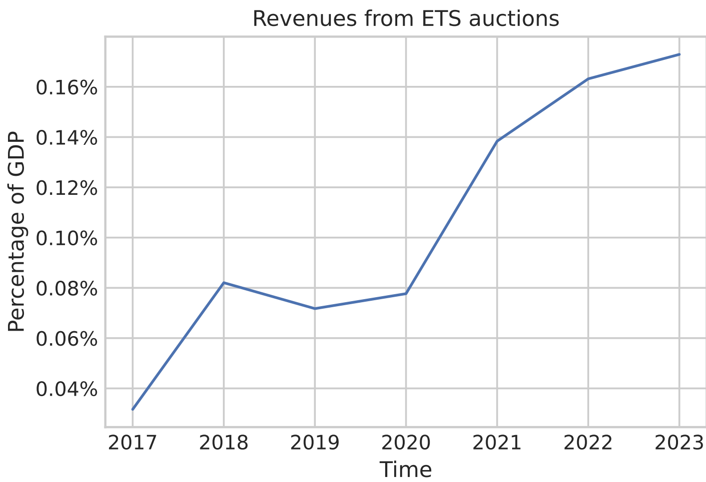


**FIGURE 25:** Revenues from ETS auctions for Italy as a share of GDP. Sources: EEX, Eurostat and author's calculations.

One middle-ground solution consists in considering what the revenues would be if the price from the ETS was to be applied equally to all GHG emissions in the country. The total revenues from such a tax are represented in the bottom panel of figure 26, distinguishing between the case where only corporate GHG emissions are taxed, and when the revenues also cover emissions by households. While the subsequent scenario divergence in prices makes the calibration complicated, one can rely on the short period where ETS prices and NGFS prices coincide, which is also where NGFS scenarios still have the same carbon price value. Then, based on figure 26, we calibrate emissions in the model such that the GHG tax revenues in the baseline amount to about 0.8% of GDP.

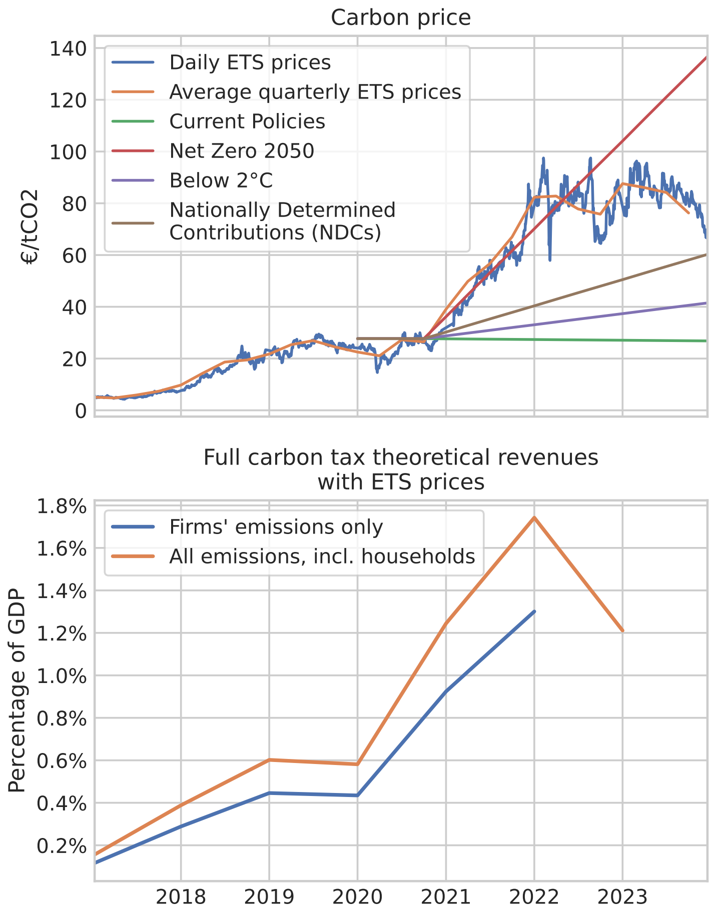


**Figure 26:** Revenues from a carbon tax if all carbon emissions from all sectors were taxed at the ETS price. Source: Eurostat, EEX, and author's calculations.