Introducing carbon tax in Italy: Is there room for a quadruple-dividend effect?

Tiziano Distefano[*] and *Simone D'Alessandro*[†]

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Abstract

This study aims to contribute to the literature on the environmental effectiveness and societal impacts of a carbon tax. As a case study, we select Italy where this policy is absent although often debated in the parliamentary arena. We run numerical simulations, based on an extension of the *EUROGREEN* macro-system dynamic model (D'Alessandro et al., 2020) to evaluate the possible threat and advantages of this policy tool from 2010 to 2050.

We follow a sequential scenario strategy: first, we build a baseline that includes the Italian Energetic Plan (PNIEC), then we introduce carbon tax which amount increases over time. On top of that, we test two hypotheses regarding possible adaptive behaviours by both consumers and producers. We investigate whether a "quadruple-dividend" effect can be achieved, by evaluating the long-term impacts on GDP and unemployment, public indebtedness, carbon emissions, and income inequality.

Scenario outcomes suggest that the carbon tax *i*) has mild effects in curbing carbon emission if compared with the PNIEC as the difference between the two scenarios is just about 2%, with respect to the 1990 level, in 2050, *ii*) generates revenues capable to contrast regressive effects, if redistributed to low-income households, with a reduction of about 2 Gini-points if compared with the PNIEC, and *iii*) attains a quadruple-dividend effect only if consumer and industries adapt to the policy. We argue that Italy could benefit from the introduction of a carbon tax. We also discuss the necessity to combine top-down policies with other public interventions to boost bottom-up adaptive strategies. This joint process could make environmental taxation more acceptable and facilitate a fairer sustainable energy transition.

[*]Corresponding Author. Department of Economics and Management, University of Florence. E-mail: tiziano.distefano@unipi.it.

[†]University of Pisa

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1 Introduction

The idea to implement a carbon tax (CT) to curb carbon emissions dates back to the seminal work of Pigou (1920) who firstly introduced the polluter-pay principle to account for the negative externality generated by greenhouse gas emissions. The idea is rather simple: imposing a tax for each ton of CO_2 emitted should push brown industries to invest in cleaner production processes, to keep competitiveness on, and then reducing the overall air pollution by internalizing (via price) the negative externality thereby generated. Recently the debate on environmental taxation is gaining momentum as a fundamental tool in the transition towards a low-carbon economy (Wesseh Jr and Lin, 2019) able to ensure high employment levels (Carraro and Siniscalco, 2013). Indeed, differently from the emission trading system, the carbon tax generates public revenues that can be redistributed to mitigate the possible negative socio-economic side-effects in terms of economic performances and income distribution.

Although its promises call for a wide application of the carbon tax, in a context of highly required environmental reforms to tackle climate change, the possibility to put this policy tool in practice is far from being easy and only few countries introduced it so far. Based on the last report of the World Bank (see Ramstein et al., 2019), in 2018 only less than 50 countries – responsible for $\sim$20% of global emissions – implemented a carbon tax or scheduled it for implementation, generating a tax revenue of about US$ 44 billion. However, the range of the tax greatly varies from a minimum of only 1 US$ per ton of CO_2 (Mexico, Ukraine, and Poland) to a maximum of 127 US$/t$CO_2$ (Sweden). In Italy a proper carbon tax has never been introduced although an environmental tax reform was implemented at the beginning of 1999. It was based on a re-modulation of excise duties on the transport sector and the introduction of a consumption tax on coal and natural bitumen (see Tiezzi, 2005, for a description).

A key concept to assess the impact of the environmental taxation is the so-called double-dividend hypothesis (see Freire-González, 2018, for a review) defined as the possibility that environmental taxes can both "reduce pollution (the first dividend) and reduce the overall economic costs associated with the tax system by using the revenue generated to displace other more distortionary taxes that slow economic growth at the same time (the second dividend)" (European Environmental Agency[1]). In recent years, the need to include also the social effects lead to the definition of the triple-dividend effect by considering improvements in terms of long-term employment and GDP growth, carbon emissions and public indebtedness (Pereira et al., 2016). In this vein, we further extend this list by including the distributional effect by looking at income inequality. Hence, we aim at analyzing the promises and threats of carbon tax in Italy to check under what conditions a *quadruple-dividend* effect can be reached.

[1] See https://www.eea.europa.eu/help/glossary/eea-glossary/double-dividend.

1.1 Literature Review

From a methodological viewpoint, the literature splits in two branches. On the one hand, mainstream economists aim to calculate analytically the 'optimal' carbon tax by using computable general equilibrium (CGE) models. Notably, Nordhaus (1993), developed a Dynamic Integrated Climate-Economy model (DICE) to calculate the optimal global carbon tax associated with lump-sum rebates. DICE-type and CGE models have further extended our understanding on how to incorporate climate damage functions (Diaz and Moore, 2017) also considering multiple interacting climate tipping points with irreversible economic damages (Cai et al., 2016). It appears that a conclusive answer to the optimal level of carbon tax has not yet been achieved since that the optimal carbon tax reported by the literature varies between a few tens and a few hundreds of dollars per ton of carbon (Tol, 2020). However, when inequality concerns are considered, following a 'climate and development' scheme as proposed by the Agenda 2030, then higher tax rates are considered more suitable to raise funding for redistribution and poverty alleviation (Clarke et al., 2009; Sörgel et al., 2021). In terms of economic performance, Chamhuri et al. (2009) showed that successively higher carbon tax rates can be paired with lower emissions without affecting GDP growth in Malaysia, while Khastar et al. (2020), applying a GTAP-E general equilibrium model, showed that carbon tax policies lead to adverse effects on GDP but industries in Finland end up with higher competitiveness. In terms of distributional effects, Oladosu and Rose (2007) suggested that a CT of 25 US\$/tCO_2 in the US is mildly progressive in income distribution, Allan et al. (2014) indicated that a CT of 50 £/tCO_2 secured a double dividend in Scotland, although Kirchner et al. (2019) showed that lump-sum payments are not the best way of balancing the trade-off between equity and efficiency in Austria. Zhang et al. (2017) considered two integrated policy mixes, wherein carbon tax revenue is recycled to reduce capital tax or support clean energy subsidy in order to ensure a double dividend from the CT in China.

On the other hand, scholars have applied the Input-Output (IO) approach to evaluate both the reduction of emissions and the degree of progressivity (if any) of environmental taxation. Tiezzi (2005) found no regressive effects from the simulation of a green taxation in Italy because it has been implemented only on the transport sector. Moreover, system dynamics modelling has been applied in India, where Gupta et al. (2019) showed that carbon tax can substantially contribute in cutting emissions from road passenger transport. On the contrary, Wier et al. (2005) – combining the IO with the household expenditure (i.e., national consumer survey statistics) – allowing for substitutional effects within the economic sectors, found that the carbon tax has regressive effects in Denmark. Other recent studies provided evidence of adverse distributional effects as a consequence of the CT (e.g., Mathur and Morris, 2014; Renner, 2018). However, Fremstad and Paul (2019) showed that if carbon tax revenues fund a carbon dividend then this policy might have progressive effects in the US. Recycling schemes to make carbon tax progressive vary and include, among others, lump-sum transfers, linear income tax reductions and equal per capita refund (Klenert and Mattauch, 2016).

Finally, with respect to the international trade, the idea of a unilateral carbon budget adjustment (CBA) was introduced to face politicians and industry representatives' alike fear that imports from countries without carbon regulations can gain cost-of-production advantages over domestic goods (Condon and Ignaciuk, 2013). The assessment of the effectiveness of export adjustments is not yet conclusive. A meta-analysis by Branger and Quirion (2014) found that CBA played an important role in reducing leakage while other studies found that most of the leakage reduction from CBA is due to only import adjustments (Böhringer et al., 2012). The literature review of Cosbey et al. (2020) showed that many of the most important welfare effects of CBA inherently depend on assumptions about specific design choices, which could influence conclusions about the costs and benefits of CBA.

As seen, a conclusive response about the effects of carbon tax has not yet reached as the emergence of contrasting results reveals. In part, this might be due to the contextual conditions that characterise each country; however, we identify as a major weakness, in the previous studies, the lack of recognition of the complex relations and dynamical feedback effects among the social, economic and environmental spheres. This calls for a wider approach able to take into account non-linear dynamics, uncertainty, agents' heterogeneity and the institutional context (see Hafner et al., 2020, for a review). We aim at filling this gap by extending the *EUROGREEN* model, developed by D'Alessandro et al. (2020), to question under what conditions a quadruple-dividend effect can be achieved. We therefore evaluate the long-term impacts of a carbon tax on: GDP and labour, public indebtedness, carbon emissions, and income inequality. In this regards, we build alternative scenarios to evaluate the impacts of carbon tax in Italy and we extend previous studies by defining a wide framework that includes the main socio-economic and environmental variables and their reciprocal linkages.

Our study acknowledges that carbon tax design plays a key role in affecting the distributional impacts, and that trade-offs between efficiency and equity always exist when designing carbon tax (Wang et al., 2016). However, the extent of these trade-offs and the possibility to achieve a quadruple-dividend effect largely depend on the pace of innovation for energy efficiency improvements and on the possibility of consumers to adapt by changing their consumption bundle.

2 Model

This study extends the *EUROGREEN* model (see D'Alessandro et al., 2020; Cieplinski et al., 2021, for a full description) that is grounded on Ecological Macroeconomics (Fontana and Sawyer, 2016) within a post-Keynesian framework (see Lavoie, 2014, for a detailed description). The present model is based on system dynamics and the core is represented by the application of the Input-Output (IO) approach that allows to combine monetary and energy units, as well as labour force. This approach is gaining momentum as a viable tool for modeling complex systems under energy constraints (Nieto et al., 2020).

Figure 1 shows the structure of the model in a nutshell by representing the main variables and linkages from which it is possible to simulate the dynamic and feedback loop effects. Note that, differently from the available and valuable literature that recently applied similar approaches to build scenarios on energy transition (e.g. Walsh et al., 2017; Capellán-Pérez et al., 2020), in our study the main socio-economic variables follow endogenous paths. Hence, we do not impose, for instance, any expected GDP growth or planned labour productivity improvements but they are outcomes rather than assumptions. The advantage is that we do not force the system to follow pre-determined paths that, by contrast, emerge from the inner dynamics of the model. However,

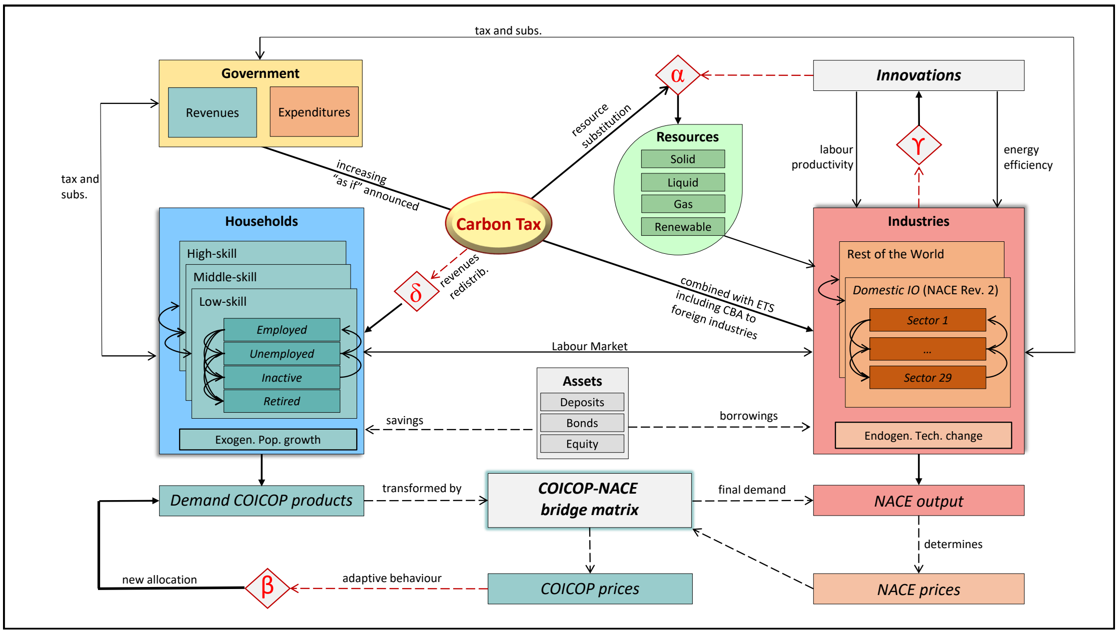

Figure 1: Macroview. It presents the main variables and connections of the current extended version of the *EUROGREEN* model (D'Alessandro et al., 2020). We distinguish between the COICOP (see Table A2.2) households' consumption categories and the NACE Rev. 2 (see Table A2.3) industrial classification for which we built a bridge matrix. Red rhombuses indicates the exogenous parameters (policy or behavioural hypothesis) applied to build each scenario: α is applied to replicate the PNIEC plan in the baseline scenario, in particular it changes the energy source combination to increase the use of renewable energy sources; β determines the elasticity of demand and changes the consumption bundle accordingly; γ affects the pace of innovations for energy-efficiency improvements, and δ redistributes carbon tax revenues according to specific income thresholds.

given the high degree of complexity and the large number of variables and parameters used, we had to consider some exogenous features, such as: *imports* are calculated by using constant import share coefficients (on the basis of historical real data); *exports* depend on a constant elasticity to domestic price variation and on exogenous industry-specific growth rate; the labour force dynamics is affected by an exogenous *skill-specific trend*, derived from the data, to take into account the developments in education; the workers are always employed under a *full-time* contract; and the *governments' expenditure* for final demand changes over time according to an exogenous data-driven trend.[2] In what follows, we only focus on main methodological novelties here introduced with respect to the *EUROGREEN* model.

i) **Energy system**: we collect data from Eurostat on the physical energy flow account (PEFA) that presents supply and use tables on the physical flows of energy (in TJ) and that distinguishes between natural renewable resources (supplied by the environment) and energy products supplied by the firms. Then, to obtain the total energy demand (E_i) by sector i we apply a coefficient of conversion (ζ_i, calibrated on real data) that returns the TJ required for each unit of economic output (x_i), namely

$$E_i(t) = x_i(t) \cdot \zeta_i. \tag{1}$$

Energy production requires three main fossil sources – i.e. solid, liquid, gas – each of which has a different impact in terms of CO_2 emissions. To avoid double counting issues, we consider, following PEFA's criteria, that electricity is not polluting because it is partially derived from fossil fuels whose emissions have already been accounted for. Then, we calculate (from real data) the amount of each energy source s from E_i, from a source-sector specific share θ_i^s (such that $\sum_s \theta_i^s = 1$), and then we apply a source-sector specific coefficient of conversion (ϕ_i^s) to obtain the source-sector specific carbon emissions Ω_i^s. Namely

$$E_i^s(t) = E_i(t) \cdot \theta_i^s(t), \tag{2}$$

$$\Omega_i^s(t) = E_i^s(t) \cdot \phi_i^s. \tag{3}$$

Note that θ_i^s varies over time because the shares of energy sources depend on investments for energy-efficiency improvements, on the activation of energy policies, and on carbon tax, as described in the next section.

ii) **COICOP-NACE bridge matrix**: in order to assess the impact of carbon tax at a lower scale (i.e., individual consumption) we combine data collected on the basis of different classifications (Cai and Rueda-Cantuche, 2019). This issue of data merging is of highly relevance in macroeconomic policy analysis models (Capros et al., 2013). In our case, this means that data coming from the Household Budget Survey (HSB) – which collect information about the purpose for which expenditures are made (i.e., COICOP classification) – must be organized according to the Statistical Classification of Products by Activity (CPA). Hence, a first conversion from

[2] The interested reader can find the complete description of the original model developed by D'Alessandro et al. (2020) in the Supplementary Information.

COICOP to CPA is required (Kronenberg, 2011). The COICOP-NACE bridge matrix ($\boldsymbol{B}^c$) is based on data elaborated from Eurostat (Cai and Vandyck, 2020; Cazcarro et al., 2022) and subsequently is balanced with respect to the IO structure using the RAS algorithm (see Distefano et al., 2020, for an explanation). See the Appendix A.1.1 for a step-by-step description and Tables A2.2 and A2.3, for the full list of COICOP and NACE's categories, respectively.

iii) **Demand elasticity.** The COICOP-NACE bridge matrix $\boldsymbol{B}^c$ assigns to each COICOP category the respective share of each NACE sector (Sommer and Kratena, 2017). By the same token, we can recover the inflation by COICOP products (π^c), once we have data for the inflation by NACE sectors (that are directly affected by the technological progress and policy interventions) by using the transpose of the bridge matrix, namely: $\boldsymbol{\pi}^c(t) = (\boldsymbol{B}^c)^T \boldsymbol{\pi}(t)$, where $\pi(t)$ is the vector of inflation, with respect to the previous year, by NACE sectors. We consider 12 groups (g) obtained by combining three skills – dependent on the level of education of individuals (low, middle, and high) – and four working status (employed, unemployed inactive, and retired). Moreover, we assume that each individual in each group acts as a representative agent and then the average propensity to consume is the same within each group. We assume variations of industrial prices level lead to responses in final demand by COICOP products via the coefficient β^c. More precisely, we assume that each individual belonging to a specific group (g) reacts only if the average inflation of a COICOP product c differs from the average inflation of her whole consumption bundle, namely

$$\Delta\pi_g^c = \pi^c - \pi_g = \pi^c - \sum_c \pi^c \cdot \beta_g^c, \tag{4}$$

where $\sum_c \beta_g^c = 1$. We consider the elasticity (ϵ^c) as the sensitivity to a price increase in c compared to price changes faced over all consumption commodities, then the vector of consumption shares varies over time as:

$$\beta_g^c(t) = [1 - \epsilon^c(t) \cdot \Delta\pi_g^c(t)] \cdot \beta_g^c(t-1), \tag{5}$$

with $0 \leq \epsilon^c \leq 1$ because we assume that the demand gradually reacts to the inflation.[3] This is justified by the fact that, although energy demand is rigid, it might become more elastic in the long-term when consumers can gradually adapt to the increase of prices related to carbon tax. The assumption over the dynamic of $\epsilon^c(t)$ will determine a specific scenario, as described below. For instance, if $\epsilon^c(t) = 0$ then the consumer is totally unresponsive to price changes and the consumption shares keep the same as the initial one, while if $\epsilon^c(t) = 1$ then she reacts proportionally to the difference in the inflation rates ($\Delta\pi_g^c$).

[3] Independently from the elasticity, it is possible to demonstrate that $\sum_c \beta_g^c(t) = 1$ for any period, by combining Eq. (5) with Eq. (4).

iv) **"Leontief-type" innovations.** Firms try to modify their intermediate demand, tracked by the input-output table, depending on price changes. In our framework this adjustment is mediated by changes in technical coefficients $a_{j,k}$ that return the share of input bought from sector j to produce a unit of output in sector k. Then, $\Delta a_{j,k}$ is considered as a proxy of technological change; if it increases (decreases) it means that k needs more (less) input from j per each unit of production. As explained in D'Alessandro et al. (2020), we consider an innovation process that is in part rooted on a stochastic process and in part is driven by firms' investments. In particular, we assume four possible cases: no innovations (T_1), new technology that is either relatively more labour- (T_2) or energy- (T_3) intensive, and an innovation that allows to save both labour and energy (T_4). Note that the probability of T_2 and T_3 depends on the firms choice regarding the direction and volumes of investments. So, if firms invest more on energy-efficiency improvements, than the probability of T_3 increases. However, the stochastic nature of the innovative process does not ensure that T_3-type innovations always emerge in case of more investments. Once the firms decide what type of technologies to adopt – on the basis of a cost-minimizing decision rule – then the shares of inputs ($a_{j,k}$) used to realise their product are modified according to the historical changes. The size of the jump is picked from a Gaussian distribution with mean and standard deviations obtained from past input-output tables (1996-2009) coming from the national accounts: namely, $\Delta a_{j,k} \overset{d}{\sim} N(\overline{a}_{j,k}, \sigma_{a_{j,k}})$.[4]

The introduction of carbon tax boosts firms to direct investments towards energy-saving innovations. We introduce a parameter (γ) as a proxy of the degree of adaptation. Similarly to the consumption module, we have that $0 \leq \gamma \leq 1$ because we assume that as the CT increases the intermediate cost of the energy-intensive inputs increases and then firms try to reduce energy use and/or to substitute brown with green energy through a change in the composition of inputs (i.e., the technical coefficients). Note that, if $\gamma = 0$ then the Leontief matrix can vary according to the historical trends, while when $\gamma > 0$ then the size of change when $T3$-type innovations are introduced is higher. We model this behaviour by assuming that, at the industry level, the average of the variation in the technical coefficients of the Leontief matrix is proportional to the historical standard deviation, namely

$$a_{j,k}(t) = a_{j,k}(t-1) + \Delta a_{j,k} \cdot (1 + \gamma(t) \cdot \sigma_{a_{j,k}}), \tag{6}$$

where γ varies over time as described in the next section. Note that, in case of $T3$-type innovations the sign of $\Delta a_{j,k}$ is negative when the sector j sells energy-intensive and/or brown products. This process might be the consequence of external effects or coordination practices among firms that may reinforce technology improvements.

[4] See the Supplementary Information in D'Alessandro et al. (2020) for a detailed description of the modelisation of the technological progress and the calibration of historical changes.

3 Scenario Setting

Given the complexity of the socio-economic system, we follow a "sequential scenario" strategy (Nieto et al., 2020) in the definition of the narratives in order to isolate the impacts of each different hypothesis and evaluate their cumulative effects. In other words, we assume that each new scenario includes all the hypotheses of the previous ones more a new single condition. This procedure ensures to better isolate the effect of a new single assumption, thus avoiding spurious interpretations. In particular, we define four scenarios:

1. **Baseline**: it represents the business-as-usual case, so it is based on the current economic structure. However, we include the main policies indicated in the Italian *PNIEC*, such as a partial exogenous yearly reduction of sectoral energy demand of 0.8% (see MiSE-MATTM-MIT, 2020, pag. 66) and an *electrification* process that aims at increasing the electric power generation with renewable resources as indicated in the PEFA Manual[5]. Simultaneously, this measure affects the energy-mix composition such that the share of each non-energy industries' investments in renewable energy generation. In this regard, we assume that, in each period, the source-sector specific share θ_i^s changes according to the exogenous coefficient α_i^s that imposes the phasing-out of solid and liquid fuels by 2025 and 2050, respectively. Namely

$$\theta_i^s(t) = \theta_i^s(t-1) \cdot \alpha_i^s(t),$$
$$s.t. \sum_s \theta_i^s(t) = 1.$$

2. **Carbon Tax** (CT_0): it starts from €30 per ton of CO_2 in 2020 and it increases yearly by about €5/tCO_2, until 2050 when it reaches the maximum of €188/tCO_2 in 2050, as described in D'Alessandro et al. (2020). Note that, we decide to design the carbon tax so that it reaches high levels because, on the base of the empirical evidence (Runst and Thonipara, 2020), it should result as an effective tool. We consider the impact of international trade, to address concerns about carbon leakage risks (EU-Commission, 2021), by imposing an equivalent CT on imported goods according to their incorporated carbon emissions (i.e., Carbon Border Adjustment, CBA). Note that, even under this assumption, both CT and CBA increase the production cost and the price of final output, thus contributing to reduce the competitiveness of exports.

   Moreover, we take data from the European Environmental Agency regarding allowances and emissions of the firms that participate to the European Emission Trading System (EU-ETS). In this regard, to avoid double counting, we subtract the amount of CO_2 emissions

[5] Note that "renewable energy forms are actually captured in two products: 'Electrical energy' (i.e. electricity, P26) and 'Derived heat' (P27)" (Eurostat, 2014, p. 44)

already regulated by the EU-ETS when calculating the CT. Hence, the total cost faced by polluting sectors is given by what they paid in the EU-ETS on net emissions – for simplicity and to avoid arbitrage we assume that the EU-ETS price aligns with the carbon tax – and the CT paid on emissions not regulated by the EU-ETS. Finally, we introduce a simple rule to redistribute the CT revenues in favour of low-income groups by considering the second gross income floor threshold τ_2 (of 15,000.00€) as defined in the Italian taxation system. Hence, each household belonging to a given group receives an average income of y_g plus a subsidy δ_g – otherwise, if $y_g > \tau_2$ then $\delta_g = 0$ – financed through the CT in order that the poorer will benefit more. Namely

$$\delta_g(t) = CT(t) \cdot \frac{\tau_2 - y_g(t-1)}{\sum_g(\tau_2 - y_g(t-1))}. \tag{7}$$

3. **Demand adaptation** (CT_β): it adds to CT_0 the possibility of consumers to adapt to price variations due to the introduction of the carbon tax, as described by Eq.(5). In particular, we assume that consumers gradually adapt to the CT and then that ϵ^c gradually goes from 0 (no reaction to price changes) to 1 (maximum adaptation) by following this simple rule:

$$\epsilon^c(t) = \frac{CT(t)}{max(CT)}. \tag{8}$$

   Note that when $t < 2020$, then $\epsilon^c(t) = 0$ because the CT was not implemented.

4. **Energy-efficiency improvements** ($CT_{\beta+\gamma}$): it adds on top of CT_β higher levels of investments for energy-efficiency improvements, as described above, to develop new technologies able to substitute the polluting ones that becomes less convenient when the CT is introduced. The size of the change in the technical coefficients, for any sector pair, is proportional to γ. It's weight heightens inasmuch CT increases, because we assume that firms, as the polluting inputs become costlier, try to reduce their use in the production process, namely

$$\gamma(t) = \frac{CT(t)}{max(CT)}, \tag{9}$$

   and when $t < 2020$, then $\gamma(t) = 0$ because the CT were not implemented. Note that in both cases, consumer and firms adapt gradually to carbon tax because the underlying assumption is that they behave "as if" the government announce the targeted CT over time and then this information is incorporated in agents' expectations.

Note that the last two scenarios aim at evaluating the effectiveness of the CT under the hypothesis that agents adapt to the policy. Then, the adaptive behaviour should be interpreted as an hypothetical case that underlines the importance to align top down policies with bottom up responses, avoiding negative social frictions to the acceptance of the environmental taxation.

We run the above-described scenarios from 2010 to 2050, in Italy. The empirical calibration of the parameters and initial values for the Italian economy, underpinned on official data, provide a consistent and coherent basis to understand the feasibility of carbon tax measure. To fix the unknown parameters of the model we have considered official data from 2010 to 2018 (when available) and implemented the optimization function provided by the software Vensim SDD[6] to calibrate the parameters in order to align with the real data collected for the main variables. Figures below report the real data (when available) together with the numerical simulations.

4 Results

For the sake of clarity, we present the scenario outcomes in three separate subsections given the large number of indicators considered. In particular, we show separately the consequences of a *CT* in terms of energy end environmental (4.1), socio-economic (4.2), and distributional (4.3) effects. In each case, the Baseline scenario (black line) is compared to the scenarios described in Section 3. Note that, carbon tax is simulated from the year 2020 (vertical dotted line in each Figure) onward, without considering the economic shutdown due to the current pandemic crisis whose modelisation would require an investigation that goes beyond the scope of the present study, but that we are considering for next researches. We plot the averages and the 95% confidence interval out of 1000 simulations in order to avoid arbitrary outcomes and to clean out stochastic effects associated to numerical simulations.[7]

4.1 Energy and environment

Figure 2 plots the patterns related to the main energy and environmental indicators considered in this study. We start with the CO_2 emissions because it is the key environmental indicator to assess the effectiveness of carbon tax. The *PNIEC* plan commits Italy to a reduction of -40% and -60% points in 2030 and 2050, respectively, compared with the level of emissions in 1990. Panel 2a shows that the *CT* slightly affects the path of CO_2 emissions if compared with the Baseline (black) in which carbon pollution reduces of about 52% points in 2050, equivalently to $\sim$ 1% yearly reduction from 2020. The CT_0 scenario (green line) determines only a moderate difference, of about 2% points on average, mostly because the tax revenues are redistributed to low-income groups thus determining a negative side-effect, from the environmental point of view, due to the increase in final consumption that translates in higher energy uses. Hence, in case of no adaptive behaviours, it appears that the higher consumption levels, led by *CT* subsidies,

[6]We run a multi-objective parameter optimization mode (which allows to automatize runs performed in simulation mode) as provided by the software Vendim SDD. Technical details can be found here: https://vensim.com/optimization/#model-calibration.

[7]Note that the results are robust to the number of simulations and they look similar even if we increases the trials.

offsets most of the benefits related to increases of renewable sources in the energy power system. However, when both consumers (red line) and firms (blue line) adapt to higher energy prices then the improvements are remarkable. Indeed, under the $CT_{\beta+\gamma}$ scenario the emissions are cut by 61.85% (± 3.75%) by the 2050, in line with what targeted by the *PNIEC*.

To explain these differences, we briefly comment here the changes in the energy system under each scenario, while in subsection 4.2 we discuss the economic outcomes. Panel 2b shows that part of the differences are determined by the higher percentage of clean electric power generation. The CT seems to have little effects, but if it is paired with a higher elasticity of substitution of private demand (green line) then the share of renewable in the electric power generation reaches about 80% in 2050, so doubling the value of 2020. The addition of high investments for energy efficiency improvements determine a further increase of ∼10% of renewable sources allowing to generate cleaner electricity. Note that an upward trend is observed even under the Baseline (black line) because we include the planned interventions of the *PNIEC* in the business-as-usual case, so affecting each scenario. Similar considerations come from the analysis of the energy intensity index (panel 2c) that is a proxy of the energy efficiency of the economy. Under the Baseline (black) and CT_0 (green) it slightly improves over the whole period, while remarkable differences are observed only under the other two cases. Again, the combination of adaptive households demand and innovations for energy-efficiency improvements allows for the saving energy (per unit of production), with an overall reduction of more than 30 points from 2020 to 2050. Finally, when looking at the variation in the distribution of private consumption bundle (panel 2d),we observe that the impact on the demand of energy products is less heavy if firms are consistently involved in Leontief-type innovations. In other words, a higher reaction of private investments to the CT determines lower energy price variations allowing the consumers to keep higher levels of energy use – although cleaner (see also Figure A3.2 in Appendix A.3).

4.2 Economic and fiscal performances

From the economic side, the main indicator usually considered is the real GDP and most of the institutions and governments are interested in the aftermaths of an imposition of a tax on national production and consumption. Panel 3a shows an increasing trend of the real GDP under each scenario, but with higher rates in case of adaptive behaviours. Under the CT_0 scenario the adverse economic effects due to carbon tax are compensated by the redistribution of the tax revenues to the poorer which boost consumption (and emissions). On the contrary, the scenarios CT_β (red) and $CT_{\beta+\gamma}$ (blue) follow steeper ascending trajectories although higher GDP does not translate in higher emissions, thus ensuring a relatively decoupling effect.

Panel 3c plots the pathways of total real exports in each scenario. The outcomes suggest that the carbon tax plus the CBA negatively affects the international competitiveness of Italy because it increases the input costs (both domestic and imported). However, if agents adapt, the competitiveness can be recovered as shown by the higher level of real exports in the long run under CT_β and $CT_{\beta+\gamma}$ scenarios. This might be explained by looking at the output-to-GDP ratio (Panel 3c) which is a proxy economic efficiency: indeed, given the same level of material output if the ratio decreases it means that the economic systems is able to get higher valued added with the same level of production, and vice versa. It appears that the CT_0 case would worsen the competitiveness, while if consumers and firms adapt, then the ratio stays at a considerable lower level with respect to the other cases.

To conclude this subsection, we evaluate the yearly public deficit-to-GDP ratio as a proxy of the fiscal sustainability of carbon tax. Panel 3d shows an U-shaped trajectory under the Baseline and CT_0 cases departing from about 2.5% in 2020, reaching a minimum in the 2030s of about 0.5% and then it rises again until 2050 going back to the initial percentage. In any case, it stands within the yearly rate of about 3% in 2050 that represents the roof of the current EU Excessive Deficit Procedure. Even better is the fiscal performance when economic agents are adaptive: in both cases, mostly under the $CT_{\beta+\gamma}$ scenario (blue line), it appears that the public deficit-to-GDP ratio stabilises below 1%, in the long-run, thanks to a higher economic growth.

4.3 Labour and inequality

The imposition of carbon tax brings concern on the distributional effects – other than the environmental and economic ones seen above – that belongs to the debate about the degree of progressivity of the CT. So, to complete our analysis, we calculate the Gini index as a measure of income inequality.[8]

Under the Baseline, the Gini index follows an ascending trajectory (Panel 4a), passing from about 35% in 2010 to more than 37% in 2050, meaning that the Italian PNIEC plan seems to generate slightly regressive distributive effects. However, the picture changes when carbon tax is introduced and the corresponding carbon tax revenues are redistributed to lower-income groups (following the rule applied by Eq. (7)). Indeed, the dynamics of income inequality departs from the Baseline and decreases of about 2 Gini points if compared with the PNIEC. The assumption related to behavioural changes (i.e., β and γ) does not alter the pattern in a significant way. The key message is that there is room to use the CT revenues to directly tackle inequality without affecting the environmental performance; rather, even better results are obtained if an even redistribution is coupled with pro-environmental behavioural changes.

Panel 4c reports the number of employed workers to complement the above results. It appears that in the Baseline scenario the employment increases less, from about 21 millions people in the 2020s to around 25.5 millions at the end of the period. Panel 4d shows the projections with respect to the unemployment rate that follows cyclical patterns in all scenarios in the range

[8] In our case it is calculated on the basis of 13 heterogeneous population groups defined by the three skills and four occupational statuses of the households, plus the capitalists. See D'Alessandro et al. (2020) for a detailed description.

between 7% and 10%. The main difference is given by the amplitudes of the cycles that are ampler when carbon tax is implemented. However, the presence of faster innovations for energy-efficiency improvements allows a reduction of unemployment at the end of the simulation period (∼8% in 2050). This difference is also explained by panel 4b that reports a slower increase of the labour productivity under $CT_{\beta+\gamma}$ case with respect to the other scenarios. This is confirmed by previous empirical studies that showed the positive job creation effects of environmentally-friendly technological change (Gagliardi et al., 2016) and so, in our case, they result in a win-win solution able to curb emissions while keeping higher levels of GDP and employment.

5 Discussion

5.1 Limitations

This study tried to provide a wide framework to evaluate the direct and the side-effects of carbon tax, in Italy, under both a socio-economic and energy-environmental viewpoints. To this scope, we developed a comprehensive model in which several dynamic relations and feedback loop effects have been included. However, a higher complexity of the model goes hand in hand with higher computational costs and data requirements. This represents the first possible limitations of the current study. Although the data were taken from highly reliable institutions such as the Eurostat, ISTAT and the International Energy Agency, we had to merge all this information coherently with the model requirements. The main example is the construction of the bridge matrix that connects private household consumption to the Input-Output sectors that required the translation of three different product categorisation (i.e., COICOP, CPA, and NACE Rev. 2). All in all, despite the unavailable uncertainties present in the data, the final database resulted quite accurate, reliable, and consistent with official values.

A second issue may arise from the decision to run a country-specific study that forced us to over-simplify the impact of the international trade; for instance, we did not distinguished by the country of origin for imported goods. In the case of Italy this might be relevant since it is highly dependent on imports of energy from few key countries, like France and Russia. Hence, a deeper description of the international trade would have allowed for the definition of fine-tuned burden carbon tax rates. We decided, following most of the available literature, to focus on a specific country also to highlight the role of country-specific contingencies in policy evaluations. Third, given the different level of aggregation between the PNIEC plan and the current model, we cannot distinguish between the multiple renewable energy technologies (RET) considered in the Italian plan to obtain efficiency gains, hence we apply an exogenous coefficient "as if" they were implemented at the firm level. Moreover, we did not include any barriers to the use and application of RET concerning variability management measures or lack of primary materials (and related geopolitical aspects) to build the infrastructures (solar power plant, geothermal heat pumps, etc) required to produce renewable energy (see Scholten et al., 2020, for a discussion). Finally, we did not consider the overarching negative impacts of the current pandemic and Russo-Ukraine war because the modelisation of the short- and long-term consequences would require a separate study that goes beyond the purpose of the current analysis. All things considered, the lack of available data and the excessive increase in the complexity of the model (and in the number of equations) would have make this kind of analysis difficult to implement.

5.2 Summary and policy conclusion

This study proposed a dynamic macro-simulation model to evaluate the socio-economic and environmental-energy aftermaths of carbon tax, in Italy. To provide a wide perspective we ran four alternative scenarios – from 2010 to 2050 – characterised by different degrees of systemic responses, in terms of consumers adaptive behaviour and firms propensity to invest in energy efficient technologies. The main methodological contributions with respect to the available literature were threefold: firstly, we show the outcomes by considering several socio-economic and environmental-energy indicators to provide a holistic framework to ground a wiser policy evaluation. Secondly, we included simple *adaptive behaviours* by the economic agents (consumers and firms) in response to carbon tax. This decision entails the possibility to overcome a rigid framework and to evaluate how endogenous structural changes modify the impacts of the CT. To this purpose, instead of dealing with an analytical approach, we opted for numerical simulations that are able to simulate the possible outcomes when dealing with complex systems in which a large number of variables and parameters vary simultaneously. Thirdly, the *sequential scenario* strategy yields both short- and long-run results and makes it possible to compare what would happen if a new condition (e.g., variable, policy, parameter, and so on) is introduced. So, our flexible framework – grounded on the $EUROGREEN$ model (D'Alessandro et al., 2020) – is generalisable and it contemplates the possibility to add other policies (social and/or environmental) thus allowing the definition of fine-tuned policy-packages calibrated on the base of contingent conditions.

Our main results suggested that carbon tax can be used to reduce income inequality if redistributed to low-income groups. In this case, the increase in final demand makes the CT less effective in curbing carbon emissions if compared with the PNIEC plan, resulting in a reduction of -54.2% (±3.45%) and -52.1% (±4.04%), respectively, in 2050 with respect to the 1990 levels. However, if consumers and firms follow adaptive behaviours a 'quadruple-dividend' effect is observed: remarkable emission reductions of -61.85% (±3.75%) are associated to better economic performance – in 30 years the real GDP level and the number of employee increased of +42.39% (±2.67%) and +21.30% (±2.97%), respectively – lower income inequality (-$\sim$ 2 Gini points), and sustainable public indebtedness – with a deficit to GDP ratio of about 0.6% in

2050.[9]

In this vein, we want to conclude by discussing a possible way to increase the the political acceptance of carbon tax policy (Wissema and Dellink, 2007). If one looks at real-case examples, it emerges that in many occasions carbon tax provoked protests as those exemplified by the "Yellow Vest" movement in France. However, a deeper look show us that one of the main reason behind this negative reaction has to be found in the distributional concerns as exemplified by the statement of a movement organizer who declared: "We're not anti-environmental [...]. This is a movement against abusive taxation period." What can be done to alleviate the social unrest? It appears that the criteria followed by a government to allocate the carbon tax revenues is crucial for the public's acceptance (Steenkamp, 2021). Our results indicate that the carbon tax revenues can effectively be recycled, with a very simple scheme, in favour of low-income households to sustain the satisfaction of basic needs, including the energetic ones (e.g., heating, cooking, transport). This shows that environmental taxes does not necessarily entail regressive effects. In line with most recent results from the literature (e.g., Vieira et al., 2021), we argue that additional policies are necessary to achieve the 2050 net-zero target because of socioeconomic frictions, which have been often overlooked. Hence, a progressive carbon tax scheme should be integrated with other interventions to boost adaptive behaviours (e.g., reallocating the consumption bundle and/or finding out-of-market solutions to compensate for the increase of energy prices). These interventions might include, but are not limited to: i) education to promote sustainable practices (Suárez-Perales et al., 2021), ii) green eco-label standards to inform pro-environmental consumer behaviour (Taufique et al., 2016), iii) energy use caps to limit the total amount of energy (Kiss, 2018), and iv) a "Kurzarbeit" strategy to ensure a shorter workweek with no shortfall in salaries and then more free time paired with an income safety net (see Ashford et al., 2020). All in all, we argue that Italy could benefit from a 'quadruple-dividend effect' from the introduction of a progressive carbon tax only if this top-down policy tool is paired with efforts in favour of bottom-up adaptive strategies to make it more acceptable and able to attain a fairer sustainable energy transition.

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A Appendix

A.1 Data and definitions

The data sources employed to calibrate the model, from 2010 to 2018, are summarized below.

- *Social and National Accounts*:[10] the Italian Institute of Statistics (ISTAT) provides data about the inter-industry intermediate and international trade, including information about the final demand, taxation, and value added (wages and profits). The data are consistent with the NACE (Rev. 2) classification.[11] The ISTAT also provides data on the household budget survey (HBS) that focuses on consumption expenditure behaviours of households residing in Italy (see https://www.istat.it/en/archivio/180353). In agreement with Eurostat, the survey is based on the harmonized international classification of expenditure voices (Classification of Individual Consumption by Purpose – COICOP) to ensure international comparability.

- *Energy Accounts*: the energy data come from two datasets. The ISTAT-PEFA reports the matrices of supply and demand of energy fluxes (in terajoules) by source for each (NACE) industry and for households, for the years 2014 and 2015. In particular, the demand for energy is split into two parts, a matrix (B) which supplies total use – including final use, losses, non-energy use, and for transformation – of energy, and a matrix (C) which reports the share of polluting energy that generates CO_2 emissions. We integrate these data with those from the International Energy Agency (IEA) and EUROSTAT's energy balance to obtain final energy use and the actual amount of CO_2 emissions by source and industry, including the residential sector, from the Air Emission Account (AEA).[12]

- *Labour market data*: productivity, skill-specific wages and employment by industry, fixed capital stock and capital productivity and hours worked are obtained from the EU-KLEMS project database for Italy.[13]

- *Government Balance*[14]: ISTAT collects detailed information on public expenditure, debt and revenues from taxation. See Table A2.1 for the list of revenues and expenditures.

[10] The Italian Input-output tables can be found here: https://www4.istat.it/it/archivio/210298.

[11] The detailed classification is available on https://rb.gy/l6ouec.

[12] A detailed description of the energy balance is found https://ec.europa.eu/eurostat/web/energy/data/energy-balanceshere while data on greenhouse gas emissions are available https://ec.europa.eu/eurostat/web/environment/emissions-of-greenhouse-gases-and-air-pollutants/air-emissions-accounts.

[13] The data are available http://www.euklems.net/index_analytical.shtml.

[14] Available https://www.istat.it/it/archivio/finanza+pubblica.

A.1.1 COICOP-NACE Bridge matrix

We decided to implement the RAS algorithm to overcome the inconsistencies when passing from CPA to NACE, since it has been proved to be efficient and highly reliable when a matrix must be balanced to respect given constraints (see Distefano et al., 2020, for an explanation). Indeed, the RAS algorithm is a simple iterative process of bi-proportional adjustment that rescales the initial matrix in order to respect the total values by columns and rows (of our IO matrix) until it converges toward a unique non-negative matrix.

The step-by-step procedure can be summarised as follows:

i download the matrix **A0** of final demand composition in CPA-COICOP terms from (Cai and Vandyck, 2020; Cazcarro et al., 2020);

ii create the vector r of total household demand from Eurostat IO data. Note that r will represent the row-constraint of RAS, i.e. the row sum of the new matrix after-RAS must equal r;

iii compute the vector $\overline{s}$ as the column sum of $\mathbf{A}_0$;

iv calculate the scalar coefficient $\eta = \frac{\sum_i r_i}{\sum_i \overline{s}_i}$ to clean out any inconsistency between the total consumption in COICOP and NACE categories. This step is necessary because RAS requires that total by row equals total by column;

v calculate the RAS column-constrains $s = \eta \cdot \overline{s}$;

vi run the RAS algorithm departing from $\mathbf{A}_0$, given row (r) and column (s) constraints to obtain the new bridge matrix: $A = rA_0s$;

vii normalize the matrix $\mathbf{A}$ with respect to the NACE classification in order to obtain the unitary conversion factor from COICOP to NACE, i.e. the matrix $\mathbf{B}^c = \mathbf{A} \cdot \hat{s}^{-1}$, where the hat stands for diagonal matrix. Hence, knowing the total households demand for a given COICOP product (f^c) we can construct the vector of NACE final demand (f) associated to every industry as $f_i = b_i^c \cdot f^c$, where $\sum_i b_i^c = 1$.

A.2 Tables

Table A2.1: Government balance: revenue and expenditure sources.

Expenditures	**Revenues**
Government consumption	Value added tax
Wages	Labour taxes
Investment	Corporate income tax
Interest on public debt	Progressive income tax
Pensions	Aggregate social contribution
Unemployment benefits	Tax on financial income and wealth
Sickness, disability and family benefits	Carbon tax

See the Supplementary Information of D'Alessandro et al. (2020) for more details.

Table A2.2: Official classification of Individual consumption expenditure of households by purpose (COICOP). Note that here we keep a higher breakdown with respect to the original COICOP 01-12 classification in order to obtain 18 categories as indicated by the codes reported in the second column.

Numb.	**COICOP code**	**Description**
1	*CP01*	*Food and non-alcoholic beverages*
2	*CP02*	*Alcoholic beverages and tobacco*
3	*CP03*	*Clothing and footwear*
4	*CP04.1*	*Actual rentals for housing*
5	*CP04.3 +* *CP04.4*	*Regular maintenance, repair and* *other services of the dwelling*
6	*CP04.5*	*Electricity, gas and other fuels*
7	*CP05*	*Furnishings, household equipment* *and routine maintenance of the house*
8	*CP06*	*Health*
9	*CP07.1 +* *CP07.2*	*Purchase of vehicles +* *Operation of personal transport equipment*
10	*CP07.3*	*Transport services*
11	*CP08*	*Communications*
12	*CP09*	*Recreation and culture*
13	*CP10*	*Education*
14	*CP11*	*Restaurants and hotels*
15	*CP12.1 +* *CP12.3*	*Personal care*
16	*CP12.4*	*Social protection +*
17	*CP12.5 +* *CP12.6*	*Insurance +* *Financial services n.e.c.*
18	*CP12.7*	*Other services n.e.c.*

See https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Classification_of_individual_consumption_by_purpose_(COICOP) for a detailed description of the COICOP classification.

Table A2.3: Official classification sectoral activities (NACE Rev. 2). Note that here we make an aggregation in order to obtain 29 sectors as indicated by the codes reported in the second column.

Numb.	**NACE Rev. 2 code**	**Description**
1	*A)*	*Agriculture, Forestry and Fishing*
2	*B)*	*Mining and quarrying*
3	*C)*	*Manufacturing*
4	*C19)*	*Manufacture of coke and refined petroleum products*
5	*C33)*	*Repair and installation of machinery and equipment*
6	*D35.1)*	*Electric power generation, transmission and distribution*
7	*D35.2) + D35.3*	*Manufacture of gas; distribution of gaseous fuels through mains + Steam and air conditioning supply*
8	*E)*	*Water supply; sewerage, waste management and remediation activities*
9	*F)*	*Construction*
10	*G)*	*Wholesale and retail trade*
11	*G45.2+G45.4)*	*Sale, maintenance and repair of motor vehicles and motorcycles and related parts and accessories*
12	*H49)*	*Land transport and transport via pipelines*
13	*H50)*	*Water transport*
14	*H51)*	*Air transport*
15	*H52)*	*Warehousing and support activities for transportation*
16	*H53)*	*Postal and courier activities*
17	*I)*	*Accommodation and food service activities*
18	*J)*	*Information and communication*
19	*K)*	*Financial and insurance services*
20	*L)*	*Real estate activities*
21	*M)*	*Professional, scientific and technical activities*
22	*M72)*	*Scientific research and development*
23	*N)*	*Administrative and support service activities*
24	*O)*	*Public Administration and Defence*
25	*P)*	*Education*
26	*Q)*	*Human health and social work activities*
27	*R)*	*Arts,entertainment and recreation*
28	*S)*	*Other services activities*
29	*S95)*	*Repair of computers and personal and household goods*

See the RAMON - Reference And Management Of Nomenclatures, from Eurostat, for a detailed description of the NACE Rev. 2 classification.

A.3 Disaggregated results

In order to provide a more detailed explanation, we also report the change in the number of employees by skill in the two key macro-sectors that are directly affected by the CT, i.e. the *Energy* and the *Transport* sectors.[15] As expected, the *Energy* sector (top panels of Figure A3.1) is slightly negatively affected by the introduction of carbon tax. The impact is greater inasmuch consumers and firms adapt to the policy. From the demand-side if consumers have the possibility to reallocate their consumption bundle, then they reduce the use of energy-intensive commodities that are becoming more costly. From the supply-side, if firms innovate towards more energy efficient technologies then they reduce the energy use per unit of input. The combination of these two effects generates an overall contraction in energy production that reflects in lower employment. Notably, the most affected category are the low skilled workers (light red areas). By contrast, the *Transport* sector followed an opposite trend, with an increasing number of workers in each scenario. This can be partly explained by the level of aggregation of our model: changes in intermediate-inputs and energy-saving technologies required does not alter the level of transportation inasmuch as if alternative means of transports (e.g., electric cars and public transports) were included. Again, the last scenario ($CT_{\beta+\gamma}$) results in a lower increase, for similar reason as those explained above. However, in this case the middle class seems more negatively affected.

We also analyse the effect of carbon tax on private energy consumption: this is possible by taking advantage of our novel approach underpinned on the COICOP-NACE bridge matrix (as explained in Section 2). Figure A3.2 compares the share of private consumption in energy products (COICOP classification) across groups (g). In line with the available literature (Huang et al., 2020; Okonkwo, 2021), they emerge three interesting facts: i) lower skill levels and worse occupational status determine higher shares of energy consumption, ii) when the economy is flexible and the agents adapt to accommodate to the CT the expenditure in energy products falls, and iii) higher levels of innovations entails higher total energy production. Point *a1)* is mostly due to the fact that poorer people must allocate a higher percentage of their income to the energy consumption that is a necessary commodity. It suggests that, if the economy is rigid, the CT might have a regressive effect in terms of consumption instead of income because it generates higher real energy costs. Point *a2)* relates to the households' possibility to reshape their consumption bundle to face the increase in energy prices. In the long-run the share drastically decrease reaching similar percentages (∼3-4%) in every group. This means that a responsive behaviour of household and firms might narrow the inequalities on the consumption side, mostly when necessary goods are considered. A similar pattern is observed when we introduce the assumption of a faster technological progress (γ). However, in this case the level of energy

[15] *Energy* includes the NACE sectors B, C19, D35 and E, while *Transport* is composed by air, land, transport sectors (from H49 to H53). See Table A2.3 in the Appendix for a description.

consumption lies at a slightly higher shares. This outcome seems in line with the literature on the “energy rebound effect” related to technological progress (Zhang et al., 2017): innovations for energy efficiency improvements lead to a decline in the real cost of energy and, at the same time, boosts economic growth; then, the combination of these two drivers might lead to and increase of total energy demand and consumption.

Figures/Fig_CO2red_std3-eps-converted-to.pdf

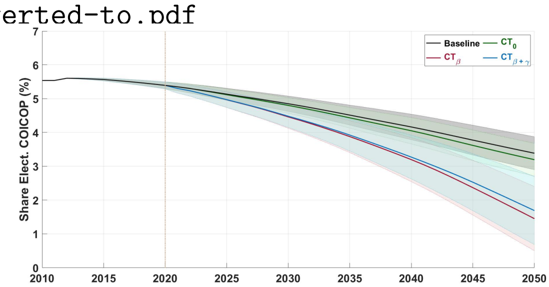
(a) Carbon emissions

Figures/Fig_Renew_share_Electricity_std-eps-conv

(b) Clean electricity

Figures/Fig_En_Intens_std-eps-converted-to.pdf

(c) TPES-to-GDP ratio



(d) Households' energy consumption

Figure 2: Scenario analysis: environmental-energy indicators. Comparison of real data (violet) with the numerical outcomes – from 2010 to 2050 – under the Baseline (black) and the other three scenarios: CT_0 (green), CT_β (red), and $CT_{\beta+\gamma}$ (blue). The following indicators are considered: (a) CO_2 emissions normalized with respect to 1990, (b) percentage of renewable energy sources in the electricity power generation, (c) energy intensity ratio as TPES/GDP normalized with respect to 2015, and (d) share of household's energy consumption. The vertical dotted line indicates the year 2020 when the policies are introduced. The solid lines and shaded areas around them indicate the averages and 95% confidence intervals, respectively, out of 1000 independent simulations.

Figures/Fig_GDP_std3-eps-converted-to.pdf

(a) Economic growth

Figures/Fig_expreal100_std3-eps-converted-to.pdf

(b) Total exports

Figures/Fig_outgdp_std3-eps-converted-to.pdf

(c) Economic efficiency

Figures/Fig_DefGDP_std-eps-converted-to.pdf

(d) Public deficit-to-GDP rate

Figure 3: Scenario analysis: economic and fiscal indicators. Comparison of real data (violet) with the numerical outcomes – from 2010 to 2050 – under the Baseline (black) and the other three scenarios: CT_0 (green), CT_β (red), and $CT_{\beta+\gamma}$ (blue). The following indicators are considered: (a) yearly real GDP, (b) total real exports, (c) real output-to-GDP ratio, and (d) yearly public deficit-to-GDP ratio. The vertical dotted line indicates the year 2020 when the policies are introduced. The solid lines and shaded areas around them indicate the averages and 95% confidence intervals, respectively, out of 500 independent simulations.

Figures/Fig_Gini_std3-eps-converted-to.pdf

(a) Gini Index

Figures/Fig_lambda_std-eps-converted-to.pdf

(b) Labour productivity

Figures/Fig_Empl_std3-eps-converted-to.pdf

(c) Occupation

Figures/Fig_Urate_std3-eps-converted-to.pdf

(d) Unemployment rate

Figure 4: Scenario analysis: Inequality and labour market. Comparison – from 2010 to 2050 – of the numerical outcomes under the Baseline (black) and the other three scenarios: CT_0 (green), CT_β (red), and $CT_{\beta+\gamma}$ (blue). The following indicators are considered: (a) Gini index, (b) labour productivity index, (c) number of employees (in millions), and (d) unemployment rate. The Gini index (top panel 4a) measures the degree of inequality in the income distribution, from a minimum value of 0% (no inequality) to 100% (maximum inequality). Panel (4c) shows the number of employed workers (in millions). The vertical dotted line indicates the year 2020 when the policies are introduced. The solid lines and shaded areas around them indicate the averages and 95% confidence intervals, respectively, out of 500 independent simulations.

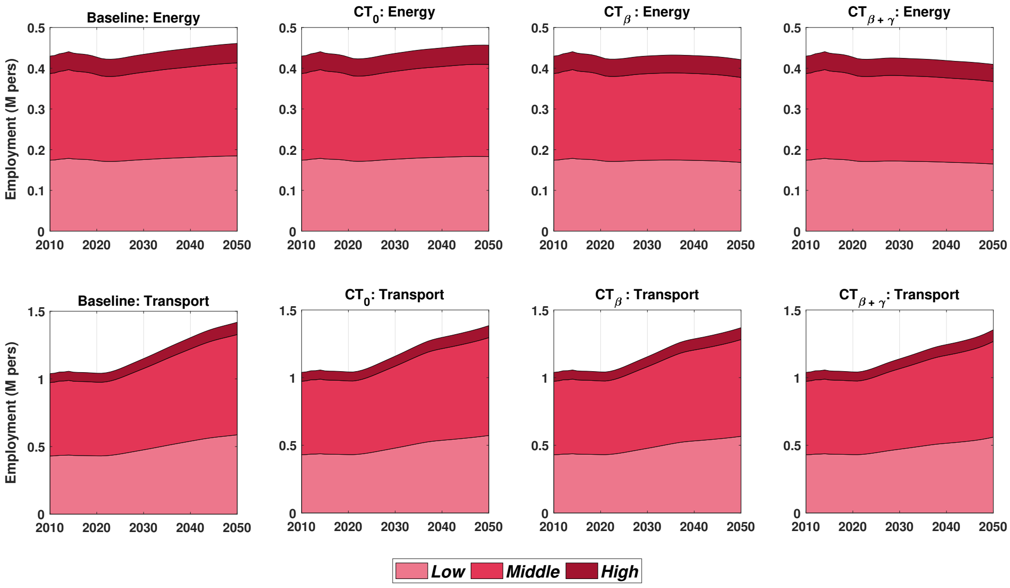


Figure A3.1: Scenario analysis: employment by skill. Comparison of the share of private consumption for energy products (COICOP classification) from 2010 to 2050 (every 10 years) under the Baseline (blue) and the other three scenarios: CT_0 (orange), CT_β (yellow), and $CT_{\beta+\gamma}$ (violet). They are compared 12 population groups defined by the combination of three educational levels (low, medium, high) and four occupational statuses (employed, unemployed, inactive, retired).

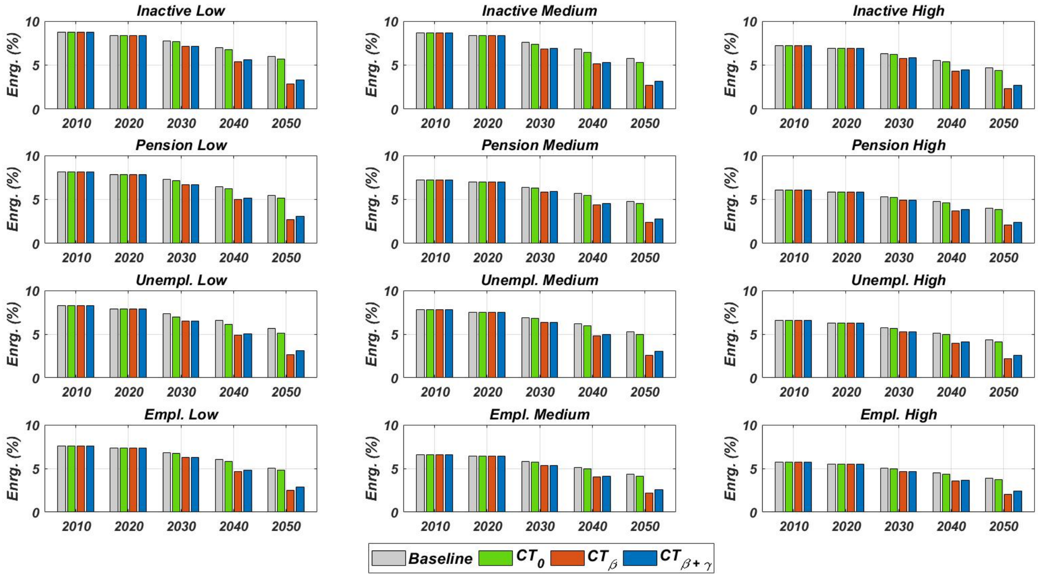


Figure A3.2: Scenario analysis: share of household's energy consumption. Comparison of the share of private consumption for energy products (COICOP classification) from 2010 to 2050 (every 10 years) under the Baseline (grey) and the other three scenarios: CT_0 (green), CT_β (red), and $CT_{\beta+\gamma}$ (blue). They are compared 12 population groups defined by the combination of three educational levels (low, medium, high) and four occupational statuses (employed, unemployed, inactive, retired).

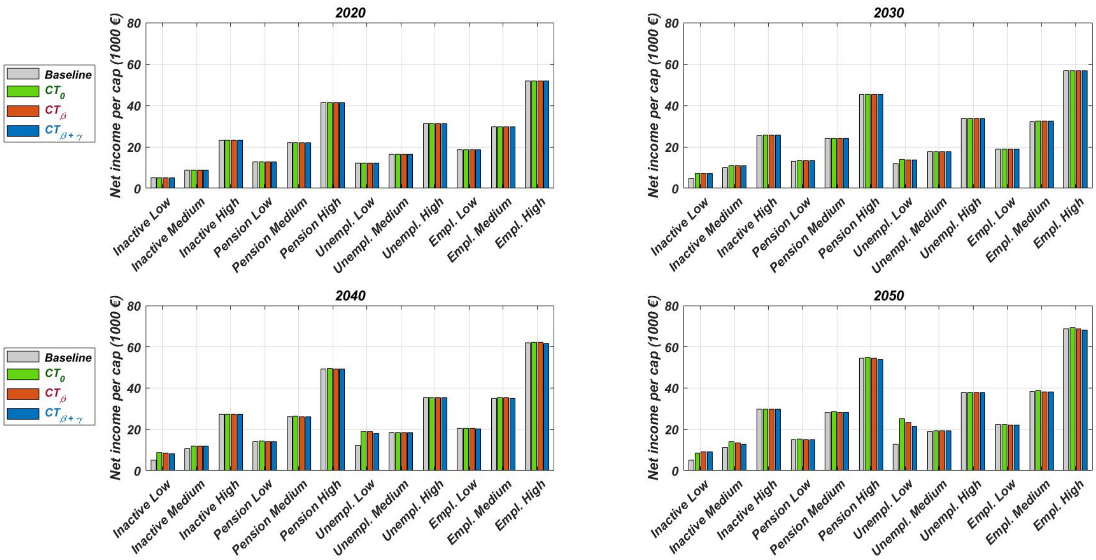


Figure A3.3: Scenario analysis: income distribution by group. Comparison of the average income by group from 2010 to 2050 (every 10 years) under the Baseline (grey) and the other three scenarios: CT_0 (green), CT_β (red), and $CT_{\beta+\gamma}$ (blue). They are compared 12 population groups defined by the combination of three educational levels (low, medium, high) and four occupational statuses (employed, unemployed, inactive, retired).