Journal of Evolutionary Economics (2023) 33:869–892
https://doi.org/10.1007/s00191-023-00827-5

REGULAR ARTICLE

Is environmental innovation the key to addressing the dual economic and sustainability challenge of the Italian economy?

Francesca Rubiconto[1,2]

Accepted: 22 June 2023 / Published online: 25 August 2023
© The Author(s) 2023

Abstract

The effects of rising global temperatures are becoming increasingly evident, with observable consequences such as the melting of polar ice caps, the occurrence of cyclones and hurricanes, desertification, and the destruction of ecosystems. The Italian economy is particularly vulnerable to the climate challenge, due to the prolonged slowdown in economic growth and the high unemployment that have plagued this economy over the last decades. Environmental innovation could be the key to tackling climate change, while at the same time promoting growth and employment. A comprehensive assessment of the effects of environmental innovation on growth and employment at the macroeconomic level should consider the compensation mechanisms associated with productivity gains, the substitution effects between more or less polluting goods, and the role of demand and consumer preferences. However, a comprehensive analysis that includes all of these direct and indirect effects of environmental innovation at the macroeconomic level is still lacking. This study aims to bridge this gap, introducing a structuralist computable general equilibrium model to simulate the effects of an increase in productivity and a change in consumer preferences in favour of less polluting industries in the Italian economy over the period 1995–2050. The results of the simulations indicate that a change in consumer preferences in favour of environmentally friendly goods in the Italian context may be more effective than an increase in productivity in stimulating demand, growth, and employment.

Keywords Climate change · Environmental innovation · Demand · Employment · Consumer preferences

✉ Francesca Rubiconto
francesca.rubiconto@wur.nl; rubiconto@merit.unu.edu

1 Wageningen University and Research, Urban Economics Group, Hollandseweg 1, 6708 KN Wageningen, The Netherlands

2 United Nations University – MERIT, Boschstraat 24, 6211 AX Maastricht, The Netherlands

JEL Classification C68 · D57 · E27 · O33 · Q52 · Q55

1 Introduction

The consequences of increasing radiative forcing and global temperatures are already evident, with notable impacts including rising sea levels, ocean acidification, desertification, cyclones, and hurricanes (IPCC 2019a, b; WMO 2018). A more rapid transition in infrastructures and industrial systems is needed to reach a zero level of emissions within 2050 (IPCC 2018). Despite the economic recession and the contraction in industrial output, Italy is still one of the largest emitters in the European Union (EEA 2019). The need for a more efficient use of resources adds to the structural problems that have plagued the Italian economy for decades (ISTAT 2019). The combination of slowing consumption, slumping productivity, and scarce dynamism of exports has weakened the economy's growth potential, causing a widening gap with its main trading partners (Storm and Naastepad 2006). Given the current state of affairs, the promise of sustainable growth, aimed at stimulating employment and competitiveness, is far from being fulfilled (European Commission 2011).

Environmental innovation is proposed in this context as a potential solution to these economic and environmental issues. Environmental innovation can be decisive in reducing polluting emissions (Carrión-Flores and Innes 2010). Furthermore, it has distinctive and superior effects on environmental performance compared to general innovative activities, although the strength of these effects varies across countries (Töbelmann and Wendler 2020). Most of the literature on the topic investigates the determinants of environmental innovation and the role of environmental regulations in stimulating competitiveness, with positive effects on demand and employment (Barbieri et al. 2016; Borghesi et al. 2013; Horbach 2008; Horbach and Rennings 2013; Porter and Linde 1995). The literature on the economic effects of environmental innovation is sparser and more focused at the firm and industry levels (Andries and Stephan 2019; Barbieri et al. 2016; Horbach 2010; Horbach and Rennings 2013; Rennings et al. 2013). Therefore, a clear assessment of the effects of environmental innovation on demand and employment at the macroeconomic level is still missing.

The question is more complex than it may appear in this brief introduction. Any innovation induces numerous direct and indirect effects on demand, productivity, output, and employment, which are difficult to identify. These effects vary according to the type of innovation and the historical and institutional context. An increase in productivity in the less polluting industries can be associated with compensation mechanisms via demand, prices, and capital goods (Antonucci and Pianta 2002; Pianta 2003; Vivarelli 2007). Furthermore, a change in consumer preferences in favour of the same industries can induce substitution effects between polluting and environmentally friendly goods. Therefore, a comprehensive analysis should include all these direct and indirect effects on demand, output, and employment.

This paper is the first attempt to investigate the direct and indirect effects of environmental innovation on demand, growth, and employment at the macroeconomic level, including the role of consumer preferences and the substitution effects between more and less polluting products. An increase in productivity and a change in consumer preferences in favour of the less polluting Italian industries are analysed and compared. The effects on demand, output, and employment in the two scenarios are compared to evaluate which instrument is the most effective in tackling the dual economic and environmental challenge of the Italian economy. The scarcity of internationally comparable data is the main obstacle in investigating these effects beyond specific sectors. Therefore, the paper draws on different strands of literature and empirical calibration and simulation techniques to undertake this investigation. In particular, it combines the mathematical rigour of the computable general equilibrium (CGE) framework with functions and closures from the structuralist literature (Taylor 1990, 2004) to introduce a basic discrete-time model. The model is calibrated to the Italian economy and used to simulate alternative scenarios over the period 1995 to 2050.

The paper is structured as follows. Section 2 introduces the main drivers of the structuralist CGE model. Section 3 details data and methodology. Section 4 proposes a new calibration method to determine the value of the parameters and measure the performance of the model. Section 5 presents the results of the simulations. The quantitative results are summarised to identify the magnitude of the effects and the extent of the redistribution of consumption, investment, output, and hours worked in favour of less polluting industries. However, the analysis focuses on the main qualitative and structural changes in the economy to derive economic policy indications. Sections 6 and 7 discuss the results and provide some concluding remarks.

2 Model structure

The structuralist CGE model introduced in this section is specifically built to investigate the direct and indirect effects of environmental innovation in the context of the Italian economy. Environmental innovation produces a series of direct and indirect effects on demand, output, employment, accumulation of capacity, and capital. Since numerous historical and institutional factors govern the interactions between these variables, investigating the effects of environmental innovation is a complex and multifaceted issue. Furthermore, these variables interact simultaneously, influencing the intensity and direction of the effects of environmental innovation. The general equilibrium framework reproduces all simultaneous interactions between these variables. Each equation in the model represents the external factors that affect a specific variable and the relationships between the latter and the other variables in the model. The variation of a specific parameter determines a series of ripple effects throughout the system. Therefore, the set of simultaneous equations accounts for compensation mechanisms through demand, prices, and capital goods.

Most of the CGE models currently existing are based on restrictive assumptions such as the existence of perfectly competitive markets and the perfect flexibility of prices and wages, which are in contrast with the purpose and context of the analysis. Therefore, several functions from the structuralist literature (Taylor 1990, 2004) are introduced into the general equilibrium framework to overcome such restrictive assumptions and incorporate the characteristics of the slow-growing Italian economy like fragmented and oligopolistic markets and underutilisation of productive resources (ISTAT 2019; Storm and Naastepad 2006). This section discusses the main drivers of the model. The complete structure and the list of variables are reported in the Supplementary Materials (Appendix A).

The main macroeconomic closures for the set of simultaneous equations are the identities between demand and supply for each sector (Eq. 1). Given intermediate inputs produced ($\sum_j INT_{ij}$) and changes in inventories ($DINV_i$) in each sector i, the gross output (X_i) adjusts in each period to investment of origin ($INVO_i$) and consumption by government ($CONS_{gn\_i}$) and households ($CONS_{h\_i}$). Equation (1) replaces the standard identity between saving and investment, attributing a central role to effective demand.

$$X_i = \sum_j INT_{ij} + CONS_{h\_i} + CONS_{gn\_i} + INVO_i + DINV_i \tag{1}$$

Equation (1) identifies investment and capital accumulation as fundamental drivers of growth, as in the standard CGE models. However, investment is not simply set equal to savings, but it is determined endogenously through the principle of effective demand. The structuralist investment functions (Taylor 1990, 2004) incorporate the role of demand and profitability as main drivers of capital accumulation (Eq. 2). In particular, the gross fixed capital formation by sector of destination ($INVD_i$) is a function of the capital stock from the previous period ($KAP_{(t-1)i}$), the coefficient of autonomous investment (g_{0i}), the rate of profit (r_i), and the rate of capacity utilisation (u_i).

$$INVD_i = KAP_{(t-1)i}(g_{0i} + \alpha_i r_i + \beta_i u_i) \tag{2}$$

The rate of capacity utilisation (u_i) is another fundamental feature of the structuralist literature, which reflects the state of underutilisation of productive resources in the Italian economy. The rate of capacity utilisation is also a main driver of markup and prices. In particular, the current markup rate (τ_i) depends on its lagged value ($\tau_{(t-1)i}$) and the difference between the current (u_i) and the target rate of capacity utilisation (u_i^*) (Eq. 3). The endogenous markup function is specifically introduced to account for the role of demand as driver of income distribution and output prices. However, the coefficient of the markup function (ϕ_i) is assumed to be low due to the increase in market concentration. Therefore, the markup responds slowly to variations in demand. Any variation in demand is also reflected in the price of output (p_i), which is set as a markup (τ_i) on intermediate costs ($p_i INT_{ii} + p_j INT_{ji}$) and labour cost ($wLAB_i$) in each sector (Eq. 4).

$$\tau_i = \tau_{(t-1)i} + \varphi_i(u_i - u_i^*) \tag{3}$$

$$p_i = (1 + ptax_i)(1 + \tau_i)\frac{\left(p_i INT_{ii} + p_j INT_{ji} + wLAB_i\right)}{X_i} \tag{4}$$

The level of markup determines the distribution of income between capital and labour. In turn, the expenditure functions determine the portion of capital and labour income allocated to the consumption of households, government, and non-profit organisations (Eq. 5).

Another important element of differentiation from standard CGE models is the centrality of consumer preferences compared to the traditional focus on productivity increases. The consumption expenditures of households ($CONS_{nom\_h}$) are calculated as the share of disposable income from capital ($(1 - ktax)KINC$) and labour ($(1 - ltax)LINC$) corresponding to their respective propensities to consume (Eq. 5). The aggregate nominal consumption of households is allocated to each sector through the demand functions (Eq. 6). The demand functions are derived from the constrained maximisation of constant elasticity of substitution (CES) utility functions and incorporate the substitution effects between polluting and environmentally friendly products. Given the elasticity of substitution (ϵ), consumer preferences (s) and relative prices (p_i, p_j) determine the quantity consumed of each good ($CONS_{h\_i}$). The share parameter (s) is initially assumed to be constant. However, this assumption will be relaxed in section 5.2, which introduces a change in preferences in favour of the less polluting sectors. The expenditures of government and non-profit organisations are also allocated to more and less polluting goods through CES demand functions.

$$CONS_{nom\_h} = c_r(1 - ktax)KINC + c_w(1 - ltax)LINC \tag{5}$$

$$CONS_{h\_i} = \frac{CONS_{nom\_h}}{p_i + p_j(\frac{p_i(1-s)}{p_j s})^{\epsilon}} \tag{6}$$

In conclusion, the model attributes a central role to effective demand, which represents a main driver of growth, investment, and capital accumulation. Thanks to the structuralist investment and pricing functions, the model incorporates the compensation mechanisms associated with an increase in productivity. The CES utility functions represent the substitution effects between polluting and environmentally friendly goods following a change in preferences. Finally, the endogenous markup functions reproduce the existence of oligopolistic structures and determine the degree of responsiveness of the system to a change in demand and capacity utilisation. Therefore, the model can be used to investigate the direct and indirect effects of innovation on demand, output, and employment in the Italian economy.

3 Methodology and data

The structuralist CGE model introduced in the previous section is used to investigate the effects of a change in productivity or consumer preferences in favour of the less polluting Italian industries. The Italian industries are first classified into two groups, based on their economic and environmental contribution. The purpose of this classification is to identify the industries whose contribution to the production of economic value is more significant than the contribution to emissions. The basic assumption is that an increase in consumption and investment in these industries can contribute to the mitigation of climate change, at the same time supporting growth and employment. The classification is introduced in section 3.1.

The classification is used to construct the time series of all model variables over the period 1995–2005. The main data source for the construction of the time series is the World Input-Output Database Release 2013 (Dietzenbacher et al. 2013; Timmer et al., 2015). The 2013 release covers the period from 1995 to 2011, including 27 countries from the European Union and other 13 major countries in the world. The WIOD data used in this study are the national use and supply tables (SUTs), the national input-output tables (NIOTs), the world input-output tables (WIOTs), the socio-economic accounts (SEAs), and the environmental satellite accounts. The construction of the time series is detailed in section 3.2.

The model is calibrated on the time series for the period 1995 to 2005, using a new method. This method combines an extensive literature review to define the estimation range of each parameter with a Pearson correlation test between the target vector and response vectors corresponding to alternative parameter combinations. The main aim is to identify the value of the parameters that will be used for the simulation in a more rigorous manner. The calibrated model is then run over the period 1995–2050. The main purpose is to understand if the current growth path can lead to a significant redistribution of output and employment towards the less polluting industries within the target set for zeroing emissions.

Building on the base simulation, two main alternative scenarios are introduced. The first is an increase in the growth rate of productivity of less polluting industries. The second is a change in consumer preferences in favour of environmentally friendly goods. The effects on demand, growth, and employment in the two scenarios are analysed and compared. The purpose is not to obtain quantitative forecasts, but rather to conduct a qualitative investigation into the effectiveness of different policy instruments in tackling the dual environmental and economic challenge of the Italian economy.

3.1 Environmental creditors and debtors

In order to investigate the effects of an increase in productivity and a change in preferences in favour of environmentally friendly products, the Italian economy must be divided into more and less polluting industries. The 35 industries of the NACE 1.1 classification are divided into two groups: Environmental Creditors and Environmental Debtors. The Environmental Creditors include all industries whose contribution to the economic value of the sector (manufacturing or services) is significantly higher than the contribution to greenhouse gas emissions in the same sector. The Environmental Debtors comprise the remaining industries.

The purpose of this subsection is to identify appropriate indicators for this breakdown. The indicators should allow to compare the contribution to climate change and the economic contribution of each sector in a specific period. However, they should not depend on the difference in the marginal cost of reducing emissions.

The first indicator introduced is the contribution to emissions (EMC). The EMC is defined as the ratio of the emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) of a specific industry to the total emissions produced of the same pollutants, expressed in kilotons of carbon dioxide equivalent (CO_2 e). The air emission accounts (Genty 2012) provide information on these pollutants disaggregated by industry and use. Since each pollutant has a different capacity for absorbing heat and persisting in the atmosphere, methane and nitrous oxide are first converted into carbon dioxide equivalent (CO_2 e), based on their global warming potential (GWP) (IPCC 2007). The second indicator is the contribution to emissions over value added (EMVAC). The EMVAC is defined as the ratio between the contribution to emissions of a specific industry (EMC) and its contribution to the total production of value added (VAC), expressed in millions of euros 1995. Both indicators are calculated for the entire period 1995–2005, to ensure the stability of the classification over time.

The EMC and EMVAC indicators are tested on the Italian economy separately and in a combined manner to produce a sufficiently consistent classification. The EMVAC indicator allows to identify industries whose contribution to the economic value produced is higher than the contribution to polluting emissions (EMVAC<1). However, a classification based exclusively on this indicator would overestimate the importance of the environmentally friendly sector, as the three most polluting industries 'Electricity, Gas, and Water Supply' (secE), 'Agriculture, Hunting, Forestry, and Fishing' (secAtB), and 'Other Non-Metallic Mineral' (sec26) account for most of the GHG emissions (51%). In addition, some sectors that contribute significantly to emissions such as 'Food, Beverages, and Tobacco' (sec15t16) would be included among the environmental creditors.

Even using a lower threshold for the same indicator, the classification would produce inconsistent results. For instance, if only the industries with an EMVAC lower than 0.5 were selected as environmental creditors, the whole service sector except for transport would fall into this category. The combined use of the EMVAC and the EMC indicators allows to obtain a more representative picture. The industries whose average contribution to emissions over value added is less than unity (EMVAC<1) in the period 1995–2005 are first selected. The median of the average contributions to emissions for all industries over the period 1995–2005 is calculated for this subgroup. The industries whose contribution is lower than the median of the subgroup are classified as 'Environmental Creditors', the remaining industries as 'Environmental Debtors'.

The composition of both groups is illustrated in Table (1). The environmental debtors include 25 industries, one of which belongs to the primary sector, 13 to the secondary sector, and 11 to the tertiary sector. They account for 70% of the value added and contribute 81% of the total hours worked. The environmental creditors include the remaining 10 industries, four of which belong to the secondary sector and six to the tertiary sector.

The classification proposed presents some limitations. Firstly, there are important complementarities between environmental creditors and debtors. For example, manufacturing of transport equipment and transport activities are classified as environmental debtors. However, the repair of motor vehicles and transport support activities are classified as environmental creditors. Secondly, the environmental creditors cannot replace some core activities such as agriculture and food production. However, the purpose of this analysis is not to understand how to replace specific productive activities, but rather to understand to what extent a strengthening of some low environmental impact sectors such as recycling and education can contribute to the mitigation of climate change and at the same time foster growth and employment. Thirdly, the aggregation into two groups involves a loss of information on the characteristics of specific industries. However, the main interest of the paper is to verify the existence of structural differences between the two groups and to investigate the economic restructuring in favour of less polluting industries. Finally, the classification of environmental creditors and debtors could change in the long run, due to technical change, exogenous shocks, or government interventions. The availability of further data and research on the effects of environmental innovation over time and the distribution of environmental creditors and debtors within each sector would provide a fundamental contribution to this analysis in the long run.

3.2 The time series (1995–2005)

Based on the classification introduced above, the time series of the real and nominal variables for environmental creditors and debtors over the period 1995–2005 can be constructed. The NIOTs represent the main data source for the construction of the real time series. The tables include both domestically produced and imported products for each use category. Furthermore, they specify the allocation of each domestic product to intermediate and final uses, including exports. To investigate the structural and redistributive effects associated with changes in preferences and productivity, the data are reorganised to reproduce the functioning of a closed economy with two sectors.

The economy is first divided into two main sectors based on the classification introduced above. Firstly, this division emphasizes the distinctive characteristics of each group and the importance of planning differentiated economic policy interventions. Secondly, it allows identifying changes over time of the main trends in the environmentally friendly and polluting industries. Thirdly, it underlines the structural changes in the Italian economy, with particular reference to the redistribution of consumption, investment, output, and employment towards less polluting sectors. Finally, it allows to model how a change in productivity or consumer preferences in favour of a specific group of industries can accelerate these structural changes. Since Italy is the main focus of the analysis, the data are further reorganised to reproduce the functioning of a closed economy for two main purposes. The first is to investigate the structural and redistributive effects of innovation within the domestic economy, regardless of trade flows with other countries and their embedded emissions. The second is to avoid artificially reproducing the functioning of a small open economy.

In the context of a closed economy, all previously exported goods and services would be redirected to domestic uses. At the same time, all imports of products for intermediate and final uses would be lacking. Therefore, each NIOT for the period 1995–2005 is restructured to reproduce this context. Firstly, the matrices of intermediate and final uses are aggregated based on the previous classification (Table 1) to divide the economy into environmental creditors and debtors.

Table 1 Environmental creditors and debtors

Environmental debtors	Code
Agriculture, Hunting, Forestry and Fishing	secAtB
Mining and Quarrying	secC
Food, beverages and tobacco	sec15t16
Textiles and textile products	sec17t18
Pulp, paper, paper products, printing and publishing	sec21t22
Coke, refined petroleum and nuclear fuel	sec23
Chemical and chemical products	sec24
Rubber and plastics	sec25
Other non-metallic minerals	sec26
Basic metals and fabricated metals	sec27t28
Machinery, Nec	sec29
Transport equipment	sec34t35
Electricity, gas and water supply	secE
Construction	secF
Wholesale trade and commission trade, except of motor vehicles and motorcycles	sec51
Retail trade, except of motor vehicles and motorcycles; repair of household goods	sec52
Hotel and restaurants	secH
Inland transport	sec60
Water transport	sec61
Air transport	sec62
Renting of M&Eq and other business activities	sec71t74
Public admin and defence; compulsory social security	secL
Health and social work	secN
Other community, social and personal services	secO
Private household with employed persons	secP
Environmental Creditors	Code
Leather, leather products and footwear	sec19
Wood and products of wood and cork	sec20
Electrical and optical equipment	sec30t33
Manufacturing, Nec; Recycling	sec36t37
Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel	sec50
Other supporting and auxiliary transport activities; activities of travel agencies	sec63
Post and telecommunications	sec64
Financial intermediation	secJ
Real estate activities	sec70
Education	secM

Source: Author's elaboration from the Italian air emissions accounts and SEAs (WIOD, 2013)

Secondly, imports and exports are reallocated to reproduce the functioning of a closed economy. In particular, the matrices of intermediate inputs imported and domestically produced are aggregated, including the international trade and transportation margins. The exports net of intermediate inputs and transportation margins are reallocated to the final domestic uses for each sector based on the weights from the corresponding WIOT. A time series of export–destination investment matrices is specifically constructed for this purpose. The methodology is applied to each national input-output table over the period 1995–2005. The result is a time series of matrices of intermediate and final uses in current prices for a closed economy.

The time series of input-output matrices in current prices is deflated using the WIOTs in previous year's prices (PYP WIOTs). The data from each PYP WIOT are used to build the corresponding national input-output table in PYP. The latter is then reorganised following the methodology detailed above. Each pair of tables in current and previous years' prices provides the price indexes associated with each sector and used for the conversion from year t to year t–1. Therefore, intermediate and final uses for each sector can be brought to the base year using the respective time series of price indexes. The input-output matrices of intermediate and final uses in real terms provide the values of the main variables over the period 1995–2005, in particular gross output (X_i), intermediate inputs (INT_{ii}, INT_{ji}), consumption by households ($CONS_{h\_i}$) and government ($CONS_{g\_i}$) and gross fixed capital formation ($INVO_i$). The time series of the capital stock (KAP_i) are derived from the socioeconomic accounts.

The gross fixed capital formation appears by industry of origin ($INVO_i$) in the demand function (Eq. 1) and by industry of destination ($INVD_i$) in the capital accumulation function (Eq. 2). To relate the investment of origin to the investment of destination, the coefficients of the origin–destination investment matrix must be estimated. The latter can be built from a vector of investment of origin and a vector of investment of destination of the same length, using the RAS method (Supplementary Materials, Appendix C).

Another fundamental variable is the current rate of capacity utilisation (u_i), which has been identified as a driver of investment, markup, and prices (Eqs. 2–3). The Joint Harmonised EU Programme of Business and Consumer Survey provides harmonized data on current operating capacity as a percentage of full capacity for the 28 member states of the European Union, based on NACE Revision 1.1 (European Commission 2016). The quarterly figures from the survey data are transformed into yearly rates and weighted based on the contribution to the total value added produced in the sector. The rate of capacity utilisation for each sector is calculated as the weighted average of the rates of the industries belonging to the same sector.

Finally, the main sources of data for the nominal variables are the SEAs. The time series for capital and labour compensation ($KINC_i$, $LINC$) and for the number of hours worked in each sector (LAB_i) can be derived directly from the accounts. Given sources of income and investment, the rates of markup and remuneration of capital and labour can also be computed. All variables are converted from US dollars to euros, using the exchange rates from the WIOD database (September 2012 release). The time series for both real and nominal variables are reported in the Supplementary Materials (Appendix B).

4 Calibration (1995–2005)

The time series constructed in the previous section are used to calibrate the model over the period 1995–2005. The new calibration method introduced in this section aims at addressing the main criticisms emerged in the literature (Dawkins et al. 2001; Hoover 1995; Watson 1993). The first refers to the norm of calibrating the model on benchmark data that reproduce a single equilibrium observation. To overcome this limitation, the values of the parameters are estimated over the entire period 1995–2005. The second concerns the lack of rigour in the choice of parameters (Hoover 1995). To address this criticism, a literature review is first conducted for each of the main parameters to define its range of estimation. A Pearson correlation test is then carried out to identify the value of the parameter within this range. The third criticism concerns the absence of a reference metric to evaluate the performance of the model (Watson 1993). Therefore, a replication test is conducted to ensure that the simulated trends reproduce the real trends with a mean absolute percentage error lower than 5%.

The real values calculated in the previous section are first attributed to the independent variables and the dependent variable of each equation of the model. The result is a time series of the same equation over the period 1995–2005 in which the parameters represent the unknowns to be estimated. A review of previous empirical studies is then conducted for each of the main parameters (par_i,par_j) figuring in the equation. The values of the parameters are estimated within the range defined on the basis of the literature. The extremes of the estimation range for each parameter are obtained as a 10% variation around the average value from the literature ($avpar_i$ – 10%; $avpar_i$+ 10%). The first ten instances of the parameters are identified for the entire period of analysis (par_{ist}, par_{jst} $\forall s=1,...,10;t=1,...,n$). The average value of the parameters ($avpar_{is}$, $avpar_{js}$) for each instance (s) is used to solve the initial equation over the observed period.

The resulting vector (v_i) is compared to the target vector (v) associated with the actual trend of the dependent variable, using the Pearson correlation test. The combination of parameters which shows the lowest p-value in the correlation test between the associated vector and the target vector is selected for the final simulation. The results of the estimation procedure are reported in the Supplementary Materials (Appendix D). Finally, the values of the parameters estimated in the new calibration procedure are used to conduct a replication exercise over the period 1995–2005. The main aim of this exercise is to verify that the trend of the main variables simulated through the model follows the actual trend of the same variables, with a mean percentage error lower than 5%. The results of the replication exercise are reported in the Supplementary Materials (Appendix E). The following subsections detail the application of the method to the main equations of the model to estimate the coefficients of the expenditure (4.1), consumption (4.2), markup (4.3) and investment functions (4.4).

4.1 Coefficients of the expenditure functions

The expenditure function represented in Eq. (5) determines the shares of capital and labour income allocated to the consumption of households. The time series for capital and labour income $(KINC, LINC)$ were derived from the socioeconomic accounts, as detailed in the previous section. Therefore, the main parameters to be estimated from the same equation are the propensities to consume for capital and labour income (c_r, c_w). The previous literature focuses on saving propensities associated with different income groups and the resulting redistributive effects (Bhaduri and Marglin 1990). In particular, if the propensity to save out of labour income is significantly lower than the propensity to save out of capital income, any redistribution from wages to profits reduces aggregate consumption.

Most studies on the main OECD economies provide empirical support to the saving differential hypothesis, with an estimated average difference between the propensity to save out of wages and the propensity to save out of profits of 0.36–0.46 (Bowles and Boyer 1995; Stockhammer 2009; Storm and Naastepad 2006). The difference could be even more important, with values around zero for wage earners and around unity for profit earners (Hein and Ochsen 2003). However, the estimates vary depending on the size and the degree of openness of the economy. The consumption differential between profit and wage income is lower for small open economies like Austria and the Netherlands (0.23–0.30) compared to medium-sized and less open economies such as France and Germany (0.33–0.44) (Hein and Vogel 2007; Hein and Vogel 2009; Stockhammer and Ederer 2008; Stockhammer et al. 2011).

Based on the overview presented in this section, the difference between the propensity to consume out of wages (c_w) and the propensity to consume out of profits (c_r) is supposed to vary between 0.32 and 0.44. Both propensities are estimated within this range, following the procedure detailed above. The average values of the propensities to consume out of capital and labour income reporting the lowest p values in the Pearson correlation test are respectively 0.51 and 0.88.

4.2 Coefficients of the consumption functions

The expenditures of government and households are allocated to the more and less polluting products through the CES demand functions (Eq. 6). Given the time series of real quantities consumed $(CONS_{gn\_i}, CONS_{h\_i})$ and relative prices (p_i, p_j), their preferences for each good and the degree of substitutability between the same goods can be determined. Therefore, the parameters to be estimated are the share parameters of the utility functions (s, z) and the elasticities of substitution (σ, ϵ). The literature on the substitutability between polluting and environmentally friendly goods is scarce, therefore this subsection refers to the studies on the elasticity of substitution between clean and dirty inputs. The elasticity of substitution is important in determining the direction of technological change (Acemoglu et al. 2012). The complementarity between clean and dirty sources can prevent the switch to environmentally friendly technologies, even with government intervention (Pelli 2012). Most studies estimate that this parameter is significantly higher than unity, with values between 1.61 and 2 for the energy sector (Lanzi et al. 2011; Malikov et al. 2018; Papageorgiou et al. 2017; Popp 2004). Estimates for non-energy sectors are more varied (Malikov et al. 2018; Papageorgiou et al. 2017).

Drawing on the few empirical studies based on a CES function, the range of estimation for the elasticities of substitution between more and less polluting products is 1.87–2.29. The estimated value of the elasticity for both government and households (σ, ϵ) over the observed period is 1.95. The estimated values of the share parameters for government (z) and households (s) are 0.35 and 0.42, respectively. Based on these estimates, private consumers appear to attribute a greater value to cleaner goods than public actors, although the degree of substitutability with the dirty good is the same.

4.3 Coefficients of the markup functions

The endogenous markup functions introduced in Eq. (3) illustrate the influence of demand on markup and prices. In particular, the markup (τ_i) depends on the difference between the current (u_i) and the target rate of capacity utilisation (u_i^*) through the coefficient (ϕ_i). The time series for rates of capacity utilisation and markup rates were derived in the previous sections. Therefore, the parameters to be estimated from the same equation are the coefficients of the markup function (ϕ_i) and the target rate of capacity utilisation (u_i^*).

Since any deviation from the target rate involves price variations through the markup function, the target rate (u_i^*) can be identified with the non-accelerating inflation rate of capacity utilisation (NAIRCU). The NAIRCU has been introduced as an alternative indicator for European countries, where the estimates of the non-accelerating inflation rate of unemployment (NAIRU) are less reliable due to the role of hysteresis (Franz and Gordon 1993). The indicator is directly measurable from survey data and performs reasonably well compared to other benchmark measures (Fessler et al. 2014; Köberl and Lein 2011). The available empirical studies find a similar role of partial hysteresis and demand effect across countries (Franz and Gordon 1993). However, the estimates vary significantly depending on efficiency and entrepreneurial attitudes, with values ranging from 75 for Italy to about 85 for Germany, Switzerland, and United States (Franz and Gordon 1993; Köberl and Lein 2011; Nahuis 2003).

Based on the limited literature available, the target rate of capacity utilisation in each sector is supposed to vary between 0.75 and 0.91. The coefficient of the markup function in each sector is estimated within the range of 0–1. A positive value of the coefficient ensures a pro-cyclical behaviour of the markup rate and its convergence to the steady state. A value close to zero implies the existence of oligopolistic market structures, which prevent the immediate adjustment of prices to changes in demand. The estimated value of the target rate of capacity utilisation is lower for environmental creditors (0.76) than for environmental debtors (0.79), indicating a weaker potential for expanding demand without creating inflationary pressures in this sector. Both rates are lower than the median value from the literature, but in line with Nahuis (2003) which indicates a limited capacity to increase the utilisation of resources in Italy. Conversely, the markup coefficient of the environmental debtors (0.17) is considerably smaller than that of the environmental creditors (0.81), suggesting a lower price responsiveness to demand variations in this sector. The persistent state of underutilisation of resources combined with the weak responsiveness of the markup rate to changes in demand could explain the relative stability of the markup rate in this sector.

4.4 Coefficients of the investment functions

The rates of capacity utilisation are also important drivers of the structuralist investment functions, together with the rates of profits (r_i) (Eq. 2). The time series of capital stock, profit and utilisation rates were calculated in the previous section. Therefore, the parameters to be estimated are the rate of autonomous investment (g_{0i}), the coefficient of the rate of profit (α_i) and the coefficient of the rate of capacity utilisation (β_i). The coefficients of the investment function are investigated in numerous empirical studies as fundamental levers of demand and profitability. Most empirical studies identify a positive and significant effect of profitability on investment and an even more remarkable demand effect (Storm and Naastepad 2006). However, the role of demand and profitability in driving capital accumulation differ widely across countries. The investment responsiveness to profitability ranges from 0.53 in Japan to 0.14 in the United Kingdom and is weakly significant in Germany (Bowles and Boyer 1995; Hein and Vogel 2009; Stockhammer et al. 2011). While the effect of demand on capital accumulation is fairly stable (0.2), the effect of profitability appears to weaken over time (Glyn 1997; Hein and Ochsen 2003).

Even taking exports into consideration, a 'wage-led regime' prevails in France, Germany, Italy, and Spain, while Japan and the United States are classified as 'profit-led regimes' (Bowles and Boyer 1995; Hein and Vogel 2009; Storm and Naastepad 2006). Further studies suggest that large and less open economies such as France, Germany, the United Kingdom, and the United States exhibit characteristics of wage-led regimes, while the small open economies of Austria and the Netherlands are profit-led (Hein and Vogel 2007). However, a reduction in the wage share can have important contractionary effects on domestic demand even in small open economies like Austria and the Netherlands (Naastepad 2006; Stockhammer and Ederer 2008). The euro area can also be considered as a large integrated economy following a wage-led pattern, with an important role of consumption and demand (Stockhammer 2009).

In conclusion, previous studies identify a wage-led regime in the largest and relatively closed continental European economies, at least when the role of exports is not accounted for. However, the estimates of the coefficients of the investment function are not comparable, due to the different specifications and indicators used. Therefore, the entire range identified in the literature is taken into account. The coefficient of the rate of profit (α_i) is estimated within the range of 0–0.5, while the coefficient of the rate of capacity utilisation (β_i) is estimated within the range of 0–1. The rate of autonomous investment (g_{0i}) is supposed to vary between 0 and 0.05.

The estimated coefficient of the rate of capacity utilisation (0.07) is almost three times higher than the coefficient of the rate of profit (0.03) in the environmentally friendly sector. The opposite occurs in the more-polluting sector, where the coefficient of the rate of capacity utilisation is about one third (0.02) of the coefficient of the profit rate (0.05). The demand effect appears to be dominant in the first sector, while profitability is the main driver in the second sector.

5 Main results

5.1 Baseline

The results of the simulation over the period 1995–2050 reveal that the important structural changes required to cope with the climatic emergency do not occur within the time frame considered. Not only do the environmental creditors fail to capture the main share of output, but the redistribution of consumption and investment towards the latter is modest. The unit labour requirements decrease at a higher rate in the less polluting sector. However, the markup rate continues to rise, partially offsetting the decline in relative prices. Once the current rate of capacity utilisation reaches the target value (0.76), it gradually declines. Relative prices follow a similar trend, rising in the first decade and gradually slowing down in the following decades. The convergence is smoother in the more polluting sector, where the initial rate of capacity utilisation is closer to the target rate (0.79) and the response of the markup rate to changes in demand is weaker. The markup decreases constantly over the observed period. Essentially, the gap between the two sectors in terms of markup, profitability and utilised capacity persists.

The concomitant decline in utilisation and profit rates also slows down capital accumulation in the more polluting sector. Conversely, increasing returns stimulate capital accumulation in the less polluting sector. However, the low responsiveness of investment to profitability weakens this effect. As a result, the redistributive effects are modest. The green share of household consumption ($rconsh_c$) marginally increases from 33 to 35%, while the green share of investment ($rinvd_c$) rises from 15 to 19%. Following the modest increment in the consumption and investment ratio, the output share of the environmental creditors (rx_c) increases marginally from 24 to 26%. The expansion in demand is therefore insufficient to compensate for the labour losses associated with the increase in productivity in the same sector. Therefore, their share of hours worked declines from 19 to 16%. In conclusion, the difference in productivity and profitability between the sectors is not sufficient to ensure a restructuring of the economic system in favour of the environmental creditors, due to the low level of initial capital, the high initial markup rate, and its scarce responsiveness to changes in demand.

5.2 Change in consumer preferences

A change in consumer preferences accelerates the structural changes described in the previous section, fostering consumption, investment, and output in the

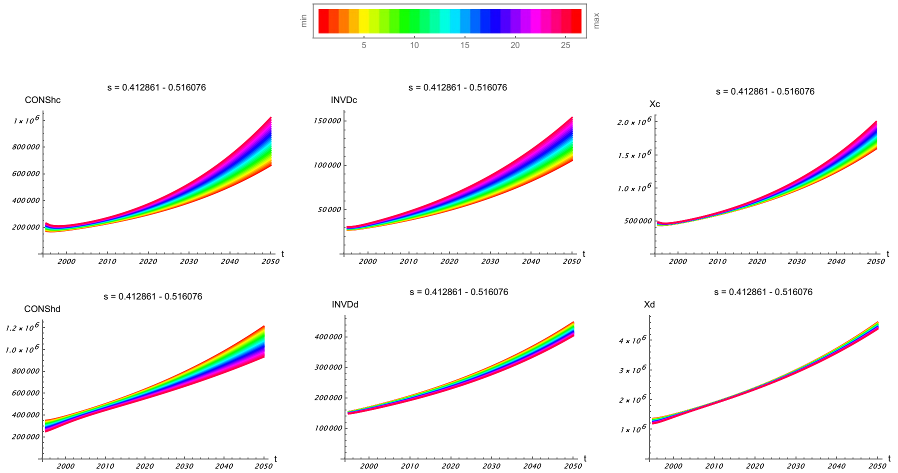

Fig. 1 Main effects of a change in consumer preferences (1995–2050). Source: Author's own elaboration

less polluting sector. The change in preferences is simulated through a 25% increment in the share parameter s of the household utility function compared to the base scenario. The increase is analysed through successive simulations in progressive steps of 5% (Fig. 1). The change in preferences produces a more than proportional increase in the household consumption of environmentally friendly goods ($CONSh_c$). The rise in consumption in turn stimulates the expansion in output (X_c) and employment. The effect on available productive capacity is limited in the short run, therefore the rates of capacity utilisation (u_c) and markup (τ_c) rise with output. Thanks to the combined increase in markup and utilisation rates, the rate of profit (r_c) surges. Finally, the rise in demand and profitability fosters the gross fixed capital formation in the same sector ($INVD_c$). Over time, the accumulation of capital and the consequent increase in production capacity erase the increment in the rates of markup and capacity utilisation, while the expansive effects on consumption and investment are strengthened (50 and 43% respectively). The result is a significant increase in gross output and hours worked in the last scenario (25%).

The effects in the most polluting sector are negative, but smaller. The change in consumer preferences causes a less than proportional decrease in household consumption ($CONSh_d$) of the more polluting goods in the short run. As a result, output (X_d) and employment (LAB_d) suffer a modest reduction compared to the base scenario. The rates of capacity utilisation (u_d) and markup (τ_d) decrease in the same proportion. However, the reduction in the rate of profit (r_d) is more significant. The decline in utilisation and profit rates curtails the investment in the same sector ($INDV_d$), but the effect remains modest. Over time, the rate of capacity utilisation converges toward the target, while markup (τ_d) and profitability (r_d) collapse. Therefore, the decline in investment is more important (10%), while consumption losses are contained (22%). As a result, the decline in output and hours worked in the last scenario is modest (5%).

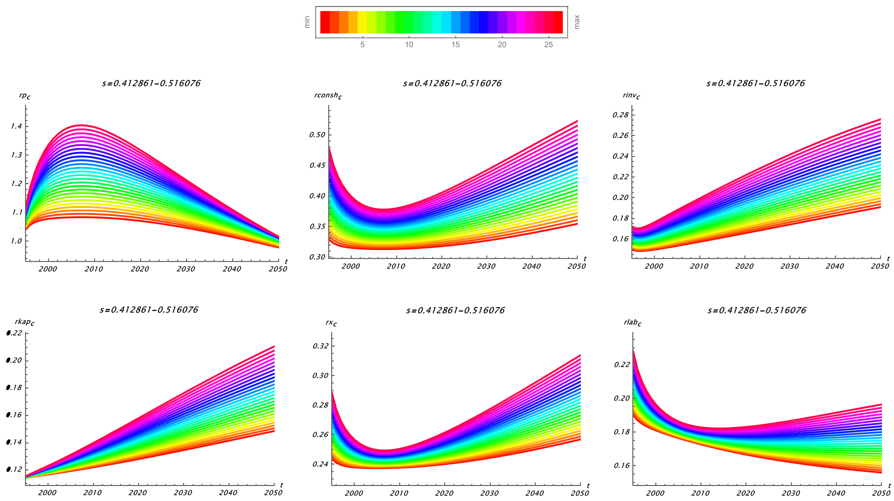

Fig. 2 Redistributive effects of a change in preferences (1995–2050). Source: Author's own elaboration

The strongly expansionary effect in the less polluting sector and the modest decline in the more polluting sector cause a redistribution of consumption, investment, output, and employment in favour of the environmental creditors (Fig. 2). Following a change in preferences, the relative price of environmentally friendly products increases rapidly and then gradually converges towards the baseline. The rise in the relative price slows down the redistribution in favour of the environmental creditors, which nevertheless conquer the main share of consumption at the end of the period (52%). They also increase their share of investment (28%) and capital (21%), but the effect is less important. As a result, the redistribution of output (32%) and employment is significant but more contained (20%).

5.3 Productivity increase

The effect of a change in household preferences in favour of the environmental creditors is compared to the effect of an increase in productivity in the same sector. An increase in the growth rate of productivity of the environmental creditors (gb_c) from 1.4 to 1.9% is simulated, which corresponds to a 25% decline in the unit labour requirements in the same sector over the observed period *(bc)*. The increase is analysed through successive simulations in progressive steps of 5%, as in the previous case (Fig. 3). The increase in productivity boosts profitability in the same sector, raising the markup rate (τ_c) and the profit rate (r_c). The rise in the markup rate partially offsets the decline in the unit labour requirements, causing a modest decrease in the price of output compared to the baseline. The result is a moderate increase in consumption ($CONSh_c$) and investment ($INVC_c$) (5–6%) and a marginal increase in gross output (X_c) in the last scenario (3%). The demand effect is insufficient to

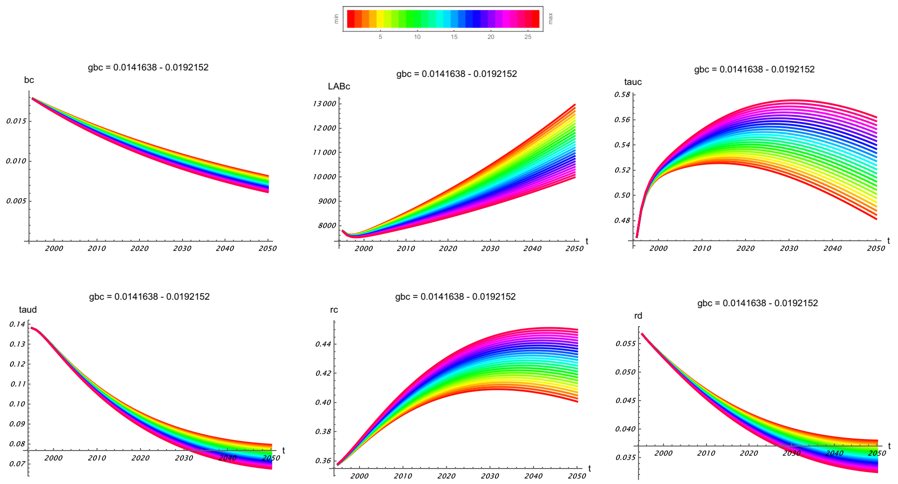

Fig. 3 Main effects of an increase in productivity (1995–2050). Source: Author's own elaboration

compensate the labour losses due to the increase in productivity, resulting in a significant decline in the number of hours worked in the same sector (LAB_c) (22%).

The boost in profitability in the first sector corresponds to an erosion in profitability in the second sector. Both the markup (τ_d) and profit rate (r_d) of the environmental debtors decline. Despite the decline in the markup rate, the reduction in the price of output is modest. Therefore, the effect on consumption is marginal. Since the rate of capacity utilisation is stable, the effect on investment is also unimportant. Therefore, both the output and the number of hours worked in the same sector are stable. In sum, the increment in productivity widens the gap in markup and profitability between the two sectors, but has modest effects on the real variables, with the exception of employment. The redistributive effects are even less evident (Fig. 4). The share of hours worked suffers a modest decline. However, the increase in the share of consumption of the environmental creditors compared to the baseline is minimal and the effect on the other variables is insignificant.

6 Discussion

The analysis identified fundamental differences between environmental creditors and debtors in terms of initial resources, ability to expand demand and drivers of capital accumulation. The target rate of capacity utilisation of the environmental creditors is lower, which limits their ability to drive demand without generating inflation. The initial capital stock and the autonomous investment rate are also lower for the environmental creditors, which constrains capital accumulation. Their markup rate is considerably higher than that of the environmental debtors, but it is more responsive to changes in demand. The latter is the main driver of investment in this sector, while profitability prevails in the more polluting sector.

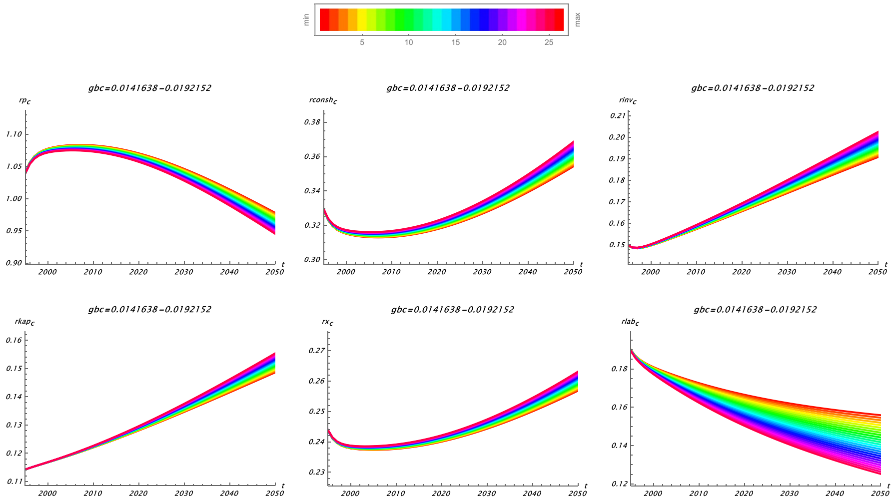

Fig. 4 Redistributive effects of an increase in productivity (1995–2050). Source: Author's own elaboration

An effective policy should take into consideration the differences in the structural characteristics of high and low environmental impact industries. Given the greater responsiveness of investment to demand in the less polluting industries, the introduction of targeted policies to support consumption could foster the accumulation of capital and the expansion of productive capacity in the same industries. Furthermore, the expansion in productive capacity would contain the inflationary effects associated with a rise in demand in the same sector. Finally, an increase in competition in the market for environmentally friendly products could have very positive effects, as the expansion of demand would offset the negative effect of a reduction in markup on investment and capital accumulation.

The base simulation over the period 1995–2050 suggests that the economic redistribution towards less polluting industries is much slower than desired. Despite the persistent gap in terms of productivity and profitability between the two sectors, the redistribution of consumption, investment, and output in favour of the environmental creditors is modest. Furthermore, their share of hours worked decreases significantly. The high markup rate and its low responsiveness to increases in demand prevent the transfer of productivity growth into significant price reductions. The scarce initial capital and limited investment response to profitability hinder capital accumulation in the same sector. The growth rates of consumption, investment and output of the environmentally friendly sector are marginally higher in the long run. However, this difference is insufficient to bridge the initial gap and implement the structural changes necessary to face the climate emergency within the time frame considered.

The alternative scenarios indicate that environmental innovation could contribute to the mitigation of climate change while promoting growth and employment in the Italian economy. However, in the context of sluggish demand and fragmented markets, the expansionary effects are contained. A 25% increase in the productivity of the less polluting sector produces only a modest rise in consumption and investment in the same sector over the entire simulation period (5–6%). Therefore, the final increase in output is marginal (3%). However, the hours worked in the same sector are considerably reduced (22%). Since the growth rate of productivity is constant in the more polluting sector, the decrease in consumption, investment, hours worked, and output is marginal. The redistributive effects are also unimportant.

A change in consumer preferences in favour of the environmental creditors has far more important effects than an increase in productivity. A 25% increase in the share parameter of the utility function generates a 50% rise in the household consumption of environmentally friendly products over the entire simulation period. The rise in both demand and profitability fosters capital accumulation in the less polluting sector, resulting in a 43% increase in investment over the same period. The final increase in output and hours worked is important (25%). The opposite occurs in the more polluting sector, where consumption declines and the erosion in profitability depresses capital accumulation. However, the loss of output and hours worked remains modest (5%). The redistributive effects are also more evident in this scenario. The environmental creditors capture the largest share of private consumption at the end of the simulation (52%) and control an important share of investment (28%) and output (32%). The increase in the share of hours worked is less significant (20%).

The results of the simulations underline the importance of consumer preferences and demand. The role of demand and preferences is neglected in most macroeconomic studies that focus on variations in productivity. However, in a context of economic stagnation and low competitiveness, an increase in productivity may not be transferred to consumers through price reductions and therefore be insufficient to support an expansion in demand. Furthermore, the role of demand as an engine of growth, employment and capital accumulation is usually underestimated. However, the results of this study suggest that a change in preferences in favour of environmentally friendly goods can have important effects on demand, growth, and employment in the context of the Italian economy. Therefore, policies to raise consumer awareness and support for investment in research and development of quality products with a reduced environmental impact could be decisive.

7 Conclusion

The simulation conducted over the period 1995–2050 indicates that the differences in the initial endowments and in the structural characteristics between sectors prevent the restructuring of the Italian economy towards the less polluting industries. The role of demand in driving capital accumulation and prices is more important in the less polluting sector. However, the low levels of capital stock and target rate of capacity utilisation constrain its ability to foster demand and growth. The adoption of targeted policies that support demand and the controlled expansion of production capacity could accelerate the growth of the less polluting sector without generating excess inflation.

The role of demand and consumer preferences emerges also in the alternative scenarios. An increase in the rate of productivity growth in the environmentally friendly sector expands consumption through slowing inflation. However, the resulting increase in markup in the same sector contains the effect on prices, resulting in a modest increase in output and a significant loss of hours worked. Conversely, a change in preferences in favour of environmentally friendly products fosters demand and capital accumulation in the same sector, with modest losses in the more polluting sector. Furthermore, it prevents the decline in hours worked associated with a faster increase in productivity in the environmentally friendly sector. In conclusion, the prolonged slowdown in demand and the scarce competitiveness of the Italian economy contains the positive effects of an increase in productivity on demand and growth. In this context, policies that promote the qualitative improvement of environmentally friendly products and raise consumer awareness of the effects of climate change could be more effective in stimulating demand, growth, and employment.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00191-023-00827-5.

Acknowledgements I sincerely appreciate the time and effort that the reviewers dedicated to providing feedback on my manuscript and am grateful for the insightful comments, constructive suggestions, and valuable improvements to my paper.

Funding This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability The data that support the findings of this study are available from the corresponding author upon request.

Declarations

Competing interests The author certifies that she has no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethical conduct This article does not contain any studies with animals performed by the authors.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Acemoglu D, Aghion P, Bursztyn L, Hemous D (2012) The environment and directed technical change. Am Econ Rev 102(1):131–166. https://doi.org/10.1093/oxrep/gru031

IPCC (2018) Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. In: Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla P.R, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews J.B.R, Chen Y, Zhou X, Gomis M.I, Lonnoy E, Maycock T, Tignor M, Waterfield T (eds). Cambridge University Press, Cambridge, UK and New York, NY, USA, pp 616. https://doi.org/10.1017/9781009157940
Andries P, Stephan U (2019) Environmental innovation and firm performance: How firm size and motives matter. Sustainability 11(3585):. https://doi.org/10.3390/su11133585
Antonucci T, Pianta M (2002) Employment Effects of Product and Process Innovation in Europe. Int Rev Appl Econ 16(3):295–307. https://doi.org/10.1080/02692170210136127
Barbieri N, Ghisetti C, Gilli M, Marin G, Nicolli F (2016) A survey of the literature on environmental innovation based on main path analysis. J Econ Surv 30(3):596–623. https://doi.org/10.1111/joes.12149
Bhaduri A, Marglin S (1990) Unemployment and the real wage: the economic basis for contesting political ideologies. Cambridge J Econ 14:375–393. https://doi.org/10.1093/oxfordjournals.cje.a035141
Borghesi S, Costantini V, Crespi F, Mazzanti M (2013) Environmental innovation and socio-economic dynamics in institutional and policy contexts. J Evol Econ 23(2):241–245. https://doi.org/10.1007/s00191-013-0309-5
Bowles S, Boyer R (1995) Wages, aggregate demand, and employment in an open economy: an empirical investigation. In Macroeconomic policy after the conservative era: studies in investment, saving and finance. Cambridge University Press, Cambridge, pp 143–171
Carrión-Flores CE, Innes R (2010) Environmental innovation and environmental performance. J Environ Econ Manag 59(1):27–42. https://doi.org/10.1016/j.jeem.2009.05.003
Dawkins C, Srinivasan TN, Whalley J (2001) Chapter 58 Calibration. In Handbook of Econometrics, 5th edn. Elsevier B.V., Cambridge, pp 3653–3703. https://doi.org/10.1016/S1573-4412(01)05011-5
Dietzenbacher E, Los B, Stehrer R, Timmer M, de Vries G (2013) The Construction of World Input-Output Tables in the WIOD Project. Econ Syst Res 25(1):71–98. https://doi.org/10.1080/09535314.2012.761180
EEA (2019) Annual European Union greenhouse gas inventory 1990–2017 and inventory report 2019. Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. (Report No 6/2019). European Environment Agency's (EEA) European Topic Centre on Climate Change Mitigation and Energy (ETC/CME), pp 962. https://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2019
European Commission (2011) Roadmap to a Resource Efficient Europe COM(2011) 571. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Roadmap to a Resource Efficient Europe (Document No. 52011DC0571). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0571
European Commission (2016) The Joint Harmonised EU Programme of Business and Consumer Surveys. User Guide, Directorate-General for Economic and Financial Affairs. https://ec.europa.eu/economy_finance/db_indicators/surveys/documents/bcs_user_guide_en.pdf
Fessler P, Rumler F, Schwarz G (2014) A micro-based non-inflationary rate of capacity utilisation as a measure of inflationary pressure: evidence for Austria. Empirica 41:23–36. https://doi.org/10.1007/s10663-013-9230-2
Franz W, Gordon RJ (1993) German and American wage and price dynamics. Differences and common themes. Eur Econ Rev 37(4):719–754.https://doi.org/10.1016/0014-2921(93)90084-N
Genty A (2012) Final database of environmental satellite accounts: technical report on their compilation, WIOD Deliverable 4.6. https://www.rug.nl/ggdc/valuechain/wiod/wiod-2013-release?lang=en
Glyn A (1997) Does aggregate profitability really matter? Cambridge J Econ 21(5):593–619. https://doi.org/10.1093/oxfordjournals.cje.a013688
Hein E, Ochsen C (2003) Regimes of Interest Rates, Income Shares, Savings and Investment: a Kaleckian Model and Empirical Estimations for some Advanced OECD Economies. Metroeconomica 54(4):404–433. https://doi.org/10.1111/1467-999X.00173
Hein E, Vogel L (2007) Distribution and growth reconsidered: empirical results for six OECD countries. Cambridge J Econ 32(3):479–511. https://doi.org/10.1093/cje/bem047

Hein E, Vogel L (2009) Distribution and Growth in France and Germany: Single Equation Estimations and Model Simulations Based on the Bhaduri/Marglin Model. Rev Polit Econ 21(2):245–272. https://doi.org/10.1080/09538250902834053

Hoover KD (1995) Facts and Artifacts: Calibration and the empirical assessment of real-business-cycle models. Oxford Economic Papers New Series 47(1):24–44. https://www.jstor.org/stable/2663662

Horbach J (2008) Determinants of environmental innovation-New evidence from German panel data sources. Res Policy 37(1):163–173. https://doi.org/10.1016/j.respol.2007.08.006

Horbach J (2010) The impact of innovation activities on employment in the environmental sector – empirical results for germany at the firm level. J Econ Stat 230(4):403–419. https://doi.org/10.1515/jbnst-2010-0403

Horbach J, Rennings K (2013) Environmental innovation and employment dynamics in different technology fields - An analysis based on the German community innovation survey 2009. J Clean Prod 57:158–165. https://doi.org/10.1016/j.jclepro.2013.05.034

IPCC (2019a) Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. In: Shukla PR, Skea J, Calvo Buendia E, Masson-Delmotte V, Pörtner H-O, Roberts DC, Zhai P, Slade R, Connors S, van Diemen R, Ferrat M, Haughey E, Luz , Neogi S, Pathak M, Petzold J, Portugal Pereira J, Vyas P, Huntley E, Kissick K, Belkacemi M, Malley J (eds). https://www.ipcc.ch/srccl/

IPCC (2019b) IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. In: Pörtner H-O, Roberts D.C, Masson-Delmotte V, Zhai P, Tignor M, Poloczanska E, Mintenbeck K, Alegría A, Nicolai M, Okem A, Petzold J, Rama B, Weyer NM (eds). Cambridge University Press, Cambridge, UK and New York, NY, USA, pp 755. https://doi.org/10.1017/9781009157964

ISTAT (2019) Rapport Annuale 2019. La situazione del Paese. Istituto di Stastistica Nazionale.https://www.istat.it/storage/rapporto-annuale/2019/Rapportoannuale2019.pdf

Köberl EM, Lein SM (2011) The NIRCU and the Phillips curve: an approach based on micro data. Can J Econ 44(2):673–694. https://doi.org/10.1111/j.1540-5982.2011.01649.x

Lanzi E, Sue Wing I, Carraro C, De Cian E, Hascic I, Johnstone N (2011) Directed Technical Change in the Energy Sector: an Empirical Test of Induced Directed Innovation. SURED Conference Proceedings 2010, pp. 1-31. https://ethz.ch/content/dam/ethz/special-interest/mtec/cer-eth/resource-econ-dam/documents/research/sured/sured-2010/SURED-10_142_Lanzi_Wing.pdf

Malikov E, Sun K, Kumbhakar SC (2018) Nonparametric estimates of the clean and dirty energy substitutability. Econ Lett 168:118–122. https://doi.org/10.1016/j.econlet.2018.04.017

Naastepad CWM (2006) Technology, demand and distribution: a cumulative growth model with an application to the Dutch productivity growth slowdown. Cambridge J Econ 30:403–434. https://doi.org/10.1093/cje/bei063

Nahuis NJ (2003) An alternative demand indicator: The "non-accelerating inflation rate of capacity utilization." Appl Econ 35(11):1339–1344. https://doi.org/10.1080/0003684032000095947

Papageorgiou C, Saam M, Schulte P (2017) Substitution between clean and dirty energy inputs: a macroeconomic perspective. Rev Econ Stat 99(2):281–290. https://doi.org/10.1162/REST

Pelli M (2012) The Elasticity of Substitution between Clean and Dirty Inputs in the Production of Electricity. SURED Conference Proceedings 2012, pp. 1–40. https://ethz.ch/content/dam/ethz/special-interest/mtec/cer-eth/resource-econ-dam/documents/research/sured/sured-2012/SURED-12_086_Pelli.pdf

Pianta M (2003) Innovation and Employment. In Handbook of Innovation. Oxford University Press, Oxford. https://doi.org/10.1109/EMR.1975.4306441

Popp D (2004) ENTICE: Endogenous technological change in the DICE model of global warming. J Environ Econ Manag 48(1):742–768. https://doi.org/10.1016/j.jeem.2003.09.002

Porter ME, van der Linde C (1995) Toward a New Conception of the Environment-Competitiveness Relationship. J Econ Perspect 9(4):97–118. https://doi.org/10.1257/jep.9.4.97

Rennings K, Markewitz P, Vögele S (2013) How clean is clean? Incremental versus radical technological change in coal-fired power plants. J Evol Econ 23(2):331–355. https://doi.org/10.1007/s00191-010-0198-9

IPCC (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 996. https://www.ipcc.ch/report/ar4/wg1/

Stockhammer E (2009) Functional income distribution and aggregate demand in the euro area. Cambridge J Econ 33(1):139–159. https://doi.org/10.1093/cje/ben026
Stockhammer E, Ederer S (2008) Demand effects of the falling wage share in Austria. Empirica 35(5):481–502. https://doi.org/10.1007/s10663-008-9069-0
Stockhammer E, Hein E, Grafl L (2011) Globalization and the effects of changes in functional income distribution on aggregate demand in Germany. Int Rev Appl Econ 25(1):1–23. https://doi.org/10.1080/02692170903426096
Storm S, Naastepad CWM (2006). OECD demand regimes (1960–2000). J Post Keynesian Econ 7(2):. https://doi.org/10.2753/PKE0160-3477290203
Taylor L (1990) Socially relevant policy analysis structuralist computable general equilibrium models for the developing world. MIT Press, Cambridge
Taylor L (2004) Reconstructing Macroeconomics: Structuralist Proposals and Critiques of the Mainstream. Harvard University Press. https://doi.org/10.2307/j.ctv1q16rzr
Timmer MP, Dietzenbacher E, Los B, Stehrer R, de Vries GJ (2015) An illustrated user guide to the world input–output database: the case of global automotive production. Rev Int Econ 23:575–605. https://doi.org/10.1111/roie.12178
Töbelmann D, Wendler T (2020) The impact of environmental innovation on carbon dioxide emissions. J Clean Product 244:.https://doi.org/10.1016/j.jclepro.2019.118787
Vivarelli M (2007) Innovation and Employment: A Survey. IZA Discussion Paper No. 2621. SSRN Electronic Journal. https://ssrn.com/abstract=969621 or http://dx.doi.org/10.2139/ssrn.969621
Watson MW (1993) Measures of Fit for Calibrated Models. J Polit Econ 101(6):1011–1041 (https://www.jstor.org/stable/2138570)
WMO (2018) WMO Greenhouse Gas Bulletin (GHG Bulletin) - No.14: The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2017. World Meteorological Organization. https://library.wmo.int/doc_num.php?explnum_id=5455

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.