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Green policy and diversity of consumers' environmental intentions and behavior

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Abstract

This paper considers the intention-behavior gap, i.e., only a proportion of environmentally conscious individuals translate their purchasing intentions into actual demand, and explores how carbon tax and selective R&D subsidy affect individuals' incentives for human capital accumulation, wage inequality between both unskilled and skilled workers and among skilled workers, and growth. The results show that when a tighter carbon tax regime is implemented, a positive or negative relationship between wage inequality and growth may emerge depending on the intensity of the intention-behavior gap and the relative mark-up value of better quality products and better environmental quality products. A simulation analysis of the U.S. economy confirms the results and shows that a higher step size of innovation of climate-friendly products shortens the time needed to take an environmental sustainable path, even when the intention-behavior gap is large.

Keywords: Endogenous Technological Change; Pollution abatement; Inequality; Growth.

JEL Classification: I240; O300; O440; Q580.

1 Introduction

It is a widely accepted view that the negative consequences of climate change are numerous and wide-ranging. The COP26 in Glasgow decision calls on countries to "revisit and strengthen" their 2030 targets to align them with the Paris Agreement by limiting the temperature increase to 1.5^{o}C above pre-industrial levels. One approach that has been put forward as a means of achieving these

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objectives is the notion of green growth, a concept often associated with technological progress to make growth more cleaner and resilient.[1]

In this respect, a report by the Commission on Carbon Pricing (Prices, 2017) explains that producing cleaner technologies is a human capital intensive activity so that education decisions become closely interlinked with environmental policies. Indeed, there is strong evidence supporting the links between education and the determinants of growth in terms of investment in technology and in generating innovation itself, and there also is large empirical evidence that climate change policies induce innovation in environment-friendly technologies (see, among others, Stern and Valero, 2021; Valero, 2021; Dechezleprêtre et al., 2019; Dechezleprêtre and Popp, 2015; Popp, 2010; Holdren, 2006). However, a prevailing debate is about a conflict between environmental and equality concerns of workers with different skills and human capital accumulation (see, e.g., Aloi and Tournemaine, 2013; Serret and Johnstone, 2006 for a thorough analysis of this issue and related policy implications). In this context, therefore, connecting growth, human capital accumulation, and environmental quality requires a model where skilled and unskilled workers emerge from an individual's choice in response to environmental policy.[2]

However, the relevance of this debate has overshadowed the preferences and choices of individuals about the consumption of goods with a different environmental impact. In this respect, several empirical analyses have found that both preferences regarding climate issues and the willingness-to-pay to mitigate climate change by paying higher product prices are heterogeneously distributed among individuals (Layton and Brown, 2000; Hassett et al., 2009, 2010; Rausch et al., 2010; Wicker and Becken, 2013; Dienes, 2015; see, for a literature review, Allo and Loureiro, 2014).[3] In particular, empirical analyses show that a customer segment has emerged in recent decades known as environmentally conscious consumers or green consumers (see, among others, Wijekoon and Sabri, 2021; Leszczyńska, 2014; Moisander, 2007). However, most of this research work has revealed only a weak positive relationship between the attitude towards green purchasing and actual purchase behavior. Polls and surveys constantly show inconsistency between what consumers declare and what they actually do in terms of sustainable behavior. This inconsistency is well acknowledged in the literature and is referred to as the green attitude-behavior gap (Park and Lin, 2018), the green intention-behavior gap (Frank and Brock, 2018), or the motivation-behavior gap (Groening et al., 2018; see Elhaffar, 2020 for a litera-

[1] The OECD defines green growth as 'fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies'. See, Toman (2012) for a review of the different aspects of the definition of green growth.

[2] The OECD recognizes that "the success of a green growth strategy will also involve achieving smooth and just adjustment in labor markets by ensuring that workers have the means to find opportunity in change." (OECD, 2011, page 20).

[3] Many governments' efforts and goals are aimed at implementing environmental policies which typically come at a cost to both individuals and firms, i.e., higher taxes, higher product prices, higher fuel bills, etc. (see e.g., OECD, 2015; Popp, 2010; Holdren, 2006).

ture review).[4] Nowadays, despite environmental concern and positive attitudes of customers towards sustainability and green products, the market share of green products remains limited to just 7-8% of the global market (Market Research Report, 2021). These pastes become even more relevant because many governments' efforts and goals are aimed at implementing environmental policies which typically come at a cost to both individuals and firms, i.e., higher taxes, higher product prices, higher fuel bills, etc. (see e.g., OECD, 2015; Popp, 2010; Holdren, 2006). As an example, recently the Plastic Packaging Tax (PPT) came into force in the UK on 1 April 2022, and it applies at a rate of £210.82/tonne on plastic packaging with less than 30% recycled plastic, manufactured or imported into the UK (including packaging on goods which are imported). The Decision (EU, Euratom) n. 2020/2053 of 14 December 2020 made available to the Commission a new category of own resources based on national contributions calculated on the basis of non-recycled plastic packaging waste in each Member State, the rate of which had been set at 0,80 euro/Kg. Due to that, some countries have decided to introduce their own plastic tax. Spain, for example, is now launching a plastic tax on single-use plastic packaging starting from 2023.

This paper takes account of the intention-behavior gap and explores how carbon tax, or more generally environmentally related taxes (henceforth: ERT), and selective R&D subsidies affect individuals' incentives for human capital accumulation, wage inequality between both unskilled and skilled workers and among skilled workers, and the growth performance of the economy. To this aim, in the tradition of the Schumpeterian growth literature (see e.g., Grossman and Helpman, 1991; Aghion and Howitt, 1992; Jones 1995; Howitt, 1999), and building on Dinopoulos and Segerstrom (1999), an R&D-driven growth model in which each individual may choose to be either an unskilled or a skilled worker through endogenous educational choices is adopted. In the manufacturing sector, energy and labor contribute to the production of final varieties that are the target of purposeful R&D efforts aimed at improving both the quality services and the environmental quality services of each variety. During the production stage, any degree of substitution between labor and energy is allowed.

To take account of the intention-behavior gap, we consider that individuals' care about the environmental quality of consumption goods, and yet only a proportion of environmentally conscious individuals translate their purchasing intentions into actual demand.[5]

[4] As a result, purchasing behavior models tend to be supplemented by a number of other cognitive factors (e.g., environmental concern, environmental knowledge, environmental and social consciousness, environmental literacy, perceived consumer effectiveness, self-efficacy, self-construal, equity sensitivity, consumption value perceptions, consideration of future consequences and value orientation). According to the latest studies, environmental concern is one of the strongest antecedents of attitude towards green products and/or green purchase intention (see e.g., Joshia and Rahmanb, 2015).

[5] This implies that market *size* of good providing better quality services is higher than that of goods providing better environmental quality services. Yet, the analysis considers that firms producing better environmental quality products may have a relatively high or low market *share* depending on whether the intention-behavior gap is correspondingly low or wide.

The results show that when firms producing better quality products have a higher step size of innovation, they charge a higher mark up value and they earn higher profits. Because the intention-behavior gap also implies a higher market size of these firms, its intensity does not affect the qualitative effects of a tighter ERT on the economic performance. Indeed, tighter ERT increases the price charged to consumers due to the tighter tax and reduces the demand of the goods. This in turn also reduces the total cost of production. In this case, the positive cost reduction effect outweighs the negative quantity effect and the profits of firms increase. Since firms producing better quality products charge a higher mark up value, their profits increase relatively more than those of firms producing better environmental quality products. Consequently, the innovative firms that aim to market better environmental quality versions of products, and that expect to gain relatively lower profits, obtain a higher R&D subsidy to sustain their innovative projects. In the aggregate, the combination of these effects results in a higher demand of skilled labor, and this increases wage inequality between both unskilled and skilled workers and among skilled workers, the individuals' incentives for human capital accumulation, and the per capita growth rate.

However, when firms producing better environmental quality service products have a higher step size of innovation, they charge a higher mark-up value. Since the intention-behavior gap also implies a lower market share for these products, its intensity generates different effects on individuals' incentives for human capital accumulation, wage inequality, and the per capita growth rate when a tighter ERT is implemented.

When the intention-behavior gap is large, firms that produce better quality products have a relatively high market share and they earn higher profits. Tighter ERT increases the price charged to consumers because of the higher tax and reduces the demand for goods. However, in this case because the best quality products have a lower mark up value and a very high market share (the intention-behavior gap is large), the increase in the tax implies a very low decrease in aggregate demand for goods and in total cost of production. In the aggregate, the negative quantity effect outweighs the positive cost reduction effect and the profits of firms decrease. This results in a lower demand for skilled labor and in lower skill premium that reduces the unit cost of the R&D effort. Consequently, the selective R&D subsidy paid to better environmental quality service innovations becomes lower. In the aggregate, this results in a lower demand for skilled labor, lower wage inequality between both unskilled and skilled workers and among skilled workers, lower individuals' incentives for human capital accumulation, and a lower aggregate innovation rate.

On the contrary, when the intention-behavior gap is low, firms producing better environmental quality products have a relatively high market share and gain higher profits. Tighter ERT generates the same mechanisms described for the previous scenario. Yet, in this case the innovative firms that aim to market better quality versions of products and that expect to gain lower profits obtain a higher R&D subsidy to sustain their innovative projects. In the aggregate, the positive effect of a higher R&D subsidy paid to better quality innovative firms offsets the lower expected profit flows of innovative firm introducing better environmental quality versions of products, and this spurs the demand for skilled labor, individuals' incentives for human capital accumulation and wage inequality between both unskilled and skilled workers and among skilled workers. Yet, the aggregate innovation rate and the growth rate of GDP per capita remain approximately constant because the low intention-behavior gap implies that the market share of better quality products and better environmental quality products are closer each other, and the lower innovation incentive of firms producing better environmental products offsets the higher innovation incentive of firms producing better quality products.

It is worth noting that, in each scenario, the ERT and the selective R&D subsidy allow the time needed to achieve environmental sustainability to be shortened, even in the presence of a large intention-behavior gap in the economy.

Moreover, the effects of different intensities of the intention-behavior gap - i.e., different proportions of environmentally conscious individuals who translate their purchasing intentions into actual demand - on individuals' incentives for human capital accumulation, wage inequality, and growth, for a given carbon tax, are also analyzed. The results show that when firms producing better quality products gain higher profits than firms producing better environmental quality products and the intention-behavior gap becomes larger in the economy, the competitive advantage of firms producing better quality products increases, and their profits become higher. Consequently, the innovative firms that aim to market better environmental quality versions of products and that expect to gain lower profits, obtain a higher R&D subsidy to sustain their innovative projects. In the aggregate, the combination of these effects increases the aggregate demand for skilled workers, wage inequality between unskilled and skilled workers, individuals' incentives for human capital accumulation, and the aggregate innovation rate, i.e., a positive relationship between wage inequality and growth is found. On the contrary, in the scenarios where firms producing better environmental quality products gain higher profits than firms producing better quality products, a larger intention-behavior gap in the economy erodes the competitive advantage of firms providing better environmental quality services, and their profits are correspondingly lower, while the profits of firms producing better quality products are higher because their relative market share becomes higher when the intention-behavior gap becomes larger. This implies a reduction in the gap between the profits of better environmental quality products and those of better quality products that generates a lower selective R&D subsidy paid to sustain the innovative effort of firms. In the aggregate, the combination of these opposite effects results in lower demand for skilled workers, lower wage inequality between both unskilled and skilled workers and among skilled workers, lower individuals' incentives for human capital accumulation, while the growth rate per capita can be higher. This is the case when the R&D subsidy is paid to innovative firms that introduce better quality services products because such an R&D subsidy reinforces the innovation incentives of these firms that obtain a higher relative market share when the intention-behavior gap becomes larger. Therefore, a negative relationship between wage inequality and growth is found in this case.[6]

The rest of the paper is organized as follows. Section 2 links the paper to the related literature. Section 3 sets up the model and describes the BGP equilibrium. In Section 4, comparative static and calibration analyses of the model for the U.S. economy are carried out and policy results are obtained while Section 5 draws some conclusions.

2 Related Literature

This paper contributes to the existing literature which deals with the effects of environmental-related tax on individuals' educational choice, wage inequality, and endogenous technological innovations. Over the last 15 years, more and more emphasis has been placed on the role of endogenous technological change in analyzing how green growth can be obtained with climate policies. This literature is very extensive and any attempt at summarizing it would do injustice to many worthy contributions (see e.g., Xepapadeas, 2000; Brock, Taylor, 2005; Ricci 2007; Gillingham, Newer, and Pizer, 2008; Popp, Newell, and Jaffe, 2009, Bretschger 2017).[7]

In contrast with the large literature concerning theoretical models on environment and growth which use physical or knowledge capital, contributions focusing on education are less numerous. Human capital as an engine of growth was incorporated into growth theory by Uzawa (1965), refined by Lucas (1988), and later emphasized by Romer (1986, 1990) as an engine of the first strand of R&D-driven endogenous growth models.[8] The Uzawa-Lucas growth model was adapted to environmental economics by Hettich (1998) who considers leisure time and derives a positive growth effect of environmental taxation as a consequence of inputs being reallocated from polluting production to (clean) education. In a similar model, Oueslati (2002) analyzes both the short and long-run growth and welfare effect of an environmental tax and shows that households substitute education time for leisure time in order to counteract reduced consumption due to tighter environmental taxes, and this boosts growth. Bosi and Ragot (2013) compute the optimal policy in a continuous time endogenous growth model à la Lucas (1988) and derive a positive relationship between

[6]These results are magnified when a tighter tax burden on better environmental quality products is implemented.

[7]Other relevant questions refer to how future endogenous technologies can substitute decreasing energy use like fossil fuels (see e.g., Bretschger, 2017; Bretschger and Smulders, 2012; Peretto, 2009, 2012), and how the transition to renewable energy sources should optimally take place (see, among others, Acemoglu et al., 2016; Van der Ploeg and Withagen, 2011; Riechman et al., 2008). These topics are beyond the scope of this paper.

[8]In this literature, there has been a very important debate about the presence of counterfactual scale effects in the first-generation models, such as Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992). In response to this critique, subsequent generations of R&D-based growth models have been developed to remove the strong scale effect (i.e., a positive relationship between population size and long-run growth). See Jones (1999) for a review of these subsequent generations of R&D-based growth models. Strulik (2005) inserts endogenous human capital accumulation through education à la Lucas (1988) in an R&D-based endogenous model of the third type generation.

pollution and working time that competes with time for education. Recently, Borissov, Brausmann, and Bretschger (2019) hypothesized a positive human capital spillover in education à la Lucas (1988) and perfect substitutability between dirty and clean varieties, and demonstrate that a temporary environmental tax can permanently settle the economy in the clean steady-state equilibrium.

The relationship between climate change and pollution damages and the wage inequality between skilled and unskilled workers has attracted both empirical and theoretical analyses. Ohlendorf et al. (2020) present a meta-analysis of the empirical literature and conclude with mixed results. Jha, Mattwes and Muller (2019) argue that actual empirical analyses seem inconclusive also due to the multiple channels through which the environmental regulations, such as the Clean Air Act (CAA) in the U.S., affect firms and workers. Yet, their empirical analysis shows that stricter environmental regulation in the U.S. can exacerbate wage inequality even if it benefits most individuals and society as a whole. From a theoretical point of view, some relevant contributions analyze the interactions among health, inequality and pollution. Aloi and Tournemaine (2013) formalize a model in which pollution has a direct effect on human capital accumulation and find that a stricter environmental policy always reduces wage inequality, as lower-skilled individuals are assumed to be more affected by pollution, and that this policy can also improve growth if the tax is not too high. Recently, Constant (2019) analyzes the economic implications of an environmental policy taking account for the life expectancy where the health status also depends on individual human capital.[9] In contrast to the existing literature, this paper focuses on the interplay between human capital accumulation and the consumers' environmental concerns rather than on the health status of individuals. Recently, Aghion et al. (2023) develop a step-by-step innovation model to investigate the joint effect of consumers' environmental concerns and product-market competition on firms' decisions whether to innovate clean or dirty. Their results suggest that the combination of an increase in pro-social attitudes and product market competition can have the same effect on green innovation as major increase in fuel prices. Differently from Aghion et al. (2023) this paper considers consumers' environmental concerns and the largely documented intention-behavior gap for "purchasing green", and explores how a carbon tax and selective R&D subsidy affects firms' decisions whether to innovate clean or dirty, and also analyzes the effect on human capital accumulation and wage inequality between unskilled and skilled labor within a Schumpeterian growth model.[10]

[9] Constant (2019) also provides a review of the literature on health, inequality and pollution.

[10] This contribution does not build on the accumulation of physical capital in order to do justice to material balance principles (see e.g., Peretto 2009, Bretschger and Smulders 2012). Hémous and Olsen (2020) offer an excellent and commented review of the literature on directed technological change models in the environmental context.

3 Households

The model shares the same assumptions about consumer preferences and innovation processes with Dinopoulos and Segerstrom (1999) but differs because consumers care about the environmental impact of the goods they buy. As in Dinopoulos and Segerstrom (1999), households differ in the uniformly distributed personal ability $\theta \in [0,1]$ of their individual members to become skilled workers, and long-run intergenerational perfect persistence in the ability for human capital accumulation exists.[11] The size of each household grows at a constant and exogenous rate $n > 0$, so that total population at any time $t \geq 0$ is $N(t) = N(0)\, e^{nt}$, where $N(0) > 0$ is the initial population size. Each household provides labor services in exchange for wages and saves by holding assets of firms engaged in R&D. Each individual member of each household θ is endowed with a unit of labor which is inelastically supplied.

All households are assumed to have intertemporal additive separable rational preferences for a continuum set of varieties, indexed by $\omega \in [0,1]$, whose consumption may generate polluting emissions and climate change. The optimization problem of a family with ability θ is:

$$\underset{q_\theta(\bullet)}{Max} U_\theta \equiv \int_0^\infty N(0) e^{-(\rho-n)s} \ln u_\theta(s)\, ds \tag{1}$$

subject to the following constraints:

$$\ln u_\theta(s) \equiv \int_0^1 \ln\left(\sum_j \sum_i \lambda^j_{(\omega,s)} q_\theta(j,i,\omega,s) \max\left(\frac{1}{ea^i_{(\omega,s)}}, 1\right)\right) d\omega, \tag{2}$$

$$c_\theta(s) \equiv \int_0^1 p(j,i,\omega,s)\, q_\theta(j,i,\omega,s)\, d\omega, \tag{3}$$

$$W_\theta(t) + Z_\theta(t) = \int_t^\infty N_0 e^{-\int_t^s [r(v)-n]dv} c_\theta(s)\, ds. \tag{4}$$

Eq. (1) is the discounted utility of a household with ability θ, $\rho > 0$ is the subjective intertemporal utility discount rate, with $\rho > n$. Eq. (2) is the instantaneous utility. A few remarks are useful here for eq. (2). $q_\theta(j,i,\omega,s)$ denotes the quantity consumed by an individual with ability $\theta \in [0,1]$ of a good ω at

[11] As stated in Dinopoulos and Segerstrom (1999) there is a continuum of households indexed by ability $\theta \in [0,1]$. All members of household θ have the same ability level equal to θ, and all households have the same number of members at each point in time. The intergenerational persistence of human capital has been also used by Glomm and Ravikumar (1992), De la Croix and Doepke (2003), and Borissov, Brausmann, and Bretschger (2019). Recently, Adermon, Lindahl and Palme (2021) provide a framework for estimating long-run intergenerational persistence using direct measures based on observed extended family relations (the dynasty) of the entire Swedish population. Using various human capital measures, the authors show that traditional parent-child estimates underestimate long-run intergenerational persistence by at least one-third. The results of Adermon, Lindahl and Palme (2021) are found to be robust to different extensions to the main analysis.

time $s \geq 0$. $j \in \{0, 1, 2, ...\}$ indicates the improvements of the quality services of the good ω and $i \in \{0, 1, 2, ...\}$ denotes the improvements of the environmental quality services of the good ω. The parameter $\lambda > 1$ captures the size of each quality service improvement. The variable e captures the quantity of CO_2-equivalent polluting emissions per each unit of product $\omega \in [0, 1]$, parameter $a \in (0, 1)$ captures the abatement of the polluting emissions. Therefore, $ea^i_{(\omega,s)}$ denotes actual polluting emissions and $\frac{1}{ea^i_{(\omega,s)}}$ denotes the environmental quality services of each variety ω at time $s \geq 0$. In other words, $\frac{1}{a} > 1$ captures the size of each environmental quality service improvement. To simplify exposition, symmetry across varieties is assumed so that the quantity of polluting emissions is the same for each variety and it is normalized to a constant value, i.e., $e = 1$ for each $\omega \in [0, 1]$.[12] As in Aghion et al. (2023), these preferences embody a form of ethical motivation. The individual's contribution to aggregate emissions is negligible, i.e., does not affect the quality of the environment, and yet she might intrinsically dislike contributing to this type of negative externality. The individual might feels guilty (socially embarrassed) about the pollution she contributes to generate when consuming, and therefore is willing to pay a sort of premium for cleaner consumption goods. This aspect will be further clarified shortly.[13]

Eq. (3) defines the consumption value for an individual with ability θ, $c_\theta(s)$ is the nominal expenditure, $p(j, i, \omega, s)$ is the price of good ω of quality services j and environmental quality i at time s. Eq. (4) is the intertemporal budget constraint for each individual with ability θ, $W_\theta(t)$ is the family's discounted wage income from time t on, and $Z_\theta(t)$ is the value of the family's financial assets at time t.

Following the same steps as in Dinopoulos and Segerstrom (1999), the problem of a household with ability θ can be solved in three steps. First, maximizing sub-utility (2) subject to the expenditure constraint (3) yields a unit elastic demand function for the product(s) in each variety with the lowest-quality adjusted price. Because all products within a variety ω are perfect substitutes by assumption, only the product(s) with the lowest-quality adjusted price are purchased by consumers.

Second, maximizing discounted utility (1) subject to the intertemporal budget constraint (4), we obtain the usual intertemporal optimization condition for

[12] The model can account for a heterogenous quantity of CO_2-equivalent polluting emissions $e(\omega)$ per unit of product and the analysis and results still hold. Moreover, when the actual polluting emissions get the 'safe value' $\hat{e}$ and no damage to the environment is generated, i.e., if $a^i_{(\omega,s)} e_\omega \leq \hat{e} \in (0, 1)$ the consumption of variety a ω generates no damage to the environment. To simplify exposition and with no loss of generality in both analysis and results, homogeneity across all varieties is assumed.

[13] We assume that households also differ in their willingness to pay η for the environmental quality services of the product distributed in $[0, 1]$ according to any continuous cumulative distribution function (cdf) $F(\eta)$ with usual properties $F^{'}(\eta) > 0$, $F(0) = 0$, $F(1) = 1$. Therefore, each household is described by the pair (θ, η). It is assumed that the individual's type η and personal ability θ are independently distributed. To simplify notation and exposition we omit the household's index η here, and it will be reconsidered later when useful for the comprehension of the paper. No insights is lost in the meantime.

the per capita consumption

$$\frac{\dot{c}_{\theta}(t)}{c_{\theta}(t)} = r(t) - \rho \tag{5}$$

Third, training/employment decisions are made to maximize each family's discounted wage income. As in Dinopoulos and Segerstrom (1999), the supply of unskilled labor at time t is (see Appendix A1)

$$L(t) = \theta_0 N(t) = \left(\sigma \frac{w_L}{w_H} + \gamma\right) N(t), \tag{6}$$

and the supply of skilled labor at time t is

$$H(t) = (\theta_0 + 1 - 2\gamma)(1 - \theta_0) \frac{\psi}{2} N(t), \tag{7}$$

where θ_0 is the ability threshold which renders an individual indifferent to becoming skilled or to remaining unskilled for all her life, $\psi = \left(e^{n(D-T)}\right) / \left(e^{nD} - 1\right) < 1$ $\sigma \equiv \left(1 - e^{-\rho D}\right) / \left(e^{-\rho T} - e^{-\rho D}\right)$ and γ is the minimum ability level that allows human capital accumulation, i.e., an individual with ability $\theta > \theta_0$ will decide to train and will accumulate quantity $(\theta - \gamma)$ of human capital.[14] The higher the individual ability, the higher the accumulated human capital and the higher the total amount of wages earned by the individual. Intertemporal budget constraint in eq. (4) implies that an individual with higher ability will benefit from a higher consumption flow. Along the BGP the growth rate of both unskilled and skilled labor is equal to n.

3.1 Demand and the intention-behavior gap

In light of instantaneous household preferences, the consumer θ demand quantity for each best quality services product $q_{\theta}^{q}(\omega, t)$ is

$$q_{\theta}^{q}(\omega, t) \equiv \frac{c_{\theta}(t)}{p_{\omega}^{q}}, \tag{8}$$

where p_{ω}^{q} is the price of the best quality services product. Summing up the demand for each product $\omega \in [0, 1]$ for the entire population, the total demand quantity for each best quality services product is:

$$q^{q}(\omega, t) \equiv \frac{c(t) N(t)}{p_{\omega}^{q}}, \tag{9}$$

where $c(t) \equiv \int_0^1 c_{\theta}(t) \, d\theta$ indicates the per capita consumption fraction of each variety ω.

[14] Dinopoulos and Segerstrom (1999) interpret γ as a wage dispersion parameter, with higher γ associated with larger percentage differences between the wages of highest and lowest paid skilled workers (see footnote 13 in Dinopoulos and Segerstrom, 1999).

To take account of the intention-behavior gap, we consider that only a share of consumers who care about the environmental quality of products translates their purchasing intentions into actual demand. We model this aspect in the simplest way for the purposes of this paper. In particular, while individuals care about the environmental impact of the goods they consume, they differ in the willingness to pay for the environmental quality services of the products, and this heterogenous willingness to pay η is distributed in $[0,1]$ according to any continuous cumulative distribution function (cdf) $F(\eta)$ with usual properties $F'(\eta) > 0$, $F(0) = 0$, $F(1) = 1$. It is assumed that the individual's type η and personal ability θ are independently distributed. The individual type η is private information, and its cumulative distribution function across households is assumed to be common knowledge. All members of household η have the same willingness to pay level equal to η, and all households have the same number of members at each point in time.[15] Once a new version of a product with better environmental quality services is produced, the demand of this top environmental quality product of all individuals' type $\eta \leq a$ is zero in equilibrium, and $(1 - F(a))$ is the population share with a strictly positive demand for the state-of-the-art environmental quality products (see Appendices A2 and A3). This aspect captures the intention-behavior gap in the model set-up.

Therefore, in light of instantaneous household preferences the consumer θ with environmental concerns $\eta > a$ demand quantity for each best environmental quality services product $q_\theta^a(\omega, t)$ is:

$$q_\theta^a(\omega, t) \equiv \frac{c_\theta(t)}{p_\omega^a}, \tag{10}$$

where p_ω^a is the price (gross of the tax burden) of the best environmental quality product. Summing up the demand for each product $\omega \in [0,1]$ for the share of population that translates their purchasing intentions into actual demand, i.e., for all individuals θ with environmental concerns $\eta > a$, the total demand quantity for each best environmental quality product is:

$$q^a(\omega, t) \equiv \frac{c(t) N(t) (1 - F(a))}{p_\omega^a}, \tag{11}$$

where $(1 - F(a))$ is the population fraction that translates the purchasing intentions into actual demand for the state-of-the-art environmental quality product ω. Therefore, the lower $(1 - F(a))$ the larger the intention-behavior gap is.

3.2 Manufacturing

Following the R&D-driven endogenous growth literature (see e.g. Grossman and Helpman, 1991; Aghion and Howitt, 1992) production of the top quality of each

[15] Empirical analyses show that heterogeneous preferences of the public's WTP to mitigate climate change are quite stable under very different time horizon of climate change mitigation intervention. In particular, considering two time horizons, a near-term impact of 60 years and a longer-term impact with a 150-year horizon, Layton and Brown (2000) show that the preferences elicited for the two vastly different time horizons are the same.

variety is conducted by monopolistic firms which are protected by a perfectly enforceable patent law, or intellectual property rights (IPR) in general. Firms produce each variety ω of the second-best quality services and environmental quality under a constant returns to scale (CRS) technology by means of both labor and energy. The inputs of the manufacturing production are acquired in perfectly competitive markets, and to save on space and with no loss of generality in the analysis, we consider the cost function of firms. To fix ideas, the unit cost function can be obtained from a CES production function with any degree of substitution between labor and energy.

As in Dinopoulos and Segerstrom (1999) manufacturing production is assumed to be more unskilled labor intensive than R&D, and to simplify exposition and with no loss of generality in both analysis and results, it is assumed that only unskilled labor is employed in the manufacturing sector. A firm in each variety ω has a constant unit cost function $mc\,(w_L, p_e)$, where p_e is the price of energy sources used by the manufacturing firm, taken as given in the manufacturing sector.[16] To simplify notation we denote the constant unit cost function with mc from now onward, so that the total cost of production of a variety ω is $mcq^l\,(\omega, t)$, where $l = \{q, a\}$ indicates the quality services and the environmental quality services respectively. The cost functions adopted here allows for any degree of substitution between labor and energy. Unskilled labor is assumed to be the numeraire of the economy so that $w_L = 1$ for each $t \geq 0$.

Since symmetry across varieties is assumed, the quantity of polluting emissions is the same for each variety $\omega \in [0, 1]$. Let τ be the tax value per unit of polluting emissions when no pollution abatement exists ($i^{\max} = 0$, where $i^{\max}$ denotes the number of innovations achieved at time t), and the per unit of product tax burden is τe. When improvements in the abatement of polluting emissions have been achieved ($i^{\max} \geq 1$), the tax is assumed to follow the same pace as pollution abatement innovations and the fiscal burden on actual emissions becomes $\left(\frac{\tau}{a^{i^{\max}}}\right) ea^{i^{\max}} = \tau$ for each variety ω. This tax scheme allows a balanced growth path (BGP) equilibrium to be taken.[17]

In light of the above, the price of a variety ω gross of the tax burden is $p^l_\omega = p_{n,\omega} + \tau$, where $l = \{q, a\}$ indicates the quality services and the environ-

[16] Empirical studies have shown that mineral prices, including oil, coal and natural gas, have either been roughly trendless over time or have been stationary around deterministic trends with infrequent structural breaks (Lin and Wagner, 2007). The model set-up can be extended in a simple way to include an upstream sector producing energy. However, this extension does not add new insights to the paper. When considering the energy sector, the analysis described in the next sections can be replicated and the results and policy implications hold along the BGP equilibrium.

[17] We can also consider that government gives a sort of fiscal premium to firms producing better environmental quality products. In this case, the fiscal burden on polluitng emissions becomes $\left(\frac{\tau}{a^{(i^{\max}-m)}}\right) ea^{i^{\max}}$, where $m \geq 0$ is a non-negative integer. For $m = 0$ the fiscal burden on polluting emissions becomes $\left(\frac{\tau}{a^{i^{\max}}}\right) ea^{i^{\max}} = \tau$ for each variety ω. For $m \geq 1$ the fiscal burden on polluting emissions of the top environmental quality product becomes $\left(\frac{\tau}{a^{(i^{\max}-m)}}\right) ea^{i^{\max}} = \tau a^m < \tau$. Therefore, the higher m is, the lower the environmental tax on the state-of-the-art environmental quality products is. The qualitative results of the paper hold when considering this extension.

mental quality services respectively, $p_{n,\omega}$ is the price net of the carbon tax. The incumbent firm solves the following maximization problem for instantaneous profit flows net of the tax burden:

$$\underset{q^l(\omega,t)}{Max}\left(p^l_{n,\omega}+\tau\right)q^l(\omega,t)-mcq^l(\omega,t)-q^l(\omega,t)\,\tau. \tag{12}$$

The above maximization problem reduces to:

$$\underset{q^l(\omega,t)}{Max}\; p^l_{n,\omega}q^l(\omega,t)-mcq^l(\omega,t) \tag{13}$$

where $e=1$ has been used.[18] When the innovation's target is an improvement in quality services, the solution to the maximization problem as in equation (13) implies $p^q_{\omega,n}=\lambda mc$, where λ is the mark-up on the marginal cost. When the innovation's target is an improvement in environmental quality services, the solution to the maximization problem as in equation (13) implies $p^a_{n,\omega}=\frac{mc}{a}$. Then, the price gross of the environmental tax on consumers respectively are $p^q_\omega=\lambda mc+\tau$ and $p^a_\omega=\frac{mc}{a}+\tau$ (see Appendix A2).

The stream of profits accruing to the monopolist who manufactures the state-of-the-art of the quality services and the environmental quality services of each variety ω respectively are therefore:

$$\pi^q(\omega,t)=(\lambda-1)\,mcq^q(\omega,t)\,, \tag{14}$$

and

$$\pi^a(\omega,t)=(1-F(a))\left(\frac{1}{a}-1\right)mcq^a(\omega,t)\,, \tag{15}$$

where the optimal aggregate demand of each variety is considered respectively as in equations (9) and (11), and $(1-F(a))$ is the population fraction with a strictly positive demand for the state-of-the-art environmental quality product ω.

3.3 R&D Sector

R&D activity is assumed to be more skilled labor intensive than manufacturing, and to simplify exposition it is assumed that skilled labor is the only input in the R&D sector. In quality ladder models, the next quality of a given variety is invented by the R&D that is performed by challenger researchers in order to replace the incumbent producer and gain monopolistic rents.[19] Here we refer to

[18] Spinesi (2022) studies the effects that a different share of a carbon tax charged to final consumption and production produces on wage inequality and growth within a Schumpeterian growth model. Such an analysis goes beyond the scope of the paper.

[19] As usual in quality ladder models à la Grossman and Helpman (1991) and Aghion and Howitt (1992), Arrow's effect is at work. Cozzi (2007) has proved that the standard Schumpeterian growth models are compatible with positive and finite R&D investment by the incumbent monopolist. All the analysis in this paper is compatible with Cozzi's (2007) findings. Therefore, this model allows for positive, yet non-strategic sighted, R&D investment by the incumbent monopolist.

each variety ω which can be targeted by quality services and environmental quality services. Every R&D firm f can produce an instantaneous Poisson arrival rate of innovation $I_f(\omega, t)$ in the variety $\omega \in [0, 1]$ it targets using CRS technology described by a unit cost function $b(1 - s_f) w_H X(\omega, t)$, with $b > 0$ common in all varieties, $s_f \in [0, 1)$ is the R&D subsidy paid to the innovating firms that aim to introducing the next best quality services product and the next best environmental quality product, and $X(\omega, t) > 0$ measuring the degree of complexity in the invention of the next quality/abatement improvement in variety $\omega \in [0, 1]$. The returns to R&D investment are independently distributed across firms, across varieties, and over time.[20] Due to CRS technology in R&D activity, the size of each R&D laboratory and their number remain undetermined. Given the unit cost function for the production of new ideas and innovations, the aggregate R&D labor intensity in each variety ω can be obtained by means of Shephard's lemma, i.e., $l(\omega, t) = \frac{\partial[b(1-s_f)w_H X(\omega,t)]}{\partial w_H} = b(1 - s_f) X(\omega, t)$.

The technological complexity argument as indexed by factor $X(\cdot)$ was introduced to R&D-based endogenous growth models after Charles Jones' (1995a,b) empirical criticism of the first strand of Schumpeterian endogenous growth models which showed the scale effects on per-capita output growth rate. To remove the strong scale effect, the "permanent effects on growth" (PEG) of policy measures specification for the law of motion of the technological complexity index suggested by Dinopoulos and Segerstrom (1999) is adopted:[21]

$$X(\omega, t) = kN(t) \tag{16}$$

with $k > 0$, thereby formalizing the idea that it is more difficult to introduce a new product line in a more crowded market.

It is assumed that each variety $\omega \in [0, 1]$ at each time $t \geq 0$ has a probability z and $(1 - z)$ to be targeted by quality services improvement and environmental quality services (pollution abatement services) improvement, respectively, and that these probabilities are independent across firms, across varieties, and over time. Therefore, looking at a variety ω over time, by the law of large numbers, z and $(1 - z)$ denote the share of quality services innovations and environmental quality service innovations along each variety $\omega \in [0, 1]$, respectively. At the same time, looking at all varieties ω at each time $t \geq 0$, z and $(1 - z)$ denote the share of varieties targeted by successful quality service innovations and environmental quality service innovations, respectively. In light of the above, the incumbent firm in each variety ω can be targeted by the next quality service improvement with probability z and it can be targeted by the next environmental quality service improvement with probability $(1 - z)$.

Let $v^l(\omega, t)$ denote the expected discounted profit flows of a successful firm in variety ω at time t, with $l = \{q, a\}$, denote the expected discounted profit flows of a successful quality leader in variety ω at time t producing the best

[20] Therefore, the arrival rate of innovation in variety ω at time t is $I(\omega, t) = \sum_f I_f(\omega, t)$, which represents the aggregate summation of the Poisson arrival rate of innovation produced by all R&D firms targeting product $\omega \in [0, 1]$.

[21] Such a dilution solution to the strong scale effect is the best way to fit the empirical evidence as proven in Madsen (2008).

quality services (q) and the best environmental quality services (a), respectively. $v^l(\omega,t)$ that can be written as (see Appendix A5):

$$v^l(\omega,t) = \frac{\pi^l(\omega,t)}{r + I(\omega,t) - n}, \tag{17}$$

where $I(\omega,t)$ is the aggregate Poisson arrival rate of innovation in variety ω at time t. Each R&D firm targeting variety $\omega \in [0,1]$ and aiming at discovering the next best quality services product chooses its R&D intensity to maximize $v^q(\omega,t) I_f^q(\omega,t) - b(1-s_q) w_H(t) X(\omega,t) I_f^q(\omega,t)$, where $s_q \in [0,1)$ is the uniform R&D subsidy paid to the firms that aim to introduce the next best quality services product. The R&D sector is characterized by a perfectly competitive environment, with free entry and exit and CRS technology. This implies that for all product lines ω targeted by positive R&D, the following no-arbitrage condition holds:

$$v^q(\omega,t) = \frac{\pi^q(\omega,t)}{\rho + I(\omega,t) - n} = b(1-s_q) w_H(t) X(\omega,t), \tag{18}$$

Repeating the same arguments as above for each R&D firm that aims at discover the next best environmental quality services product, the following no-arbitrage condition holds:

$$v^a(\omega,t) = \frac{\pi^a(\omega,t)}{\rho + I(\omega,t) - n} = b(1-s_a) w_H(t) X(\omega,t). \tag{19}$$

where $s_a \in [0,1)$ is the uniform R&D subsidy paid to the firms that aim to introduce the next best environmental quality product.

The no-arbitrage equations (18) and (19) are targeted by the same aggregate Poisson arrival rate of innovation, but the instantaneous profit flows differ. In this way, along a BGP equilibrium with strictly positive R&D effort for better quality services and better environmental quality services, the R&D subsidies s_q and s_a should allow the same R&D cost for each innovating firm, i.e., the right hand side of both no-arbitrage equations (18) and (19) should be equal. When this is not the case, a corner, trivial solution would emerge with no R&D effort aimed either at better quality services or better environmental quality services in equilibrium. Therefore, the rest of the analysis focuses on the existence of a strictly positive R&D effort aimed at the improvement of both quality and environmental quality services. To simplify exposition, with no loss of generality on both analysis and results, it is assumed that the R&D subsidy is only paid to the firm with lower profit flows in the no-arbitrage equations (18) and (19). In particular, the R&D subsidy is only paid until the lower R&D cost exactly offsets the lower rents in the same variety. This process allows a BGP equilibrium where both (18) and (19) are satisfied.[22]

[22] See Cozzi (2006) for an analysis of an asymmetric Poisson arrival rate of innovation in Schumpeterian growth models.

3.4 Balanced Growth Path

Given the economic environment described above, this part considers the general equilibrium implications of the economy along the BGP. In the following equations the time index t has been eliminated for the sake of simplicity unless it is strictly necessary for comprehension of the text. Note that z and $(1-z)$ denote the share of varieties targeted by quality services innovations and environmental quality service innovations respectively. Since each final good monopolist employs economy-wide unskilled labor to manufacturing products, the unskilled labor market clearing equilibrium condition is:

$$\begin{aligned} N\theta_0 &= \int_0^z mc_{w_L} q^q(\omega)\, d\omega + \int_z^1 (1-F(a))\, mc_{w_L} q^a(\omega)\, d\omega = \\ &= mc_{w_L} cN \left[\frac{z\left(\frac{mc}{a}+\tau\right)+(1-z)(1-F(a))(\lambda mc+\tau)}{(\lambda mc+\tau)\left(\frac{mc}{a}+\tau\right)} \right], \end{aligned} \tag{20}$$

where on the right side of the condition (20) the Shephard's lemma has been used to obtain the labor demand of manufacturing firms. From equation (20) the steady state value of the per-capita consumption c boils down to:

$$c = \frac{\theta_0}{mc_{w_L}} A, \tag{21}$$

where $A = \frac{(\lambda mc+\tau)\left(\frac{mc}{a}+\tau\right)}{z\left(\frac{mc}{a}+\tau\right)+(1-z)(1-F(a))(\lambda mc+\tau)}$.

As for unskilled labor, we can boil down the market clearing equilibrium condition for the skilled labor force. Using equation (7), the CRS technology production function of innovating firms, and the law of large numbers, the skilled labor market equilibrium condition is:

$$\begin{aligned} (\theta_0 + 1 - 2\gamma)(1-\theta_0)\tfrac{\psi}{2} N = \\ = b\left[zI(\omega)\, X(\omega)\, d\omega + (1-z)\, I(\omega)\, X(\omega)\, d\omega\right] \end{aligned} \tag{22}$$

The PEG formulation implies $X(\omega)/N = k$. Therefore, eq. (22) can be rewritten as:

$$(\theta_0 + 1 - 2\gamma)(1-\theta_0)\frac{\psi}{2} = bkI, \tag{23}$$

where $I \equiv [zI(\omega)\, d\omega + (1-z)\, I(\omega)\, d\omega]$. Then, considering equations (23), either (B1.7) or (B1.8) when $\Pi > 1$ or $\Pi < 1$ respectively, the following can be derived

Proposition 1 *Under PEG specification a steady state exists such that* $\theta_0^* \in (\gamma, 1)$.

Proof. See Appendix B. ■

4 Policy results and simulation analysis

In order to illustrate the causal mechanisms and results of the model, calibration and comparative static analyses are performed. In particular, the effects of tighter ERT and the effects of different intensities of the intention-behavior gap - i.e., different proportion of environmentally conscious individuals who translate their purchasing intentions into actual demand - on individuals' incentives for human capital accumulation, wage inequality, and growth are analyzed.

At this stage, it is worth noting that both the analysis and results are robust to alternative interpretations of the R&D-driven growth model set-up. Indeed, the Schumpeterian quality ladder model of the final products' set-up used here may be reinterpreted as an R&D sector that improves the production process rather than the quality of each final variety. In this case, all varieties should be read as intermediate inputs that contribute to producing a unique final good (see, e.g., Grossman and Helpman 1991).

4.1 Tighter ERT

This section analyzes the effects of tighter ERT τ and a selective R&D subsidy on polluting emissions, on individuals' incentives for human capital accumulation, on wage inequality between both unskilled and skilled workers and among skilled workers, and on the per capita output growth rate. To this aim, comparative static and numerical analyses are carried out.

When firms producing better quality products have a higher step size of innovation, they charge a higher mark up value and they earn higher profits, i.e., $\lambda > \frac{1}{a}$ and $\Pi > 1$ hold. Moreover, the existence of the intention-behavior gap also implies a higher market size of these firms. In this scenario, tighter ERT increases the price charged to consumers due to the tighter tax and reduces the demand of the goods. This in turn also reduces the total cost of production. In this case, the positive cost reduction effect outweighs the negative quantity effect and the profits of firms increase. Since firms producing better quality products charge a higher mark up value, their profits increase relatively more than those of firms producing better environmental quality products. Consequently, the innovative firms that aim to market better environmental quality versions of products, and that expect to gain relatively lower profits, obtain a higher R&D subsidy to sustain their innovative projects.[23] In the aggregate, the combination of these effects results in a higher demand of skilled labor, and this increases wage inequality between both unskilled and skilled workers and among skilled workers, the individuals' incentives for human capital accumulation, and the per capita growth rate. Therefore, in this case the intensity of the intention-behavior gap does not affect the qualitative effects of tighter ERT. Therefore, the following can be stated:

Proposition 2 *When firms producing better quality products have a higher*

[23] The selective R&D subsidy is only paid to better environmental quality innovations, i.e., $s_q = 0$ and $s_a = ((\Pi - 1)/\Pi) \in (0, 1)$.

mark-up value than firms producing better environmental quality service products, and independently from the intensity of the intention-behavior gap i.e., $\lambda > \frac{1}{a}$ hold and for each $F(a) \in (0,1)$, tighter ERT and a selective R&D subsidy paid to environmental quality service products innovations determine: 1) higher wage inequality between unskilled and skilled workers and among skilled workers, 2) a stronger incentive for human capital accumulation, 3) a higher aggregate innovation rate, 4) a higher GDP per capita growth rate

Proof. *See Appendix D.* ■

However, when firms producing better environmental quality service products have a higher step size of innovation, they charge a higher mark-up value, i.e., $\lambda < \frac{1}{a}$ holds. Since the intention-behavior gap also implies a lower market share for these products, its intensity generates different effects on individuals' incentives for human capital accumulation, wage inequality, and the per capita growth rate when a tighter ERT is implemented.

When the intention-behavior gap is large, companies that produce better quality products have a relatively high market share and they earn more profits, i.e., conditions $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) > \bar{F}\right)\right\}$ and $\Pi > 1$ hold. Tighter ERT increases the price charged to consumers because of the higher tax and reduces the demand for goods. This in turn also reduces the total cost of production. However, in this case because the best quality products have a lower mark up value and a very high market share (the intention-behavior gap is large), the increase in the tax implies a very low decrease in aggregate demand for goods and the total cost of production. In the aggregate, the negative quantity effect outweighs the positive cost reduction effect and the profits of firms decrease. This results in a lower demand for skilled labor and in lower skill premium that reduces the unit cost of the R&D effort. Consequently, the selective R&D subsidy paid to better environmental quality service innovations becomes lower.[24] In the aggregate, this results in a lower demand for skilled labor, lower wage inequality between both unskilled and skilled workers and among skilled workers, lower individuals' incentives for human capital accumulation, and a lower aggregate innovation rate. Therefore, the following can be stated:

Proposition 3 *When firms producing better environmental quality service products have a higher mark-up value than firms producing better quality service products and the intention-behavior gap is large, i.e., if $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) > \bar{F}\right)\right\}$ holds, tighter ERT and a selective R&D subsidy determine: 1) lower wage inequality between unskilled and skilled workers and among skilled workers, 2) a lower incentive for human capital accumulation, 3) a lower aggregate innovation rate, 4) a lower GDP per capita growth rate.*

Proof. *See Appendix D.* ■

On the contrary, when the intention-behavior gap is low, firms producing better environmental quality products have a relatively high market share and gain higher profits, i.e., conditions $\left\{\lambda < \frac{1}{a} \cap F(a) < \bar{F}\right\}$ and $\Pi < 1$ hold. Tighter

[24] In this case, the selective R&D subsidies are $s_q = 0$ and $s_a = ((\Pi - 1)/\Pi) \in (0,1)$.

ERT generates the same mechanisms described for the previous scenario. Yet, in this case the innovative firms that aim to market better quality versions of products and that expect to gain lower profits obtain a higher R&D subsidy to sustain their innovative projects. In the aggregate, the positive effect of a higher R&D subsidy paid to better quality innovative firms offsets the lower expected profit flows of innovative firm introducing better environmental quality versions of products, and this spurs the demand for skilled labor, individuals' incentives for human capital accumulation and wage inequality between both unskilled and skilled workers and among skilled workers. Yet, the aggregate innovation rate and the growth rate of GDP per capita remain approximately constant because the low intention-behavior gap implies that the market share of better quality products and better environmental quality products are closer each other, and the lower innovation incentive of firms producing better environmental products offsets the higher innovation incentive of firms producing better quality products. Therefore, the following can be stated:

Proposition 4 *When firms producing better environmental quality service products have a higher mark-up value than firms producing better quality service products and the intention-behavior gap is low, i.e., if* $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F\left(a\right) < \bar{F}\right)\right\}$ *holds, tighter ERT and a selective R&D subsidy determine: 1) higher wage inequality between unskilled and skilled workers and among skilled workers, 2) a stronger incentive for human capital accumulation, 3) an approximately invariant aggregate innovation rate, 4) an approximately invariant GDP per capita growth rate.*

Proof. *See Appendix D.* ■

Note that along the BGP equilibrium, a lower (higher) θ_0 is associated with larger (smaller) percentage differences between the wages of highest and lowest paid skilled workers, so that tighter ERT that decrease (increase) θ_0 also increase (decrease) wage inequality among skilled workers, i.e. residual wage inequality. Finally, it is worth noting that the results described above hold for any degree of substitution between labor and energy in the manufacturing sector.

4.2 Simulation analysis

The model is calibrated for the U.S. economy because necessary data are available for this country (see Appendix C for details of the calibration). Table 1 shows some key calibration parameters for the U.S. economy. The first and second columns, respectively, present the value of the actual data of all ERT τ (as a percentage of GDP) and the actual data of the homogeneous R&D subsidy s (as a percentage of GDP). The next three columns, respectively, present the threshold ability parameter θ_0 and the skill premium $\delta = \frac{w_H}{w_L}$, both taken by actual data, and the actual data for R&D expenditures (as a percentage of GDP), used as a proxy for the aggregate innovation rate I. These actual data are compared with the predicted values of the threshold ability parameter θ_0 and the innovation rate I of the last two columns in Table 1. To calibrate the threshold ability parameter θ_0 and the aggregate innovation rate I of this benchmark calibration of the U.S. economy, equations (**??**) and (**??**) are utilized (see Appendix C for details).

A comparison between the last four columns in Table 1 highlights how the model's predicted value for the threshold ability parameter and the innovation rate - i.e., predicted θ_0 and I - well matches empirical data for the U.S. economy, i.e., actual data for θ_0 and I.

Table 1: U.S. Economy

Act. ERT	Act. s	Act. θ_0	Act. δ	Act. I	Pred. θ_0	Pred. I
0.87	0.16	0.729	1.73	2.65	*0.723*	*2.65*

To illustrate the causal mechanisms of the model set-up, sensitivity tests are carried out on individuals' incentives for human capital accumulation, wage inequality (skill premium), and the aggregate innovation rate.

4.2.1 Tighter ERT: simulation analysis

The comparative static results of a tighter ERT described above are illustrated with a simulation analysis along the lines of the previous section. In particular, we calculate what the threshold ability parameter θ_0, the skill premium δ, the selective R&D subsidies s_ζ, with $\zeta \in \{q, a\}$, and the aggregate innovation rate I would be considering tighter ERT and the hypothetical value of the selective R&D subsidy. The numerical simulation considers the three relevant scenarios as summarized in the Propositions 2 to 4. First, we consider the scenario where firms producing better quality products have a higher mark-up value and gain higher profits independently from the intensity of the intention-behavior gap i.e., condition $\lambda > \frac{1}{a}$ holds and for each $F(a) \in (0, 1)$ (see Table 2). Second, we consider the scenario where firms producing better environmental quality service products have a higher mark-up value and the intention-behavior gap is large, i.e., condition $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) > \bar{F}\right)\right\}$ holds (see Table 3). Last, we consider the scenario where firms producing better environmental quality service products have a higher mark-up value and the intention-behavior gap is low, i.e., condition $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) < \bar{F}\right)\right\}$ holds (see Tables 4,5).[25]

The first column in Tables 2, 3, 4, and 5 indicates the hypothetical ERT value, the second, third, fourth and fifth columns in Tables 2, 3, 4, and 5 respectively indicate the hypothetical selective R&D subsidy paid to innovative firms that aim to introducing better environmental quality products and better quality products (i.e., s_a and s_q respectively), the hypothetical threshold ability parameter θ_0, the hypothetical skill premium δ, and the hypothetical aggregate

[25] The same qualitative patterns as in Tables 2 to 5 are obtained considering tighter ERTs than the actual value $\tau = 0.87$, and a higher value of $m > 0$. As in the previous section, in the scenario where $\lambda > \frac{1}{a}$, the value of parameter a is set to 0.8 to get a mark-up value for pollution abatement service products of $\frac{1}{a} = 1.25 < 1.38 = \lambda$; in the scenarios where $\lambda < \frac{1}{a}$, the value of parameter a is set to 0.65 to get a mark-up value for pollution abatement service products of $\frac{1}{a} = 1.54 > 1.38 = \lambda$, that is close to the highest but one mark-up value estimated by Hall (2018).

innovation rate I. The numbers in parentheses denote the (percentage) change in the hypothetical skill premium and the hypothetical aggregate innovation rate with respect to the actual data as in Table 1.[26]

Table 2: U.S. with selective R&D subsidy: $s_a > 0$, $s_q = 0$ $(\lambda > \frac{1}{a})$

Hyp. ERT	Hyp. s_a	Hyp. θ_0	Hyp. δ	Hyp. I^*
0.87	0.383	0.688	1.83 (+5.78%)	2.91 (+9.81%)
2.0	0.386	0.687	1.84 (+6.36%)	2.93 (+10.57%)
4.0	0.388	0.687	1.84 (+6.36%)	2.93 (+10.57%)
8.0	0.389	0.686	1.84 (+6.36%)	2.94 (+11.00%))

Table 3: U.S. with selective R&D subsidies: $s_a > 0$, $s_q = 0$ $(\{(\lambda < \frac{1}{a}) \cap (F(a) > \bar{F})\})$

Hyp. ERT	Hyp. s_a	Hyp. θ_0	Hyp. δ	Hyp. I^*
0.87	0.238	0.681	1.85 (+5.78%)	2.98 (+9.81%)
2.0	0.231	0.683	1.85 (+5.78%)	2.96 (+11.70%)
4.0	0.226	0.684	1.85 (+5.78%)	2.95 (+11.32%)
8.0	0.223	0.685	1.84 (+6.36%)	2.95 (+11.32%)

Table 4: U.S. with selective R&D subsidy: $s_a = 0$, $s_q > 0$ $(\{(\lambda < \frac{1}{a}) \cap (F(a) < \bar{F})\})$

Hyp. ERT	Hyp. s_q	Hyp. θ_0	Hyp. δ	Hyp. I^*
0.87	0.028	0.538	2.35 (+36.10%)	1.36 (−48.67%)
2.0	0.038	0.535	2.37 (+36.87%)	1.36 (−48.67%)
4.0	0.044	0.533	2.38 (+37.40%)	1.36 (−48.67%)
8.0	0.049	0.531	2.39 (+37.92%)	1.36 (−48.67%)

Table 5: U.S. with selective R&D subsidy $s_a > 0$, $s_q = 0$ $(\{(\lambda < \frac{1}{a}) \cap (F(a) < \bar{F})\})$

[26] It is worth noting that actual taxes on general consumption accounted for less than 4% in the U.S. in the 2019 fiscal year. Taxes on general consumption include all taxes and duties levied on the production, extraction, sale, transfer, leasing or delivery of goods, and the rendering of services, or regarding the use of goods or permission to use goods or perform activities (OECD, 2020). The heading thus covers: a) multi-stage cumulative taxes; b) general sales taxes - whether levied at manufacture/production, wholesale or retail level; c) value-added taxes; d) excises; e) taxes levied on the import and export of goods; f) taxes levied in respect of the use of goods and taxes on permission to use goods, or perform certain activities; g) taxes on the extraction, processing or production of minerals and other products.

Hyp. ERT	Hyp. s_a	Hyp. θ_0	Hyp. δ	Hyp. I^*
0.87	*0.028*	*0.533*	*2.38* (+37.40%)	*1.38* (−45.66%)
2.0	*0.038*	*0.528*	*2.40* (+38.72%)	*1.38* (−45.66%)
4.0	*0.044*	*0.524*	*2.42* (+39.80%)	*1.38* (−45.66%)
8.0	*0.049*	*0.522*	*2.43* (+40.34%)	*1.38* (−46.03%)

The sensitivity analysis in Tables 2, 3, 4, and 5 confirm the comparative static results summarized in Propositions 2 to 4. In addition to the comparative static results, Tables 2 and 3 show that tighter ERT and selective R&D subsidy paid to pollution abatement innovating firms would result in a higher GDP per capita growth rate and higher wage inequality than the actual data for the U.S. economy and that, in both scenarios, the increase in the per capita growth rate would be far larger than the increase in wage inequality. Results in Tables 4 and 5 show that a tighter ERT would result in far stronger individuals' incentives for human capital accumulation and a far higher skill premium than the actual U.S. data. Indeed, these scenarios show that the increase in wage inequality and the decrease in the aggregate innovation rate would both be very large compared to the actual data for the U.S. economy. However, this sensitivity test shows that the economy would benefit from a higher per capita growth rate when the selective R&D subsidy were paid pollution abatement innovations.

Finally, repeating the numerical analysis seen above for a less regressive ERT regime, i.e., a tighter ERT value for higher values of $m > 0$, it is found that the economy is characterized by lower individuals' human capital accumulation and lower aggregate innovation rate than a fully regressive environmental tax regime seen above, i.e., a tighter ERT for $m = 0$. These results are omitted for reasons of space, but are available on request from the author.

4.2.2 The intensity of the intention-behavior gap: simulation analysis

This section explores the effects of different intensities of the intention-behavior gap. To save on space, this sensitivity test considers the actual value of ERT, i.e., $\tau = 0.87$ is utilized, and the results hold for tighter ERT τ.[27]

In cases in which better quality products have a higher jump size of innovation and charge a higher mark-up value, i.e., if $\lambda > \frac{1}{a}$, inequality (B4.1) is always satisfied (see Appendix D, $\bar{F} = -0.45$) and five different intensities of the intention-behavior gap are considered: $F(a) = 0.2$, $F(a) = 0.35$, $F(a) = 0.58$, $F(a) = 0.7$, and $F(a) = 0.9$. Results for individuals' incentive for human capital accumulation and the aggregate innovation rate are shown in Figures

[27] The results of this sensitivity test also hold for each value of the ERT premium m for better environmental quality products. In particular, the results hold when the fiscal burden on actual emissions is $\left(\frac{\tau}{a^{(i^{\max}-m)}}\right) ea^{i^{\max}}$, where $m \geq 0$ is a non-negative integer. Therefore, the higher m is, the lower the environmental tax on the state-of-the-art environmental quality products is.

1(a,b). In cases in which condition $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F\left(a\right) > \bar{F}\right)\right\}$ holds, from inequality (B4.1) the threshold value is $\bar{F} = 0.25$. Therefore, four different intensities of the intention-behavior gap are considered such that $F\left(a\right) > \bar{F} = 0.25$: $F\left(a\right) = 0.4$, $F\left(a\right) = 0.58$, $F\left(a\right) = 0.7$, and $F\left(a\right) = 0.9$. Results for individuals' incentives for human capital accumulation and the aggregate innovation rate are shown in Figures 2(a,b).[28]

Figure 1(a,b): $\lambda > \frac{1}{a}$, $\forall F(a) > 0$

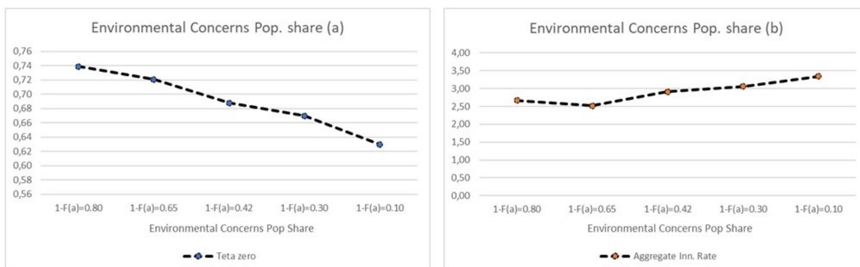
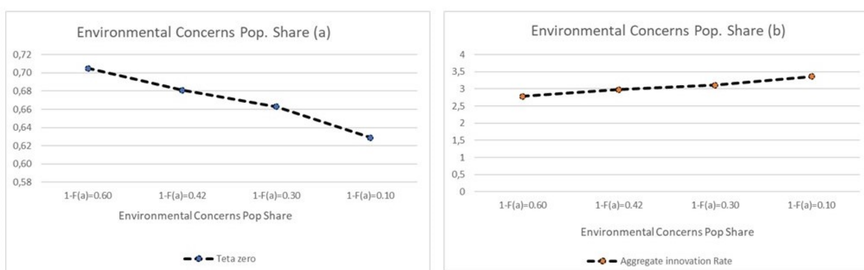


Figure 2(a,b): $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) > \bar{F}\right)\right\}$



Results in Figures 1(a,b) and 2(a,b) show that show that when firms producing better quality products gain higher profits than firms producing better environmental quality products - which can happen when these products have a higher mark-up value $\lambda > \frac{1}{a}$, and when they have a lower mark-up value and a relatively high market share $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F\left(a\right) > \bar{F}\right)\right\}$ - and the intention-behavior gap becomes larger in the economy, the competitive advantage of firms producing better quality products increases, and their profits become higher.

[28] Before to show the results, it is worthnoting that the average mark-up value of the U.S. economy estimated by Hall (2018) is $\lambda = 1.38$. In this, and the following sensitivity tests, in the scenario where $\lambda > \frac{1}{a}$, the value of parameter a is set to 0.8 to get a mark-up value for pollution abatement products of $\frac{1}{a} = 1.25 < 1.38 = \lambda$; in the scenarios where $\lambda < \frac{1}{a}$, the value of parameter a is set to 0.65 to get a mark-up value for pollution abatement products of $\frac{1}{a} = 1.54 > 1.38 = \lambda$, which is close to the highest but one mark-up value estimated by Hall (2018).

Consequently, the innovative firms that aim to market better environmental quality versions of products and that expect to gain lower profits, obtain a higher R&D subsidy to sustain their innovative projects. In the aggregate, the combination of these effects increases the aggregate demand for skilled workers, wage inequality between unskilled and skilled workers, individuals' incentives for human capital accumulation, and the aggregate innovation rate, i.e., a positive relationship between wage inequality and growth is found.

Let us consider now the scenario where better environmental quality products have a higher jump size of innovation and then charge a higher mark-up value, while the intention-behavior gap is low. In this case, firms producing better environmental quality service products gain higher profits, i.e., $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) < \bar{F}\right)\right\}$ and $\Pi < 1$ hold. Results for individuals' incentives for human capital accumulation and the aggregate innovation rate are shown in Figures 3(a,b) and 4(a,b).[29]

Figure 3(a,b): $\left\{\left(\lambda<\frac{1}{a}\right)\cap\left(F(a)<\bar{F}\right)\right\}$, $s_q=0$, $s_a>0$

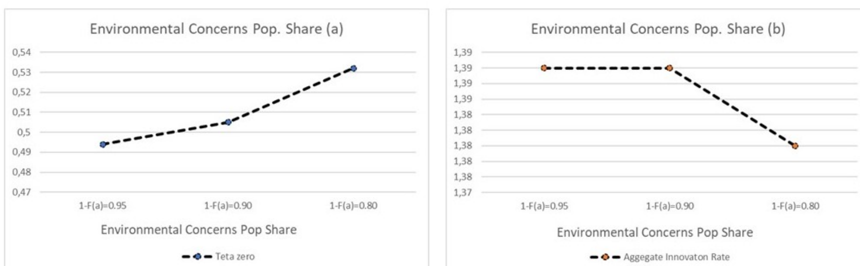
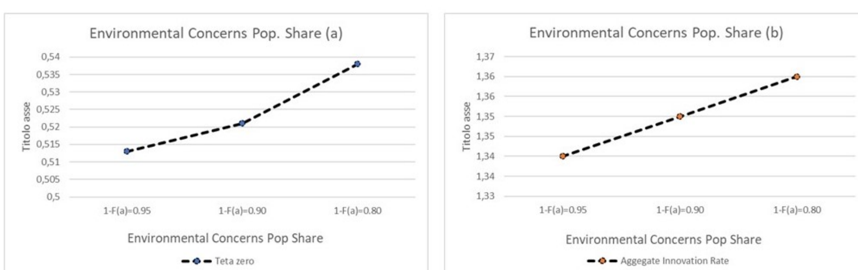


Figure 4(a,b): $\left\{\left(\lambda<\frac{1}{a}\right)\cap\left(F(a)<\bar{F}\right)\right\}$, $s_q>0$, $s_a=0$



[29] In cases in which condition $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) < \bar{F}\right)\right\}$ holds, three different intensities of the intention-behavior gap are considered such that $F(a) < \bar{F} = 0.25$: $F(a) = 0.2$, $F(a) = 0.1$, $F(a) = 0.05$, and results where the selective R&D subsidy is only paid to better environmental quality service innovations are shown in Figures 3(a,b), while results where the selective R&D subsidy is only paid to better quality products are shown in Figures 4(a,b).

In this scenario, a larger intention-behavior gap, i.e., a lower $(1 - F(a))$, erodes the competitive advantage of firms producing the environmental quality state-of-the-art products and their profits are correspondingly lower, while the profits of firms producing better quality products are higher because their relative market share becomes higher when the intention-behavior gap becomes larger. This implies a reduction in the gap between the profits of better environmental quality products and those of better quality products that generates a lower selective R&D subsidy paid to sustain the innovative effort of firms. In the aggregate, the combination of these opposite effects results in lower demand for skilled workers, lower wage inequality between both unskilled and skilled workers and among skilled workers, lower individuals' incentives for human capital accumulation, while the growth rate per capita can be higher. In particular, the effects on the aggregate innovation rate and on the growth rate of GDP per capita depends on which types of varieties obtain the selective R&D subsidy. The payment of the selective R&D subsidy to innovative firms that introduce better environmental quality services products, i.e., $s_a > 0$ and $s_q = 0$, offsets the reduction of profits of these firms, and this allow the aggregate innovation rate to remain approximately constant and to become lower only when the intention-behavior gap is very large, i.e., for $(1 - F(a)) < 0.05$ as shown in Figure 3(a,b). On the contrary, the payment of the R&D subsidy to innovative firms that introduce better quality services products, i.e., $s_q > 0$ and $s_a = 0$, further reinforces the innovation incentives of these firms and allow the aggregate innovation rate to be higher when the intention-behavior gap becomes larger. Therefore, a negative relationship between wage inequality and growth is found in this case.[30]

5 Balanced green growth path and environmental sustainability

Since the policy scheme consisting of a carbon tax (ERT) and a selective R&D subsidy should be temporarily implemented until the balanced green growth path is taken, we calculate what the threshold ability parameter, the skill premium, and the innovation rate would be along the balanced green growth path (BGGP) in which the carbon tax and the selective R&D subsidy are zero. Results are indicated in Table 6. The first column in Table 6 indicates the hypothetical threshold ability parameter to accumulate human capital θ_{0gp}, the second and the third columns respectively indicate the hypothetical skill premium δ_{gp} and the hypothetical aggregate innovation rate I^*_{gp}. The numbers in parentheses respectively in the second and third columns in Table 6 indicate the relative change of the hypothetical scenario compared with actual data for the U.S. economy.

Table 6: Balanced Green Growth Path

[30] The same patterns as in Figures 1(a,b) to 4(a,b) are obtained considering tighter ERTs than the actual value $\tau = 0.87$, and a higher value of $m > 0$.

Hyp. θ_{0gp}	Hyp. δ_{gp}	Hyp. I^*_{gp}
0.754	1.67 (-3.35%)	2.40 (-9.43%)

Table 6 shows that, along the balanced green growth path, the economy is characterized by lower wage inequality and a lower per capita growth rate than the actual data for the U.S. economy as shown in Table 1.

The environmental sustainability of the economy in the long run implies, by definition, that the flow of polluting emissions $a^i_{(\omega,s)}e$ is below a 'safe value' $\hat{e}$, i.e., $a^i_{(\omega,s)}e < \hat{e}$ for each $\omega \in [0,1]$, and polluting emissions generate no damage to the environment. Therefore, when the economy is on a BGP equilibrium, the environmental sustainability at time $t > 0$ implies that the following inequality must hold:[31]

$$\int_z^1 \theta_0 N a^i_{(\omega,t)} d\omega \leq \int_z^1 \theta_{0gp} N \hat{e}, \tag{24}$$

where the terms $\theta_0 N$ and $\theta_{0gp} N$ denote the aggregate production of all varieties at time t along the BGP and along the balanced green growth path, respectively. Let us define $a^{i(t)} = \int_z^1 a^i_{(\omega,t)} d\omega$, where $i(t)$ denotes the number of pollution abatement innovations achieved in the economy in the interval $[0,t]$ along the BGP equilibrium. The term $i(t)$ follows a Poisson process, and along the BGP the expected value of the number of pollution abatement innovations achieved in the interval $[0,t]$ is $(1-z)It$. Since a, $\hat{e}$, θ_0, θ_{0gp} all belong to the interval $(0,1)$, from condition (24) the following inequality for the expected number of pollution abatement innovations must hold: $(1-z)It \geq \frac{|\ln \theta_{0gp}| - |\ln \theta_0| + |\ln \hat{e}|}{|\ln a|}$ follows. This last inequality implies that the lower the threshold ability parameter to accumulate human capital θ_0 along a BGP the lower the expected number of innovations the economy needs to have environmental sustainability at a give time t, and the lower the threshold ability parameter to accumulate human capital θ_0 and the higher the aggregate innovation rate I along the BGP the lower the time t the economy takes to take the BGGP.

To further show this result, numerical simulation is performed. In particular, how long the economy takes for environmental sustainability, i.e., the time that solves for t inequality $(1-z)It \geq \frac{|\ln \theta_{0gp}| - |\ln \theta_0| + |\ln \hat{e}|}{|\ln a|}$ as strict equality, is calculated considering the three most relevant scenarios described above. For each two values of the ERT are considered: the actual value of ERT $\tau = 0.87$ and the hypothetical value $\tau = 4.0$.[32] Results are shown in Table 7. The first

[31] From eq. (B1.2), the aggregate flow of polluting emissions at each time $t > 0$ is $\int_z^1 \frac{(1-F(a))\theta_0 NA}{mc_{w_L}\left(\frac{mc}{a}\right)}$, where the ERT $\tau = 0$ and $e = 1$ are considered. Therefore, on the BGP equilibrium, the environmental sustainability at time $t > 0$ implies that the following inequality must hold: $\int_z^1 \frac{(1-F(a))\theta_0 NA}{mc_{w_L}\left(\frac{mc}{a}\right)} \leq \frac{(1-F(a))\theta_{0gp} NA}{mc_{w_L}\left(\frac{mc}{a}\right)}\hat{e}$.

[32] It is worth noting that actual taxes on general consumption accounted for less than 4% in the U.S. in the 2019 fiscal year. Taxes on general consumption include all taxes and duties levied on the production, extraction, sale, transfer, leasing or delivery of goods, and the rendering of services, or regarding the use of goods or permission to use goods or perform

column in Table 7 considers the scenario where firms producing better quality products have a higher mark-up value, and independently from the intensity of the intention-behavior gap i.e., condition $\lambda > \frac{1}{a}$ holds and for each $F(a) \in (0,1)$. The second column in Table 7 considers the scenario where firms producing better environmental quality service products have a higher mark-up value and the intention-behavior gap is large, i.e., condition $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) > \bar{F}\right)\right\}$ holds. The third column in Table 7 considers the scenario where firms producing better environmental quality service products have a higher mark-up value and the intention-behavior gap is low, i.e., condition $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) < \bar{F}\right)\right\}$ holds.

For each scenario (column), the second row in Table 7 indicates how long the economy takes for environmental sustainability considering the actual value of ERT $\tau = 0.87$, the third row in Table 7 indicates how long the economy takes for environmental sustainability considering the value of ERT $\tau = 4.0$. Note that in Table 7 how long the economy takes for environmental sustainability is the time that solves for t inequality $(1-z)\,It \geq \frac{|\ln \theta_{0gp}| - |\ln \theta_0| + |\ln \hat{e}|}{|\ln a|}$ as strict equality. The numbers in parentheses denote the corresponding value of the hypothetical threshold ability parameter to accumulate human capital θ_0 and of the aggregate innovation rate I as those obtained with the numerical simulation in Tables 2 to 5. In each scenario, the value for $\hat{e}$ is normalized to $\hat{e} = 0.1$, so that safe polluting emissions represent 10 percent of actual polluting emissions. Different values for $\hat{e}$ do not alter the qualitative results.

Table 7: Time for environmental sustainability

$\lambda > \frac{1}{a}, \forall F(a) > 0$	$\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) > \bar{F}\right)$	$\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) < \bar{F}\right)$
ERT = 0.87, t = 34.05	ERT = 0.87, t = 17.14	ERT = 0.87, t = 33.54
(θ_0=0.688, I=2.91)	(θ_0=0.681, I=2.98)	(θ_0=0.538, I=1.36)
ERT = 4.0, t = 33.79	ERT = 4.0, t = 17.35	ERT = 4.0, t = 33.32
(θ_0=0.687, I=2.93)	(θ_0=0.684, I=2.95)	(θ_0=0.651, I=1.36)

The results in Table 7 highlight the key role the aggregate innovation rate in pursuing and achieving environmental sustainability together with the role of a higher step size of innovation of better environmental quality innovations, i.e., $\frac{1}{a} > \lambda$. Indeed, a comparison of columns in Table 7 shows the positive and relevant role of the aggregate innovation rate and of the higher step size of innovation of better environmental quality innovations in reducing the time needed to achieve environmental sustainability, even in the presence of a large intention-behavior gap in the economy.

activities (OECD, 2020). The heading thus covers: a) multi-stage cumulative taxes; b) general sales taxes - whether levied at manufacture/production, wholesale or retail level; c) value-added taxes; d) excises; e) taxes levied on the import and export of goods; f) taxes levied in respect of the use of goods and taxes on permission to use goods, or perform certain activities; g) taxes on the extraction, processing or production of minerals and other products.

6 Conclusions

This paper takes account of the intention-behavior gap largely observed in the data, i.e., that only a proportion of environmentally conscious individuals translate their purchasing intentions into actual demand, and studies the effects of an environmental tax and selective R&D subsidy on individuals' incentives for human capital accumulation, wage inequality between both skilled and unskilled workers and among skilled workers, and growth. To this aim, in the tradition of the Schumpeterian growth literature, an endogenous R&D-driven growth model in which individuals endogenously choose to accumulate human capital through education is used. In the manufacturing sector, energy is used together with labor and any degree of substitution between inputs is admitted.

The results show that, in the presence of the green-intention behavior gap of individuals, a tighter carbon tax and a selective R&D subsidy paid to innovative firms that introduce better environmental quality products allow the balanced green growth path to be taken earlier and in finite time. However, results show that this environmental policy can increase or decrease individuals' incentives for human capital accumulation, and a positive or negative relationship between inequality and growth may emerge depending on the intensity of the intention-behavior gap and the relative mark-up value between the better quality service products and the better environmental quality service products. In particular, when better quality products gain higher profits - and this is the case when these products have a higher mark-up value and when they have a lower mark-up value and the intention-behavior gap is large - a positive relationship between inequality and growth is found. On the contrary, a slightly negative relationship between inequality and growth emerges when better environmental quality products gain higher profits because of a higher mark-up value and a low intention-behavior gap in the economy.

Finally, similar results are obtained in each of the above scenarios when the intensity of the behavior-intention gap widens for a given value of the environmental tax.

Appendix A

A1. The supply of unskilled and skilled labor is the same as in Dinopoulos and Segerstrom (1999). Individuals are finitely lived members of infinitely lived households, being continuously born at a constant rate b, and dying at a constant rate d, with $b-d=n>0$. $D>0$ denotes the exogenous given duration of their life. As in Dinopoulos and Segerstrom (1999), in order for the number of births at time t to match the number of deaths at $t+D$, the above parameters must satisfy $d=\frac{n}{e^{nD}-1}$ and $b=\frac{ne^{nD}}{e^{nD}-1}$. Each individual chooses to train and become skilled at the beginning of life; the duration of the training period - when the individual cannot work - is exogenously fixed at $T<D$. Hence an individual with ability θ decides to train if and only if the following arbitrage condition is satisfied:

$$\begin{array}{c}\int_t^{t+D} e^{-\int_t^s r(v)dv} w_L(s)\,ds < \\ \int_{t+T}^{t+D} e^{-\int_t^s r(v)dv} \max(\theta-\gamma,0)\,w_H(s)\,ds,\end{array} \tag{A1}$$

with $0<\gamma<1/2$. Note that an individual with ability $\theta>\gamma$ is postulatedly able to accumulate human capital $(\theta-\gamma)$ after training, whereas an individual with an ability lower than γ (i.e. $\theta\leq\gamma$) never gets any skill from schooling. Therefore, a skilled worker with ability $\theta>\gamma>0$ earns a wage $(\theta-\gamma)\,w_H$ after training for a period $D-T>0$, and does not earn any wage during her period of training. Like Dinopoulos and Segerstrom (1999), the analysis focuses on the balanced growth path (BGP) equilibrium, in which all variables grow at a constant rate and w_L, w_H, and c_θ are all constant, furthermore $r(s)=\rho$ at all dates. Considering eq. (A1) with equality, the ability threshold θ_0 is obtained which renders an individual indifferent to becoming skilled or to remaining unskilled for all her life. Hence, the individual will train if and only if her ability is higher than

$$\theta_0=\left[\left(1-e^{-\rho D}\right)/\left(e^{-\rho T}-e^{-\rho D}\right)\right]\frac{w_L}{w_H}+\gamma=\sigma\frac{w_L}{w_H}+\gamma. \tag{A2}$$

where $\sigma\equiv\left(1-e^{-\rho D}\right)/\left(e^{-\rho T}-e^{-\rho D}\right)$. An individual with ability $\theta>\theta_0$ will decide to train and will accumulate quantity $(\theta-\gamma)$ of human capital.

The supply of unskilled labor at time t, $L(t)$, equals the number of individuals in the population who decide to remain unskilled, i.e. $L(t)=\theta_0 N(t)$. For the derivation of the skilled labor force at time t, note that $(1-\theta_0)\,N(t)$ individuals either work as skilled workers or are training to become skilled workers. In this subpopulation the skilled workers are all individuals who were born between $(t-D)$ and $(t-T)$, $\int_{t-D}^{t-T} b(1-\theta_0)\,N(s)\,ds=(1-\theta_0)\,\psi N(t)$, where $\psi\equiv\left(e^{n(D-T)}\right)/\left(e^{nD}-1\right)<1$. The average skill level of workers who have finished training is $[(1-\gamma)/2]+[(\theta_0-\gamma)/2]=(\theta_0+1-2\gamma)/2$. Therefore the supply of skilled labor at time t, measured in efficiency units, is given by $H(t)=(\theta_0+1-2\gamma)(1-\theta_0)\frac{\psi}{2}N(t)$. Q.E.D.

A2. Each variety $\omega\in[0,1]$ can be the target of purposeful innovation aimed at quality services improvement and environmental quality improvements (abatement of polluting emissions) with a probability z and $(1-z)$ respectively, and these probabilities are i.i.d. across firms, across varieties, and over time.

In both cases, with non-drastic innovations and Bertrand competition along each variety $\omega \in [0,1]$, a limit pricing strategy by the top-quality services and top-environmental quality services producers is adopted. Due to free entry in producing the second best quality, profit flows should be zero in equilibrium. In light of the above, with probability z the next innovation introduces a better quality services product and - given the top environmental quality services $\frac{1}{a^{i^{\max}}}$, with $i^{\max} \geq 0$ - the price-quality ratio of the top quality leader producing quality services $(j+1)$ of a variety ω is $\frac{p^q_{n,\omega}}{\left(\lambda^{j+1}/a^{i^{\max}}\right)}$, where λ is the exogenous and constant quality services jump in each variety, whereas the price-quality ratio of the follower producing quality services j of the same variety is $\frac{mc}{\left(\lambda^{j}/a^{i^{\max}}\right)}$. The quality services leader has the lowest price-quality ratio whenever $\frac{p^q_{n,\omega}}{\lambda^{j+1}} \leq \frac{mc}{\lambda^j}$, i.e., whenever $p^q_{n,\omega} \leq \lambda mc$, which implies $p^q_{n,\omega} = \lambda mc$. With probability $(1-z)$ the next innovation introduces a better environmental quality product and, given the given the top quality services $\lambda^{j^{\max}}$, with $j^{\max} \geq 0$, the price-quality ratio of the top environmental quality leader producing with the $(i+1)\,th$ version of a variety is $\frac{p^a_{n,\omega}}{\left(\lambda^{j^{\max}}/a^{i+1}\right)}$, whereas the price-quality ratio of the follower producing with the $(i)\,th$ version of the same variety is $\frac{mc}{\left(\lambda^{j^{\max}}/a^{i}\right)}$. The top environmental quality leader has the lowest price-quality ratio whenever $\frac{p^a_{n,\omega}}{\left(\lambda^{j^{\max}}/a^{i+1}\right)} \leq \frac{mc}{\left(\lambda^{j^{\max}}/a^{i}\right)}$, i.e., whenever $p^a_{n,\omega} \leq \frac{mc}{a}$, which implies $p^a_{n,\omega} = \frac{mc}{a}$. Since the probability z and $(1-z)$ to introduce the next best quality service product and the next best environmental quality product, respectively, are i.i.d. across firms, across varieties, and over time, this process repeats every time a new innovation is introduced, and the top quality services leader has the lowest price-quality ratio $p^q_{n,\omega} = \lambda mc$ and the top environmental quality leader has the lowest price-quality ratio $p^a_{n,\omega} = \frac{mc}{a}$.

To fix ideas, let us suppose that $j^{\max} = 0$ and $i^{\max} = 0$ at time $t = 0$. With probability z when an innovation occurs we have $j^{\max} = 1$ and $i^{\max} = 0$, and the top quality service leader has the lowest price-quality ratio $p^q_{n,\omega} = \lambda mc$. With probability $(1-z)$ when an innovation occurs we have $j^{\max} = 0$ and $i^{\max} = 1$, and the top environmental quality service leader has the lowest price-quality ratio $p^a_{n,\omega} = \frac{mc}{a}$. Then, when the next innovation occurs, given that the first innovation was a better quality service product, with probability z we have $j^{\max} = 2$ and $i^{\max} = 0$, and the top quality service leader has the lowest price-quality ratio $p^q_{n,\omega} = \lambda mc$; otherwise, given that the first innovation was a better quality service product, with probability $1-z$ we have $j^{\max} = 1$ and $i^{\max} = 1$, and the top environmental quality service leader has the lowest price-quality ratio $p^a_{n,\omega} = \frac{mc}{a}$. The same price-quality ratios are obtained if the first innovation was a better environmental quality product. Therefore, as argued above, since the probability z and $(1-z)$ to introduce the next best quality service product and the next best environmental quality product respectively are i.i.d. across firms, across varieties, and over time, this process repeats every time an innovation is introduced and the top quality services leader has the lowest price-quality ratio $p^q_{n,\omega} = \lambda mc$ and the top environmental quality leader has the lowest price-quality $p^a_{n,\omega} = \frac{mc}{a}$. Q.E.D.

A3. The top environmental quality leader has the lowest price-quality $p^a_{n,\omega} = \frac{mc}{a}$ because it is assumed that individuals have heterogeneous willingness-to-pay for better environmental quality services of the product. In particular, households differ in their willingness to pay η for the environmental quality services of the product distributed in $[0,1]$ according to any continuous cumulative distribution function (cdf) $F(\eta)$ with usual properties $F^{'}(\eta) > 0$, $F(0) = 0$, $F(1) = 1$. It is assumed that the individual's type η and personal ability θ are independently distributed. The individual type η is private information, and its cumulative distribution function across households is assumed to be common knowledge. Therefore, all members of household η have the same ability level equal to η, and all households have the same number of members at each point in time. Empirical analyses show that heterogeneous preferences of the public's WTP to mitigate climate change are quite stable under very different time horizon of climate change mitigation intervention. In particular, considering two time horizons, a near-term impact of 60 years and a longer-term impact with a 150-year horizon, Layton and Brown (2000) show that the preferences elicited for the two vastly different time horizons are the same. In order to gain strictly positive profit flows, the top environmental quality leader should charge a price that satisfies the following inequality $p^a_{n,\omega} = \eta\frac{mc}{a} > mc$, which implies $\eta > a$. Therefore, the demand of all individuals' type $\eta \leq a$ is zero in equilibrium. Since individual's type η is private information and only the top environmental quality product can be sold at a price higher than the marginal cost mc, all individuals' type $\eta > a$ would be willing to pay at most $p^a_{n,\omega} = \frac{mc}{a}$. In this way, the top environmental quality leader should choose the uniform price $p^a_{n,\omega} = \frac{mc}{a}$ for all individuals' type $\eta > a$ to get profit flows as high as possible. Therefore, $(1 - F(a))$ is the population share with a strictly positive demand for the state-of-the-art environmental quality products. Q.E.D.

A4. Profit flows of the patent holder along each variety ω solves the following maximization problem:

$$\underset{q^l(\omega,t)}{Max} \left(p^l_{n,\omega} + \left(\frac{\tau}{a^i}\right) ea^i\right) q^l(\omega,t) - mcq^l(\omega,t) - q^l(\omega,t)\left(\frac{\tau}{a^i}\right) ea^i. \qquad \text{(A4.1)}$$

where instantaneous profit flows net of the tax burden charged on consumers are considered, $l = \{q, a\}$. The maximization problem (A4.1) reduces to:

$$\underset{q^l(\omega,t)}{Max}\ p^l_{n,\omega} q^l(\omega,t) - mcq^l(\omega,t). \qquad \text{(A4.2)}$$

When the innovation's target is quality services improvement, the solution to the maximization problem as in equation (A4.2) implies $p^q_{\omega,n} = \lambda mc$, where λ is the mark-up on the marginal cost. When the innovation's target is pollution abatement improvement, the solution to the maximization problem as in equation (A4.2) implies $p^a_{n,\omega} = \frac{mc}{a}$. It follows that the stream of monopoly profit accruing to the monopolist who manufactures the state-of-the-art of quality services and pollution abatement services of each variety ω respectively are:

$$\pi^q(\omega,t) = (\lambda-1)\, mcq^q(\omega,t)\,, \tag{A4.3}$$

and

$$\pi^a(\omega,t) = (1-F(a))\left(\frac{1}{a}-1\right) mcq^a(\omega,t)\,. \tag{A4.4}$$

Q.E.D.

A5. Here we consider that government gives a sort of fiscal premium to firms producing better environmental quality products. In this case, the fiscal burden on polluting emissions is $\left(\frac{\tau}{a^{(i^{\max}-m)}}\right) ea^{i^{\max}}$, where $m \geq 0$ is a non-negative integer. For $m=0$ the fiscal burden on polluting emissions becomes $\left(\frac{\tau}{a^{i^{\max}}}\right) ea^{i^{\max}} = \tau$ for each variety ω. For $m \geq 1$ the fiscal burden on polluting emissions of the top environmental quality product is $\left(\frac{\tau}{a^{(i^{\max}-m)}}\right) ea^{i^{\max}} = \tau a^m < \tau$. Therefore, the higher m is, the lower the environmental tax on the state-of-the-art environmental quality products is. Therefore, profit flows of the patent holder along each variety ω solves the following maximization problem:

$$\underset{y^l(\omega,t)}{Max}\left(p^l_{n,\omega}+\left(\frac{\tau}{a^{(i^{\max}-m)}}\right) ea^{i^{\max}}\right) y^l(\omega,t) - \kappa y^l(\omega,t) - y^l(\omega,t)\left(\frac{\tau}{a^{(i^{\max}-m)}}\right) ea^{i^{\max}}. \tag{A5.1}$$

where instantaneous profit flows net of the tax burden charged on consumers are considered, $l=\{q,a\}$. The maximization problem (A5.1) reduces to:

$$\underset{y^l(\omega,t)}{Max}\; p^l_{n,\omega} y^l(\omega,t) - \kappa y^l(\omega,t)\,. \tag{A5.2}$$

As above, the innovation's target is quality services improvement, the solution to the maximization problem as in equation (A5.2) implies $p^q_{\omega,n} = \lambda mc$. When the innovation's target is pollution abatement improvement, the solution to the maximization problem as in equation (A5.2) implies $p^a_{n,\omega} = \frac{mc}{a}$. Q.E.D.

A6. Let us analyze the incumbent leader producer both of top quality services and top environmental quality services. Let us $v^l(\omega,t)$, with $l=\{q,a\}$, denote the expected discounted profit flows of a successful quality leader in variety ω at time t producing the best quality services (q) and the best environmental quality services (a), respectively. Since each incumbent firm is targeted by R&D firms that try to discover the next quality/abatement best product services, the shareholder suffers a loss $v^l(\omega,t)$ with probability $I(\omega,t)\,dt = (zI^q(\omega,t)+(1-z)\,I^a(\omega,t))\,dt$, where $I^q(\omega,t)$ and $I^a(\omega,t)$ denote the Poisson arrival rate of innovation for the next best quality services product and the next environmental quality services product, respectively. Thus, the event of no innovation occurs with probability $1-I(\omega,t)\,dt$. Over a time interval dt, the shareholder of a stock issued by a successful R&D firm receives a dividend $\pi^l(\omega,t)\,dt$, and the value of the firm appreciates by $dv^l(\omega,t) = \dot{v}^l(\omega,t)\,dt$. Since the stock market is assumed to be perfectly efficient, the expected rate of return of a stock issued by a successful R&D firm must be equal to the riskless rate of return r:

$$rdt = \frac{\dot{v}^l(\omega,t)}{v^l(\omega,t)}\left[1 - I(\omega,t)\,dt\right]dt - \frac{v^l(\omega,t) - 0}{v^l(\omega,t)} I(\omega,t)\,dt + \frac{\pi^l(\omega,t)}{v^l(\omega,t)}dt. \quad \text{(A6.1)}$$

Dividing by dt, and taking the limits as $dt \to 0$, the following condition for the expected discounted value of the firm producing either the top quality services or pollution abatement services of variety ω respectively is obtained:

$$v^l(\omega,t) = \frac{\pi^l(\omega,t)}{r + I(\omega,t) - \frac{\dot{v}^l(\omega,t)}{v^l(\omega,t)}}, \quad \text{(A6.2)}$$

As in Dinopoulos and Segerstrom (1999), along the BGP the per capita variables all grow at the same rate, it follows that $\frac{\dot{v}^l(\omega,t)}{v^l(\omega,t)} = \frac{\dot{\pi}^l(\omega,t)}{\pi^l(\omega,t)} = n$. Hence, the expected discounted value (A6.2) boils down to

$$v^l(\omega,t) = \frac{\pi^l(\omega,t)}{\rho + I(\omega,t) - n}. \quad \text{(A6.3)}$$

where $r = \rho$ since the analysis refers to the BGP, and $\rho > n$. Q.E.D.

Appendix B

The Appendix proves the existence of a unique steady state value for threshold ability parameter θ_0. In the following equations the time index t has been eliminated for the sake of simplicity, unless it is strictly necessary for comprehension of the text.

B1. Substituting (21) in (9) and (11), we can write the quantity of each variety targeted by quality service innovations and environmental quality service innovations respectively as:

$$q^q(\omega) = \frac{\theta_0 NA}{mc_{w_L}(\lambda mc + \tau)}, \quad \text{(B1.1)}$$

and

$$q^a(\omega) = \frac{(1 - F(a))\,\theta_0 NA}{mc_{w_L}\left(\frac{mc}{a} + \tau\right)}. \quad \text{(B1.2)}$$

The stream of monopoly profit flows accruing to the firm that manufactures the state-of-the-art of quality services and environmental quality services respectively are therefore:

$$\pi^q(\omega) = (\lambda - 1)\,mc\frac{\theta_0 NA}{mc_{w_L}(\lambda mc + \tau)}, \quad \text{(B1.3)}$$

and

$$\pi^a(\omega) = \left(\frac{1}{a} - 1\right) mc\frac{(1 - F(a))\,\theta_0 NA}{mc_{w_L}\left(\frac{mc}{a} + \tau\right)}. \quad \text{(B1.4)}$$

Considering (18) and (B1.3), the no-arbitrage condition for the state-of-the-art quality services of variety ω can be written as:

$$(\lambda - 1)\,mc\frac{\theta_0 A_m}{mc_{w_L}(\lambda mc + \tau)} = bk(1 - s_q)\frac{\sigma}{\theta_0 - \gamma}\left[\rho + I(\omega) - n\right], \quad \text{(B1.5)}$$

where $X(\omega,t)/N(t) = k$, and $w_H = \frac{\sigma}{\theta_0-\gamma}$ have been used. Considering (19) and (B1.4), the no-arbitrage condition for the state-of-the-art environmental quality services of variety ω can be written as:

$$\left(\frac{1}{a}-1\right) mc\frac{(1-F(a))\,\theta_0 A}{mc_{w_L}\left(\frac{mc}{a}+\tau\right)} = bk\,(1-s_a)\,\frac{\sigma}{\theta_0-\gamma}\left[\rho+I(\omega)-n\right], \qquad \text{(B1.6)}$$

where $X(\omega,t)/N(t) = k$, and $w_H = \frac{\sigma}{\theta_0-\gamma}$ have been used.

Let us define the ratio of equation (B1.3) to (B1.4) $\Pi = \frac{\pi^q(\omega)}{\pi^a(\omega)} = \frac{(\lambda-1)\left(\frac{mc}{a}+\tau\right)}{\left(\frac{1}{a}-1\right)(1-F(a))(\lambda mc+\tau)}$. If $\Pi = \frac{\pi^q(\omega)}{\pi^a(\omega)} > 1$, then $\frac{v^q(\omega)}{v^a(\omega)} = \frac{\pi^q(\omega)}{\pi^a(\omega)} = \frac{1-s_q}{1-s_a} > 1$. Along the BGP equilibrium the R&D subsidy is paid to the firm with lower profit flows in such a way that equalities $\frac{v^q(\omega)}{v^a(\omega)} = \frac{\pi^q(\omega)}{\pi^a(\omega)} = \frac{1-s_q}{1-s_a}$ hold, so that $s_q = 0$ and $(1-s_a) = \Pi^{-1} \in (0,1)$, i.e., $s_a = \frac{\Pi-1}{\Pi}$, and the selective R&D subsidy is only paid to environmental quality service innovations (see Appendix A5). Solving either equation (B1.5) or (B1.6) for $I(\omega)$ the following Poisson arrival rate of innovation is obtained along each variety:

$$I(\omega)_{\{s_q=0\}} = \theta_0(\theta_0-\gamma)\,\frac{(\lambda-1)\,mcA}{mc_{w_L}\sigma bk\,(\lambda mc+\tau)} - (\rho-n)\,. \qquad \text{(B1.7)}$$

where $I(\omega,t)_{\{s_q=0\}}$ denotes the Poisson arrival rate of innovation targeting variety ω when $s_q = 0$ and $(1-s_a) = \Pi^{-1} \in (0,1)$.

On the contrary, if $\Pi = \frac{\pi^q(\omega)}{\pi^a(\omega)} < 1$, we have $\frac{v^q(\omega)}{v^a(\omega)} = \frac{\pi^q(\omega)}{\pi^a(\omega)} = \frac{1-s_q}{1-s_a} < 1$. When the R&D subsidy is only paid to the firm with lower profit flows we have $s_a = 0$ and $(1-s_q) = \Pi \in (0,1)$, i.e., $s_q = 1-\Pi$ (see Appendix A5). Solving either equation (B1.5) or (B1.6) for $I(\omega)$ the following Poisson arrival rate of innovation is obtained along each variety:

$$I(\omega)_{\{s_a=0\}} = \theta_0(\theta_0-\gamma)\,\frac{(1-F(a))\left(\frac{1}{a}-1\right)mcA}{mc_{w_L}\sigma bk\left(\frac{mc}{a}+\tau\right)} - (\rho-n)\,. \qquad \text{(B1.8)}$$

where $I(\omega)_{\{s_a=0\}}$ denotes the Poisson arrival rate of innovation targeting variety ω when $s_a = 0$ and $(1-s_q) = \Pi \in (0,1)$. Note that, in this case, if the selective R&D subsidy were only paid to environmental quality service innovations, a corner solution would be obtained where only better innovative environmental quality effort and no quality service innovations would be positive. In such a case, the aggregate Poisson arrival rate of innovation would be obtained considering eq. (B1.8).

B2. Let us consider the skilled labor market equilibrium condition as in eq. (23):

$$(\theta_0+1-2\gamma)(1-\theta_0)\,\frac{\psi}{2} = bkI \qquad \text{(B2.1)}$$

Let us assume first that $\Pi = \frac{\pi^q(\omega)}{\pi^a(\omega)} > 1$, so that $\frac{v^q(\omega)}{v^a(\omega)} = \frac{\pi^q(\omega)}{\pi^a(\omega)} = \frac{1-s_q}{1-s_a} > 1$. Since along the BGP equilibrium the R&D subsidy is only paid to the firm with lower profit flows, we have $s_q = 0$ and $(1 - s_a) = \Pi^{-1} \in (0, 1)$. Solving either equation (B1.5) or (B1.6) for $I(\omega)_{\{s_q=0\}}$ and using the law of large numbers, the aggregate Poisson arrival rate of innovation is:

$$I(\omega)_{\{s_q=0\}} = \theta_0 (\theta_0 - \gamma) \frac{(\lambda - 1) mcA}{mc_{w_L} \sigma bk (\lambda mc + \tau)} - (\rho - n), \tag{B2.2}$$

where $I(\omega)_{\{s_q=0\}}$ denotes the aggregate Poisson arrival rate of innovation targeting variety ω when $s_q = 0$ and $(1 - s_a) = \Pi^{-1} \in (0, 1)$.

Considering equation (B2.2) the skilled labor market clearing condition (B2.1) can be written as:

$$\begin{aligned} &(\theta_0 + 1 - 2\gamma)(1 - \theta_0) \tfrac{\psi}{2} = \\ &= \theta_0 (\theta_0 - \gamma) \Omega - bk (\rho - n), \end{aligned} \tag{B2.3}$$

where $\Omega \equiv \frac{(\lambda-1)mc}{\sigma mc_{w_L}} \frac{A}{(\lambda mc+\tau)}$.

The left hand side of the equation (B2.3) is a strictly concave quadratic polynomial in θ_0 with roots $(2\gamma - 1) < 0$ (recall $\gamma \in \left(0, \frac{1}{2}\right)$) and 1. The right hand side of the same equation is a strictly convex quadratic polynomial in θ_0 with two real roots, one negative and one positive, where the positive root is:

$$\theta_0 = \frac{1}{2} \left(\gamma + \sqrt{\gamma^2 + \frac{4bk(\rho - n)}{\Omega}} \right) \in (\gamma, 1) \tag{B2.4}$$

if the stated parameter restrictions are satisfied. Therefore, one and only one real and positive steady state solution $\tilde{\theta}_0^* \in (\gamma, 1)$ exists. Q.E.D.

B3. Let us assume now that $\Pi = \frac{\pi^q(\omega)}{\pi^a(\omega)} < 1$, so that $\frac{v^q(\omega)}{v^a(\omega)} = \frac{\pi^q(\omega)}{\pi^a(\omega)} = \frac{1-s_q}{1-s_a} < 1$. Since along the BGP equilibrium the R&D subsidy is only paid to the firm with lower profit flows, we have $s_a = 0$ and $(1 - s_q) = \Pi \in (0, 1)$. Solving either equation (B1.5) or (B1.6) for $I(\omega)_{\{s_a=0\}}$ and using the law of large numbers, the aggregate Poisson arrival rate of innovation is:

$$I(\omega)_{\{s_a=0\}} = \theta_0 (\theta_0 - \gamma) \frac{(1 - F(a)) \left(\frac{1}{a} - 1\right) mcA}{mc_{w_L} \sigma bk \left(\frac{mc}{a} + \tau\right)} - (\rho - n). \tag{B3.1}$$

where $I(\omega)_{\{s_a=0\}}$ denotes the aggregate Poisson arrival rate of innovation targeting variety ω when $s_a = 0$ and $(1 - s_q) = \Pi \in (0, 1)$.

Considering equation (B3.1) the skilled labor market clearing condition (B2.1) can be written as:

$$\begin{aligned} &(\theta_0 + 1 - 2\gamma)(1 - \theta_0) \tfrac{\psi}{2} = \\ &= \theta_0 (\theta_0 - \gamma) \tilde{\Omega} - bk (\rho - n), \end{aligned} \tag{B3.2}$$

where $\tilde{\Omega} \equiv \frac{\left(\frac{1}{a}-1\right)mc}{\sigma mc_{w_L}} \frac{(1-F(a))A}{\left(\frac{mc}{a}+\tau\right)}$.

The left hand side of the equation (B3.2) is a strictly concave quadratic polynomial in θ_0 with roots $(2\gamma - 1) < 0$ and 1. The right hand side of the same equation is a strictly convex quadratic polynomial in θ_0 with two real roots, one negative and one positive, where the positive root is:

$$\theta_0 = \frac{1}{2}\left(\gamma + \sqrt{\gamma^2 + \frac{4bk(\rho - n)}{\tilde{\Omega}}}\right) \in (\gamma, 1) \tag{B3.3}$$

if the stated parameter restrictions are satisfied. Therefore, one and only one real and positive steady state solution $\tilde{\theta}_0^* \in (\gamma, 1)$ exists.

Therefore, equations (23), either (B1.7) or (B1.8) imply a constant value of the threshold ability θ_0^*, that implies a constant value of the aggregate quantities (B1.1) and (B1.2), profits (B1.3) and (B1.4), no-arbitrage conditions (B1.5) and (B1.6), the per capita consumption (21). In this way, the Euler equation is satisfied for $r(t) = \rho$. Therefore, the economy is on the steady-state. This also implies that the per capita average instantaneous utility function grows at the same pace of the aggregate innovation, i.e., $\frac{\dot{u}}{u} = I\left[z \ln \lambda + (1-z)\ln\left(\frac{1}{a}\right)\right]$. As usual, the individual utility growth rate is also interpreted as the measure of the log-run economic growth rate of the economy which is the per capita BGP of the economy (see, e.g., Dinopoulos and Segerstrom, 1999; Segerstrom, 1998). Q.E.D.

B4. This Appendix obtains the selective R&D subsidy. Let us bear in mind the definition $\Pi = \frac{\pi^q(\omega)}{\pi^a(\omega)} = \frac{(\lambda-1)\left(\frac{mc}{a}+\tau\right)}{\left(\frac{1}{a}-1\right)(1-F(a))(\lambda mc+\tau)}$. Therefore, $\Pi > 1$ whenever

$$F(a) > 1 - \frac{(\lambda-1)\left(\frac{mc}{a}+\tau\right)}{\left(\frac{1}{a}-1\right)(\lambda mc+\tau)} \equiv \bar{F}. \tag{B4.1}$$

Note that, the threshold $\bar{F} < 1$ when the following inequality is satisfied: $\tau(1-\lambda) < \frac{mc}{a}(2\lambda - 1 - a)$, that always holds because $\tau(1-\lambda) < 0$ and $\frac{mc}{a}(2\lambda - 1 - a) > 0$ always hold. For $\Pi > 1$, i.e., inequality (B4.1) holds, two cases $\lambda > \frac{1}{a}$ and $\lambda < \frac{1}{a}$ need to be considered. If $\lambda > \frac{1}{a}$, inequality (B4.1) always holds because $\bar{F} = \frac{\tau\left(\frac{1}{a}-\lambda\right)-\lambda mc}{\left(\frac{1}{a}-1\right)(\lambda mc+\tau)} < 0$, and therefore the selective R&D subsidies are $s_q = 0$ and $(1 - s_a) = \Pi^{-1} \in (0,1)$, i.e., $s_a = \frac{\Pi-1}{\Pi}$. The same selective R&D subsidies are paid if $\lambda < \frac{1}{a}$, and $F(a) > \bar{F}$ because inequality (**??**) holds.

On the contrary, for $\Pi < 1$ the only possible scenario is $\lambda < \frac{1}{a}$. Indeed, for $\Pi < 1$ inequality (B4.1) can be rewritten as

$$F(a) < \frac{\tau(1-\lambda) + \tau\left(\frac{1}{a}-1\right) + mc\left(\frac{1}{a}-\lambda\right)}{\left(\frac{1}{a}-1\right)(\lambda mc+\tau)}. \tag{B4.2}$$

Since $\lambda > 1$ and $\frac{1}{a} > 1$ always hold, the first two terms on the rhs of inequality (B4.2) are strictly negative. If $\lambda > \frac{1}{a}$ held, the last term on the rhs of inequality (B4.2) would also be strictly negative, and $F(a) < 0$, that is not possible because $F(a) \geq 0$ by definition. Therefore, for $\Pi < 1$, $\lambda < \frac{1}{a}$ holds. In this case, the R&D subsidies are $s_a = 0$ and $(1 - s_q) = \Pi \in (0,1)$, i.e., $s_q = 1 - \Pi$. Q.E.D.

Appendix C

This Appendix explains how the parameter values are calibrated. To calibrate the threshold ability parameter θ_0 and the aggregate innovation rate of the baseline calibration as in Table 1, equations (**??**) and (**??**) are utilized. To calibrate the threshold ability parameter θ_0 and the aggregate innovation rate I in the sensitivity tests, eq. (23) is used to get the threshold ability parameter θ_0, equations (B1.7) and (B1.8) are used to get the aggregate innovation rate I when $\Pi > 1$ and $\Pi < 1$, respectively. To this aim, the variables $\sigma \equiv \frac{\left(1-e^{-\rho D}\right)}{\left(e^{-\rho T}-e^{-\rho D}\right)}$, $\psi \equiv \frac{\left(e^{n(D-T)}\right)}{\left(e^{nD}-1\right)}$, $\gamma = \theta_0 - \frac{\sigma}{(w_H/w_L)}$, $\Omega \equiv \frac{(\lambda-1)mc}{\sigma mc_{w_L}} \frac{A}{(\lambda mc+\tau)}$, $\tilde{\Omega} \equiv \frac{\left(\frac{1}{a}-1\right)mc}{\sigma mc_{w_L}} \frac{(1-F(a))A}{\left(\frac{mc}{a}+\tau\right)}$ are used. Table 8 shows some key parameter values with the respective source used.

Table 8: Baseline Calibration U.S.

$n = 0.1$	WDI (2020)
$\rho = 0.045$	WDI (2020)
$\lambda = 1.38$	Hall (2018)
$1 - z = 0.54$	OECD (2021)
$\tau = 0.87$	OECD (2021)
$s = 0.16$	(Muresianu and Watson, 2021; Guenther, 2016)
$mc = 0.787$	OECD (2021)
$mc_{w_L} = 0.6$	U.S. Bureau of Labor Statistics (2017)
$\theta_0 = 0.729$	Barro-Lee (2013)
$\delta = (w_H/w_L) = 1.73$	Goldin-Katz (2007), Neves et al. (2018)
$\sigma = 1.246$	calibrated
$\psi = 0.92$	calibrated
$\gamma = 0.0088$	calibrated
$b = 1$	calibrated and fitted
$k = 0.82$	calibrated and fitted

The data for the population growth rate $n = 0.01$ comes from the WDI (2020) and is the average value for the period 1990-2019. This is done because the model assumes an exogenous and constant population growth rate. To calculate $\sigma \equiv \frac{\left(1-e^{-\rho D}\right)}{\left(e^{-\rho T}-e^{-\rho D}\right)}$ and $\psi \equiv \frac{\left(e^{n(D-T)}\right)}{\left(e^{nD}-1\right)}$, the subjective discount rate ρ is set to 0.045 to generate an interest rate of 4.5%. This value is the long-term real interest rate for the period 1990-2019 taken from the OECD Statistics dataset (annual percentage) and it also coincides with the estimated value of Neves et al. (2018). A different value of ρ from that set here does not alter the calibration qualitative results. Moreover, it is assumed that the amount of time an individual spends at work D is 40 years, and the length of training T is 4 years. These are standard measures for a developed economy as in Dinopoulos and Segerstrom (1999). We therefore get $\sigma = 1.246$ and $\psi = 0.92$. To calculate $\gamma = \theta_0 - \frac{\sigma}{(w_H/w_L)}$, the variable $(1 - \theta_0)$ represents the population fraction that becomes skilled. The value $\theta_0 = 0.729$ for the U.S. is obtained from Barro and Lee (2013) and refers to the average value of the educational attainment of the total population aged 25 and over that has completed tertiary level of education for the period 1990-2019. In line with this value, the measure of the skill premium $\delta = (w_H/w_L) = 1.73$ comes from Goldin and Katz (2007) as documented in Fig. 1 and Table A1.8 - also calculated in Neves et al. (2018) - and refers to the average skill premium for the period 1990-2005. The parameter γ is then internally calibrated through the eq. (A2), and is $\gamma = \theta_0 - \frac{\sigma}{(w_H/w_L)} = 0.0088$.

The size of innovation measures the gross mark-up enjoyed by innovators. Hall (2018) estimates the mark-up to be in the range of 1.04 and 1.85 between 1988 and 2015 for the U.S. economy with an average value of $\lambda = 1.38$. The highest mark-up value estimated by Hall (2018) is $\lambda = 1.85$ and refers to the Agriculture, Forestry, Fishing and Hunting sectors, while the last but one mark-up value of $\lambda = 1.55$ refers to Accommodation and Food Services. In the cases in which $\lambda > \frac{1}{a}$, the value of parameter a is set to 0.8 to get a mark-up value for pollution abatement products of $\frac{1}{a} = 1.25 < 1.38 = \lambda$; slight perturbations of the value $a = 0.8$, such that $\frac{1}{a} < \lambda = 1.38$ holds, do not alter the results. In the cases in which $\lambda < \frac{1}{a}$, the value of parameter a is set to 0.65 to get a mark-up value for pollution abatement products of $\frac{1}{a} = 1.54 > 1.38 = \lambda$, that is close to the highest but one mark-up value estimated by Hall (2018) of $\lambda = 1.55$; slight perturbations of the value $a = 0.65$, such that $\frac{1}{a} > \lambda = 1.38$ holds, do not alter the results. Considering the sensitivity analysis, the environmental concerns population share used in Figures 1(a,b) is $F(a) = 0.58$, so that the population share that demand green products is $1 - F(a) = 0.42$. This value was first estimated by Bjerke (1992) who found that about 42% of respondents were willing to pay a premium for ecological products. Moreover, Bjerke (1992) shows that there is a group of over 30% of consumers who have positive attitudes but who do not buy ecological products, and a group of about 16% who are willing to pay without it reflecting in the market shares. Grunert (1992) and Kristensen and Creel (2012) find that about 60% are willing to pay a premium. More recently, Canavari et al. (2003) found that the proposed premium price for organic peaches and apples was accepted by 65.8% of the Italian respondents in their survey.

The parameters z and $(1 - z)$ represent the share of varieties targeted by better quality services and better environmental quality service (pollution abatement services) innovations respectively. Therefore, data on all GHG emissions (Total GHG per unit of GDP in CO_2 equivalents, units: Kilograms per 1000 US dollars, Thousands) for the period 1990-2018 from the OECD Statistics dataset are utilized. All GHG emissions data from OECD statistics include: 1A1. Energy industries, 1A2. Manufacturing industries and construction; 1A3. Transport; 1A4. Residential and other sectors; 1A5. Other-Energy; 1B. Fugitive emissions from fuels; 1C. CO_2 from transport and storage; 2. Industrial process and product use; 3. Agriculture; 5 Waste; 6 Others. Land use, land use change and forestry are only excluded. The average value for the period 1990-2018 is 0.54 which is used as a proxy of the share $(1 - z)$ of varieties targeted by pollution abatement innovations. Considering other measures of polluting emissions given by all the available actual data from the WDI (2020) - namely both CO_2 emissions (kt) and Other greenhouse gas emissions, HFC, PFC and SF6 (thousand metric tons of CO_2 equivalent, converted to kt) as well as CO_2 emissions (kg per 2017 PPP $ of GDP) - does not alter the calibration results.

To calibrate the tax on pollution, data on all environmentally related taxes (ERT) as a percentage of the GDP from the OECD Statistics dataset for the period 1995-2016 for the U.S. economy are utilized. These data on ERT refer to energy products (including vehicle fuels); motor vehicles and transport services; measured or estimated emissions to air and water, ozone depleting substances, certain non-point sources of water pollution, waste management and noise, as well as management of water, land, soil, forests, biodiversity, wildlife and fish stocks. The data have been cross-validated and complemented with Revenue statistics from the OECD Tax statistics database and official national sources. The ERT average value for the period 1995-2016 for the U.S. is $\tau = 0.87$.

To calibrate the R&D subsidy, the U.S. data on R&D tax credit are utilized. In the U.S., the actual R&D tax credit allows companies to claim credits for spending on qualified research expenditures (QREs). To date, the R&D tax credit has four separate elements: regular credit, alternative simplified credit (ASC), energy research credit, and basic (or university) research credit. The regular R&D credit equals 20 percent of a firm's QREs above a certain baseline level. The ASC equals 14 percent of a firm's QREs above half of its average QREs over the past three years, i.e., a moving average. If the firm has no QREs over the previous three years, the credit is 6 percent of QREs for the current year (Muresianu and Watson, 2021; Guenther, 2016). In this respect, companies defined as established firms are firms with gross receipts and QREs in at least three of the tax years from 1984 to 1988. Start-up firms are companies that had their first year with QREs and gross receipts after 1988, or firms that had fewer than three years of both QREs and gross receipts between 1984 and 1988. The choice of 1984 to 1988 was originally a transitional policy and has not been updated. The actual energy research credit equals 20 percent of a firm's QREs on payments to non-profit organizations for the purpose of conducting energy research in the public interest. It can also be claimed on payments to colleges, universities, federal labs, and small firms, provided the taxpayer does not hold a majority stake in the firm performing the research. The R&D tax credit applies to several QREs. It includes wages paid to workers engaged in qualified research activities, supplies (including any depreciable or non-depreciable property other than land), contracts for third parties (limited to 65 percent of the cost incurred), and basic research payments to qualified educational institutions or other scientific research organizations (limited to 75 percent of the cost incurred). In this respect, spending must meet several criteria to qualify for the credit. Taxpayers must show that research spending is based on hard sciences such as engineering, computer science, chemistry, and so on, and is related to the development of a new or improved component. Taxpayers must also prove the project's goal is to "resolve technological uncertainty" and establish a process to eliminate technological uncertainty (Holtzman, 2017). The value of the R&D subsidy is set $s = 0.16$ as an average value of regular and alternative simplified credit. Perturbations of this value according to actual data on alternative simplified credit tax do not alter the calibration results.

Due to the lack of physical capital in the model set-up, the total cost of firms, i.e., mc, is reduced by the average value (as a percentage of GDP) of Gross Capital Formation (henceforth: GCF). The U.S. GCF average value (as a percentage of GDP) for the period 1990-2019 comes from the OECD (2021) data and is 0.213, so that $mc = 1 - 0.213 = 0.787$ is obtained. Consistently with the value of all the other variables, the parameters obtained with the Shephard's lemma - i.e. mc_{w_L} - should represent the value of the labor employment as a percentage of the GDP. The U.S. labor share average value for the period 1990-2016 comes from the U.S. Bureau of Labor Statistics (2017) and is $mc_{w_L} = 0.6$.

The labor coefficient b in the R&D sector is set to 1 for the U.S. as a benchmark parameter. The R&D complexity parameter k for the PEG specification is calibrated internally at $k = 0.82$. In the calibration procedure both the labor coefficient $b = 1$ and the R&D complexity parameter $k = 0.82$ as in equation (16) are calculated to render the simulated values of the threshold ability parameter θ_0 and the innovation rate I consistent with actual data. In particular, in the baseline calibration, the threshold ability value θ_0 obtained through the calibration is compared to the average value of the educational attainment of the total population aged 25 and over that has completed the tertiary level of education for the period 1990-2019 obtained from Barro and Lee (2013). The innovation rate obtained through the calibration is compared with average R&D expenditures (as a percentage of GDP) for the period 1990-2019 which is used as a proxy for the innovation rate as in Berman-Bound-Griliches (1994). To calibrate the threshold ability parameter θ_0 and the aggregate innovation rate I of the benchmark calibration of the U.S. as in Table 1, equations (**??**) and (**??**) are utilized. In this benchmark calibration, the actual value of the ERT (as a percentage of GDP) $\tau = 0.87$ and the actual value of the R&D subsidy (as a percentage of GDP) $s = 0.16$ are utilized. The innovation rate obtained through the calibration is then compared with average R&D expenditures (as a percentage of GDP) for the period 1990-2019, which is used as a proxy for the innovation rate as in Berman-Bound-Griliches (1994). Finally, to calibrate the threshold ability parameter θ_0 and the aggregate innovation rate along the balanced green growth path as in Table 2 (with $s = \tau = 0$), equations (**??**) and (**??**) are utilized.

Appendix D

D1. Let us prove that the threshold $\bar{F}$ is a strictly increasing function in the carbon tax τ. Using calculus, the following is obtained:

$$\begin{gathered} \frac{\partial \bar{F}}{\partial \tau} = \frac{\frac{1}{a} - \lambda}{\frac{1}{a} - 1} \frac{\phi(\lambda - 1)}{(\lambda\phi + \tau)^2} > 0, \text{ for } \frac{1}{a} > \lambda, \\ \text{and} \\ \frac{\partial \bar{F}}{\partial \tau} = \frac{\frac{1}{a} - \lambda}{\frac{1}{a} - 1} \frac{\phi(\lambda - 1)}{(\lambda\phi + \tau)^2} < 0, \text{ for } \lambda > \frac{1}{a}, \end{gathered} \tag{D1.1}$$

Since inequality (B4.1) always holds when $\lambda > \frac{1}{a}$, and $\frac{\partial \bar{F}}{\partial \tau} < 0$ for $\left(\frac{1}{a} - \lambda\right) < 0$, inequality (B4.1) continues to hold with a tighter ERT τ. On the contrary if $\frac{1}{a} > \lambda$, the first inequality in condition (D1.1) implies that a tighter ERT τ increases the threshold $\bar{F}$ and inequality (B4.1) is less easily satisfied. Therefore, if $\frac{1}{a} > \lambda$ a tighter ERT τ shrinks the range of the BGP equilibrium with positive R&D subsidy for better environmental quality products and zero R&D subsidy for better quality services products, i.e., $s_a = \frac{\Pi - 1}{\Pi}$ and $s_q = 0$. Q.E.D.

D2. This Appendix proves the effects of tighter ERT on the incentives for human capital accumulation and then on the per capita growth rate of the economy. To begin with, let us consider the case in which $\Pi > 1$ and the selective R&D subsidies are $s_q = 0$ and $s_a = \frac{\Pi-1}{\Pi} \in (0,1)$, i.e., inequality (B4.1) holds which may occur when at least one of the conditions $\lambda > \frac{1}{a}$ and $\left\{\lambda < \frac{1}{a} \cap F(a) > \bar{F}\right\}$ are verified. In equation (B2.4) the ERT τ lies in the variable $\Omega \equiv \frac{(\lambda-1)mc}{\sigma mc_{w_L}} \frac{A}{(\lambda mc+\tau)}$. After substituting the variable A into Ω, it can be written as $\Omega = \frac{(\lambda-1)mc}{\sigma mc_{w_L}} \frac{1}{z + \frac{(1-z)(1-F(a))(\lambda mc+\tau)}{\left(\frac{mc}{a}+\tau\right)}}$. To determine the effects of a marginal change in the ERT τ on the threshold ability parameter $\bar{\theta}_0^*$ we can focus on the last term of the denominator of the variable Ω. To this aim, let us define $\Upsilon = \frac{(\lambda mc+\tau)}{\left(\frac{mc}{a}+\tau\right)}$. Using calculus the following relationship is proven:

$$\begin{gathered} \frac{\partial \Upsilon}{\partial \tau} = mc\frac{\frac{1}{a}-\lambda}{\left(\frac{mc}{a}+\tau\right)^2} < 0, \text{ for } \lambda > \frac{1}{a}, \\ \text{and} \\ \frac{\partial \Upsilon}{\partial \tau} = mc\frac{\frac{1}{a}-\lambda}{\left(\frac{mc}{a}+\tau\right)^2} > 0, \text{ for } \left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) > \bar{F}\right)\right\}. \end{gathered} \tag{D2.1}$$

From the first row of condition (D2.1), when $\lambda > \frac{1}{a}$ holds, a tighter ERT τ implies $\frac{\partial \Upsilon}{\partial \tau} < 0$. Therefore, a tighter ERT τ implies a higher Ω, a lower positive root in equation (B2.4), a lower threshold ability parameter $\bar{\theta}_0^*$, and a higher aggregate Poisson arrival rate of innovation $I^*_{\{s_q=0\}}$ along the new BGP equilibrium are obtained. On the contrary, from the last row of condition (D2.1), when $\left\{\left(\lambda < \frac{1}{a}\right) \cap \left(F(a) > \bar{F}\right)\right\}$ holds, a tighter ERT τ implies $\frac{\partial \Upsilon}{\partial \tau} > 0$. Therefore, a tighter ERT τ implies a lower Ω, a higher positive root in equation (B2.4), a higher threshold ability parameter $\bar{\theta}_0^*$, and a lower aggregate Poisson arrival rate of innovation $I^*_{\{s_q=0\}}$ along the new BGP equilibrium are obtained. Q.E.D.

Let us turn now to the case in which $\Pi < 1$ and the selective R&D subsidies are $s_a = 0$, $(1 - s_q) = 1 - \Pi$, i.e., inequality (**??**) does not hold which is verified when condition $\left\{\lambda < \frac{1}{a} \cap F(a) < \bar{F}\right\}$ holds. In eq. (B3.3) the ERT τ lies in the variable $\tilde{\Omega} \equiv \frac{\left(\frac{1}{a}-1\right)mc}{\sigma mc_{w_L}} \frac{(1-F(a))A}{\left(\frac{mc}{a}+\tau\right)}$. After substituting the variable A into $\tilde{\Omega}$, it can be rewritten as $\tilde{\Omega} \equiv \frac{\left(\frac{1}{a}-1\right)mc}{\sigma mc_{w_L}} \frac{1}{\frac{z\left(\frac{mc}{a}+\tau\right)}{(1-F(a))(\lambda mc+\tau)} + (1-z)}$. To determine the effects of a marginal change in the ERT τ on the threshold ability parameter $\tilde{\theta}_0^*$ along the new BGP equilibrium, we can focus on the last term of the denominator of $\tilde{\Omega}$. To this aim, let us define $\tilde{\Upsilon} = \frac{\left(\frac{mc}{a}+\tau\right)}{(\lambda mc+\tau)}$. Using calculus, the following relationship is proven:

$$\frac{\partial \tilde{\Upsilon}}{\partial \tau} = mc\frac{\lambda - \frac{1}{a}}{(\lambda mc + \tau)^2} < 0 \text{ for } \left\{ \left(\lambda < \frac{1}{a}\right) \cap \ \left(F(a) < \bar{F}\right) \right\}. \qquad \text{(D2.2)}$$

Therefore, a tighter ERT τ implies a lower $\tilde{\Upsilon}$, a higher $\tilde{\Omega}$, a lower positive root in equation (B3.3), a lower threshold ability parameter $\tilde{\theta}_0^*$, and a higher aggregate Poisson arrival rate of innovation $I^*_{\{s_a=0\}}$ along the new BGP equilibrium. Q.E.D.

D3. Let us analyze the effect of a tighter ERT on the selective R&D subsidy.

When $\Pi > 1$ - which may occur when at least one of the conditions $\lambda > \frac{1}{a}$ and $\left\{\lambda < \frac{1}{a} \cap F(a) > \bar{F}\right\}$ is verified - the selective R&D subsidy only paid to pollution abatement innovations is $s_a = \frac{\Pi - 1}{\Pi} = 1 - \Pi^{-1}$, where $\Pi^{-1} = \frac{\left(\frac{1}{a}-1\right)(1-F(a))}{(\lambda-1)}\frac{(\lambda mc+\tau)}{\left(\frac{mc}{a}+\tau\right)}$. Therefore, $\frac{\partial \Pi^{-1}}{\partial \tau} = \frac{\left(\frac{1}{a}-1\right)(1-F(a))}{(\lambda-1)}\frac{mc\left(\frac{1}{a}-\lambda\right)}{\left(\frac{mc}{a}+\tau\right)^2}$. When $\lambda > \frac{1}{a}$ holds, $\frac{\partial \Pi^{-1}}{\partial \tau} < 0$ and $\frac{\partial s_a}{\partial \tau} = -\frac{\partial \Pi^{-1}}{\partial \tau} > 0$, i.e., a tighter ERT τ increases the selective R&D subsidy paid to pollution abatement innovations. On the contrary, when condition $\left\{\left(\lambda < \frac{1}{a}\right) \cap \ \left(F(a) > \bar{F}\right)\right\}$ holds, $\frac{\partial \Pi^{-1}}{\partial \tau} > 0$, and $\frac{\partial s_a}{\partial \tau} = -\frac{\partial \Pi^{-1}}{\partial \tau} < 0$, i.e., a tighter ERT τ decreases the selective R&D subsidy paid to pollution abatement innovations. When $\Pi < 1$, which occurs when condition $\left\{\lambda < \frac{1}{a} \cap F(a) < \bar{F}\right\}$ is verified, the selective R&D subsidy paid to better quality innovations is $s_q = 1 - \Pi$, where $\Pi = \frac{(\lambda-1)}{\left(\frac{1}{a}-1\right)(1-F(a))}\frac{\left(\frac{mc}{a}+\tau\right)}{(\lambda mc+\tau)}$. Therefore, $\frac{\partial \Pi}{\partial \tau} = \frac{(\lambda-1)}{\left(\frac{1}{a}-1\right)(1-F(a))}\frac{mc\left(\lambda-\frac{1}{a}\right)}{(\lambda mc+\tau)^2} < 0$ because $\lambda < \frac{1}{a}$ holds in this scenario, and $\frac{\partial s_q}{\partial \tau} = -\frac{\partial \Pi}{\partial \tau} > 0$, i.e., a tighter ERT increases the selective R&D subsidy paid to better quality innovations that in such a scenario is also the R&D subsidy paid to pollution abatement innovations. Q.E.D.

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