CARBON SUBSIDIES TO GREENING EDUCATIONAL AND BUSINESS ACTIVITIES[1]

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Abstract. This paper proposes a comparative framework to identify the impacts of alternative uses of carbon revenue and their redistribution. Although different studies have focused on the optimal carbon price path, the role of carbon revenue recycling is understudied. On this basis, we examine the macroeconomic impact of two carbon recycling strategies: i) encouraging investment in low-carbon projects at the firm level; and ii) subsidies to pursue SDGs, promoting the greening of human capital in the educational sector. To this end, this document presents an original Dynamic Stochastic General Equilibrium (DSGE) model that includes the higher education sector, low-carbon firms, and climate change. Our analysis shows that both strategies increase green human capital through two different channels. However, funding academics is crucial to improving the quality of education and promoting sustainable development in the long term. In contrast, firm-level green subsidies have a significant impact on short-term low-carbon productivity and mainly affect hiring and investment decisions. In both cases, these measures improve households' welfare.

1. Introduction

This study aims to investigate the effectiveness of carbon taxation and its potential macroeconomic implications in relation to green human capital. Although several studies have demonstrated the optimal level and dynamic for carbon prices (Acemoglu *et al.*, 2012), the most effective method for returning carbon tax revenues to the public has not been adequately determined. In recent years, global carbon pricing revenue increased significantly, to US$84 billion in 2021, representing a noteworthy additional source to fund climate mitigation, industry competitiveness, and economic and development goals (Agnolucci *et al.*, 2023). Global carbon pricing

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[1] For research articles with several authors, a short sentence specifying their individual contributions can be provided here. The affiliations and contacts of the authors should NOT be reported here, but at the bottom of the last page.

revenue rose by almost 60% compared to 2020 levels, with emissions trading system revenues surpassing carbon tax revenues for the first time due to higher emissions trading system prices. Therefore, policymakers are paying increasing attention to how carbon revenues can be allocated most effectively.

However, while carbon revenues have been mostly used to fund measures that reduce emissions by promoting investment in low-carbon technologies. On the contrary, these funds could also be used to pursue broader objectives, such as health and human capital, i.e., direct funding to higher education institutions to improve education and research activities, particularly in climate change area, could be a potential strategy (World Bank, 2019). Nonetheless, the international climate policy debate has mainly focused on supply-side incentives in recent years. Although several studies have examined the adverse effects of carbon emissions increases and their policy implications in the Dynamic Stochastic General Equilibrium (DSGE) context (Fisher and Springborn, 2011; Heutel, 2012; Annicchiarico *et al.*, 2015), the role of human capital and educational policies has not been adequately considered. To fill this gap, this paper provides a comparative framework to identify the impacts of alternative uses of carbon revenue, mainly focusing on the *education sector.* In detail, this paper seeks to answer the following research questions*: What are the macroeconomic implications of employing a carbon revenues strategy to fund sustainable activities at the university level? How does this strategy differ from utilizing carbon revenues to subsidize low-carbon firms?* To answer this question, we extend a standard Environmental Dynamic Stochastic General Equilibrium (E-DSGE) model to include the higher education sector, high-carbon and low-carbon firms, and the climate module. Our research contribution extends the existing literature that employs DSGE models to investigate environmental issues (known as E-DSGE). Previous studies in this domain primarily focus on the supply side of the economy when addressing environmental implications (Fischer and Springborn, 2011; Heutel, 2012; Annicchiarico and Di Dio, 2015; Annicchiarico and Di Dio, 2017). Despite these contributions, two significant research gaps exist. First, our study innovates in its research topic, with few studies analysing carbon revenue recycling in a general equilibrium framework. Previous works neglect the potential impact of using carbon revenues for educational goals. Thus, our study analyses the effects of using carbon revenue to finance tuition subsidies. Second, our work innovates in its modelling approach. In a general equilibrium framework, no previous studies have examined the interaction between education supply, macroeconomic outcomes, and their impact on environmental issues This paper is structured as follows. Section 2 describes the DSGE model. In section 3, we present the model calibration. Section 4 discusses model performances and policy experiments. Finally, section 5 concludes.

2. The Model

The economy is populated by households, academic departments, academic institutions, green and traditional human capital, final and intermediate goods-producing firms, a government, and the climate system. The structure of the model consists of a standard TANK (Two Agents New Keynesian) model augmented to include the academic institution sector and a climate module. The model presents two types of households differing with respect to their ability to access financial and labor markets, namely Ricardian (Skilled) and Non-Ricardian (Unskilled). Ricardian households offer labor services in the green and dirty sectors and the green and traditional departments as skilled workers and teachers, respectively. In addition, Ricardian Households offers capital for both firms. On the contrary, non-Ricardian households offer labor services in the green and dirty sectors as unskilled workers, and they can spend part of their time in education activities (green or traditional). The production sector produces a unique final good combining two intermediate goods, dirty and green. This study provides two alternative types of human capital accumulation: green and traditional. In the following, we discuss the behavior of HEIs and departments, the remaining part of the model corresponds to the standard E-DSGE modeling.

2.1. Higher Education Institutions

The educational sector is defined by two hierarchic levels: academic departments and institutions. Departments hire teachers in perfectly competitive factor markets to convert time spent in education, from the non-Ricardian households into the new human capital F_t.The representative academic department employs teachers to provide two kinds of education, namely traditional and green. Academic institutions aggregate green and traditional courses to provide the total educational supply, considering costs related to each course implementation.

2.1.1 Green Departments

The intermediate green educational sector is dominated by a continuum of monopolistically competitive green departments indexed by $j \in [0,1]$ facing a demand function from the higher education sector. Notably, green departments produce new green human capital by combining time to green education ($E_{G,t}$) with teaching production hours ($N^R_{HG,t}$), as in the follows:

$$F(j)_{G,t} = A_{HG,t}\left[E(j)_{G,t}\right]^{\theta_G}\left[N(j)^R_{HG,t}\right]^{\theta_{NG'}} \in (0,1)\,, \tag{1}$$

where θ_G defines the marginal return to time spent in green education to former green human capital, because of the diminishing return to education, it takes values in the interval $(0,1)$; θ_{NG} defines the share of traditional teachers in the human capital formation; $A_{HG,t}$ measures the efficiency of human capital production technology. In addition, following The European University Association (EUA) survey, we consider quadratic adjustment costs of green sector teacher recruitment that reveal that tertiary institutions face several barriers to greening and environmental sustainability. They found a lack of employee engagement, coordination of activities, and strategic support among them. These types of challenges are formalized as follows:

$$\Gamma_t(N(j)_{HG}^R) = \frac{\gamma_N}{2}\left(\frac{N(j)_{HG,t}^R}{N(j)_{HG,t-1}^R} - 1\right)^2 N(j)_{HG,t}^{R}, \tag{2}$$

where γ_N represent the green teachers adjustment cost parameter. Accordingly, to its production function, input costs and adjustment costs on new green teachers, green Departments maximizes the following profits:

$$\max_{N(j)_{HG,t}^R} \Pi(j)_{G,t}^{AI} = \left(1+\tau_t^h\right)\frac{P_{G,t}^E}{P_t}F(j)_{G,t} - \frac{W(j)_{HG,t}N(j)_{HG,t}^R}{P_t} - \Gamma_t(N(j)_{HG}^R), \tag{3}$$

τ_t^h defines a green education subsidy for each of new green additionally green course implemented. From the maximization problem, we derive the input price equation given by:

$$\frac{W(j)_{HG,t}}{P_t} = \left(1+\tau_t^h\right)\frac{P_{G,t}^E}{P_t}\theta_{NG}\frac{F(j)_{G,t}}{N(j)_{GT,t}^R} - \left[\gamma_N\left(\frac{N(j)_{HG,t}^R}{N(j)_{HG,t-1}^R} - 1\right)\frac{N(j)_{HG,t}^R}{N(j)_{HG,t-1}^R} + \frac{\gamma_N}{2}\left(\frac{N(j)_{HG,t}^R}{N(j)_{HG,t-1}^R} - 1\right)^2\right] +$$

$$+\gamma_N\left(\frac{N(j)_{HG,t+1}^R}{N(j)_{HG,t}^R} - 1\right)\left(\frac{N(j)_{HG,t+1}^R}{N(j)_{HG,t}^R}\right)^2, \tag{4}$$

In our model, the rate of return per unit of green teaching labor $W_{HG,t}$ is defined as marginal products of $N_{GT,t}^R$.

2.1.2 Traditional Departments

The intermediate traditional educational sector is dominated by a continuum of monopolistically competitive traditional departments indexed by $j \in [0,1]$ facing a demand function from the higher education sector. Traditional Departments produce standard human capital by combining time to traditional education $\left(E_{T,t}\right)$ with teaching production hours ($N^{R}_{HG,t}$), as in the follows:

$$F(j)_{T,t} = A_{HT,t}\left[E(j)_{T,t}\right]^{\theta_{GT}}\left[N(j)^{R}_{HT,t}\right]^{\theta_{GNT},} \in (0,1)\,, \tag{5}$$

where θ_{T} defines the marginal return to time spent in education green in human capital formation, because of the diminishing return to education, it takes values in the interval (0,1); θ_{NT} defines the share of traditional teachers in the human capital formation; $A_{HG,t}$ measures the efficiency of human capital production technology. Traditional academic departments maximize the following profit:

$$\max_{N^{R}_{HT,t}} \ \Pi^{AI}_{G,t} = \frac{P^{E}_{T,t}}{P_t} F(j)_{T,t} \frac{W_{HT,t} N(j)^{R}_{HT,t}}{P_t}, \tag{6}$$

From the maximization problem, we derive the input price equation given by:

$$\frac{W(j)_{HT,t}}{P_t} = \theta_{NT} \frac{P^{E}_{T,t}}{P_t} \frac{F(j)_{T,t}}{N(j)^{R}_{HT,t}} \tag{7}$$

In our model, the rate of return per unit of traditional teaching labor $W_{HT,t}$ is defined as marginal products of $N^{R}_{HT,t}$.

2.1.3 Academic Institutions

The final educational supply is produced according to the following production function:

$$F_t(j) = \left\{(\gamma^{e})^{1/\sigma_e}\left[F(j)_{G,t}\right]^{\frac{\sigma_e - 1}{\sigma_e}} + (1-\gamma^{e})^{1/\sigma_e}\left[F(j)_{T,t}\right]^{\frac{\sigma_e - 1}{\sigma_e}}\right\}^{\frac{\sigma_e}{\sigma_e - 1}}, \ \gamma^{e} \in (0,1)\,, \tag{8}$$

where γ^{e} represents the share of intermediate green course used in the defining the final educational supply and $\sigma_e > 0$ is the elasticity of substitution between green and traditional intermediate course; γ^{e} represents the degree of environmental sustainability in the academic institution. Similarly, the demand curves for the two courses can be derived as follows:

$$F_{G,t} = \gamma^{e}\left(\frac{P^{E}_{G,t}}{P^{E}_{t}}\right)^{-\sigma_e} F_t, \tag{9}$$

$$F_{T,t} = (1-\gamma^e)\left(\frac{P_{T,t}^E}{P_t^E}\right)^{-\sigma_e} F_t, \qquad (10)$$

where $F_{i,t}$ consist of a continuum of intermediate varieties $F_{i,t}(j)$ with $j \in (0,1)$and$j \in \{G,T\}$ as follows:

$$F_{i,t} = \left(\int_0^1 F(j)_{i,t}^{(\theta_e-1)/\theta_e}\, dj\right)^{\theta_e/(\theta_e-1)} \quad \theta_e > 1 \qquad (11)$$

$$P_{i,t}^E = \left(\int_0^1 P(j)_{i,t}^{E(\theta_e-1)}\, dj\right)^{1/(\theta_e-1)} \quad \theta_e > 1 \qquad (12)$$

Notably, non-Ricardian Households pay an equal fee for both green and traditional courses, P_t^E. However, for simplicity, we set this price equal to one.

3. Calibration

This section summarizes the calibration of the model presented in this study. The model is calibrated for the Euro area. Accordingly, we refer to previous studies focused on Euro area models to calibrate the households and production sections of the model. Macroeconomic parameters are set in accordance with those used in the calibration of a basic New Keynesian model (See Table 1).

Table 1 – *Model Calibration- Macroeconomic Parameters.*

Parameters	Descriptions	Values	Source
s_{NR}	Non-Ricardian (Unskilled) share	0.57	Eurostat
γ_N	Green Teaching Adjustment Cost	71	Annicchiarico *et al.* (2017)
γ	Share of Green Goods	0.2	Giovanardi *et al.* (2023)
γ^e	Share of Green Courses	0.2	Assumed equal to γ
σ	Elasticity of Substitution Green and Dirty goods	2	Giovanardi *et al.* (2023)
σ_e	Elasticity of Substitution Green and Dirty courses	2	Giovanardi *et al.* (2023)
θ	Elasticity of Substitution- Production	3.58	NAWM-II
β^j	Discount Factor Ricardian	0.98	Standard in Literature
ψ_j^i	Inverse of Frish Elasticity	1.00	Annicchiarico and Di Dio (2015)
δ_j	Depreciation Rate Sectoral Capital	0.1	NAWM-II
α_D	Share of Dirty Capital	0.3	NAWM-II
α_D^R	Share of High Skilled Workers -Dirty Sector	0.30	Calibration based on Eurostat
α_G	Share of Green Capital	0.30	NAWM-II
α_D^R	Share of High Skilled Workers -Dirty Sector	0.30	Calibration based on Eurostat
ξ_D	Emission per unit of dirty output	0.38	Annicchiarico and Diluiso (2019)
δ_m	Emissions Decay rate	0.0035	Gibson and Heutel (2020)

In contrast to the economy sector calibration, there is relatively little econometric evidence on the parameters in human capital formation. In detail, to calibrate the Higher Education Institution Sector, we refer to previous studies. Heckman (1976) estimates the parameters of the human capital production function, relative to time spent in educational activity, in the range from 0.51 to 0.80. More precisely, Kim and Lee (2007) set θ_G and θ_T equal to 0.49 and θ_{NG} and θ_{NT} such that$\theta_j + \theta_{Nj}$ is equal to 0.8. Turning to the depreciation rate of human capital, Heckman's (1976) estimates range from 4 to 9 % per year. In this study we set $\delta_j^h = 0.04$.

4. Results

In this section we examine the impacts of two carbon revenue recycling strategies: (i) subsidies for firms-level low-carbon investments; and (ii) subsidies for sustainable development goals, including the promotion of green human capital via academic and research programs. [2] Figure 1 displays the impact of a 10% carbon tax shock on the academic sector under both carbon revenue recycling strategies. When the focus is on promoting other sustainable development goals, the shock leads to an increase in revenues used to incentivize green initiatives in academia. In response, academic institutions adjust their course offerings to promote interdisciplinary approaches to climate change. This leads to an increase in demand for teachers with expertise in sustainability topics, resulting in a 0.12% increase in the number of green teachers. The subsidy also encourages households to allocate more of their time towards acquiring skills and knowledge relevant to the low-carbon sector, resulting in a 0.03% increase in green human capital. This mechanism contributes to an increase in the availability of green human capital in the economy. However, the impact on educational variables is limited due to staff adjustment costs and decreasing marginal returns of departments' production functions. Additionally, rigidities associated with staff turnover make the impact of this fiscal policy measure on the higher education sector more persistent, even after changes in educational offerings. In contrast, traditional courses, teachers, education, and human capital experience slight decreases. Figure 2 illustrates the impact of measures to promote the provision of green courses on the goods sector. The overall dynamics of this economy are shaped by two primary factors. First, a carbon tax impacts the competitiveness of carbon-intensive firms, favoring the low-carbon industry.

[2] The simulations have been obtained using numerical analysis and perturbation methods to simulate the economy and compute the equilibrium conditions outside the steady state. We solve the model using a second-order Taylor approximation around its steady state. The model has been solved by using the Dynare, a software platform for handling a wide class of economic models, in particular dynamic stochastic general equilibrium (DSGE) and overlapping generations (OLG) models. For details, see http:// www. cepre map. cnrs. fr/ dynare/ and Adjemian *et al.* (2011).

Second, the introduction of a "green" education subsidy alters the skillset available in the workforce. The available human capital acts as the conduit between education and production sectors. A hike in the carbon tax renders the 'dirty' industry less profitable than the 'green' one (as indicated by a decrease in dirty output by roughly 0.03%). Ricardian households, anticipating future growth in the green sector, adjust their preferences accordingly. They choose to divest from the dirty sector and increase their investment in low-carbon production. This investment decision results in an increase in green output, thereby escalating the demand for low- and highly skilled workers in the low-carbon sector (0.12% and 0.03%, respectively). However, low-skilled workers experience more significant effects. An educational grant influences low-skilled abilities in the green sector, enhancing its productivity. In addition, a portion of high-skilled resources is derived from the educational sectors to instruct in the new "sustainable" courses. A second scenario explores a carbon revenue recycling strategy designed to stimulate low-carbon production. Specifically, we examine the macroeconomic implications of a 10% carbon tax shock, with carbon revenues being directly used to support low carbon firms. After implementing this measure, green output, capital, and labor increase considerably more than with measures to subsidize green education (as depicted by the red line versus blue line in Figure 2). This type of measure has ripple effects in the educational sector.

Figure 1- *Impulse response functions to a 10 % Carbon Tax Shock under: "green firms" and "green education" recycle strategies: Education Variables.*

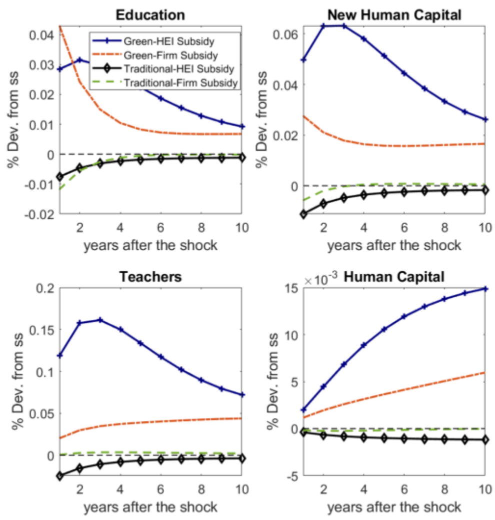
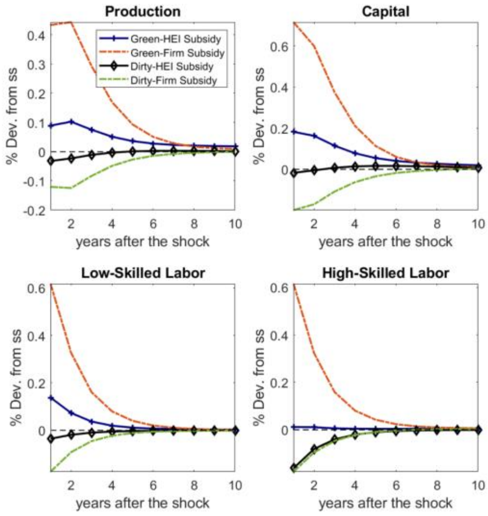
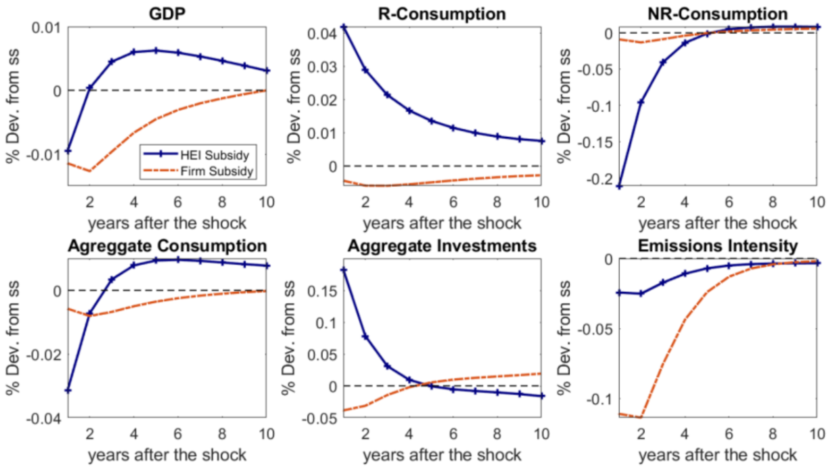


Figure 2- *Impulse response functions to a 10 % Carbon Tax Shock under: "green firms" and "green education" recycle strategies: Sectoral variables*



At the moment of the shock, green technology push measures significantly impact the demand for green education more than higher educational institution (HEI) subsidies. In essence, the rise in low-carbon production is forcing non-Ricardian households to pursue education that meets evolving market needs and acquire skills applicable in the green sector. Higher education institutions respond by tailoring their educational offerings to the demand for education, boosting the proportion of sustainable courses by 0.03%. This mechanism results in an increase in green teachers and green human capital. Conversely, traditional higher education experiences a decrease in demand and supply for conventional courses. With this comprehensive information, we can evaluate the effectiveness of both carbon tax recycling measures at a sectoral level. First, though a green production subsidy significantly influences the demand for green education, higher education institutions are less inclined to modify their educational offerings in response to this measure. Changing curricula is expensive, and only a green education grant measure can substantially influence academic decisions. However, a grant measure on green education has a lesser positive effect on low-carbon production at the shock impact (0.1% compared to 0.4% in the green production subsidy). In contrast, the significant positive effects of green human capital permit the maintenance of green output above their initial level. After examining the intersectoral dynamics, we can consider the performance of both carbon tax recycling measures in terms of aggregate variables (see Figure 3).

Figure 3- *Impulse response functions to a 10 % Carbon Tax Shock under: "green firms" and "green education" recycle strategies: Aggregate Variables.*



Measures encouraging green education increase aggregate investment and Ricardian consumption. However, they negatively affect non-Ricardian consumption and overall production. Specifically, non-Ricardian households reduce their consumption as they opt to invest more time in education, which decreases their disposable income. Nonetheless, enhancing their educational status enables to increase consumption after two years persistently. After about two years, the latter affects aggregate demand and pushes production above its original level. On the other hand, a measure of green production subsidy results in a reduction of both Ricardian and non-Ricardian consumption. Additionally, this fiscal policy has a negative impact on aggregate investment and production, with both variables decreasing by approximately 0.05 and 0.01, respectively. Unlike the previous scenario, the impact on human capital is less significant, and this mechanism prevents the aggregate variables from increasing persistently after shock exposure. Despite this, the effect on emission intensity is positive in both cases. However, in the case of subsidies for green technologies, the reduction in intensity is mainly due to a slowdown in production. In contrast, in the case of green education, the reduction occurs because the proportion of low-carbon output in the total output increases.

5. Conclusions

This paper presents a new DSGE model setup that extends the standard TANK framework to include the higher education sector, green and traditional human capital, to analyzes the impact of two different carbon recycling policies This study finds that both subsidy measures positively influence HEIs to offer sustainable education, allowing for the greening of human capital. A subsidy for educational institutions is crucial to increasing the quality of education by allowing HEIs to hire more faculty members, even though non-Ricardian households spend less time on education compared to the green firm subsidy scenario. Furthermore, a grant measure for green education allows for maintaining new investments in green human capital above the initial level for a more extended period. However, a green stimulus measure at the firm level has a more significant impact on green production. This latter occurs because green firm subsidies significantly affect the labor market and skill acquisitions, allowing for an increase in the market share of green firms. Although both measures see a decrease in GDP at the impact level, the significant positive consequences of a sustainable education push measure on green human capital enable sustainable development in the long term. Additionally, both measures contribute to improving environmental efficiency and reducing emissions intensity. The study highlights the need for more research on the interaction between different areas of environmental policy, particularly when educational and cultural issues come into play.

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