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MACROECONOMIC AND ENVIRONMENTAL EFFECTS OF PORTFOLIO DECARBONISATION STRATEGIES

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Andrea Papetti* and Massimiliano Pisani*

Abstract

We show, using three different macroeconomic models, that portfolio decarbonisation strategies, by imposing tighter financing conditions on firms that can engage in both brown and green investments, may not reduce CO2 emissions or reduce them at the cost of output loss. On the contrary, portfolio decarbonisation strategies that selectively relax and tighten the financing conditions for, respectively, green and brown investments, could lower emissions and improve macroeconomic activity.

JEL Classification: E20, E22, Q43, Q5.

Keywords: portfolio decarbonisation strategy, financing conditions, green and brown investments, macroeconomic effects.

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1 Introduction[1]

In pursuing portfolio decarbonisation strategies, investors condition the access to and the cost of finance on the degree of carbon emissions, differentiating between brown (i.e. high-emission) and green (i.e. low-emission) firms. Financial intermediaries may impose stricter financing conditions on brown firms (whose assets thus lose value, becoming "stranded") in order to possibly contain climate related risks and support the transition towards a low-carbon economy.

As highlighted, among others, by Angelini (2024) and Hartzmark and Shue (2023), portfolio decarbonisation strategies may however lead to unintended consequences. Facing higher financing costs, profit-maximizing brown firms could optimally choose to reduce rather than increase their investment in green (emission-reducing) technology, eventually increasing carbon emissions, as the incumbent polluting technology is not properly replaced. Moreover, should the goods produced by brown firms be hardly replaceable, the difficulty of supply to keep up with demand may have adverse macroeconomic effects. The result would be detrimental macroeconomic and/or environmental consequences.

In this paper, we investigate the macroeconomic and environmental effects of imposing tighter financing conditions on brown firms using a suite of macroeconomic models. Our main contribution is to provide novel modelling frameworks that explicitly assess the impact of tighter financing conditions, due to investors' decarbonisation strategies, on macroeconomic and environmental conditions. More specifically, we focus on the role of cash flows and financial frictions for firms' brown and green investment decisions. The latter could be undertaken by "virtuous" high emitters, i.e. brown firms that ambitiously and credibly work toward cutting their emissions. All reported results are illustrative (not quantitative) and do not refer to any particular country.

In a stylized partial equilibrium model in the spirit of Hartzmark and Shue (2023) we show that brown firms can become more brown if, facing an increase in their cost of capital due to the "sustainable investing practices" adopted by financial intermediaries, they optimally choose brown investment projects instead of switching to green ones. As brown projects yield more

[1]We thank Paolo Angelini, Michele Caivano, Riccardo Cristadoro, Giuseppe Ferrero, Fabrizio Ferriani, Stefano Neri, Patrizio Pagano, and Marco Taboga for useful discussions. The views expressed in this paper are those of the authors alone and should not be attributed to the Bank of Italy or the Eurosystem. All errors are of the authors.

front-loaded cash flows compared to green projects, an increase in the cost of capital resulting from decarbonisation strategies can make the present value of a brown project higher and thus preferable, although the green project has a higher cash flow growth rate. Indeed, Hartzmark and Shue (2023) find that increasing financing costs for brown firms can make brown firms more brown without making green firms more green.

Then, we turn to a model that features an endogenous link between the tightness of financing conditions and the emissions in the representative firm's abatement decisions. It builds on a simplified version of the Dynamic Integrated Climate-Economy (DICE) framework à la Nordhaus (2008). As in the DICE, industrial emissions depend on output and abatement spending. Unlike the DICE, for simplicity we assume that output depends on labor only, ignoring capital accumulation and the pollution externality. We impose that the firm has to issue (intra-period) loans to the household, paying an interest rate that positively depends on the firm's emissions. This aims at simulating the intended logic of decarbonisation policies, which are meant to reduce access to finance for high emitters. Firms use loans to finance spending in abatement activity, in order to reduce their carbon footprint.

Finally, we simulate a dynamic model in which a brown firm can invest in both brown and green capital. Brown and green capital enter its production function and emissions are assumed to be proportional to brown capital. The financial friction, which differentiates between brown and green capital, makes the relative price of capital a key variable in driving the macroeconomic dynamics. We consider different scenarios aimed at capturing the progressive and expected worsening of borrowing conditions, modeled as a fall in the loan-to-value (LTV) ratios associated with the aggregate stock of capital or with brown capital only.

All in all, the suite of models considered consistently suggests that tighter financing conditions associated with financial intermediaries' decarbonisation strategies may not necessarily lead to a reduction in firms' emissions. Unintended consequences of decarbonisation strategies may occur if tighter financing conditions on brown firms imply an excessive cost of credit to finance profitable abatement spending or an expected reduction in the (future) value of the assets used as collateral. Even if these decarbonisation strategies are successful in emissions reductions, the associated environmental achievement may come at the cost of an output loss.

Instead, a decarbonisation strategy that could selectively relax and tighten the financing conditions for, respectively, green and brown investments, could improve macroeconomic activity and lower emissions. The results suggest that a decarbonisation strategy implemented by financial intermediaries (or, more generally, by private investors) that favors "virtuous" firms that can credibly engage in green investments, irrespective of whether they are (initially) brown, is more promising than a strategy that distinguishes between brown and green firms based solely on the observed initial level of emissions. Hence, our results provide support to the so called "best-in-class" approach, calling for financing conditions to be relaxed for green investments and tightened for brown investments.

Related literature. The paper is related to a growing literature that, assessing potential ways to finance the green transition, points to the pitfalls of decarbonisation strategies that merely yield divestment from polluting firms with ensuing capital reallocation to less emission-intensive firms. Angelini (2024) suggests that a strategy of mere divestment from brown firms, although guided by individual decarbonisation targets, may not lead to actual decarbonisation in the aggregate – as high emitters may stick to their polluting technology, while low emitters may have little opportunity for improvements as their emissions are low already – favouring instead a strategy that rewards those firms that can ambitiously and credibly work toward cutting their emissions (i.e. the "best-in-class" approach mentioned above). In this respect, strategies that envisage an engagement of financial intermediaries with firms that can commit to a green project, irrespective of their initial pollution level, are found to be preferable to mere divestment from brown firms both theoretically (Green and Roth, 2024; Oehmke and Opp, 2024; Broccardo et al., 2022; Edmans et al., 2022) and empirically (Hartzmark and Shue, 2023; Berk and Van Binsbergen, 2021).

Recent studies provide contrasting evidence on the effects of decarbonisation strategies implemented by financial intermediaries. On the one hand, it seems that decarbonisation strategies have not (yet) been effectively implemented. According to Sastry et al. (2024), financial intermediaries neither reduce credit supply to the sectors targeted for decarbonisation nor increase financing for green projects. Additionally, they find no evidence that engagement by financial intermediaries with brown firms has led to a reduction in financed emissions. On the other hand, Columba et al. (2024) find instead that funds disclosing a commitment to ESG-investment reduce their ESG-risk exposure by selling brown stocks, which eventually leads brown firms to lower investment and environmental expenditures, leading to an increase in carbon emissions. Also, Iovino et al. (2023) report that dirty energy producers (measured by their carbon intensity or their fossil fuel energy production capacity) employ more tangible assets and, thus, borrow relatively more, as tangible capital is a better collateral than intangible capital. Finally, Costa et al. (2024) find that financing constraints (and a lack of green managerial capacity) reduce firms probability of investing in green technologies, leading to higher emission intensity.

The paper is organized as follows. Section 2 reports a numerical exercise based on a partial-equilibrium model. Section 3 contains setup and simulated results of a simplified version of the DICE model in which the tightness of firms' financing conditions positively depends on its CO_2 emissions. Section 4 reports setup and results of a dynamic model enriched with brown and green capital and their associated borrowing constraints. Section 5 concludes.

2 Brown and green cash flows and the increase in the cost of capital: a numerical example

We build on Hartzmark and Shue (2023) and run a numerical example to show that sustainable investment strategies can make "brown" firms more "brown". The reason is that brown projects deliver more front-loaded cash flows compared to green projects. Thus, an increase in the cost of capital, due to sustainable investing, can lead brown firms to prefer brown projects instead of dismissing them.

The firm has to decide in the initial period whether to produce output (Y_t) using brown or green capital as an input:

$$Y_t^i = (K_t^i)^\alpha, \ i = B, G \tag{1}$$

where K^B, K^G are brown and green capital, respectively, and $0 < \alpha < 1$ is a parameter measuring the output elasticity with respect to the type of capital. For simplicity, we do not model the relation between brown output and emissions. The assumption is that emissions increase with brown (i.e., brown capital-based) production.

The capital-specific accumulation laws are

$$K_t^i = (1 - \delta_K)K_{t-1}^i + I_t^i, \ i = B, G, \tag{2}$$

where $0 < \delta_K < 1$ is the depreciation rate of capital and is I^i the investment (I^B is brown investment, I^G is green investment).

In the initial period the firm decides which type of capital, brown or green (K^B or K^G), to install and accumulate in the next periods for production, on the basis of the corresponding present values, PV^B and PV^G, of the respective expected future cash flows C^B and C^G. Specifically, the brown and green investment projects are approximated as perpetuities generating free cash flows C^B and C^G, growing respectively at rates g^B and g^g. It is assumed that, before taking its decision, the firm is indifferent between brown and green investments, i.e., the corresponding present values PV_t^B and PV_t^G are equal:

$$PV^B \equiv \frac{C^B}{r^B - g^B} = \frac{C^G}{r^G - g^G} \equiv PV^G, \tag{3}$$

where r^B and r^G are the costs of brown and green capital, respectively. We also assume that

$$C^B > C^G, \ g^B < g^G \tag{4}$$

Given the above assumptions, if the firm is surprised in the initial period by a permanent and constant increase in the cost of capital $\Delta > 0$ for both investments, then the firm prefers the brown investment:

$$\frac{C^B}{r^B + \Delta - g^B} > \frac{C^G}{r^G + \Delta - g^G}. \tag{5}$$

In a nutshell the firm decides in the initial period, once and for all, to invest, in the next periods, in the brown or green physical capital depending on which, among the two types of capital, delivers the highest present value:[2]

[2] The once-and-for-all choice in the initial period between the future brown or green investment flows can be thought in terms of a (so-called) "bang-bang" solution to the optimal control problem of the firm.

$$PV = \max(PV^B, PV^G) \tag{6}$$

$$\begin{cases} \text{if } PV = PV^B \Rightarrow I_t^B = 0.3 > 0;\ I_t^G = 0; \forall \text{t, t=1,2,,...} \\ \text{if } PV = PV^G \Rightarrow I_t^B = 0;\ I_t^G = 0.3 > 0; \forall \text{t, t=1,2,,...} \end{cases} \tag{7}$$

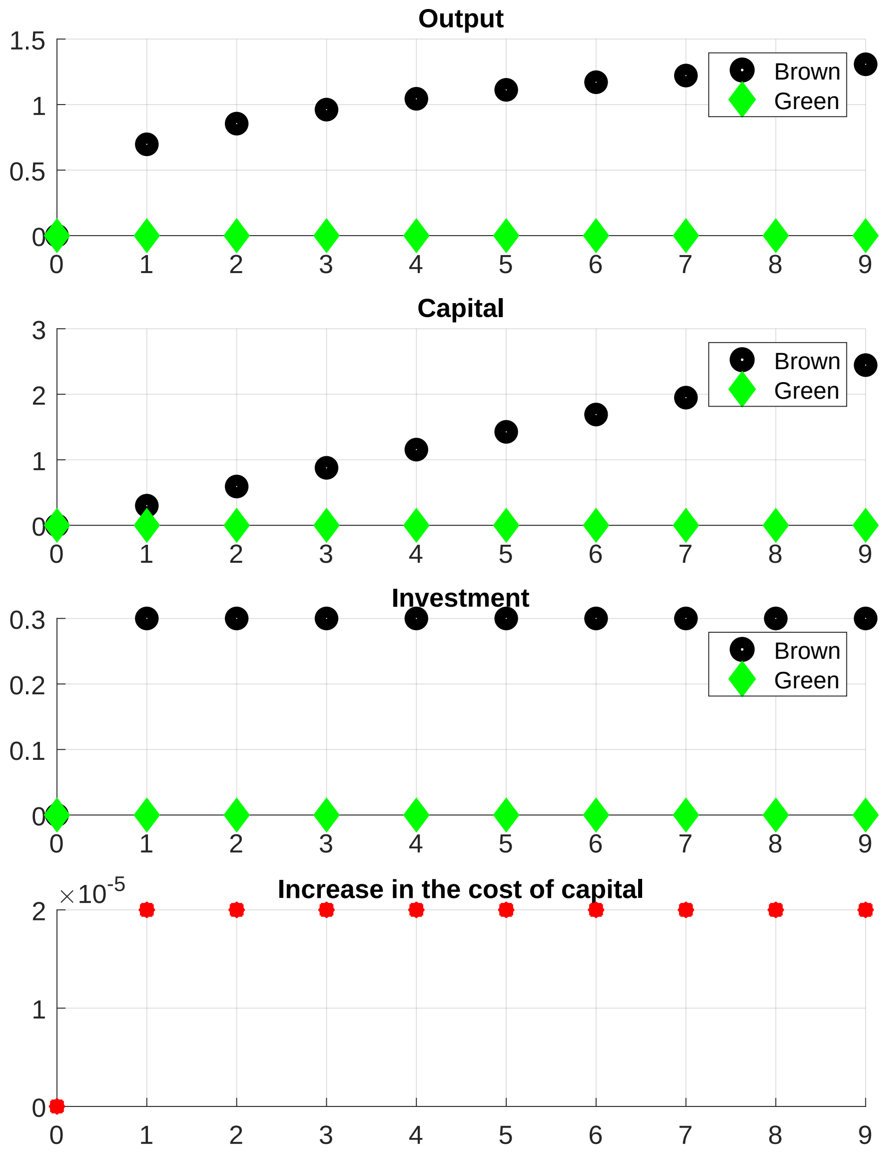
The positive value of the investment, set to 0.3 in every period, is illustrative. Table 1 contains the chosen calibration of the model. Parameter values are such that, before the increase in the cost of capital Δ materializes, $PV_t^B = PV_t^G = PV$. The chosen value of Δ is illustrative and implies that $PV_B > PV_G$.

Table 1: Parameters

Output elasticity to capital α	0.3
Depreciation rate of capital δ_K	0.025
Cash flow brown capital C^B	0.41
Cash flow green capital C^G	0.4
Growth rate of brown capital's cash flow g^B	0.025
Growth rate of green capital's cash flow g^G	0.0255
Cost of brown capital r^B	0.03
Cost of green capital r^G	0.03037827
Increase in the cost of capital Δ over time	$\{0, 0.00002, 0.00002, .., 0.00002\}$

Fig. 1 reports brown and green variables. The firm does not produce in period 0. At the beginning of period 1 is surprised by the increase Δ in the cost of capital. The firm chooses to invest, from period 1 onwards, in brown capital. Brown output increases over time. At the same time the firm does not accumulate green capital, whose value is always zero, given that green investment I_t^G is zero as well. Consistently, there is no green output production. Notice that if the increase in the cost of capital applies only to brown projects while the cost of capital for green projects remains unchanged or decreases, the firm would invest in green projects and not in brown ones.

Figure 1: Impact of higher cost of capital on brown and green variables



Note: horizontal axis, periods (quarters); vertical axis, levels.

Overall, the numerical example, based on a simple model, shows that under some conditions an increase in the cost of capital for brown firms can induce them to prefer brown over green projects, thus increasing their emissions. Conditional on an increase in the cost of capital, the firm prefers brown projects as long as they deliver more front-loaded cash flows compared to green projects.

The reported results depend on the assumed changes in financing conditions for given intertemporal distributions of projects' cash flows. In the next section we present a model that explicitly features an endogenous link between the tightness of financing conditions and the emissions.

3 Financing conditions and emissions: a stylized version of the DICE model

We set up a simplified version of the DICE model (Barrage and Nordhaus, 2023; Nordhaus, 2008). The goal is to simulate the effects of a tightening in the borrowing costs of brown firms. The model consists of a representative household, which consumes and works, and a representative firm, which produces the consumption good. Firm's production generates CO_2 emissions, which are taxed by the government. The firm is able to reduce emissions, for a given level of production, by spending in abatement technologies. In order to spend in abatement, the firm has to borrow from the household.

3.1 Household

The household maximizes the following expected intertemporal utility function

$$\max_{\{C_t, L_t, B_t\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\eta}}{1+\eta} \right] \right\}, \tag{8}$$

where E_0 is the expectation operator conditional on period-0 information, C_t denotes consumption and L_t is labor, $0 < \beta < 1$ is the discount factor, $1/\sigma > 0$ is the intertemporal elasticity of substitution and $1/\eta > 0$ is the Frisch elasticity of labor supply. The household's budget constraint is (consumption is the numeraire)

$$C_t + B_t = W_t L_t + \frac{R_t}{1 + \kappa_t \frac{E_t}{Y_t}} B_t + T_t + \Pi_t, \tag{9}$$

where $B_t > 0$ denotes intraperiod loans to the firm, W_t is the wage, R_t is the (gross) interest rate on firm's loans, $T_t > 0$ are lump-sum transfers from the government, and Π_t profits. We assume that the cost of loans is set according to the firm's emission profile: a higher firm's CO_2 emission-output ratio $\frac{E_t}{Y_t}$ discourages the household to lend, other things equal. The exogenous variable κ_t measures the sensitivity of the financing conditions to variations in $\frac{E_t}{Y_t}$. The first order conditions (FOCs) of the problem yield a standard labor supply:

$$W_t = C_t^{\sigma} L_t^{\eta}, \tag{10}$$

and an expression for the interest rate on loans:

$$R_t = 1 + \kappa_t \frac{E_t}{Y_t}. \tag{11}$$

Given $\kappa_t > 0$, an increase in the emissions-output ratio induces the household to require a higher interest rate in order to lend. A positive shock to κ_t captures a lender's lower preference for high-emitters. We label it as a "sustainable investment" shock. Notice that if $\kappa_t = 0$, the gross interest rate is one, as the loan is intraperiod.

3.2 Firm

The representative firm produces output under perfect competition and using a linear function in labor:

$$Y_t = L_t. \tag{12}$$

Following the DICE model (Barrage and Nordhaus, 2023), we assume that CO_2 emissions are a linear function of output:

$$E_t = (1 - \gamma_t)\, Y_t, \tag{13}$$

where γ_t is the abatement rate, i.e. the fraction of emissions abated for any given level of production. Given that the government imposes a carbon tax τ per unit of emissions, the firm finds it optimal to abate. In this case, following the DICE formulation, the firm spends Z_t in abatement technologies, which is a convex function of γ_t:

$$Z_t = \nu \gamma_t^{\vartheta} Y_t. \tag{14}$$

where $\nu, \vartheta > 0$ are parameters. The firm uses working-capital intraperiod loans to finance a fraction of its input costs:

$$B_t = \psi_w W_t L_t + \psi_e \tau E_t + \psi_z Z_t, \tag{15}$$

where $0 \leq \psi_w, \psi_e, \psi_z \leq 1$ denote the fractions of, respectively, labor, emissions, and abatement costs that have to be financed with the intraperiod loans carrying interest rate R_t. Subject to Eqs. (11) to (14), the firm's profit function features output minus input costs. The latter include, as in Eq. (15), the labor costs, the tax bill on emissions, and the abatement spending:

$$\Pi_t = Y_t - [1 + \psi_w (R_t - 1)] W_t Y_t - [1 + \psi_e (R_t - 1)] \tau E_t - [1 + \psi_z (R_t - 1)] \nu \gamma_t^{\vartheta} Y_t. \tag{16}$$

The FOC with respect to γ_t reads:

$$\tau + \kappa_t \left[\psi_w W_t + 2\psi_e \tau (1 - \gamma_t) + \psi_z (1 + \vartheta) \nu \gamma_t^{\vartheta} \right] = (1 + \psi_z \kappa_t) \nu \vartheta \gamma_t^{\vartheta - 1}. \tag{17}$$

The left-hand side is the marginal benefit of abating emissions: reducing tax (first term) and interest rate (second term) costs. In particular, the firm internalizes that it can pay a lower interest rate by polluting less. The right-hand side captures the marginal cost of abating, including abatement spending and its financing. If only abatement spending has to be financed (so $\psi_w = \psi_e = 0$), we get:

$$\tau + \kappa_t \psi_z (1 + \vartheta) \nu \gamma_t^{\vartheta} = (1 + \psi_z \kappa_t) \nu \vartheta \gamma_t^{\vartheta - 1}. \tag{18}$$

A positive sustainable investing shock, i.e. a higher κ_t implies a trade-off. On the one hand, the firm is willing to abate more, given that the interest rate is now more elastic to emissions; on the other hand, the firm is willing to abate less, as abatement costs are higher, given that an increase in κ_t determines a higher interest rate (this is an undesired consequence). The FOC with respect to output, yields the following condition:

$$[1 + \psi_w \kappa_t (1 - \gamma_t)] W_t + [1 + \psi_e \kappa_t (1 - \gamma_t)] \tau (1 - \gamma_t) + [1 + \psi_z \kappa_t (1 - \gamma_t)] \nu \gamma_t^{\vartheta} = 1. \qquad (19)$$

Notice that absent loans, emissions taxes, and abatement spending, we would get a standard FOC, i.e. the real wage equal to the total factor productivity (TFP), which is assumed to be equal to one.

3.3 Market clearing

We close the model with a market clearing condition, whereby output is equal to consumption plus abatement spending:

$$Y_t = C_t + Z_t. \qquad (20)$$

3.4 Calibration

The inverse of the elasticity of inter-temporal substitution (σ) and the inverse of the Frisch elasticity of labor supply (η) are set to the standard values of 1.5 and 2, respectively. In the baseline, we assume that abatement spending needs to be fully financed via corporate bonds, i.e. $\psi_z = 1$, while other input costs do not need to be financed, i.e. $\psi_w = \psi_e = 0$. On the environmental side of the model, we follow the latest version of the DICE model (Barrage and Nordhaus, 2023). We fix the parameters of the abatement cost function to $\nu = 0.109$ (i.e. the fraction of output that is required to reduce emissions to zero) and $\vartheta = 2.6$, and we target the steady-state abatement rate to $\gamma = 0.05$ by properly setting the carbon tax, once having imposed a small value (0.01) for the steady-state sustainable investing shock (κ). We assume that the shock follows an AR(1) process with persistence 0.98.

3.5 Results

We simulate a positive sustainable investing shock (Fig. 2), i.e. an increase in κ. The shock operates through two channels that have an opposite impact on abatement spending. First, the interest rate on loans becomes more sensitive to the emission/output ratio, inducing the firm to abate more emissions and, thus, reducing its interest rate costs. Second, the interest rate becomes higher for any given level of the emission-to-output ratio, inducing the firm to reduce borrowing and in turn abatement, as loans finance abatement spending. Given the chosen calibration, that follows the literature, we find that the second channel is stronger: the firm cuts abatement spending, reducing the abatement rate. Output and consumption barely move, as the interest rate increase only affects abatement activity, which is a small share of output. As the abatement rate is lower and output is virtually constant, emissions increase. This occurs despite the shock is supposed to make the firm greener, by increasing the link between the interest rate and emissions (Eq. 11).

These results are consistent with Angelini (2024), who argues that increasing the borrowing costs to the relatively more polluting firms might discourage investment in emissions-saving technologies to the point that aggregate emissions increase, similarly to what found empirically by Hartzmark and Shue (2023), Columba et al. (2024), and Costa et al. (2024). Similarly to the framework discussed in Section 2, the most effective strategy to decrease emissions is to directly reduce the cost of capital for green projects, which finance abatement spending in this model.

We emphasize that our main finding, which points to a counterproductive increase in emissions following a positive sustainable investing shock, crucially depends on the assumptions that relate to the equilibrium volume of loans.

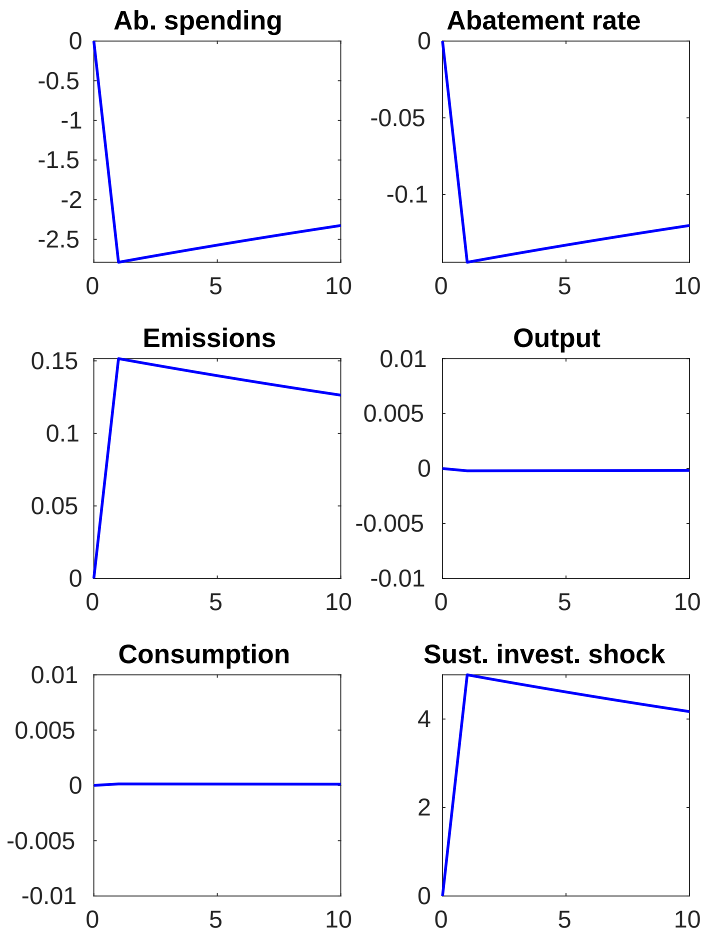
First, we are assuming that in steady state the abatement rate is relatively small ($\gamma = 0.05$), consistently with the literature (Barrage and Nordhaus, 2023 among others). This assumption implies that borrowing is relatively low, compared to the volume of production. Instead, for sufficiently higher values of the steady-state abatement rate the firm optimally chooses to increase abatement spending, in the face of a sustainable investing shock, to push down the interest rate that they are now paying on a larger volume of loans, thus reducing aggregate emissions. Nonetheless, our simulations (not reported) suggest that the steady-state abatement rate needs to have a considerably higher value (beyond about 0.7) than what customarily assumed in the literature for the sustainable investing shock to have such an emission-reducing effect.

Second, we are assuming that the firm has to borrow only to finance abatement spending. If it also borrows to finance tax and labor costs, a sustainable investing shock can induce the firm to raise abatement spending, with the goal of reducing the emissions-to-output ratio and thus the interest rate paid on a larger volume of loans. According to our simulations, it is sufficient that, on top of borrowing for abatement spending ($\psi_z = 1$), the firm needs to fully finance either labor costs ($\psi_w = 1$) or carbon tax costs ($\psi_e = 1$) to have an emission-reducing effect in response to a sustainable investing shock. However, in this case, lower emissions are accompanied by lower economic activity.

Overall, the main results suggest that a positive sustainable investing shock can, under some conditions, be counterproductive, i.e., inducing the firms to increase emissions or to reduce them by decreasing economic activity.

Results reported in this section are based on the link between interest rate on loans and CO_2 emissions in a framework with no capital in production. Instead, in the next section we explicitly model two types of capital (brown and green), whose relative price is a key variable in the macroeconomic dynamics as long as both types are used as collateral for borrowing.

Figure 2: Positive sustainable investing shock (increase in κ)



Note: horizontal axis: quarters; vertical axis: abatement rate and sustainable investment shock: percentage point deviations from steady state; other variables: % deviations from the steady state

4 Brown and green capital as collateral: a model with borrowing constraint

We illustrate and simulate a model with a borrowing constraint on entrepreneur's spending. The model is populated by a representative entrepreneur and a representative household. Both entrepreneur and household act under perfect competition and, thus, take all prices as given.

The entrepreneur produces output using brown capital, green capital, and labor, which are imperfect substitutes among one another. Brown capital differs from green capital because its utilization implies CO_2 emissions. Both are accumulated by the entrepreneur and each of them has its own accumulation law with specific adjustment costs on (corresponding) investment.

Crucially, both brown and green capital are used as collateral by the entrepreneur when borrowing from the household. Each capital enters the borrowing constraint with its own (loan-to-value) LTV ratio. Both LTV ratios' values are chosen in a discretionary way by the household through a financial intermediary that we do not explicitly model.

For simplicity we do not explicitly model the relation between emissions and brown capital. The assumption is that the former are proportional to the latter.

The household consumes, supplies her labor, and lends savings to the entrepreneur. In what follows we report the entrepreneur's and consumer's problems and the market clearing conditions.

4.1 The entrepreneur

The entrepreneur's expected intertemporal utility function is

$$E_0 \left(\sum_{t=0}^{\infty} \beta^t log(C_t) - \frac{1}{1+\eta} L_t^{1+\eta} \right), \tag{21}$$

where E_0 is the expectation operator conditional on period-0 information, β is the discount factor ($0 < \beta < 1$), C_t is consumption, L_t the entrepreneurial (i.e., managerial) labor, $1/\eta > 0$ is the Frisch labor supply elasticity.

The entrepreneur's production function is a Cobb-Douglas in household's labor, entrepreneur's labor, brown capital, and green capital:

$$Y_t = K_{b,t}^{\alpha_b} K_{g,t}^{\alpha_g} L_t^{\alpha_e} \left(L_{h,t}^d \right)^{1-\alpha_b-\alpha_g-\alpha_e}, \tag{22}$$

where $K_{b,t}$ is brown capital, $K_{g,t}$ is green capital, $L_{h,t}^d$ is demand for labor supplied by the household, and $\alpha_b, \alpha_g, \alpha_e$ are parameters measuring the output elasticities with respect to brown capital, green capital, and entrepreneur's labor ($0 < \alpha_b, \alpha_g, \alpha_e < 1$, $\alpha_b + \alpha_g + \alpha_e < 1$).

Each capital has its own accumulation law:

$$K_{i,t} = (1-\delta)K_{i,t-1} + I_{i,t}\left(1 - \frac{\psi}{2}\left(\frac{I_{i,t}}{I_{i,t-1}} - 1\right)^2\right), \; i = b, g \tag{23}$$

where $0 < \delta < 1$ is the depreciation rate, $I_{i,t}$ is investment, $\frac{\psi}{2}\left(\frac{I_{i,t}}{I_{i,t-1}} - 1\right)^2$ are quadratic adjustment costs on investment in the two types of capital, and $\psi > 0$ is a parameter.

We do not explicitly model the relation between emissions and brown capital. We assume that the changes in the former are proportional to changes the latter (i.e., $CO_{2,t} \propto K_{b,t}$).

The entrepreneur borrows using the two types of capital as collateral. The collateral constraint is

$$-B_t R_t \leq E_t\left(m_{b,t} Q_{b,t+1} K_{b,t} + m_{g,t} Q_{g,t+1} K_{g,t}\right) \tag{24}$$

where $B_t < 0$ is debt, R_t is the gross interest rate, $0 < m_{b,t}, m_{g,t} < 1$ are the LTV ratios that apply to the brown and green capital, respectively, and $Q_{b,t+1}, Q_{g,t+1}$ are the expected prices (Tobin's Q) of brown and green capital in period $t+1$, respectively. The Tobin's Q is different from one because of the presence of adjustment costs on investment (see Eq. 23).[3] In our simulations the LTV ratios are exogenously changed over time. In equilibrium the borrowing constraint, Eq. (24), is binding because the entrepreneur is assumed to be more impatient than the household, that is the entrepreneur's discount factor is assumed to be lower than the household's discount factor.[4]

The budget constraint is (consumption is assumed to be the numeraire)

$$B_t - B_{t-1}R_{t-1} = Y_t - W_t L^d_{h,t} - C_t - I_{b,t} - I_{g,t}, \tag{25}$$

where W_t is the wage paid to the household. The entrepreneur chooses an intertemporal sequence of consumption C_t, brown capital $K_{b,t}$, green capital $K_{g,t}$, household's labor $L^d_{h,t}$, entrepreneur's labor L_t, bonds B_t, investment in brown capital $I_{b,t}$, and investment in green capital $I_{g,t}$ to

[3] The Tobin's Q of the green (brown) capital is the Lagrange multiplier of the green (brown) capital accumulation law.

[4] The assumption implies that the Lagrange multiplier of the borrowing constraint is binding in the deterministic steady-state equilibrium of the model and, by continuity, in its neighborhood.

maximize the intertemporal utility (21) subject to the budget constraint (25), the borrowing constraint (24), the capital accumulation laws (23), and the technology constraint (22), given initial conditions B_{-1}, $K_{b,-1}$, $K_{g,-1}$, $I_{b,-1}$, and $I_{g,-1}$.

4.2 The household

The household acts under perfect competition. The household's expected intertemporal utility function is:

$$E_0 \left(\sum_{t=0}^{\infty} \beta_h^t \left(log(C_{h,t}) - \frac{1}{1+\eta} \left(L_{h,t}^s \right)^{1+\eta} \right) \right) \tag{26}$$

where β_h^t is the household's discount factor ($0 < \beta_h < 1$), $C_{h,t}$ is consumption, $L_{h,t}^s$ is the labor supply, $\eta > 0$ is a parameter ($1/\eta$ is the Frish elasticity of labor supply).

The budget constraint is:

$$B_{h,t} - B_{h,t-1} R_{t-1} = W_t L_{h,t}^s - C_{h,t} - TAX_t \tag{27}$$

where $B_{h,t}$ is the amount of bonds issued by the household to finance the entrepreneur ($B_h > 0$ is a loan) and $TAX_t > 0$ are lump-sum taxes paid to finance public consumption (the public sector budget is assumed to be always balanced).

The household maximizes the intertemporal utility (26) with respect to the sequence of consumption $C_{h,t}$, $B_{h,t}$, and labor supply $L_{h,t}^s$ subject to the budget constraint (27) taking as given all prices and initial conditions $B_{h,-1}$.

4.3 Market clearing conditions

The market clearing of the good is:

$$Y_t = C_t + C_{h,t} + I_{g,t} + I_{b,t} + G_t, \tag{28}$$

where G_t is public consumption spending, assumed to be always constant and equal to its steady-state value.

The market clearing of the bond is:

$$B_{h,t} + B_t = 0. \tag{29}$$

Finally, the market clearing of the household's labor is:

$$L^s_{h,t} = L^d_{h,t}. \tag{30}$$

4.4 Calibration

The model is calibrated at quarterly frequency using standard parameter values in line with previous studies and estimates available in the literature.

Table 2 contains parameters values. The discount factor of the household is set to 0.99, and that of the entrepreneur, that is more impatient, is set to 0.985. In the production function of the final good, the output elasticity with respect to green capital is set to 0.14. A similar value holds for brown capital. The output elasticity with respect to entrepreneur's labor is 0.15. The depreciation rate of both green and brown capital is set to 0.025. The adjustment costs of green and brown investments are set to 0.6. The LTV ratio for brown capital is set to 0.8, and the one for green capital is set to 0.3, in the spirit of Iovino et al. (2023), that report that dirty energy producers (measured by their carbon intensity or their fossil fuel energy production capacity) employ more tangible assets and, thus, borrow more, as tangible capital is a better collateral than intangible capital.

Table 2: Preferences and technology

Household's discount factor β_h	0.99
Entrepreneur's discount factor β	0.985
Inverse of Frisch elasticity of labor supply $1/\eta$	1.0
Depreciation rate of brown and green capital δ	0.025
Output elasticity wrt brown capital α_b	0.138
Output elasticity wrt green capital α_g	0.138
Output elasticity wrt entreprenuer's labor α_g	0.15
Brown capital LTV ratio m_b	0.8
Green capital LTV ratio m_g	0.3
Investment adjustment cost ψ	0.6

Table 3 reports the implied steady-state great ratios. We do not aim to match the great ratios of a specific economy, as our results are illustrative.

Table 3: Main variables

Interest rate	2.0
Private consumption	59.0
Household's consumption	40.0
Public consumption	20.0
Total investment	21.0
Investment in brown capital	11.0
Investment in green capital	10.0
Entrepreneur's debt	119.1

Note: Interest rate: annualized percentage points; consumption and investment: % of GDP. Entrepreneur's debt: % of annualized GDP.

4.5 Results

4.5.1 Lowering the LTV ratios (tightening of financing conditions)

We simulate a tightening of both LTV ratios by 10% of the corresponding initial (steady-state) value, from 0.8 to 0.72 in the case of the brown capital's LTV ratio and from 0.3 to 0.27 in the case of green capital's LTV ratio. The tightening starts in the fifth quarter and lasts for 20 years. The tightening is fully anticipated by the entrepreneur and the household.

Fig. 3 reports the results. Output decreases driven by the strong decrease in green and total investments. Instead, and crucially, investment in brown capital, and thus, emissions, increase in the initial eight periods. The capital rebalancing, in favor of brown capital, is caused by the entrepreneur anticipating that financing conditions will become persistently tighter. Thus, the entrepreneur prefers to accumulate immediately brown capital rather than green capital, because, crucially, the former is assumed to be a better collateral than the latter. Consistently, the Tobin's Q of brown capital initially increases, while the Q of green capital decreases. The increase in the value of brown capital allows the entrepreneur to limit the reduction in borrowing in the initial quarters.

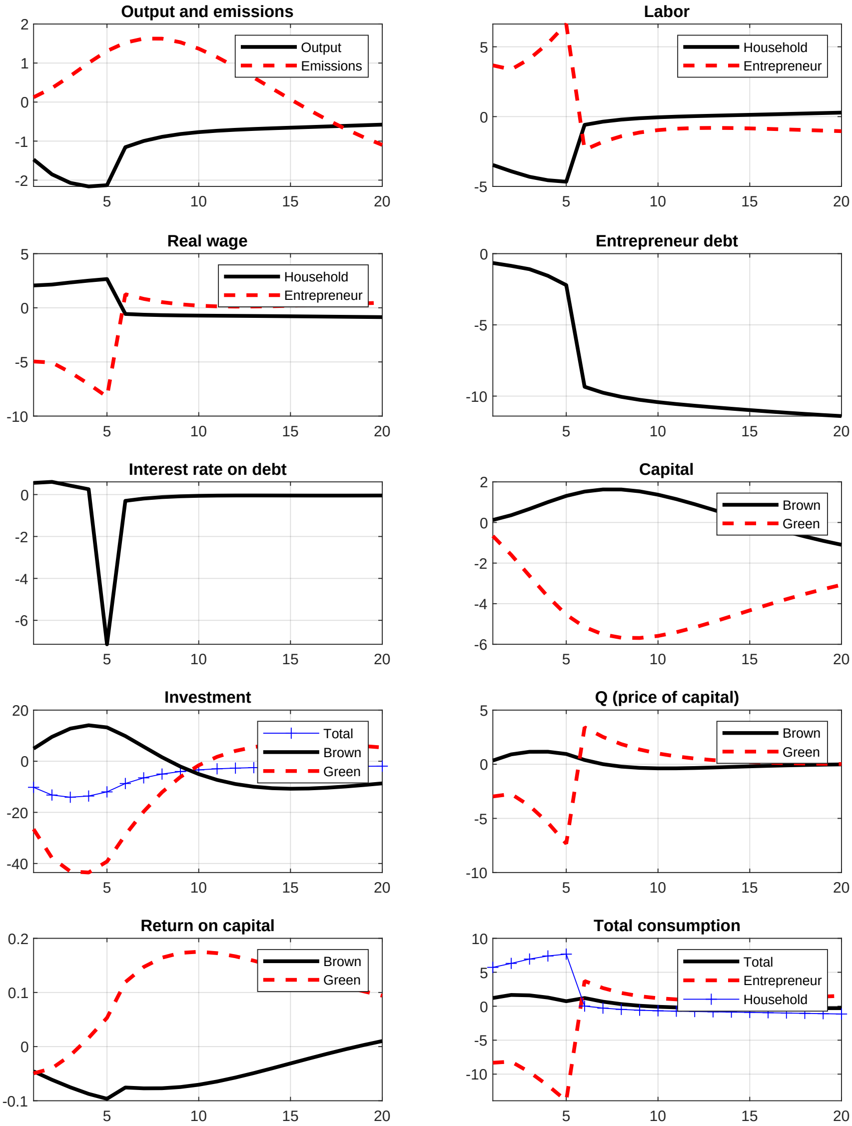
Once the LTV ratios become tighter, in the fifth quarter, both types of become less valuable collaterals. The entrepreneur gradually reduces the brown capital and also greatly reduces the green capital, so as to cut debt and sustain consumption. The latter increases from the fifth quarter, the lower amount of borrowing notwithstanding. Consistent with the lower demand for debt, the interest rate widely decreases in the fifth period.

From the fifth quarter output decreases to a less extent, driven by the lower reduction in household's labor relative to the initial periods, because the household wants to sustain her consumption, that decreases. Total (household's and entrepreneur's) consumption decreases.[5]

We highlight the role of two assumptions. First, the brown capital LTV ratio is higher than the green capital LTV ratio. Second, the anticipation effect, which results from the tightening and materializes in the fifth quarter, is anticipated in the first quarter by the entrepreneur and the household. In case the LTV ratios are (initially) similar in the steady state or the tightening

[5]The remuneration of entrepreneurial labor, i.e. the entrepreneur's "wage", is equal to the entrepreneurial labor marginal productivity, consistent with the labor demand FOC.

Figure 3: Decrease in LTV ratios (tightening of financing conditions)



Notes: horizontal axis: quarters; vertical axis: % deviations from the steady state; for interest rates: pp deviations. Entrepreneur's debt: "+ (-)" is a debt reduction (increase).

materializes immediately in the first period, the short-run responses of output, brown and green capital are qualitatively similar to the corresponding responses in the benchmark case but smaller (results are available upon request).

Overall, lower expected LTV ratios of brown and green capital have effects that are not satisfactory from both the environmental and macroeconomic perspectives. They can induce higher investment in brown capital, and thus more emissions, in the short run. In the medium and long run they can reduce brown capital, and thus CO_2 emissions, at the cost of lower economic activity.

4.5.2 Relaxing the green capital's LTV ratio and tightening the brown capital's LTV ratio

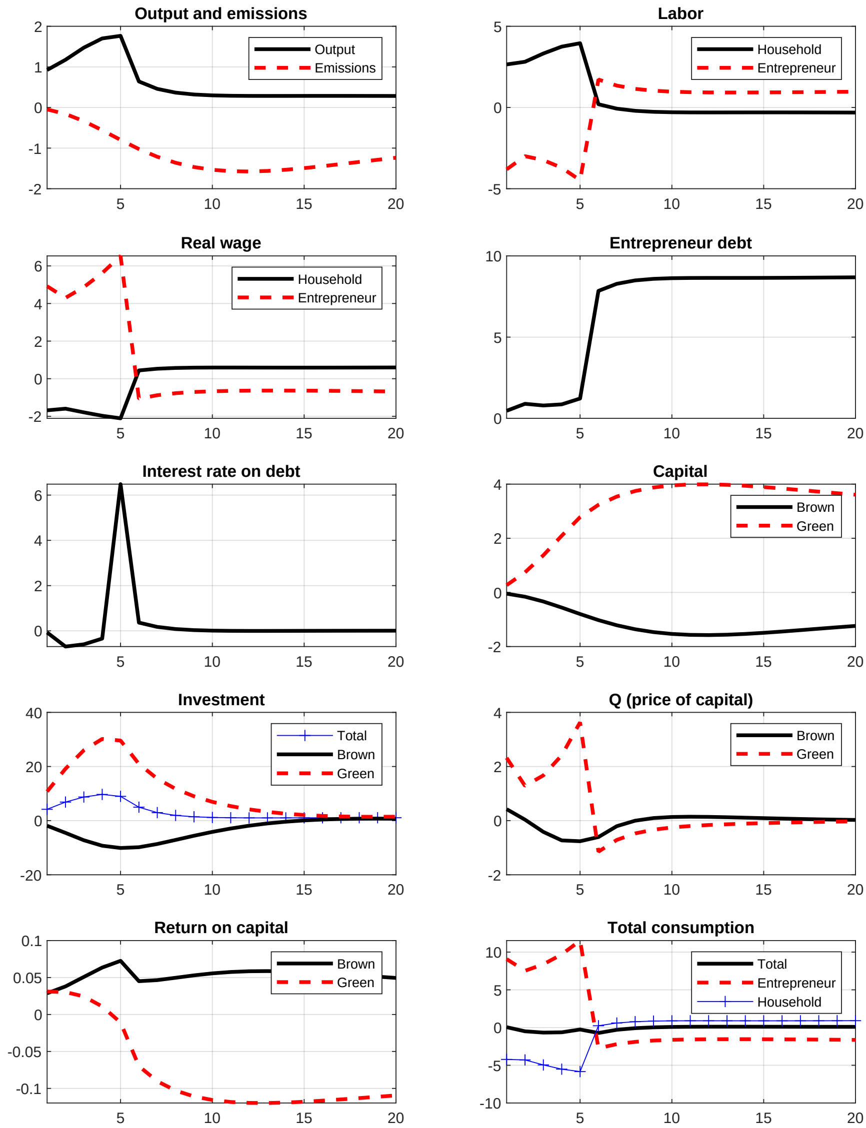
We simulate a 60% increase (i.e., relaxing) in the green capital's LTV ratio, from 0.3 to 0.48, accompanied by a simultaneous 10% reduction (i.e., a tightening) in the brown capital's LTV ratio, from 0.8 to 0.72. As in previous simulations, the two measures are implemented from the fifth quarter, for twenty years.

Fig. 4 shows the results. Initially, the entrepreneur increases its borrowing only slightly and, from the fifth period, to a much larger extent, when the green capital's LTV ratio is increased and, thus, the role of the green capital as collateral is enhanced. The relaxation of the constraint allows the entrepreneur to borrow more. This induces the interest rate on bonds to rise in the fifth period. Subsequently, the interest rate returns to (roughly) its baseline level because of the increase in the household's saving. The price of the green capital initially increases, reflecting the expected larger role of the capital as collateral. In the medium run, once the stock has increased, its price returns to its baseline level. Symmetrically, the price of the brown capital, which becomes a relatively less valuable collateral, initially decreases.

Consistent with its higher value as collateral, the entrepreneur accumulates green capital. Instead, investment in brown capital and, thus, CO_2 emissions decrease, because brown capital becomes a less valuable collateral.

In the initial periods the expansionary effects are larger than in the medium and long run, because the entrepreneur immediately raises its demand for green investment, anticipating more

Figure 4: Relaxed green LTV ratio, tighter brown LTV ratio



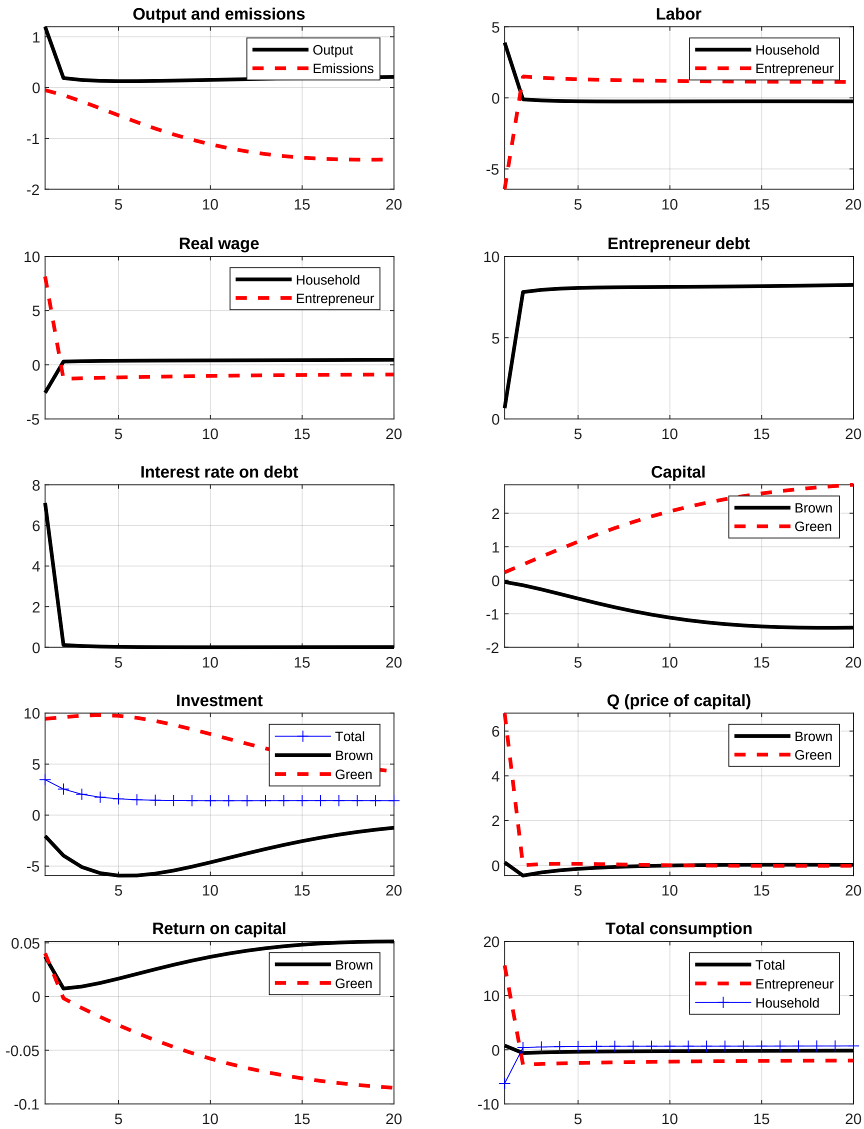
Notes: horizontal axis, quarters; vertical axis, % deviations from the steady state; for interest rates: pp deviations. Entrepreneur's debt: "+ (-)" is a debt reduction (increase).

favorable financing conditions in the future associated with the use of green capital as collateral. The household raises her consumption starting from the fifth period, jointly with her labor supply (the real wage slightly decreases). Following higher demand for green investment, production persistently rises.

Fig. 5 shows the results in the case that the very same financing measures are immediately and suddenly implemented, already in the initial period (and not starting from the fifth quarter, as in previous simulations). There is a large immediate expansion in economic activity, favored by the increase in green capital accumulation and in total consumption, only partially offset by the decrease in brown capital accumulation.

Similarly to what we argue in Section 2 and Section 3, simultaneously relaxing the LTV ratio of the green capital and tightening the LTV ratio of the brown capital can favor the deployment of green capital. At the same time, the entrepreneur reduces the investment in brown capital, thereby reducing CO_2 emissions. Moreover, economic activity would improve.

Figure 5: Relaxed green LTV ratio, tighter brown LTV ratio in the initial period



Notes: horizontal axis, quarters; vertical axis, % deviations from the steady state; for interest rates: pp deviations. Entrepreneur's debt: "+ (-)" is a debt reduction (increase).

5 Concluding remarks

In pursuing decarbonisation strategies, tighter financing conditions on brown firms may not reduce CO_2 emissions. Even if this were the case, there would be a macroeconomic cost to pay. Instead, portfolio decarbonisation strategies that selectively relax and tighten the financing conditions for, respectively, green and brown investments, can lower emissions without jeopardizing macroeconomic activity.

A decarbonisation strategy by financial intermediaries that favors "virtuous" firms that can credibly engage in green investments, irrespective of whether they are (initially) brown, is more promising than a strategy that distinguishes between brown and green firms based solely on the observed level of emissions. Hence, our results provide support to the so called "best-in-class" approach, calling for financing conditions to be relaxed for green investments and tightened for brown investments.

Our work can be extended along several dimensions. First, sticky prices can be included in (some of) the used models to assess the implications of the alternative decarbonisation strategies for inflation and monetary policy.[6] Second, the interaction between financing conditions and public subsidies to green investment can be evaluated from both macroeconomic and environmental perspectives. We leave these interesting issues for future research.

[6]See Bartocci et al. (2022) and Ferrari and Nispi Landi (2022) for an assessment of the impact of a carbon tax increase on inflation and macroeconomic activity.

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