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Auteur

Corentin Roussel

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www.beta-economics.fr

@beta_economics

Contact :
jaoulgrammare@beta-cnrs.unistra.fr

Should new prudential regulation discriminate green credit risk ? A macrofinancial study for the Output Floor case

Corentin Roussel†

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Abstract

Differentiated treatment of green credit risk in banks' capital requirements to favor green transition generates lot of debates among European prudential regulators. The aim of this paper is to examine whether the key Basel 3 finalization instrument - the Output Floor - should be applied to green credit risk in order to ensure stability of banking system and promote green finance. To do so, we assess macrofinancial and environmental benefits of such green policy for the Euro Area through the lens of a general equilibrium model. We get three main results. First, when banks get transitory 'environmental awareness', an Output Floor (OF) applied to brown credits only (i.e. a brown OF) faces a trade-off between limiting environmental aftermaths and reaching OF objectives (i.e reducing volatility of banks' capital adequacy ratio). Second, to mitigate the prudential cost of this trade-off, brown OF should be joined with additional green financial policies such as green Quantitative Easing. Third, pollutant emissions tax erodes brown OF efficiency along financial and economic cycles but limits the welfare cost implied by pollution in the long run.

Keywords: Output Floor, Credit Risk, Green Finance, Climate Change, DSGE
JEL classification: Q54, G21, E44, E51.

†BETA, University of Strasbourg, Strasbourg, France. E-mail : corentin.roussel@unistra.fr

1 Introduction

Recent agreements established in COP28 have reinforced commitment of participating countries to reduce their greenhouse gas emissions in order to meet Paris Agreements objectives, i.e. maintaining global temperature increases within 2°C above pre-industrial levels. However, "tough negotiations"[1] obtained during the COP28 reflects current fear of some participating countries to engage into climate actions that are costly for their economic activity and financial system. This fear is assimilated to the so-called *transition risk* implied by tight climate policies on macroeconomic and macrofinancial stability (Carney, 2015 ; Caratini et al., 2023). However, scientific literature is unambiguous regarding aftermaths of climate change on real and financial activity, which underlines the need of climate policies to mitigate these negative externalities (Monasterolo et al., 2017 ; D'Orazio & Popoyan, 2019 ; Benmir et al., 2020 among others). Financial risks of climate change has led to the launch of the Network of central banks and supervisors for Greening Financial System (NGFS) in 2017. Missions of NGFS consist to promote green finance and to suggest financial regulation in line with green transition objectives (NGFS, 2020). These missions play a crucial within a financial system where banks favor carbon-intensive credits because of their better risk-return ratio compared to green credits (Campiglio, 2016). Carbon-bias in banking activity contributes to the "green financial gap", i.e. the lack of sufficient financial resources to be directed towards green investments (Buchner et al., 2016). This banks behavior prevents countries from bearing a less costly green transition and thus, from guaranteeing a "soft landing" (Hu & Wu, 2023).

In order to limit transition risk on financial stability, green prudential regulations have been proposed by financial regulators and researchers. Among these proposals, D'Orazio & Popoyan, (2019) suggest the use of a CounterCyclical capital Buffers (CCyB) based on the cycle of carbon-intensive credits. Authors indicate that such macroprudential policy would be consistent to maintain financial stability and promote green transition since evolution of carbon-intensive credits are positively correlated to the rise of systemic risk in financial system. Other research works recommend green financial policies that influence Capital Adequacy

[1] See briefing note of French Ministry on Green Transition *via* following URL link : https://www.ecologie.gouv.fr/cop28-victoire-sur-sortie-des-energies-fossiles

Ratio (CAR) of banks deeply. For instance, reports of European Banking Federation (EBF) and High-Level Expert Group on Sustainable Finance (HLEG) suggest the introduction of a *Green Supporting Factor* (GSF), i.e. to discount Risk-Weighted-Assets (RWA) of green assets (EBF, 2018 ; HLEG, 2018). As mentioned by Dombrovskis (2017), the GSF would incite banks to finance green credits since the later would be less costly in banks' capital constraint. However, the GSF initiative seems not to be unanimous among financial actors because some of them argues that GSF would underestimate possible real financial risks of green assets (Matikainen, 2017, Van Lerven & Ryan-Collins, 2018). In addition, D'Orazio & Popoyan, (2019) indicate that GSF could not be able to absorb additional risk emanating from green assets with high risk. Instead of a GSF, some financial regulators and research works prefer to introduce a *Brown Penalizing Factor* (BPF), i.e. to increase RWA of brown (i.e. carbon-intensive) assets (Villeroy de Galhau, 2018; D'Orazio & Popoyan, 2019). Main advantage of the BPF is to oblige banks to hold more prudential capital for these assets whatever the level of green assets risk.

Besides previous *pro* & *con* of GSF and BPF, the current setting of both instruments omits two crucial criteria. The first one corresponds to the "adequate" level of discount (penalizing) factor for the GSF (BPF). The second criteria is the scope of application, i.e. whether the GSF (BPF) is used for RWA estimated with Internal Rating Based (IRB) approach and / or standardized approach (made by external rating agencies).

An alternative green prudential policy to answer to these uncovered fields would be to discriminate the risk of green assets in the key prudential regulation of Basel 3 finalization, i.e. the Output Floor (OF). The OF requires banks to fix a minimum level of RWA estimated with the IRB approach. This minimum (or floor) corresponds to 72.5% of RWA obtained with the standardized approach (BCBS, 2017a). As defined in Basel 3 finalization, one of the main goals of the OF is to reduce the volatility of banks' CAR in order to support stability in the banking system (BCBS, 2017b). Hence, by retrieving green assets risk from OF regulation - i.e. by implementing a "brown Output Floor" - financial regulators would be able to define an implicit discount (penalizing) factor on green (brown) assets risk. Furthermore, brown Output Floor would be only applied to RWA estimated with IRB approach, which would limit possible transition risk of the prudential instrument.

Therefore, the aim of the paper is to study the potential macrofinancial, macroeconomic and environmental impact of a brown Output Floor in a DSGE model. Moreover, this macro-theoretical framework allows to examine the ability of the green prudential instrument to maintain stability in the banking system and promote green finance.

To do so, the paper building on the DSGE model of Ferrari & Nispi-Landi (2023) since this model is well suited to analyze green financial policies. However, unlike the authors, we integrate a prudential constraint in banks' activity instead of a green leverage constraint. This new financial friction implies that heterogeneous risk between green and brown loans influences the credits portfolio strategy of banks. Moreover, we incorporate green and brown entrepreneurs who finance physical capital of green and brown firms with banks' loans. These entrepreneurs are exposed to an endogenous default probability, which generates an external financial premium in banks' lending. Default probabilities in green and brown production sector allow us to implement an IRB approach and an Output Floor setting consistent with Basel 3 regulation framework. Furthermore, modifications and extensions made in the baseline model permit to examine potential complementary effect of brown Output Floor with other green financial and real policies such as green Quantitative Easing (QE) and emissions tax on pollutant firms.

Consequently, the work made on the paper brings three main contributions in the literature. The first one is to identify potential trade-off faced by brown OF between promoting green finance and reaching OF goals, i.e. reducing volatility of banks' CAR. The second contribution is to examine the benefits of additional green financial and real policies to dampen this trade-off. The last contribution focuses on the impact of brown OF on the welfare under several green fiscal and welfare scenarios.

Main results of the paper suggest that, in the long run, a brown Output Floor produces macrofinancial and macroeconomic benefits with a lower impact on the environment than in the case of a standard Output Floor. However, along financial and economic cycles, brown OF get ambiguous effects on its capacity to reach its core objective, i.e. to reduce volatility of banks' CAR. Indeed, when a positive productivity shock occurs, brown and standard OF provides similar efficiency to reduce this volatility. However, when banks get a transitory ”green awareness” (represented by negative shock on banks’ green premium), brown OF exacerbates the volatility of banks’ CAR. This is due to the fact that brown OF amplifies the relax of green credit risk constraint triggered by banks’ ”environmental awareness”. Hence, high flow of green credits in banks’ portfolio increases the volatility of banks’ CAR. As a result, brown OF has to make a choice between higher OF efficiency and lower pollution impact. From macrofinancial perspective, this statement can be assimilated to a trade-off between financial stability and green transition.

In order to mitigate this trade-off, additional green financial and real policies can be joined to the brown OF framework. Our paper shows that a strong and permanent green Quantitative Easing (QE) helps to limit this trade-off while an emissions tax policy on pollutant firms does the opposite. The negative impact of the fiscal policy on OF efficiency comes from the fact that emissions tax favors the profitability of green firms projects. Banks redirect their credits activity towards green loans, which generates higher movements in banks’ portfolio and thus, higher volatility in banks’ CAR. Nevertheless, in the long run, the combination of emissions tax with brown OF gets a lower impact on pollution than in the case of the standard OF.

Finally, in the long run, the implementation of a brown OF dampens more the negative impact of pollution on welfare than the standard OF. In addition, combination of brown OF with tighter emissions tax policy limits significantly the negative contribution of pollution on welfare.

The rest of the paper is organized as follows : Section 2 makes a brief literature review on topics consistent with our framework. Section 3 describes key parts of the DSGE model for brown Output Floor analysis. Section 4 examines long run benefits of brown OF on economic activity, banking system and environment. Section 5 analyses the capacity of brown OF to reach its OF goals, i.e. to reduce to volatility of banks’ CAR along financial and economic cycles. This section allows to identify potential trade-off faced by the brown OF. Section 6 studies the use of additional green financial and real policies to mitigate this trade-off. Section 7 assesses the contribution of brown OF on the welfare under several green fiscal and welfare scenarios. Section 8 concludes.

2 Related literature

The paper is related to several strands of literature. First, our paper is linked to the growing literature on climate-related issues in DSGE models. Climate-related and E-DSGE models depart from Integrated Assessment Models (IAMs) such as the DICE / RICE model of Nordhaus (2018) by incorporating richer economic features. Early DSGE models working on environmental topic are those of Fischer & Springborn (2011) and Heutel (2012) by incorporating environmental policies in a RBC model. As underlined by Minesso & Pagliari (2023), the work of Heutel (2012) is the first DSGE model to include emissions externalities in order to assess optimal environmental policies along business cycle. Instead of standard RBC model, Annicchiarico & Di Dio (2015) and Economides & Xepapadeas (2018) use New Keynesian models to analyze the impact of price rigidities on efficiency of these policies.

Regarding features of environmental policies in baseline climate-related and E-DSGE models, Barrage (2020) examines interactions between monetary policy and carbon emissions tax while Benmir et al. (2020) study the optimal design of carbon tax when pollution gets a direct negative impact on households' utility. The work of Dietrich et al.(2021) evaluates the *expectation channel* of climate change, i.e. the capacity of central bank to adjust its monetary policy to limit the cost of agents' expectations about future climatic disasters on the economy.

However, contrary to our work, all papers mentioned before do not integrate an explicit banking sector with enriched features such as financial frictions and prudential regulation. Hence, our paper fits in the literature incorporating financial dimension in climate-related and E-DSGE models. The work of Chen et al.(2012) integrates a financial market segmentation in a DSGE model in order to assess the impact of central bank's asset purchase program on output and inflation. In the line with this previous work, the paper of Ferrari & Nispi-Landi (2023) studies the contribution of a green Quantitative Easing in promoting green transition. While these authors focuses on the quantitative aspect of the green QE, Giovanardi et al.(2022) examines the qualitative dimension of the policy by studying the preferential treatment of green bonds in the central bank collateral framework. Regarding prudential regulation set up in environmental DSGE models, works of Diluiso et al.(2021), Benmir & Roman (2022) and Caratini et al., 2023 indicate that macroprudential regulation is able to limit transition risk implied by ambitious environmental policies. In a deeper analysis of green prudential regulation, Punzi (2019) and Giovanardi & Kaldorf (2023) analyze differentiated capital requirements on green and conventional firms. Both previous papers is linked to the study of Green Financial Support (GSF) and Brown Penalizing Factor (BPF) made in the conceptual framework of Oehmke & Opp (2023).

Nevertheless, these papers do not go further for the discrimination of green assets risk in prudential regulation and especially in new prudential instruments like our paper does with the Output Floor. Moreover, the literature of this new prudential instrument is still in its infancy because of its postponed implementation in advanced economies (Output Floor should entry into force in January 2025 in European countries[2]). Despite this issue, some econometric and theoretical papers provide first insights about potential effects of the Output Floor. Regarding econometric literature, Pop & Pop (2022) elaborate a counter-factual study of the OF based on small and medium french companies loans in banks' portfolio. Authors indicate that OF efficiency would tend to decrease when standardized approach setting is closed to IRB one. Furthermore, the work of Stewart (2021) underlines the potential negative impact of the OF on optimal allocation in banking capital. This result would be explained by the negative OF impact on banks' profitability obtained in the paper of Neisen & Schulte-Mattler (2021). Besides these results, other works show that the OF would oblige IRB-banks to hold more capital (Binder & Lehner 2020) which would improve their resilience (EBA, 2018 ; Pfeifer & Hodula, 2021). On the theoretical part of the Output Floor literature, only the work of Acosta-Smith et al.(2021) has examined the macrofinancial and macroeconomic impact of the Output Floor in a modeling approach. The authors extends the DSGE model of Gambacorta & Karmakar (2018) and estimates it for United Kingdom economy. Their results show that the use of the Output Floor would redirect banks' activity towards loans with a risk close to one required by the prudential instrument. Despite changes in banks' portfolio strategy, authors indicate that OF implementation would reinforce financial stability in the economy. Nonetheless, the DSGE model used by the authors does not integrate default probability which prevents them to construct an IRB approach consistent to the one defined by Basel regulation. Therefore, contrary

[2]See the speech of the European Central Bank (ECB) Vice-President made June 2023. URL link to the speech: https://www.ecb.europa.eu/press/key/date/2023/html/ecb.sp230609~c9ef904931.en.html

to them, our model incorporate endogenous default probability which allow us to use the Basel IRB approach and to get a consistent Output Floor analysis. In addition, to best of my knowledge, our paper is the first to study the potential financial, economic and environmental impact of a brown Output Floor in a macrotheoretical framework.

3 The model

In order to examine macrofinancial and environmental impact of the brown Output Floor, the paper modifies and extends the DSGE model of Ferrari & Nispi-Landi (2023). Excepted for the firms and banking sector, the rest of the model is similar to the one built by Ferrari & Nispi-Landi (2023) : Households consume, make deposits in banks and work for green and brown (i.e. pollutant) firms in exchange of a salary. In the production sector, green and brown firms borrow respectively from green and brown entrepreneurs to finance their physical capital. By using this capital and households workforce as inputs, green and brown firms produce goods and sell them to intermediary firms. Then, intermediary firms are subjected to price adjustment and aggregate green and brown firms goods to sell intermediary goods to final firms. The latter use intermediary goods to produce and sell final goods to consumers. There are also capital producers who buy output produced by final-good firms and non-depreciated capital from intermediate firms in order to produce physical capital. Moreover, production of brown firms generates carbon emissions, which contribute to increase the stock of pollution. In turn, the increase of pollution has a negative impact on the productivity of green and brown firms, which affects the performance of the production sector. Finally, there is a government who uses income from fiscal policy to finance public spending fully and a central bank who sets a conventional monetary policy (Taylor rule).

In the rest of this section, we focus on modified and extended parts of the model for the standard and brown OF analysis, i.e. firms and banking sector. Remaining parts of the model are available in the online appendix of Ferrari & Nispi-Landi (2023).

3.1 Firms sector

This sector is composed of green and brown firms, intermediate firms and final firms. Outputs of green and brown firms are used as input the production of intermediate firms. Then, production of each intermediate firms is aggregated by final firms in order to produce final goods.

3.1.1 Green and brown firms

Competitive green and brown firms use capital and labor as inputs to generate outputs. In the baseline model, only distinction between green and brown firms corresponds to the capacity of brown firms production to increase pollution emissions.

Green firms produce goods y_t^G following a Cobb-Douglas production function :

$$y_t^G = A_t \left(k_{t-1}^G\right)^{\alpha} \left(h_t^G\right)^{1-\alpha} \tag{1}$$

Where k_{t-1}^G and h_t^G stands respectively for physical capital and labor used in the production of green firms. Note that capital used in the production at the period t corresponds to capital bought in the previous period. This setting allows to account to the so-called "time to build" process for the use of capital in production. Variable A_t reflects total factor productivity which depends of a stochastic shock and stock of pollution in the economy[3]. Parameter α denotes the share of capital in the production process.

Capital expenditure of green firms is financed by green entrepreneurs at the real interest rate $r_{E,t}^G$. At the end of production process, green firms reimburse capital with interests. Moreover, green firms buy capital from capital producers, which in turn buy back non-depreciated capital from green firms. As a result, in each period t, green firms want to maximize their profit function :

$$\Pi_t^G = p_t^G y_t^G - w_t h_t^G - r_{E,t}^G q_{t-1} k_{t-1}^G + (1-\delta) q_t k_{t-1}^G \tag{2}$$

Where p_t^G is the price of green firms goods, w_t is the wage given to households in exchange of their labor force. q_t corresponds to the price of capital determined by the capital producer and δ is the depreciation rate of capital.

[3]Further details on drivers of total factor productivity will be presented in next subsections.

First order conditions (henceforth FOC) on capital and labor are represented by the two following equations :

$$w_t h_t^G = (1-\alpha) p_t^G y_t^G \tag{3}$$

$$k_{t-1}^G \left(r_{E,t}^G q_{t-1} - (1-\delta) \right) = \alpha p_t^G y_t^G \tag{4}$$

In the baseline model, brown firms variables are similar to the green firms ones such as :

$$y_t^B = A_t \left(k_{t-1}^B \right)^\alpha \left(h_t^B \right)^{1-\alpha} \tag{5}$$

$$w_t h_t^B = (1-\alpha) p_t^B y_t^B \tag{6}$$

$$k_{t-1}^B \left(r_{E,t}^B q_{t-1} - (1-\delta) \right) = \alpha p_t^B y_t^B \tag{7}$$

3.1.2 Intermediate firms

There is a continuum of monopolistic intermediate firms i who produces differentiated intermediate goods $y_t^I(i)$ by using an aggregation of green and brown firms goods as inputs. Aggregation process of green and brown firms goods follows a CES function such as :

$$y_t^I(i) = \left[(1-\zeta)^{\frac{1}{\xi}} \left(y_t^G(i) \right)^{\frac{\xi-1}{\xi}} + \zeta^{\frac{1}{\xi}} \left(y_t^B(i) \right)^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}} \tag{8}$$

Where $\zeta \in [0;1]$ reflects the share of brown firms goods in inputs used by intermediate firms while ξ represents the degree of substitution between brown and green firms goods in production process of intermediate firms.

Each intermediate firm i chooses an optimal amount of inputs which solves the following intratemporal program :

$$\max_{y_t^G(i)\,;\,y_t^B(i)} \left[(1-\zeta)^{\frac{1}{\xi}} \left(y_t^G(i) \right)^{\frac{\xi-1}{\xi}} + \zeta^{\frac{1}{\xi}} \left(y_t^B(i) \right)^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}} \tag{9}$$

$$\text{s.t. :} \quad p_t^G y_t^G(i) + p_t^B y_t^B(i) = p_t^I y_t^I(i) \tag{10}$$

Where p_t^I is the price of intermediate goods. FOC of the program give demand function from green and brown sector :

$$y_t^G(i) = (1-\zeta)\left(\frac{p_t^G}{p_t^I}\right) y_t^I(i) \tag{11}$$

$$y_t^B(i) = \zeta\left(\frac{p_t^B}{p_t^I}\right) y_t^I(i) \tag{12}$$

By using demand functions and constraint equation in the program above, we can deduce the CES property of intermediate firms price :

$$p_t^I = \left[(1-\zeta)\left(p_t^G\right)^{1-\xi} + \zeta\left(p_t^B\right)^{1-\xi}\right]^{\frac{1}{1-\xi}} \tag{13}$$

Since intermediate firms operate their activity in monopolistic environment, they are able to set prices subject to the demand of final good (see equation (19) below). However, setting prices is costly and each intermediate firm i has to pay a quadratic nominal cost to adjust its price with respect to a benchmark inflation $\overline{\pi}$. By taking into account this nominal friction on price and considering p_t^I as its real marginal cost, intermediate firms i wants to maximize the following program :

$$\max_{\{p_t(i)\}_{t=0}^{\infty}} \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \Lambda_t \left[\left(\frac{p_t(i)}{p_t}\right)^{-\varepsilon} \left(\frac{p_t(i)}{p_t} - p_t^I\right) y_t - \frac{\kappa_P}{2}\left(\frac{p_t(i)}{p_{t-1}(i)} - \overline{\pi}\right)^2 y_t \right] \right\} \tag{14}$$

Where ε is the degree of substitution between intermediate firms goods, y_t and p_t corresponds respectively to the output and price of final firms. Parameter κ_P reflects the degree of the prices adjustment cost for intermediate firms. It is assumed that households own these firms which implies to discount the intertemporal program above by the stochastic discount factor Λ_t[4].

By assuming symmetric equilibrium, FOC of the previous program gives the New Keynesian Phillips Curve :

$$\pi_t\left(\pi_t - \overline{\pi}\right) = \mathbb{E}_t\left[\Lambda_{t+1}\pi_{t+1}\left(\pi_{t+1} - \overline{\pi}\right)\frac{y_{t+1}}{y_t}\right] + \frac{\varepsilon}{\kappa_P}\left(p_t^I - \frac{\varepsilon - 1}{\varepsilon}\right) \tag{15}$$

3.1.3 Final firm

Finally in firms sector, there is a representative and competitive final firm who use a CES aggregator for intermediate goods to produce final goods y_t such as :

[4] The stochastic discount factor corresponds to product between subjective discount factor β and stochastic marginal utility of households, i.e. $\Lambda_t = \beta^t \frac{\lambda_t}{\lambda_0}$

$$y_t = \left[\int_0^1 \left(y_t^I(i) \right)^{\frac{\varepsilon - 1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon - 1}} \tag{16}$$

Final firm is able to determine its goods price by choosing optimal amount of intermediate goods which solves the following program :

$$\max_{y_t^I(i)} \quad p_t y_t - \int_0^1 p_t(i) y_t^I(i) di \tag{17}$$

$$\text{s.t. :} \quad y_t = \left[\int_0^1 \left(y_t^I(i) \right)^{\frac{\varepsilon - 1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon - 1}} \tag{18}$$

Solution of the program provides the demand function for intermediate firm i :

$$y_t^I(i) = \left(\frac{p_t(i)}{p_t} \right)^{-\varepsilon} y_t \tag{19}$$

3.2 Entrepreneurs

Green and brown firms physical capital are financed by green and brown entrepreneurs respectively. In period t, green (or brown) entrepreneur e manages several heterogeneous projects with total value $q_t k_t^G(e)$ (or $q_t k_t^B(e)$). Green (or Brown) entrepreneur uses its net wealth $N_{E,t}^G(e)$ (or $N_{E,t}^B(e)$) and loans obtained from banks $b_t^G(e)$ (or $b_t^B(e)$) to finance projects. Balance sheet of each entrepreneur writes :

$$q_t k_t^h(e) - N_{E,t}^h(e) = b_t^h(e) \qquad \text{with } h \in \{G; B\} \tag{20}$$

In the same vein as Bernanke, Gertler et Gilchrist (BGG, 1999), it is supposed that entrepreneur's projects are risky and get an individual return equals to $\omega_t^h R_{E,t}^h$. Variables ω_t^h denotes the idiosyncratic risk on projects' return while $R_{E,t}^h$ reflects their aggregate gross return. Similar to Mendicino et al.(2018) and Darracq-Paries et al.(2019), it is assumed that the idiosyncratic risk $\omega_{h,t}$ follows a log-normal distribution with a mean $\mu_{ln(\omega_h)}$ and a standard deviation $\sigma_{ln(\omega_h)}$.

The variable $\omega_{h,t}$ is i.i.d with a cumulative distribution function $F(\omega_{h,t})$ which follows standard regularity properties[5]. The mean of the idiosyncratic risk ω is equal to $\mu_{ln(\omega_h)} = -0.5\sigma^2_{ln(\omega_h)}$ in order to guarantee that $\mathbb{E}_{h,t}(\omega_{h,t+1}) = 1$ at each period.

A project is profitable when its return is higher than a threshold $\omega^C_{h,t}$ such that the value of the profitable project is equal to $\overline{\omega}_{h,t}(e) = E\left(\omega_{h,t}|\omega_{h,t} \geq \omega^C_{h,t}(e)\right)$. After aggregation of all projects, profit function of the entrepreneur e is given by :

$$\Pi^E_{h,t}(e) = \mathbb{E}_t\left\{\overline{\omega}_{h,t+1}(e)R^h_{E,t+1}q_t k^h_t(e) - r^h_{t+1}b^h_t(e)\right\} \qquad \text{with } h \in \{G; B\} \tag{21}$$

Where r^h_t represents interest rate on bank loans.

Contrary to Bernanke, Gertler et Gilchrist (BGG, 1999), entrepreneurs do not know the *ex-ante* value of $\overline{\omega}_{i,t}(e)$ (i.e. before the realization of ω). By supposing null profit in previous profit function, the *ex post* value of $\omega^C_{i,t}$ has to respect the condition below :

$$\omega^C_{h,t+1}R^h_{E,t+1}q_t k^h_t(e) = r^h_{t+1}b^h_t(e) \tag{22}$$

Similar to Poutineau & Vermandel (2017), we introduce a financial accelerator in the model by assuming that entrepreneurs have bias view on the expected return of their projects. This bias distorts *ex-ante* entrepreneurs' perception of profitable projects $\overline{\omega}_{i,t}(e)$ as following :

$$g\left(\overline{\omega}_{h,t+1}(e)\right) = \overline{\omega}_h(e)^{1/(1-\varkappa)}\left(\overline{\omega}_{h,t+1}(e)\right)^{\varkappa/(\varkappa-1)} \tag{23}$$

Where $\varkappa \in [0, 1[$ reflects the bias intensity and $\overline{\omega}_h(e)$ stands for the steady-state value of $\overline{\omega}_{h,t}(e)$. Bias distortion works as following : during economic upturn, entrepreneurs' forecasts are optimistic on their aggregate profitability (i.e. $g\left(\overline{\omega}_{h,t+1}(e)\right) > \overline{\omega}_{h,t+1}(e)$), which reinforces confidence of banks in projects' quality. Then, banks further relax credit access for entrepreneurs and the latter can invest more in new profitable projects, which increases aggregate return. In the opposite, downturn episodes amplify economic and financial recession through the too pessimistic view of entrepreneurs. In the long run, entrepreneurs are not subjected to bias view in aggregate return such as $g(\overline{\omega}_i(e)) = \overline{\omega}_i(e)$.

[5]The cumulative distribution function is continuous, first order differentiable and satisfies the following condition : $\frac{\partial \omega f(\omega)}{\partial \omega} > 0$, where $f(\omega)$ is the hazard rate.

Once entrepreneur e forecasts projects' aggregate returns before the realization of ω, it is able to select profitable projects (i.e. $\geq \omega^C_{h,t}$) and choose the amount of capital $k^h_t(e)$ in order to maximize its *ex ante* profit function :

$$\Pi^E_{i,t}(e) = \mathbb{E}_t \left\{ \eta^E_{h,t+1} \left[g(\overline{\omega}_{h,t+1}(e)) R^h_{E,t+1} q_t k^h_t(e) - r^h_{t+1} b^h_t(e) \right] \right\} \tag{24}$$

Where $\eta^E_{h,t+1}$ denotes the share of profitable projects. From banks' view, this share represents the non-default probability of the entrepreneur.

The maximization of the profit function above allows to define an external premium which depends on *ex ante* aggregate profitability forecasts of entrepreneurs :

$$\frac{R^h_{E,t+1}}{r^h_{t+1}} = \frac{1}{g(\overline{\omega}_{h,t+1}(e))} = \overline{\omega}_h(e)^{-1/(1-\varkappa)} \left(\overline{\omega}_{h,t+1}(e)\right)^{-\varkappa/(\varkappa-1)} \tag{25}$$

Moreover, entrepreneurs net wealth in the beginning of period t is given by the profit obtained at the end of period $t-1$:

$$N^h_{E,t}(e) = (1-\delta^E)\Pi^E_{h,t-1}(e) \tag{26}$$

Where $\delta^E \in [0,1[$ reflects a tax rate on entrepreneurs' profit which is defined by steady-state variables of the model.

3.3 Banks

On the baseline model, it is assumed that only banks provide an amount of loans $b^B_t(j)$ to brown entrepreneurs and $b^G_t(j)$ to green ones. Each bank j finances these loans with households deposits $d_t(j)$ and own capital (or bank net worth) $n_t(j)$ such as bank's balance sheet writes :

$$b^B_t(j) + b^G_t(j) = d_t(j) + n_t(j) \tag{27}$$

Furthermore, bank's capital corresponds to accumulation of its profits such as :

$$n_t(j) = \left[1 - \Phi\left(1 - \eta^E_{B,t}\right)\right] r^B_t b^B_{t-1}(j) + \left[1 - \Phi\left(1 - \eta^E_{G,t}\right)\right] r^G_t b^G_{t-1}(j) + \frac{r_{t-1}}{\pi_t} d_{t-1}(j)$$
$$- \frac{\kappa^{CAR}}{2}\left(\frac{n_{t-1}(j)}{\text{RWA}_{t-1}(j)} - \overline{CAR}\right)^2 n_{t-1}(j) \tag{28}$$

The right-hand side of the equation above describes bank's profit which is defined as the difference between incomes and costs of banking activity. The income part corresponds to revenue generated by loans activity. Similar to Poutineau & Vermandel (2017), revenue takes into account default risk of entrepreneurs. More precisely, banks adjust their gross revenue (i.e. loans b^h_t remunerated at rate r^h_t with $h \in \{G, B\}$) by the additional cost $\Phi \in [0; 1]$ they would pay in case of entrepreneurs default (with probability $1 - \eta^E_{B,t}$ for brown entrepreneurs and $1 - \eta^E_{G,t}$ for green ones). This additional cost can be assimilated to the use of recovery agencies by banks. On the cost part of the profit equation above, banks have to remunerate households deposits at a predetermined real rate r_{t-1}/π_t (with π_t as the current inflation rate). The second component in the in cost part reflects the capital requirements constraint in banks' activity. Indeed, when Capital Adequacy Ratio (with $CAR = n/\text{RWA}$) of a bank deviates from the value required by financial regulator (i.e. $\overline{CAR} = 10.5\%$), the latter set sanctions in bank's activity. As in Gerali et al.(2010), Garcia-Revelo & Levieuge (2022) and Badarau & Roussel (2022), these sanctions take the form of a quadratic cost on CAR deviations from benchmark level $\overline{CAR}$. Parameter $\kappa^{CAR} > 0$ denotes the intensity of capital constraint in bank's activity. Close to Basel 3 framework on prudential regulation, current CAR in the model corresponds to ratio between banks capital n_t and Risk-Weighted-Assets. The RWA are computed as the product between loans to brown / green entrepreneurs and the risk-weight assigned for each loan type such as :

$$\text{RWA}_t(j) = \phi^B_t(j) b^B_t(j) + \phi^G_t(j) b^G_t(j) \tag{29}$$

Unlike Ferrari & Nispi-Landi (2023), absence of free arbitrage between green and brown loans comes from heterogeneous risk between brown and green credits instead of the required share of green loans in bank's portfolio.

Moreover, it is assumed that a bank j can exit the market with a probability $(1 - \chi)$ and collect funds $n_{t+1}(j)$ at the beginning of period $t+1$. These funds are transferred to households since the latter are bank's stockholders. Thus, with a probability χ, bank j continues its activity and the value of the bank is given by :

$$V_{j,t}\left(n_t(j)\right) = \max \mathbb{E}_t \left[\sum_{i=0}^{\infty} (1-\chi)\chi^i \beta^{i+1} \frac{\lambda_{t+1+i}}{\lambda_{t+i}} n_{t+1+i}(j) \right] \tag{30}$$

In the same vein as Gertler & Karadi (2011), after collecting deposits and providing loans in period t, bank j is able to divert an exogenous fraction θ of available funds for personal use (e.g. transfer funds to its stockholders[6]). If bank uses this option, depositors can recover the remaining fraction of assets. In order to prevent bank from "running away", depositors will lend to bank only if it has incentives to operate its activity honestly. This also means that depositors will lend to bank if the value of the latter is lower than the fraction of divertable funds :

$$V_{j,t}\left(n_t(j)\right) \geq \theta b_t(j) \tag{31}$$

Where $b_t(j) = b_t^B(j) + b_t^G(j)$. The condition above can also be seen as a friction to prevent bank from increasing their asset indefinitely. In equilibrium, the inequality of previous equation holds which means that bank never "run way" (or divert funds). This also means that every bank chooses the same leverage ratio. By taking into account equation (28) and (31), banks want to maximize the value function defined in equation (30) with respect to green and brown loans and deposits. After aggregation, FOC of the program are following :

$$l_t = \frac{\mathbb{E}_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \nu_{t+1} \left[\left(\widetilde{r_{t+1}^G} - \widetilde{r_{t+1}^B} \right) l_t^G + \frac{r_t}{\pi_{t+1}} - \frac{\kappa^{CAR}}{2} \left(\frac{n_t}{\text{RWA}_t} - \overline{CAR} \right)^2 \right] \right\}}{\theta - \mathbb{E}_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \nu_{t+1} \left(\widetilde{r_{t+1}^B} - \frac{r_t}{\pi_{t+1}} \right) \right\}} \tag{32}$$

$$\frac{\mathbb{E}_t \left\{ \widetilde{r_{t+1}^G} - \widetilde{r_{t+1}^B} \right\}}{n_t} = \mathbb{E}_t \left\{ \left(\phi_t^B - \phi_t^G \right) \kappa^{CAR} \left(\frac{n_t}{\text{RWA}_t} - \overline{CAR} \right) \left(\frac{n_t}{\text{RWA}_t} \right)^2 \right\} \tag{33}$$

Where $\widetilde{r_t^h} = \left[1 - \Phi\left(1 - \eta_{h,t}^E \right) \right] r_t^h$. The variable l_t stands for bank's leverage, i.e. $l_t \equiv \frac{b_t}{n_t}$ and l_t^G is the green bank leverage, i.e. $l_t^G \equiv, \frac{b_t^G}{n_t}$. The component ν_t can be assimilated to the bank's discount factor and is equal to :

[6]This means that households deposit in banks other than the ones they own.

$$\nu_t = (1-\chi) +$$
$$\chi\beta\mathbb{E}_t\left\{\frac{\lambda_{t+1}}{\lambda_t}\nu_{t+1}\left[\left(\widetilde{r_{t+1}^G} - \widetilde{r_{t+1}^B}\right)l_t^G + \left(\widetilde{r_{t+1}^B} - \frac{r_t}{\pi_{t+1}}\right)l_t + \frac{r_t}{\pi_{t+1}} - \frac{\kappa^{CAR}}{2}\left(\frac{n_t}{\text{RWA}_t} - \overline{CAR}\right)^2\right]\right\} \tag{34}$$

As mentioned before, we depart from the model of Ferrari & Nispi-Landi (2023) by assuming that banks' trade-off between green and brown assets comes from the heterogeneous treatment of additional capital requirements when banks increase green or brown loans. Equation (33) depicts explicitly this statement since the spread rate (non-adjusted of borrowers default probability) between green and brown loans depends on the difference between their credit risk-weight (i.e. $\left(\phi_t^B - \phi_t^G\right)$). By rearranging terms of equation (33), we can express the green premium of banks as following :

$$\begin{aligned}\mathbb{E}_t\left\{r_{t+1}^G - r_{t+1}^B\right\} =& \mathbb{E}_t\left\{\frac{n_t}{\left[1-\Phi\left(1-\eta_{G,t+1}^E\right)\right]}\left(\phi_t^B - \phi_t^G\right)\kappa^{CAR}\left(\frac{n_t}{\text{RWA}_t} - \overline{CAR}\right)\left(\frac{n_t}{\text{RWA}_t}\right)^2\right.\\ &\left. + r_{t+1}^B\left(\frac{\left[1-\Phi\left(1-\eta_{B,t+1}^E\right)\right]}{\left[1-\Phi\left(1-\eta_{G,t+1}^E\right)\right]} - 1\right)\right\}\end{aligned} \tag{35}$$

Equation (35) indicates that green premium depends on two components.

The first one is the differential treatment of additional capital requirements for green and brown loans. Note that when banks are under capitalized (i.e. $\frac{n_t(j)}{\text{RWA}_t(j)} < \overline{CAR}$) green premium decreases if credit risk of green loans is lower than the one of brown loans. This means that banks are too much exposed to solvency risk and are sanctioned by financial regulator. Banks need to compose less risky credits portfolio to reduce solvency risk and match with capital requirements. Hence, they decrease lending cost for green entrepreneurs to diminish the risk of their portfolio. We also observe that overcapitalized banks (i.e. $\frac{n_t(j)}{\text{RWA}_t(j)} > \overline{CAR}$) increase the green premium if the credit risk of brown loans is higher than the one green loans. This can be explained by the fact that banks feel overcapitalized with respect to what they need (i.e. $\overline{CAR}$). Thus, they want to rapidly liquidate this capital surplus. To do so, they increase the amount of riskier loans in their portfolio (brown credit in the example) because these loans are easier to find in credits market. The increase of this amount implies a stronger decrease of brown loans interest rate than the one of green loans.

The second component of green premium in equation (35) is the relative risk of default between green and brown entrepreneurs, i.e. $\frac{\left[1-\Phi\left(1-\eta^E_{B,t+1}\right)\right]}{\left[1-\Phi\left(1-\eta^E_{G,t+1}\right)\right]}$. This relative risk indicates that if brown entrepreneurs are less solvent than green ones, then the second component of the equation will contribute to decrease the green premium.

As a result, when banks are under capitalized, the two components of equation (35) go in the same way since higher credit risk for brown loans ($\phi^B_t > \phi^G_t$) implies higher default rate for brown entrepreneurs ($1 - \eta^E_{B,t+1} > 1 - \eta^E_{G,t+1}$). Hence, credit activity with under capitalized banks amplifies movement of green premium. On the contrary, when banks are overcapitalized, the two components evolve in opposite directions, which dampens fluctuations of green premium.

Furthermore, in our analysis, we assume that banks can encourage green transition regardless default risk of green entrepreneurs and thus, green credit risk. In the model, we define this banks' behavior by incorporating an exogenous stochastic shock ε^{GP}_t in the previous green premium equation such as :

$$\begin{aligned}\mathbb{E}_t\left\{r^G_{t+1} - r^B_{t+1}\right\} =& \mathbb{E}_t\left\{\frac{n_t}{\left[1-\Phi\left(1-\eta^E_{G,t+1}\right)\right]}\left(\phi^B_t - \phi^G_t\right)\kappa^{CAR}\left(\frac{n_t}{\text{RWA}_t} - \overline{CAR}\right)\left(\frac{n_t}{\text{RWA}_t}\right)^2\right. \\ &\left. + r^B_{t+1}\left(\frac{\left[1-\Phi\left(1-\eta^E_{B,t+1}\right)\right]}{\left[1-\Phi\left(1-\eta^E_{G,t+1}\right)\right]} - \frac{1}{\varepsilon^{GP}_t}\right)\right\}\varepsilon^{GP}_t\end{aligned} \tag{36}$$

The shock gets the following autoregressive process :

$$\varepsilon^{GP}_t = \rho_{GP} log(\varepsilon^{GP}_{t-1}) + (1-\rho_{GP}) log(\overline{\varepsilon^{GP}}) + v^{GP}_t \quad \text{with } v^{GP}_t \sim \mathcal{N}(0, \sigma^2_{GP}) \tag{37}$$

This transitory shock can be assimilated to a kind of "environmental awareness" in banking sector. For instance, in real world, this temporary change in banks behavior would be more apparent after central bank speeches regarding finance strategies for green transition. In our analysis, this shock will be useful to see if "environmental awareness" of banks would be in conflict with Output Floor objectives defined by financial regulator, i.e. reducing volatility of banks' CAR.

Finally, aggregate bank net worth (or bank capital) is composed of net worth from new banks $n_{y,t}$ and old ones $n_{o,t}$ such as :

$$n_t = n_{y,t} + n_{o,t} \tag{38}$$

Old banks correspond to the fraction χ of banks in period $t-1$ who survived in period t. Hence, law of motion of old banks net worth writes :

$$n_{o,t} = \chi \left[\left(\widetilde{r_t^G} - \widetilde{r_t^B} \right) l_{t-1}^G + \left(\widetilde{r_t^B} - \frac{r_{t-1}}{\pi_t} \right) l_{t-1} + \frac{r_{t-1}}{\pi_t} - \frac{\kappa^{CAR}}{2} \left(\frac{n_{t-1}}{\text{RWA}_{t-1}} - \overline{CAR} \right)^2 \right] n_{t-1} \tag{39}$$

It is also assumed that households transfer a share $\frac{\iota}{1-\chi}$ of assets of survived banks to new ones. This transfer gives enough capital to new banks to start their business :

$$n_{y,t} = \iota b_t \tag{40}$$

By using the two previous equations, we are able to define the law of motion of aggregate bank net worth :

$$n_t = \chi \left[\left(\widetilde{r_t^G} - \widetilde{r_t^B} \right) l_{t-1}^G + \left(\widetilde{r_t^B} - \frac{r_{t-1}}{\pi_t} \right) l_{t-1} + \frac{r_{t-1}}{\pi_t} - \frac{\kappa^{CAR}}{2} \left(\frac{n_{t-1}}{\text{RWA}_{t-1}} - \overline{CAR} \right)^2 \right] n_{t-1} + \iota b_t \tag{41}$$

3.4 Credit risk modeling and Output Floor

3.4.1 Construction of the IRB approach in the model

In line with Mendicino et al.(2018) and Darracq-Paries et al.(2019), it is supposed that each bank j can use internal rating based approach (henceforth IRB) to estimate risk-weight of green and brown entrepreneurs' credits. In the model, the use of IRB approach requires banks to assess Exposure-At-Default (EAD), Probability of Default (PD) and Loss-Given-Default (LGD) of entrepreneurs. Once bank j have determined the three components, it is able to define for green and brown loans the amount of RWA expected by the IRB approach :

$$\text{RWA}_{h,t}^{IRB}(j) = \phi_{h,t}^{IRB}(j)b_t^h(j) = CR_{h,t}(j) * 12.5 * EAD_{h,t}(j) \qquad \text{with } h \in \{G; B\} \tag{42}$$

Where $CR_{h,t}$ denotes the amount of required capital to cover credit losses and the value 12.5 corresponds to the inverse of capital requirements without capital conservation buffers (i.e. 8%). In the Basel 3 framework, the use of IRB approach implies to calculate $CR_{h,t}$ as following :

$$\begin{aligned} CR_{h,t}(j) =& LGD * \mathcal{N}\left[(1-\tau_{h,t}(b))^{-0.5}\mathcal{N}^{-1}\left(PD_{h,t}(j)\right) + \left(\frac{\tau_{h,t}(j)}{1-\tau_{h,t}(j)}\right)^{0.5}\mathcal{N}^{-1}\left(0.999\right)\right] \\ & - LGD * PD_{h,t}(j) \end{aligned} \tag{43}$$

Where $\mathcal{N}[.]$ denotes the cumulative distribution function for a standard normal random variable while $\mathcal{N}^{-1}(.)$ is the inverse of this function. In the model, default probability of entrepreneurs is equal to $PD_{i,t} = 1 - \mathbb{E}_t\{\eta_{h,t+1}\}$. The variable $\tau_{h,t}$ represents the correlation coefficient for borrowers exposures. For corporate exposure, Basel Committee mandates to compute this coefficient as below :

$$\tau_{h,t}(j) = 0.12\left[\frac{\left(1-e^{-50*PD_{h,t}(j)}\right)}{(1-e^{-50})}\right] + 0.24\left[1-\frac{\left(1-e^{-50*PD_{h,t}(j)}\right)}{(1-e^{-50})}\right]$$

Following Darracq-Paries et al.(2011), Angeloni & Faia (2013) and Mendicino et al.(2018), our model focuses on the foundation IRB (F-IRB) approach[7] by supposing that LGD for green and brown entrepreneurs' loans is fixed by financial regulator and equal to $LGD = 0.45$. In addition, similar to Darracq-Paries et al.(2011) and Darracq-Paries et al.(2016), it is assumed that EAD of credits corresponds to the amount of loans acquired by entrepreneurs which implies that $EAD_{h,t}(j) = b_t^h(j)$. Combining these two assumptions allows to define IRB credits risk-weight in the model as following :

[7]Modeling Advanced-IRB (A-IRB) approach is more complex because it implies to access private banking data.

$$\phi^{IRB}_{h,t} = \left(\mathcal{N}\left[(1-\tau_{h,t}(j))^{-0.5}\mathcal{N}^{-1}\left(PD_{h,t}(j)\right) + \left(\frac{\tau_{h,t}(j)}{1-\tau_{h,t}(j)}\right)^{0.5}\mathcal{N}^{-1}(0.999) \right] - PD_{h,t}(j) \right)$$
$$* 0.45 * 12.5 \tag{44}$$

3.4.2 Implementation of Output Floor

In Basel 3 finalization, financial regulator requires banks to define a minimum level of RWA estimated with IRB approach. This minimum level, also called Output Floor, corresponds to 72.5% of RWA obtained with standardized approach (BCBS, 2017a). Following Acosta-Smith et al.(2021), OF implementation in the model introduces a non-linear constraint in RWA estimated with IRB approach :

$$\mathrm{RWA}^{OF}_t(j) = max\left\{\mathrm{RWA}^{IRB}_{B,t}(j) + \mathrm{RWA}^{IRB}_{G,t}(j)\ ;\ 0.725 * \left(\mathrm{RWA}^{SA}_{B,t}(j) + \mathrm{RWA}^{SA}_{G,t}(j)\right)\right\} \tag{45}$$

Where $\mathrm{RWA}^{OF}_t(j)$ corresponds to RWA obtained with Output Floor and $\mathrm{RWA}^{SA}_{h,t}$ denotes RWA of entrepreneurs h assessed with standardized approach, i.e. $\mathrm{RWA}^{SA}_{h,t}(j) = \phi^{SA}_{h,t}(j)b^h_t(j)$. As in Poutineau & Vermandel (2017) et Gambacorta & Karmakar (2018), it is assumed that entrepreneurs credit risk estimated with standardized approach is equal to $\phi^{SA}_{h,t} = 1$. Since the lack of accessible and / or granular banking data for green credit risk, it is supposed that standardized approach provides the same level of credit risk for green and brown loans[8]. As a result, we can rewrite the previous equation as following :

$$\mathrm{RWA}^{OF}_t(j) = max\left\{\phi^{IRB}_{B,t}(j)b^B_t(j) + \phi^{IRB}_{G,t}(j)b^G_t(j)\ ;\ 0.725 * \left(b^B_t(j) + b^G_t(j)\right)\right\} \tag{46}$$

Furthermore, empirical evidences indicate that major banks are mostly the one to use IRB approach in credit risk estimation (Behn et al., 2016). Since banks are identical in the model, we take into account of these evidences in the model by supposing that a share γ^{IRB} of RWA is estimated with IRB approach. We also hypothesize that the share is the same for green and brown credits[9]. The remaining share $1-\gamma^{IRB}$ of RWA is estimated with standardized approach

[8] In absence of Output Floor implementation, this assumption is also applied to long run value of IRB credit risk for green and brown loans.

[9] As in the calibration of credit risk with standardized approach, lack of accessible granular banking data

such as aggregate RWA of bank j is given by :

$$\text{RWA}_t(j) = \gamma^{IRB}\left(\phi_{B,t}^{IRB}(j)b_t^B(j)\phi_{G,t}^{IRB}(j)b_t^G(j)\right) + (1-\gamma^{IRB})\left(b_t^B(j)+b_t^G(j)\right) \tag{47}$$

When the Output Floor is implemented, previous equation can be rewritten as :

$$\text{RWA}_t(j) = \gamma^{IRB}\text{RWA}_t^{OF}(j) + (1-\gamma^{IRB})\left(b_t^B(j)+b_t^G(j)\right) \tag{48}$$

Moreover, in order to clarify OF analysis in next sections, it is assumed that financial regulator imposes OF implementation to banks once the latter have defined optimal loans interest rates. Consequently, green premium condition defined in equation (36) can be rewritten as :

$$\begin{aligned}\mathbb{E}_t\left\{r_{t+1}^G - r_{t+1}^B\right\} =&\mathbb{E}_t\left\{\frac{n_t}{\left[1-\Phi\left(1-\eta_{G,t+1}^E\right)\right]}\left(\phi_{B,t}^A-\phi_{G,t}^A\right)\kappa^{CAR}\left(\frac{n_t}{\text{RWA}_t}-\overline{CAR}\right)\left(\frac{n_t}{\text{RWA}_t}\right)^2\right.\\ &\left.+r_{t+1}^B\left(\frac{\left[1-\Phi\left(1-\eta_{B,t+1}^E\right)\right]}{\left[1-\Phi\left(1-\eta_{G,t+1}^E\right)\right]}-\frac{1}{exp(\varepsilon_t^{GP})}\right)\right\}exp(\varepsilon_t^{GP})\end{aligned} \tag{49}$$

With :

$$\phi_{B,t}^A = \gamma^{IRB}\phi_{B,t}^{IRB}(j) + (1-\gamma^{IRB})$$
$$\phi_{G,t}^A = \gamma^{IRB}\phi_{G,t}^{IRB}(j) + (1-\gamma^{IRB})$$

3.5 Aftermaths of pollution in the economy

In the same line than Nordhaus (2008), Heutel (2012) and Ferrari & Nispi-Landi (2023), the baseline model integrates a pollution externality that negatively affects the economy. This externality comes from the increase of CO_2 emissions made by pollutant sector, i.e. production of brown firms in the model. Similar to the DICE model of Nordhaus (2008), it is assumed that the increase of CO_2 emissions erodes the productivity of brown and green firms[10]. This also means that brown firms do not internalize macroeconomic cost of their pollutant activity

constrains us to set homogeneous value of γ^{IRB} for green and brown loans.

[10]In further details, the increase of CO_2 emissions rises surface temperature, which affects human economic activity and thus, productivity of firms.

and have any strong incentives to reduce emissions[11]. We follow Nordhaus (2008) and Ferrari & Nispi-Landi (2023) by supposing that pollution affects Total Factor of Productivity (TFP) of green and brown firms as following :

$$A_t = (1 - D_t(x_t))a_t \tag{50}$$

Where a_t is an exogenous and stochastic shock component of the TFP, which follows an autoregressive process :

$$log(a_t) = \rho_a log(a_{t-1}) + (1 - \rho_a)log(\overline{a}) + v_t^a \quad \text{with } \; v_t^a \sim \mathcal{N}(0, \sigma_a^2) \tag{51}$$

In line with the work of Heutel (2012), the damage function $D_t(x_t)$ is increasing with respect to atmospheric carbon (i.e. pollution stock in baseline model) x_t such as :

$$D_t(x_t) = d_0 + d_1 x_t + d_2 x_t^2 \tag{52}$$

Moreover, atmospheric carbon is fueled by carbon emissions in the domestic economy (i.e. e_t) and the rest of the world (i.e. e^{row})[12] :

$$x_t = (1 - \delta_x)x_{t-1} + e_t + e^{row} \tag{53}$$

Where δ_x is the depreciation rate of pollution stock.

As mentioned previously, pollution emissions are driven by brown firms production. In line with Heutel (2012), it is assumed that emissions are an increasing and concave function of brown production :

$$e_t = (y_t^B)^{1-\psi} \tag{54}$$

Where $1 - \psi$ denotes the elasticity between emissions and brown firms production.

[11] Another section in the paper analyzes standard and brown OF efficiency when an emissions tax and abatement costs are applied to brown firms production.

[12] Since we model a closed economy, pollution emissions emanating from rest of the world is constant.

3.6 Authorities

There is a government who finances public spending by charging lump-sump taxes to household t_t. It is assumed that public fiscal income fully finances public spending, which implies the absence of public debts to balance public budget. Moreover, similar to Smets & Wouters (2007), level of public spending G is exogenously determined as a constant fraction $g \in [0, 1]$ of long term output $\overline{Y}$ such as $G = g\overline{Y}$. Parameter g also represents the steady-state public spending-to-GDP ratio.

There is a central bank who manages conventional monetary policy *via* a standard Taylor rule :

$$\frac{r_t}{\overline{r}} = \left(\frac{r_{t-1}}{\overline{r}}\right)^{\rho_r} \left[\left(\frac{\pi_t}{\overline{\pi}}\right)^{\phi_\pi} \left(\frac{y_t}{\overline{y}}\right)^{\phi_Y}\right]^{1-\rho_r} \tag{55}$$

Where $\overline{r}$, $\overline{\pi}$ and $\overline{y}$ stands for steady-state central bank rate, inflation and production respectively. Note that deposit rate is directly indexed to central bank rate.

3.7 Equilibrium conditions

Closing the model implies market clearing condition for capital, labor and goods market :

$$k_t = k_t^G + k_t^B \tag{56}$$

$$h_t = h_t^G + h_t^B \tag{57}$$

$$y_t = c_t + i_t + G_t + \frac{\kappa_P}{2}\left(\pi_t - \overline{\pi}\right)^2 y_t + \frac{\kappa^{CAR}}{2}\left(\frac{n_{t-1}}{\text{RWA}_{t-1}} - \overline{CAR}\right)^2 \tag{58}$$

Where c_t corresponds to households consumption and i_t is the investment. Parameter κ_P denotes the intensity of prices friction in goods market.

Finally, there is a financial regulator who manages prudential policy to maintain financial stability in the economy. This policy takes the form of capital requirements $\overline{CAR} = 10.5\%$ in banks' activity.

3.8 Calibration

Most of parameters' value follows the calibration made by Ferrari & Nispi-Landi (2023) for euro area and are presented in table 1.

Regarding entrepreneurs sector, bias intensity parameter $\varkappa$ is set to 0.11 as in Poutineau & Vermandel (2017) while tax rate for entrepreneurs' profit δ^E is determined endogenously to guarantee equilibrium conditions in entrepreneurs' decisions. Similar to Giovanardi et al.(2022), parameter for elasticity of substitution between brown and green capital is equal to $\xi = 2$ while steady-state share of green capital in total capital is set to 20%.

For pollution externality, we use the work of Gibson & Heutel (2023) to calibrate parameters of damage function as following : $d_0 = -0.0076$; $d_1 = 8.1e - 06$; $d_2 = 1.05e - 08$ and $\delta_x = 0.0035$.

As in Darracq-Paries et al.(2019), without Output Floor implementation, long run value of green and brown entrepreneurs credit risk weight is equal to $\phi^G = \phi^B = 0.52$[13]. This setting implies that risk weights are lower than the minimum level required by the prudential instrument, i.e. $\phi^G_{OF} = \phi^B_{OF} = 0.725$[14]. As a result, in the long run, OF implementation would force banks to adjust upward riskiness of their credit activity and thus, would impact their liabilities management. Standard deviations of idiosyncratic risk, i.e. $\sigma_{ln(\omega_h)}$, are calibrated such as default probability of green and brown entrepreneurs generate credit risk weight consistent with and without OF setting in the long run. This means that, without OF, $\sigma_{ln(\omega_G)} = \sigma_{ln(\omega_B)} = 0.191$, which implies long run default probabilities equal to $PD_G = PD_B = 0.5\%$[15]. These values are closed to the one obtained for corporate loans in Darracq-Paries et al.(2011) (equal to 0.7%). With OF implementation on green and brown loans, $\sigma_{ln(\omega_G)} = \sigma_{ln(\omega_B)} = 0.209$ and $PD_G = PD_B = 0.98\%$. Since assessment of $\sigma_{ln(\omega_G)}$ for green loans only depends on its long run credit risk, a brown OF setting implies that $\sigma_{ln(\omega_G)} = 0.191$ and $\sigma_{ln(\omega_G)} = 0.209$. As a result, $PD_G = 0.5\%$ and $PD_B = 0.98\%$. In addition, based on data of European Banking Authority, it is assumed that $\gamma^{IRB} = 0.55$. In line with Gerali et al.(2010) and Poutineau &

[13]This value corresponds to the average of long run credit risk weights assessed by the authors for several euro area countries.

[14]This is also true when only brown loans are considered in OF regulation.

[15]Long run default probabilities are computed by fixing steady-state value of ω^C at 0.6. This value is close to the one obtained in Poutineau & Vermandel (2017).

Vermandel (2017), parameter κ^{CAR} is set to 11. In order to get consistent values for parameter ι and θ, we set recovery agencies cost to $\Phi = 0.2$ and survival rate of banks to $\chi = 0.958$, which is slightly lower than value obtained in Ferrari & Nispi-Landi (2023)[16].

Table 1: Calibration of parameters and shocks

Parameter	Description	Value
β	Subjective discount factor	0.995
σ	Consumption elasticity	2
φ	Inverse of Frisch elasticity	1
ε	Degree of substitution in goods market	6
α	Share of capital in production	0.33
κ_P	Price adjustment costs	26.86
δ	Capital depreciation rate	0.025
ζ	Weight of brown good	0.2^*
$\varkappa$	Bias view of entrepreneurs	0.11%
δ_E	Tax on entrepreneurs profit	$0.4\%^*$
κ_I	Investment adjustment cost	2.48
θ	Divertable share of assets	0.675^*
χ	Bank survival probability	0.958
ι	Wealth for new banks	$1.6e-06^*$
Φ	Recovery agencies costs	0.2
κ^{CAR}	Intensity of capital requirements constraint	11
$\overline{CAR}$	Capital requirements	10.5%
d_0	Constant in damage function	-0.0076
d_1	Linear term in damage function	$8.1e-06$
d_2	Quadratic term in damage function	$1.05e-08$
ψ	Convexity of emissions function	0.304
δ_x	Pollution depreciation rate	0.0035
e^{row}	Emissions in the rest of the world	4.692^*
$\overline{\pi}$	SS inflation	1.005
g	SS public spending-to-GDP ratio	0.2
ρ_r	Persistence of monetary policy	0.8
ϕ_π	Inflation weight in Taylor rule	1.5
ϕ_y	Production weight in Taylor rule	0
ρ_a	Persistence of productivity shock	0.9
σ_a	Standard deviation productivity shock	1%
ρ_{GP}	Persistence of green premium shock	0.9
σ_{GP}	Standard deviation green premium shock	0.5%

Note : Symbol $*$ means that the value is determined endogenously at the steady-state and depends on OF setting. Value displayed in table is in absence of Output Floor.

Moreover, it is supposed that annual steady-state spread rate between green and brown loans (i.e. $\widetilde{r^G} - \widetilde{r^B}$)[17] is the same with and without OF implementation and equals to 1.2%.

[16] Parameter ι and θ are determined endogenously at the steady-state.

[17] However, steady-state value of green premium is conditional to OF setting since green premium corresponds to the spread rate adjusted of default probabilities, i.e. $r^G - r^B$.

This hypothesis implies that steady-state green premium (i.e. $r^G - r^B$) is negative when Output Floor is only applied to brown loans.

Finally, autoregressive coefficient of the banks "environmental awareness" shock is equal to $\rho_{GP} = 0.95$ while standard deviation of the shock is calibrated to $\sigma_{GP} = 0.5\%$.

4 Long run benefits of brown Output Floor regulation

As underlined by the work of Budnik et al.(2021), Output Floor implementation would provide financial and economic benefits for euro area economies in the long run. However, authors' work does not consider potential environmental gains or costs of the new prudential instrument. Moreover, Campiglio (2016) highlights that banking industry seems to have a "carbon bias" in lending activity, which does not favor the matching between banks' strategy and sustainable transition roadmaps made by policy makers. In this context, it is important for financial regulator to verify whether their new prudential instruments such as the Output Floor will favor the alignment between banks' strategy and green transition objective in the long run. To do so, an Output Floor applied to brown assets only - i.e a brown OF - could provide useful insights regarding the contribution of the new prudential instrument to this alignment. Our analysis consist to define two scenarios for the scope of Output Floor on credits : 1) A standard Output Floor applied to all banks' assets ; 2) A brown Output Floor applied to high-carbon (or brown) assets only[18].

Figure 1 depicts the macrofinancial, macroeconomic and environmental impact of standard and brown Output Floor in the long run. For each variable, index "OF BG" describes the percentage change of steady-state[19] implied by the standard Output Floor (i.e. applied to green and brown loans) while index "OF B" reflects this change for a brown Output Floor (i.e. applied to brown loans only).

On one hand, the figure indicates that Output Floor implementation increases the amount of RWA in the long run. A part of this increase can be explain by the fact that OF obliges bank's to permanently adjust upward risk-weights of their loans to meet OF requirements

[18]We do not consider an Output Floor applied only to green assets since this scenario would be not consistent with the green transition strategy of policy makers.

[19]Percentage change of steady-state with respect to steady-state obtained without Output Floor implementation.

(from $rw^{IRB} = 0.52$ to $rw^{IRB-OF} = 0.725$). Moreover, the structural rise of RWA has to be compensated by an increase of banks' capital in order to respect capital requirements (i.e. $\overline{CAR} = 10.5\%$). Since banks' capital is fueled by banks' profit, the increase of the former implies a stimulation of banking loans activity. Lower credit restriction allows entrepreneurs to increase their investment in new projects, which improves the capacity of brown and green firms to finance their capital and thus, contributes to increase the production. However, the surge of credits is higher than the increase of the production, which leads the economy to be more exposed to potential financial distresses (reflected by the increase of the credit-to-GDP ratio). Furthermore, a higher production conducts to higher carbon emissions, which increases pollution.

On the other hand, the figure shows that excluding green loans from OF requirements (i.e. brown OF) allows banks to increase the share of green credits in their portfolio. This is due to the fact green credit risk is lower than brown one, which leads to a lower default probability for green entrepreneurs and thus, a decrease of the green premium ("Green Brown Spread Rate" on the graph). Stronger banks' preference for green finance boosts green investment in real sector and increases the share of green production in aggregate output. This higher share contributes to curb the increase of carbon emissions and pollution implied by the rise of aggregate output. Furthermore, even if brown OF setting dampens the increase of aggregate credits, the economy is less subject to financial exposure (reflected by lower increase of credit-to-GDP ratio on the graph).

Consequently, results of this section indicates that financial regulator should implement a brown Output Floor in order to obtain long term financial and economic benefits of standard Output Floor and limit its negative environmental impact.

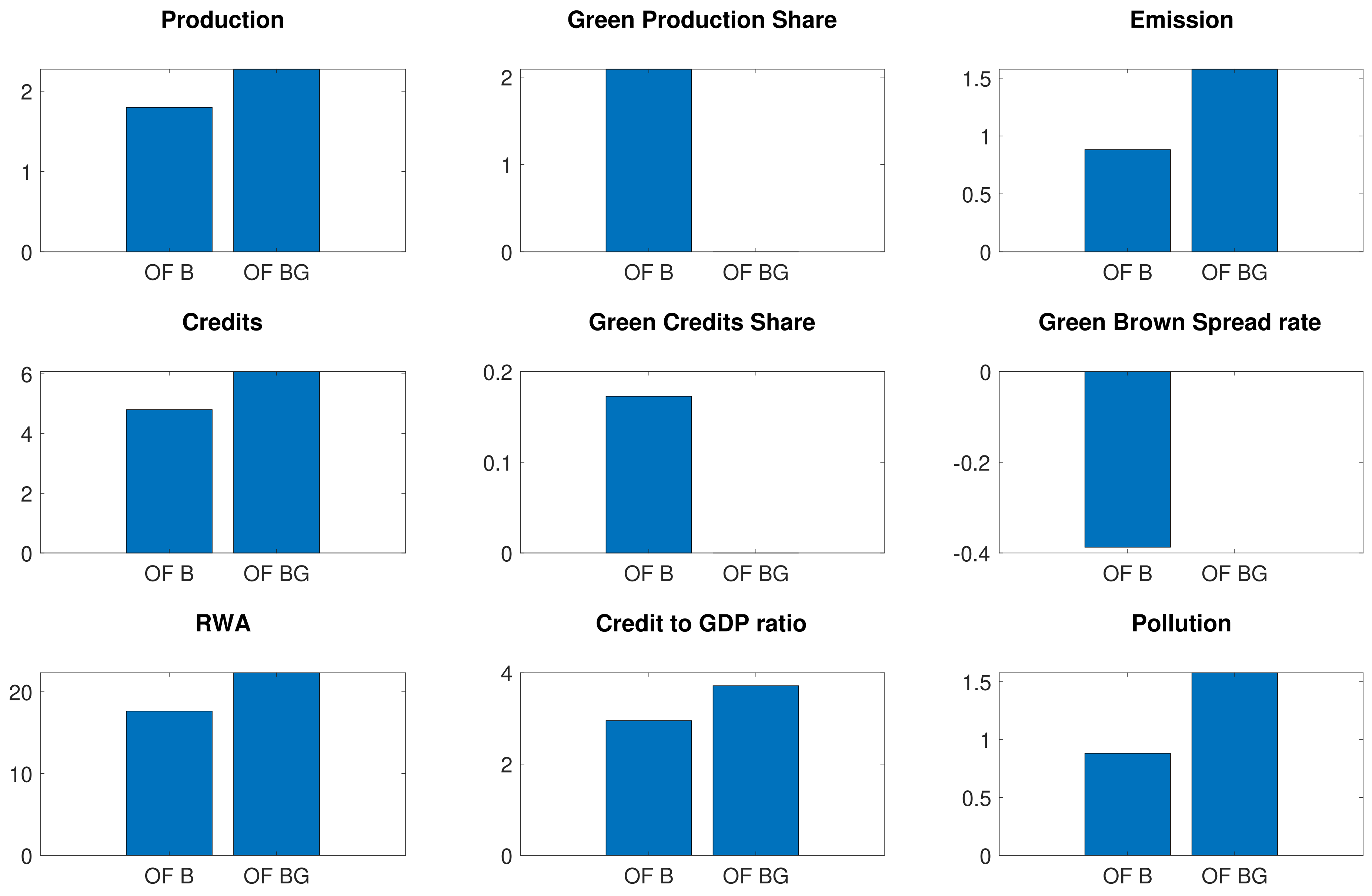

Figure 1: Long run impact of Output Floor with and without green loans credit risk regulation.

Note : Values are expressed in percentage deviation w.r.t steady-state level of variables without OF setting.

5 Alignment of green transition with Output Floor objectives along economic and financial cycle

Previous section has shown that excluding green credit risk in the scope of Output Floor regulation would channel the structural increase of pollution generated by the new prudential instrument. Nevertheless, this result does not provide a complete answer to the question of discriminating green credit risk in the use of Output Floor. Indeed, on of the main goals of the Output Floor is to limit volatility of banks' capital adequacy ratio along financial and economic cycles (BCBS, 2017a). In our model, these cycles are materialized *via* Impulse Response Functions (IRFs) of macro variables when transitory macrofinancial and macroeconomic shocks hit the economy[20].

Therefore, this section evaluates the ability of standard and brown OF to reduce volatility of banks' CAR under these shocks. Similar to Ferrari & Nispi-Landi (2023), we implement an exogenous and stochastic positive shock on Total Factor of Productivity (TFP) for brown and green firms. TFP shock is a consistent macroeconomic shock to evaluate pollution externality after a rise of aggregate output in the economy (Xiao et al., 2018; Annicchiarico et al., 2021 and Caratini et al., 2023 among others). In our exercise, macrofinancial shock is reflected by the negative green premium shock defined in equation (49) of previous model section. This shock is useful to evaluate OF efficiency when banking sector has a transitory 'environmental awareness', or alternatively, when central banks green speeches convince bank to promote green financial transition in short / medium run.

Figure 2 describes the evolution of banks' capital adequacy ratio under productivity and green premium shock. Solid lines denote IRFs when Output Floor is not implemented while dashed lines and black circles account of brown and standard OF implementation respectively. On each graph, the x-axis represents quarters.

Under positive productivity shock, banks' capital adequacy ratio increases and leads banks to be overcapitalized during almost 2 years (i.e. 8 quarters). As shown by figure 5 (presented in

[20]Theses shocks activate the Output Floor which generates a switching regime in RWA evolution. As in Acosta-Smith et al.(2021), we use DynareOBC software of Holden (2016) to solve the model under this switching regime and plot IRFs.

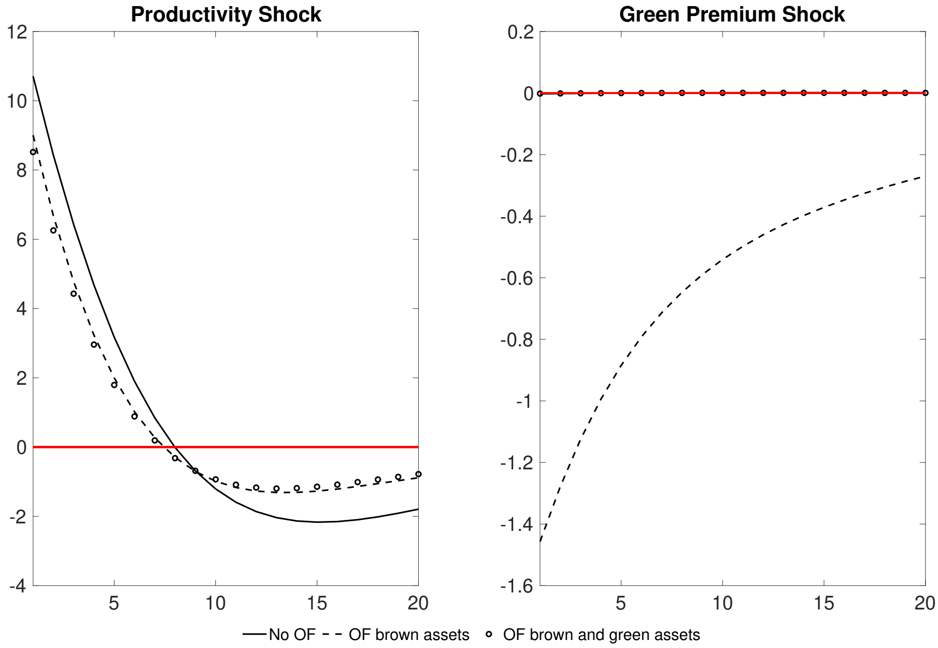

Figure 2: Evolution of banks' capital adequacy ratio under TFP and green premium shock.

Note : Values are expressed in percentage deviation from steady-state, i.e. $\overline{CAR} = 10.5\%$.

appendix), over-capitalization of banks comes from the fact that the rise of their net worth over-compensates the increase of RWA. Higher banks capital means higher profits and thus, stronger stimulation of credit activity. Lower restrictions in credits access encourages investment of brown and green firms, which amplifies the rise of production. Moreover, in medium term, this rise reduces financial exposure of the economy as indicated by the decrease of credit-to-GDP ratio. However, the rise of aggregate production leads to an increase of carbon emissions and pollution.

Furthermore, figure 2 indicates that standard and brown OF implementation allow to reduce the volatility of banks' capital adequacy ratio. This result respects OF objectives defined by prudential regulator (BCBS, 2017b). Moreover, it seems that brown OF regulation has no additional impact on the evolution of the ratio. Nevertheless, under brown OF regulation, figure 5 shows than the green premium increases (dashed lines on the graph), which implies costlier loans for green investments than for brown ones. Consequently, the share of green credits in total credits and the share of green production in total production decrease. By studying equation (49), the rise of green premium can be explained by the fact overcapitalized banks look to use capital surplus to finance more loans. Since brown loans are riskier and thus, more available than green ones, banks lowers brown credits cost to liquidate capital surplus. As a result, the need of banks to liquidate this surplus over-compensate the higher risk of detaining brown loans, which explains the increase of green premium.

Under green premium shock, figure 2 indicates that brown Output Floor regulation exacerbates volatility of banks' capital adequacy ratio[21]. This result clearly highlights that when banks are incited to promote green transition, excluding green loans in the scope of Output Floor regulation erodes the efficiency of the new prudential instrument to reduce volatility of banks' capital adequacy ratio.

Furthermore, figure 6 (presented in appendix) indicates that the decrease of green premium encourages green finance (surge of green credits share), which favors investment in green production (rise of green production share). Thus, transitory 'environmental awareness' of banks contributes to reduce carbon emissions and pollution. In addition, under brown Output Floor (dashed lines on graph), strong decrease of banks' capital adequacy ratio is mainly fueled by the surge of green loans in aggregate RWA. This surge comes from the double benefits for banks of detaining green loans since credit risk of these loans are not constraint by brown OF and banks have strong incentives to provide green loans due to their transitory 'environmental awareness'. As a result, the rise of green credits generates a significant increase of green production which contributes to stimulate aggregate production.

All in all, results of this section shows that Output Floor should not exclude green credit risk from its regulation to preserve its efficiency and especially when banks are incited to finance green transition. Hence, this conclusion shades the long term environmental benefits obtained with brown Output Floor. In other words, brown OF faces a trade-off between better banking solvency and better green transition.

[21] IRFs of banks' capital adequacy ratio without and with standard OF implementation are displayed but their amplitude are much lower than the one obtained with brown OF.

6 Do additional green financial and economic policies help to improve Output Floor efficiency ?

Previous section has underlined potential trade-off for financial regulator between OF efficiency and green transition objectives. This results sheds light on the necessity of joining brown OF regulation with additional green financial and economic policies to dampen the trade-off. In recent literature and in line with European Central Bank (ECB) plans regarding financing green transition, some papers study benefits of a green Quantitative Easing (QE) on promoting this transition (Dafermos et al., 2018; Giovanardi et al., 2022 and Ferrari & Nispi-Landi, 2023). Moreover, as explained by Ferrari & Nispi-Landi (2023), the banking structure *à la* Gertler & Karadi (2011) in our model is well suited for QE analysis. These arguments favor green QE as a candidate for additional green financial policy in our exercise. Regarding green economic policy, the most common one in recent literature consists to implement an emissions tax (and abatement costs) on pollutant firms (Benmir et al., 2020; Lessmann & Schuldt, 2023 and Minesso & Pagliari, 2023). We could guess that introduction of emissions tax and abatement costs on brown firms in our model would provide better incentives for banks to invest in green projects. However, the question of the emissions tax impact on brown Output Floor efficiency is less trivial and thus, needs a deeper analysis.

Therefore, the aim of this section is to check whether a green QE or an emissions tax on brown firms helps to improve this efficiency and to bring complementary results about the right scope of Output Floor regulation.

6.1 Green Quantitative Easing and brown Output Floor

Similar to Ferrari & Nispi-Landi (2023), the integration of a green QE implies central bank / government participation in loans market[22]. Hence, green and brown entrepreneurs can direct a part of their funding demand towards public loans supply. New balance sheet constraint of each entrepreneur e of type h writes as following :

[22] In the model, central bank and government are treated as a single entity for the QE process.

$$q_t k_t^h(e) - N_{E,t}^h(e) = b_{F,t}^h(e) + b_{P,t}^h(e) \qquad \text{with } h \in \{G; B\} \tag{59}$$

Where $b_{F,t}^h$ and $b_{P,t}^h$ denotes respectively the amount of loans provided by banks and public sector to entrepreneur of type h.

Moreover, to get tractable analysis, it is assumed that lending costs of public loans are identical to the one defined by banks as in Ferrari & Nispi-Landi (2023).

It is also supposed that public loans are financed by public bonds $d_{P,t}$ such as :

$$b_{P,t}^G + b_{P,t}^B = d_{P,t} \tag{60}$$

Where $b_{P,t}^G$ and $b_{P,t}^B$ correspond to public loans for green and brown entrepreneurs respectively.

Furthermore, public spending G are now financed through lump-sum taxes t_t and profits earned by public loan activity :

$$G = t_t + \left(r_t^G - \frac{r_{t-1}}{\pi_t}\right) b_{P,t-1}^G + \left(r_t^B - \frac{r_{t-1}}{\pi_t}\right) b_{P,t-1}^B \tag{61}$$

In addition, central bank / government is able to establish a green QE policy *via* the following rule :

$$\frac{\mu_t^G}{\overline{\mu^G}} = \left(\frac{\mu_t^G}{\overline{\mu^G}}\right)^{\rho_G} \left[\left(\frac{y_t^B}{\overline{y^B}}\right)^{\phi_G}\right]^{1-\rho_G} \tag{62}$$

Where $\mu_t^G = \frac{b_{P,t}^G}{b_{P,t}}$ denotes the share of green loans held by the public sector. Thus, $\overline{\mu^G}$ is steady-state value of this share. The previous equation indicates that public sector provides more loans to green firms when production of brown firms is above to its long term level. Coefficient ϕ_G reflects sensitivity of green QE policy to changes in brown production while parameter ρ_G represents the persistence of this policy.

Finally, the introduction of public loans implies new market clearing conditions in credit sector :

$$b_t = b_{F,t} + b_{P,t} \tag{63}$$

$$b_{F,t} = b_{F,t}^G + b_{F,t}^B \tag{64}$$

$$b_{P,t} = b_{P,t}^G + b_{P,t}^B \tag{65}$$

To study the impact of green QE on brown Output Floor efficiency under financial and economic shock, we consider three scenarios. The first one corresponds to the absence of public loans on credit sector such as baseline model, i.e. $\mu_t^G = \overline{\mu^G} = 0$. The second and third scenario integrate a long term participation of public sector in green finance that represent respectively 20% and 50% of total public loans, i.e. $\overline{\mu^G} = 0.2$ and $\overline{\mu^G} = 0.5$. As in Ferrari & Nispi-Landi (2023), parameters ρ_G and ϕ_G are respectively equal to 0.8 and 10.

Figure 3 depicts the impact of green QE on bank's capital adequacy ratio under the three scenario. On the figure, index 'OF B' indicates a brown OF implementation while index 'OF BG' means a standard OF implementation (OF applied to brown and green credits).

The figure indicates that the increase of public sector participation in green finance does not improve brown OF efficiency during the productivity shock. However, when the green premium shock occurs, public sector participation reduces the volatility of banks' CAR under brown OF regulation. Nevertheless, when Output Floor is applied to green and brown loans, public sector increasing participation seems detrimental to OF efficiency as shown by notable changes in banks' CAR. Hence, this result highlights that, when banks want to finance green transition, brown OF can be joined with a green QE to improve efficiency of the prudential instrument.

6.2 Emissions tax and Output Floor

In line with the work of Heutel (2012); Benmir et al. (2020) and Minesso & Pagliari (2023), it is supposed that government is able to introduce an emissions tax τ^b which is proportional to the volume of emissions produced by brown firms. Furthermore, brown firms are able to abate an endogenous fraction $\mu \in [0, 1]$ of their emissions. Abatement technology allows brown

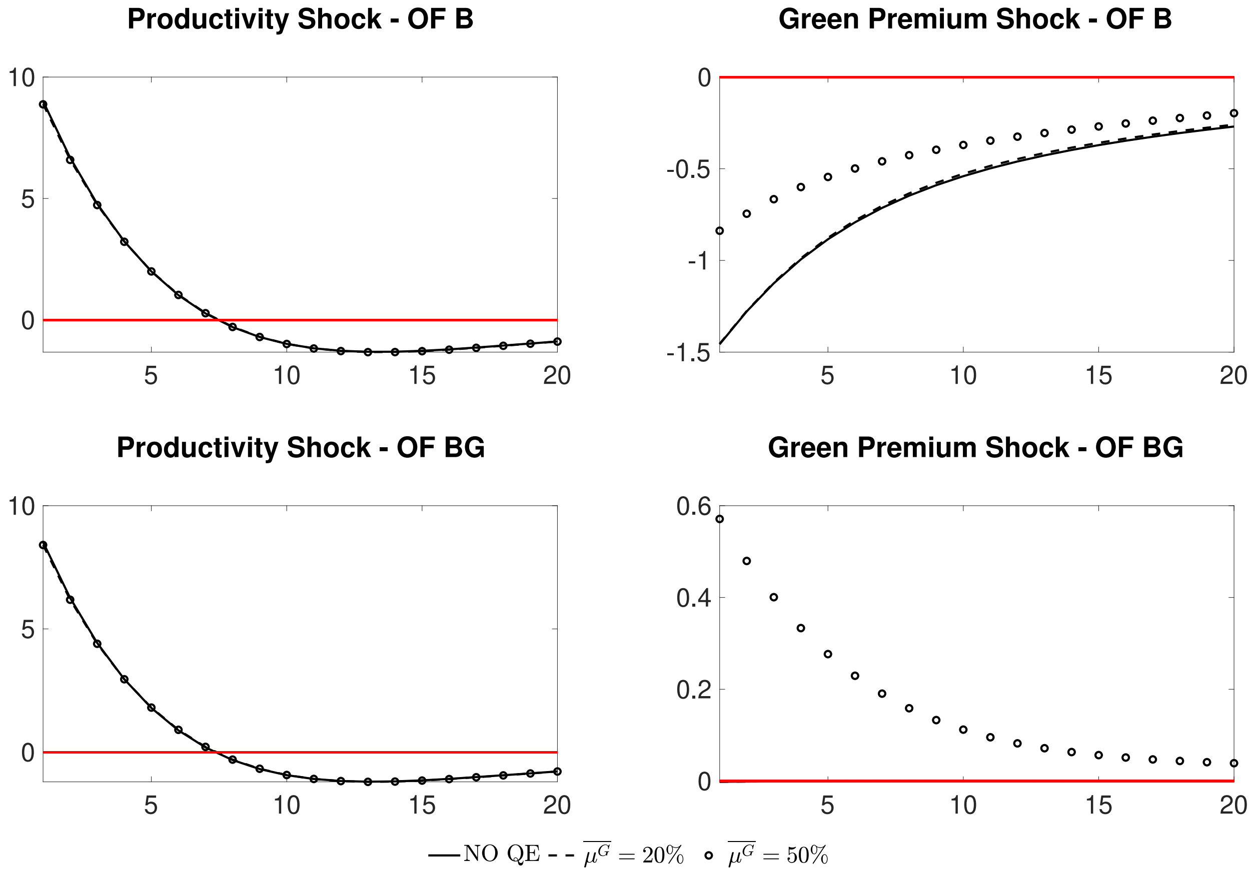

Figure 3: Impact of green QE on banks' capital adequacy ratio under TFP and green premium shock.

Note : Values are expressed in percentage deviation from steady-state, i.e. $\overline{CAR} = 10.5\%$.

firms to reduce fiscal cost of their emissions but this technology has a cost equals to $\theta_1 \mu^{\theta_2} y_t^B$. Parameter θ_1 and θ_2 reflect marginal cost of abatement technology. Introduction of emissions tax and abatement technology cost imply the following profit function for brown firms :

$$\Pi_t^B = p_t^B y_t^B - w_t h_t^B - r_{E,t}^B q_{t-1} k_{t-1}^B + (1-\delta) q_t k_{t-1}^B - \tau^B e_t - \theta_1 \mu_t^{\theta_2} y_t^B \tag{66}$$

Where

$$e_t = (1-\mu_t) \left(y_t^B\right)^{1|\psi} \tag{67}$$

Brown firms choose amount of capital, labor and abatement technology that maximizes their profit function. FOC of the program are following :

$$w_t h_t^B = (1-\alpha)\left[p_t^B y_t^B - \tau^B(1-\psi)e_t - \theta_1 \mu_t^{\theta_2} y_t^B\right] \tag{68}$$

$$k_{t-1}^B\left(r_{E,t}^B q_{t-1} - (1-\delta)q_t\right) = \alpha\left[p_t^B y_t^B - \tau^B(1-\psi)e_t - \theta_1 \mu_t^{\theta_2} y_t^B\right] \tag{69}$$

$$\mu_t = \left(\frac{\tau^B\left(y_t^B\right)^{-\psi}}{\theta_1\theta_2}\right)^{\frac{1}{\theta_2-1}} \tag{70}$$

FOC above indicate that if $\theta_2 > 1$, then brown firms are ready to use abatement technology when they burden emissions tax (i.e. $\tau^B > 0$). Positive relationship between emissions tax and abatement cost implies that stricter fiscal policy on carbon emissions encourages brown firms to use more abatement technology to dampen pollution impact of their production. Note also that brown firms internalize cost of emissions tax in allocation of their input, which influences the amount of their production. Similar to Minesso & Pagliari (2023), we set parameter θ_1 and θ_2 to 0.056 and 2.8 respectively.

To study the impact of emissions tax on standard and brown Output Floor efficiency, we assume four fiscal scenarios : 1) Absence of the tax (i.e. $\tau^B = 0$); 2) An optimal tax found in the model of Ferrari & Nispi-Landi (2023) and equals to $\tau^B = 0.4\%$; 3) A calibrated tax set to $\tau^B = 5\%$; 4) A higher calibrated tax equals to $\tau^B = 10\%$. Figure 4 depicts the impact of emissions tax on bank's capital adequacy ratio under the four fiscal scenarios.

Like green QE policy, emissions tax has no significant impact on the volatility of banks' capital adequacy when a productivity shock hits the economy. The result holds whatever the scope of the Output Floor on green and brown loans regulation. However, when banks gets exogenous incentives to finance green transition, higher emissions tax exacerbates the volatility of banks' capital adequacy ratio and thus, hampers standard and brown OF efficiency. This additional volatility comes from the fact that emissions tax erodes production of brown firms and profitability of brown entrepreneurs project. Therefore, banks provide more loans to green entrepreneurs, which generates higher fluctuations in aggregated RWA and banks' capital adequacy ratio. We observe that, compared to the no emissions tax scenario (solid black lines on graph), a tight fiscal policy (such as $\tau^B = 5$ or 10%) with a standard OF has a greater impact on CAR volatility than the brown OF.

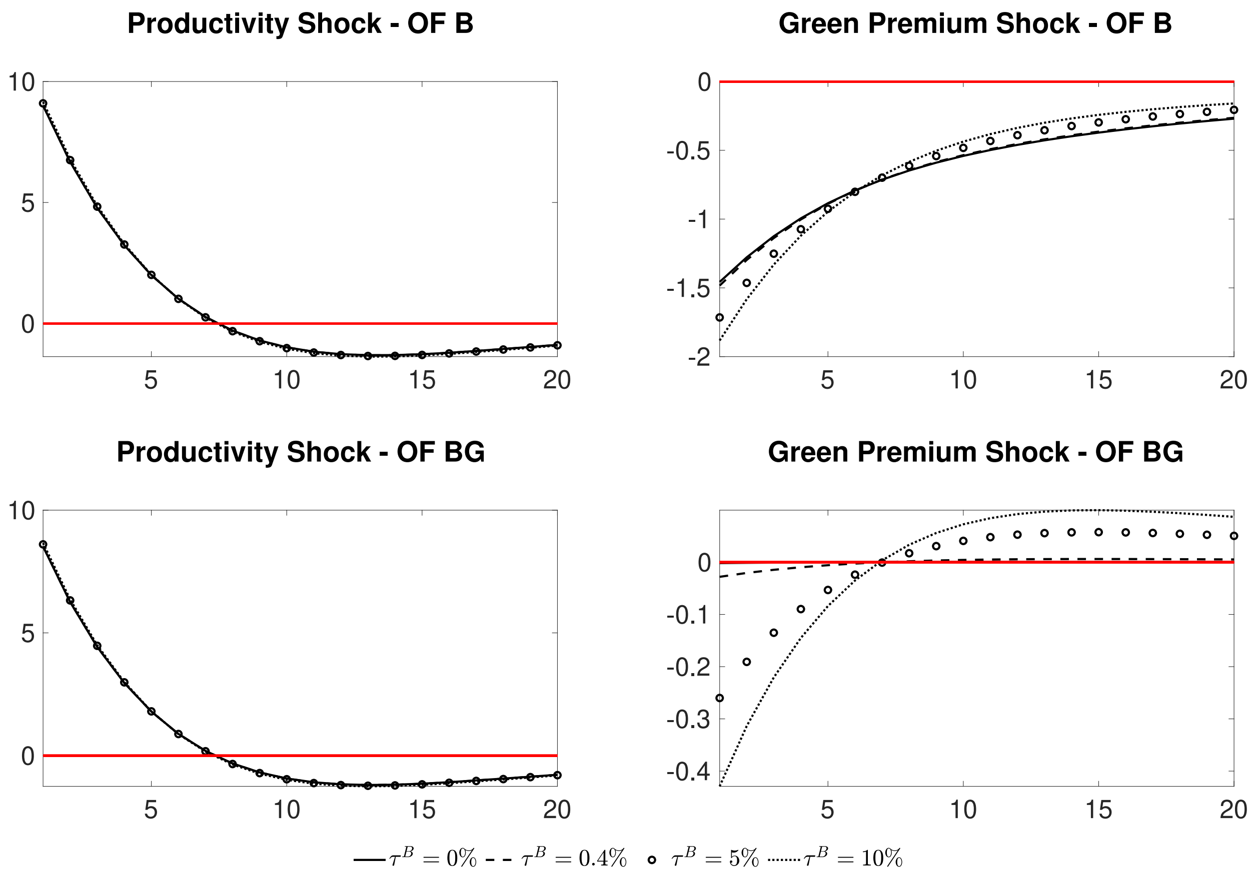

Figure 4: Impact of emissions tax on banks' capital adequacy ratio under TFP and green premium shock.

Note : Values are expressed in percentage deviation from steady-state, i.e. $\overline{CAR} = 10.5\%$.

Besides its impact on OF efficiency along financial and economic cycles, permanent emissions tax gets a long term impact on banking activity, real sector and the level of pollution[23]. This impact affects long term benefits produced by the standard and brown OF as shown by table 2[24]. On the table, we observe that increasing emissions tax erodes aggregate output even if it raises the share of green production.

Unsurprisingly, higher emissions tax leads to stronger reduction of pollution. Moreover, despite greater share of green production, emissions tax affects only the share of green loans in banks' portfolio under brown OF.

[23]The switching regime implied by the OF activation under transitory shocks prevent us from obtaining unconditional mean of variables. Hopefully, we are able to make a static analysis on long term impact of emissions tax.

[24]We cannot do this long-term study in previous permanent green QE analysis because this policy changes the composition of banks loans but not steady-level of aggregate credits. Hence, most of steady-state macroeconomic and macrofinancial variables in the model is not changed.

Table 2: Steady-state impact of emissions tax on macrofinancial and macroeconomic variables under different scope of Output Floor.

Emissions tax / Variables	Production	Green production share	Pollution	Credits	Green credits share	Green premium	RWA	Credit-to-GDP
	No Output Floor							
$\tau^B = 0.4\%$	-0.188	0.0001	-11.807	-0.395	0	0	-0.395	-0.207
$\tau^B = 5\%$	-1.933	0.011	-48.403	-4.015	0	0	-4.015	-2.122
$\tau^B = 10\%$	-3.335	0.033	-70.963	-6.867	0	0	-6.867	-3.654
	Output Floor on brown loans only							
$\tau^B = 0\%$	1.798	2.091	0.882	4.802	0.173	-0.387	17.64	2.95
$\tau^B = 0.4\%$	1.607	2.09	-11.004	4.39	0.173	-0.387	17.177	2.739
$\tau^B = 5\%$	-0.165	2.091	-47.85	0.617	0.173	-0.387	12.943	0.784
$\tau^B = 10\%$	-1.589	2.106	-70.563	-2.358	0.173	-0.387	9.603	-0.781
	Output Floor on green and brown loans							
$\tau^B = 0\%$	2.274	0	1.577	6.076	0	0	22.326	3.717
$\tau^B = 0.4\%$	2.08	0.0001	-10.372	5.656	0	0	21.842	3.503
$\tau^B = 5\%$	0.279	0.011	-47.416	1.812	0	0	17.408	1.528
$\tau^B = 10\%$	-1.168	0.033	-70.251	-1.222	0	0	13.91	-0.054

Note : Except for green premium, values express long term percentage change of variables from their steady-state obtained under the scenario of no emissions tax and no Output Floor regulation. For green premium, values are annualized and expressed in absolute long term change from steady-state values obtained under the scenario of no emissions tax and no Output Floor regulation.

This result comes from the fact that, in the model, banks' strategy on portfolio composition is mainly driven by heterogeneity of credit risk between green and brown loans. Since the absence of Output floor or its activation on green and brown loans generate homogeneous credit risk weights in long term, banks have no reason to change assets composition in their portfolio.

However, reduction of aggregate production implied by the emissions tax contributes to reduce credit access for entrepreneurs and profit for banks. Reduction of banks' profit diminishes their capital and obliges them to decrease their RWA to meet capital requirements (i.e. $\overline{CAR} = 10.5\%$).

Regarding discrimination of green credit risk in Output Floor regulation, table 2 shows that efficiency of emissions tax in reduction of pollution is better under brown OF regulation. However, this environmental benefit comes at higher cost for financial and economic activity in the long run.

Consequently, results found in this section indicate that emissions tax seems not a complementary tool to brown OF regulation especially when banks have exogenous incentives to finance green transition. In the long term, emissions tax cannot remove the brown OF trade-off found in previous sections, i.e. better green transition versus better stability of banking system.

7 Pollution externality in welfare

In the baseline model, it is assumed that pollution emissions emanating from CO_2 contribute to rise temperature, which affects economic activity. However, greenhouse gases also encompass other pollutants such as sulfur dioxide or nitrogen oxides that are detrimental for households health and *in fine* for utility function of households (Acemoglu et al., 2012; Golosov et al., 2014; Benmir et al., 2020). To take account of this statement, it is assumed that emissions correspond to a set of pollutants that hampers utility function and welfare of households.

The welfare in the baseline model is expressed as follows :

$$\mathcal{W}_{1,t} = \max \mathbb{E}_0 \left[\beta^t \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \frac{h_t^{1+\varphi}}{1+\varphi} \right) \right]$$
$$\mathcal{W}_{1,t} = \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \frac{h_t^{1+\varphi}}{1+\varphi} \right) + \beta \mathcal{W}_{1,t+1} \tag{71}$$

Where c_t and h_t correspond respectively to households consumption and hours worked. Parameters σ and φ denote consumption elasticity and the inverse of Frisch elasticity.

In line with the work of Ferrari & Nispi-Landi (2023), the welfare with pollutants cost on households health is given by :

$$\mathcal{W}_{2,t} = \max \mathbb{E}_0 \left[\beta^t \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \frac{h_t^{1+\varphi}}{1+\varphi} - \frac{\omega_1}{1+\omega_2} e_t^{1+\omega_2} \right) \right]$$
$$\mathcal{W}_{2,t} = \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \frac{h_t^{1+\varphi}}{1+\varphi} - \frac{\omega_1}{1+\omega_2} e_t^{1+\omega_2} \right) + \beta \mathcal{W}_{2,t+1} \tag{72}$$

Where parameter $\omega_1 > 0$ reflects the intensity of pollution cost in utility function and $\omega_2 > 0$ denotes the curvature of this cost. Since switching regime implied by Output Floor prevents DynareOBC from generating unconditional welfare along financial and economic cycles, we rather focus on the OF impact on steady-state welfare. From equation above, we can deduce long term welfare in the two scenarios :

$$\mathcal{W}_1 = \left(\frac{c^{1-\sigma}}{1-\sigma} - \frac{h^{1+\varphi}}{1+\varphi} \right) \frac{1}{1-\beta} \tag{73}$$

$$\mathcal{W}_2 = \left(\frac{c^{1-\sigma}}{1-\sigma} - \frac{h^{1+\varphi}}{1+\varphi} - \frac{\omega_1}{1+\omega_2} e^{1+\omega_2} \right) \frac{1}{1-\beta} \tag{74}$$

As in Ferrari & Nispi-Landi (2023), we set ω_1 and ω_2 to 0.1 and 1 respectively. By using this calibration, table 3 depicts the OF impact on steady-state welfare with and without emissions tax.

The first row of the table indicates that, without pollution cost in utility function (i.e. $\mathcal{W}_1$), implementation of Output Floor generate higher welfare in the long run. This result emphasizes OF long term benefits found by Budnik et al.(2021). However, when pollution cost is integrated in utility function, welfare decreases whatever the OF setting. This implies that the new prudential instrument seems not able to counteract negative impact of pollution on households health.

Table 3: Impact of Output Floor and emissions tax on long term welfare with and without pollution cost in utility function.

Emissions tax / OF setting	**No OF**		**OF brown loans**		**OF green and brown loans**	
	$\mathcal{W}_1$	$\mathcal{W}_2$	$\mathcal{W}_1$	$\mathcal{W}_2$	$\mathcal{W}_1$	$\mathcal{W}_2$
$\tau^B = 0\%$	0	-18.675	0.24	-18.786	0.302	-18.958
$\tau^B = 0.4\%$	-0.02	-15.169	0.224	-15.229	0.286	-15.371
$\tau^B = 5\%$	-0.232	-5.967	0.05	-5.834	0.108	-5.875
$\tau^B = 10\%$	-0.437	-2.32	-0.126	-2.073	-0.07	-2.059

Note : Values are expressed in percentage change from steady-state welfare obtained under the scenario of no OF, no emissions tax and without pollution cost in utility function.

Nevertheless, it is worth noting that introduction of emissions tax dampens the negative impact of pollution on welfare. Regarding social objective (i.e. improving agents welfare), this fiscal policy is efficient in the context of green transition.

Moreover, when Output Floor is activated, the use of prudential instrument on brown loans only generates a lower pollution cost in welfare than in the case of a standard Output Floor. Nonetheless, high emissions tax reduces the gap of pollution cost between the two Output Floor settings.

Therefore, when government is not able to set strong fiscal policy for green transition, table results call for an exclusion of green credit risk in the Output Floor regulation.

8 Conclusion

This paper studied macrofinancial, macroeconomic and environmental benefits and costs to discriminate green credit risk under new prudential regulation - Output Floor - in the current context of green transition. Introduction of green transition in financial regulator guidelines is still in debate and especially among European financial supervisors. Moreover, in the Euro Area, the Output Floor regulator will entry into force in January 2025, which gives time for supervisors to discuss about the necessity to integrate green transition concerns in objectives of the new prudential instrument. In order to contribute to this new topic, our work examines benefits and costs to discriminate green credit risk in the Output Floor regulation, i.e. to implement a brown Output Floor. To do so, we use a DSGE model encompassing a pollution externality produced by brown firms (i.e. pollutant firms) production and a banking system consistent with Output Floor analysis. Results of the paper indicated that, in the long term, OF implementation is beneficial for financial and economic activity. However, stimulation of real sector raises the long term level of pollution which is not in line with green transition promoted by governments. In order to limit the negative environmental effect, financial regulators should implement a brown Output Floor. Indeed, unregulated green credit risk represents a lower constraint in banks' capital requirements and thus, banks are incited to finance more green projects. Nevertheless, when banks are keen on financing green transition, brown Output Floor regulation amplifies volatility of banks' capital adequacy, which erodes efficiency of the prudential instrument to stabilize banking system. Therefore, under brown OF regulation, financial regulator faces a trade-off between green transition concerns and financial stability. A permanent and strong green quantitative easing policy from central bank allows to limit this trade-off. Contrary to green QE policy, a permanent tax on pollution emissions exacerbates the trade-off since the fiscal policy reduces the long term level of pollution at the expense of more volatility in banks' capital adequacy ratio. In addition, when pollution affects health of households, brown OF allows to dampen negative impact of pollution on welfare.

All in all, results of the paper indicate that if financial regulator gets a higher preference for financial stability than green transition concerns, then it will not exclude green credit risk in the Output Floor regulation, i.e. it will implement a brown OF.

Looking forward, these analysis outline several areas for future research. For instance, discussing about the optimal IRB-RWA floor for standard and brown OF. Another possible extension of the paper would be to assess the optimal share of green credits regulated by the Output Floor in order to limit the trade-off between green transition concerns and stability of banking system. Incorporating other assets in banks' portfolio such as mortgages, sovereign debt or inter-bank loans would also enrich Output Floor study in this framework. Finally, the introduction of green and macroprudential policy would allow to examine which prudential tool has a greater benefit for green transition and financial stability.

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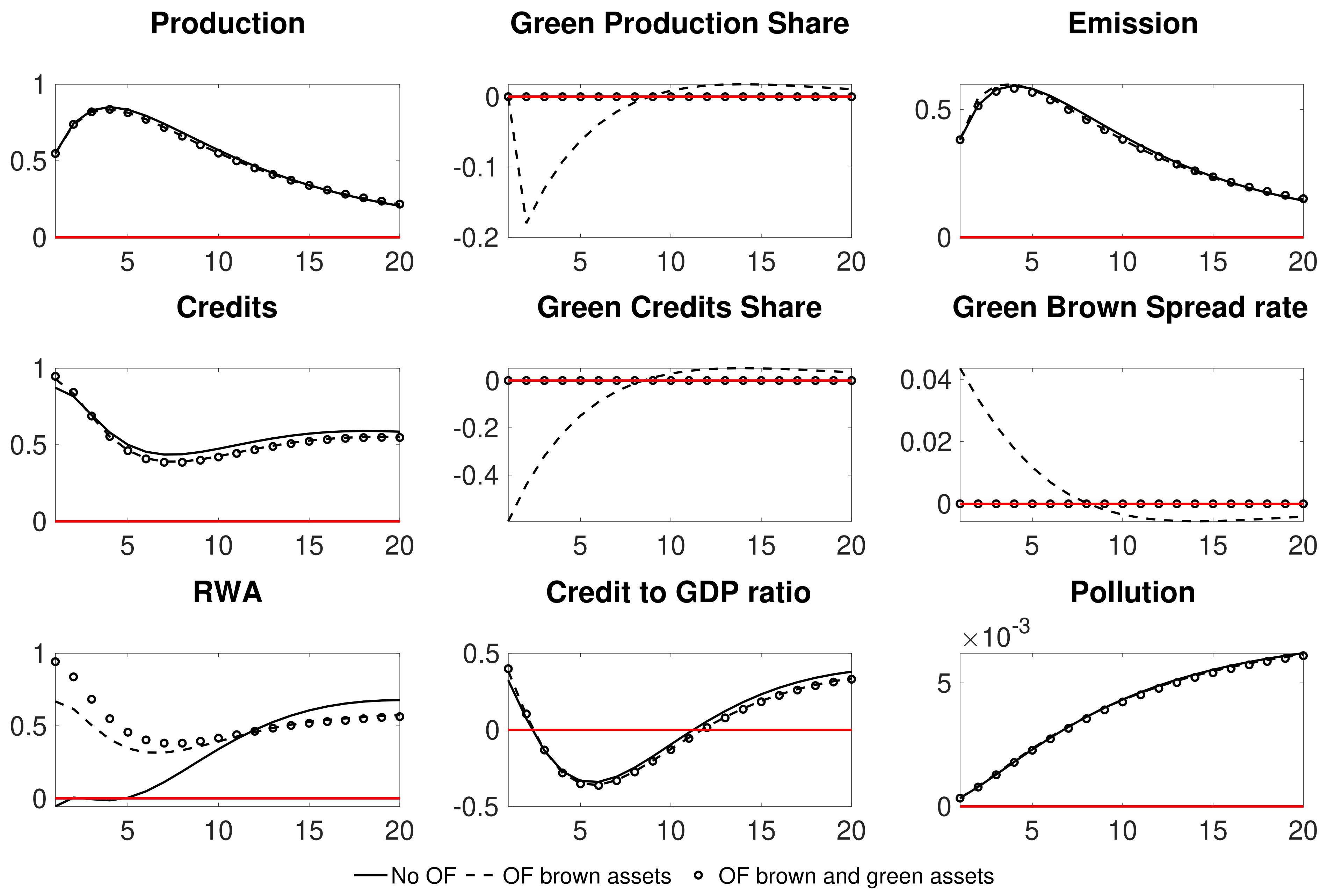

Figure 5: Impact of Output Floor in banking and real sector under positive productivity shock.

Note : Spread rate rate is annualized and expressed percentage point deviation from their steady-state level. Other variables are expressed in percentage deviation from steady-state level of variables.

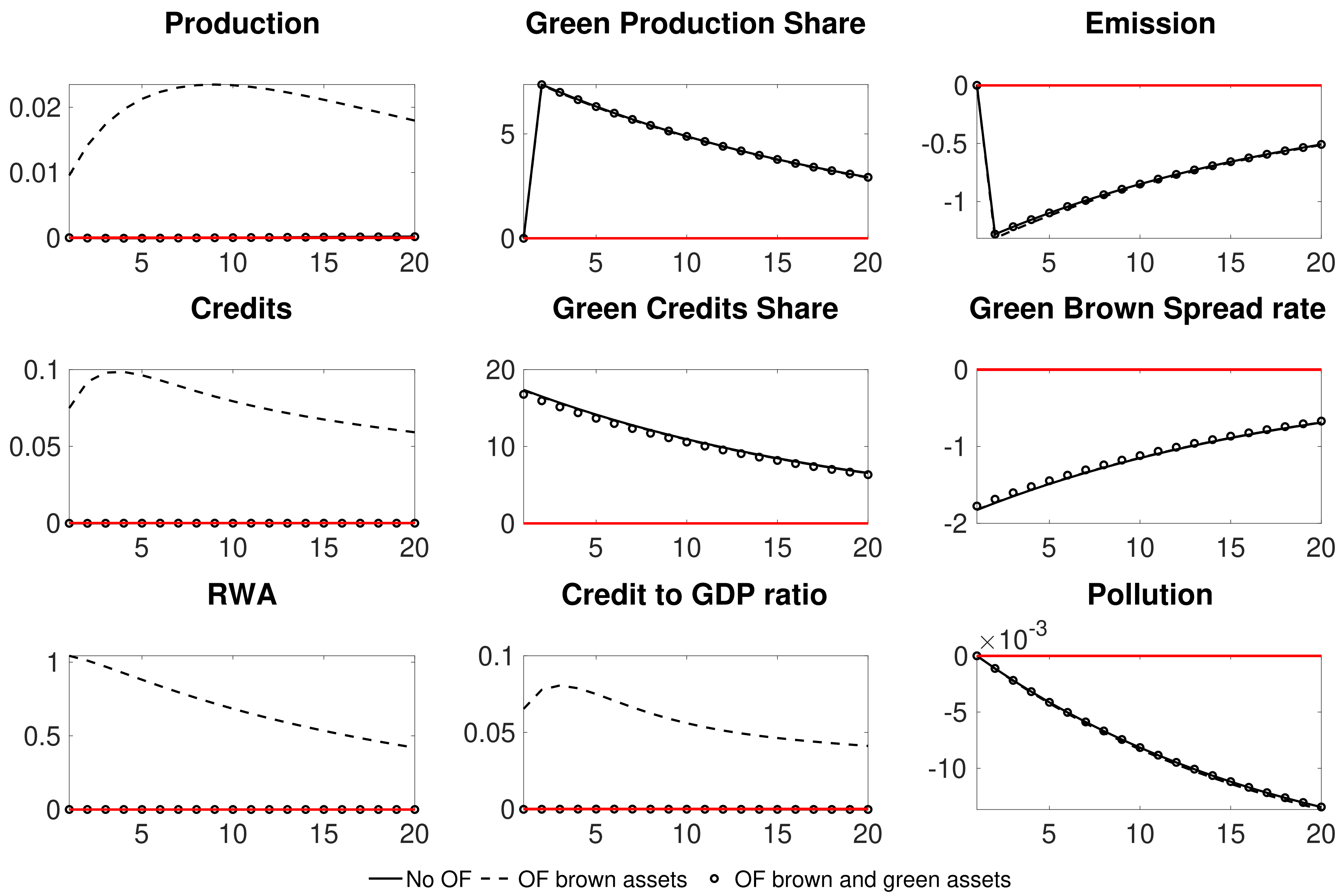

Figure 6: Impact of Output Floor in banking and real sector under negative green premium shock.

Note : Spread rate rate is annualized annualized and expressed percentage point deviation from their steady-state level. Other variables are expressed in percentage deviation from steady-state level of variables.