Shadow banking and consistency of a carbon-intensive Counter-Cyclical Capital Buffers regulation

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Abstract

This paper examines whether a Counter-Cyclical Buffer (CCyB) indexed to carbon-intensive credits, i.e., a carbon-intensive CCyB, is consistent with the banking stability objectives of financial regulators when unregulated banks operate in credit markets. To do so, we assess the consistency of the carbon-intensive CCyB regulation through the lens of a general equilibrium model that encompasses brown and green firms, as well as traditional and shadow banks. We find that a carbon-intensive CCyB regulation is not the most suitable for financial regulators when there are no asymmetric leakages between green and brown loans for traditional and shadow banks. However, a strict emissions tax applied to the production of brown firms favors the adoption of a carbon-intensive CCyB regulation by financial regulators. Moreover, a carbon-intensive CCyB could be suitable when traditional banks are more involved in the green credit market than in the brown one, but its efficiency depends on the stringency of the green fiscal regulation. This highlights the need for regulators to carefully coordinate their green policies to avoid jeopardizing the stability of the banking system.

Keywords: Counter-Cyclical Capital Buffers, Carbon-Intensive Credits, Shadow Banks, General Equilibrium Model

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1 Introduction

The consensus among regulators and scientific committees regarding the economic and financial aftermath of climate change fuels the growing debate on the design of policies that promote the green transition. The risk of climate change to the stability of the banking system has prompted financial regulators and researchers to suggest the implementation of green prudential regulations. Among these regulations, the European Banking Federation (EBF) and the High-Level Expert Group on Sustainable Finance (HLEG) propose the introduction of a Green Supporting Factor (GSF), which applies a discount to the Risk-Weighted Assets (RWA) of green assets held by banks (EBF, 2018; HLEG, 2018). The aim of the GSF is to lower the capital requirements when banks provide green assets, thus helping to finance the green transition.

Alternatively, another proposal for green prudential regulation involves penalizing the RWA of brown assets, i.e., applying a Brown Penalizing Factor (BPF) to banks' capital requirements (Villeroy de Galhau, 2018; D'Orazio and Popoyan, 2019). While the goals of the GSF and BPF are similar, the advantage of the BPF is that it forces banks to hold more capital regardless of the risk level associated with green assets. The work of Roussel (2024a) delves deeper into the design of greener RWAs, suggesting the greening of the key instrument in the finalization of Basel III: the Output Floor. The greening of the Output Floor, also referred to as the "brown" Output Floor, is effectively equivalent to applying both a GSF and a BPF simultaneously, without the challenge of determining the appropriate discount or penalizing rate for green and brown assets.

Nevertheless, the design of the GSF, BPF, and brown Output Floor regulations is more aligned with microprudential policies than with macroprudential ones, since banks may be affected differently by these green regulations[1]. Therefore, for all banks to be involved in financing the green transition, financial regulators need to implement green macroprudential policies. A macroprudential counterpart to the GSF, BPF, and brown Output Floor is the design of Counter-Cyclical Buffers (CCyB) that adjust in response to the carbon-intensive credit cycle,

[1]For example, consider banks with a credit focus on loans to profitable polluting firms or banks that use the standardized approach to estimate their RWAs.

as suggested by D'Orazio and Popoyan (2019). They propose that financial regulators activate these CCyB during periods of excessive carbon-intensive credit in the economy. Given that carbon-intensive credit constitutes a significant share of total credit, the authors argue that these CCyB could help mitigate systemic risk accumulation while simultaneously promoting the green transition.

However, the design of the carbon-intensive CCyB suggested by D'Orazio and Popoyan (2019) raises the question of whether unregulated banks' loans should be considered in the definition of the carbon-intensive CCyB. Furthermore, for such a green macroprudential proposal to be adopted by financial regulators, it must not undermine the benefits of the standard CCyB regulation in maintaining banking stability.

Therefore, the aim of our paper is to examine whether a carbon-intensive CCyB aligns with the objectives of financial regulators when shadow banks (i.e., unregulated banks) operate in the credit market.

To do so, we build on the DSGE models of Ferrari and Nispi-Landi (2023) and Roussel (2024b) by integrating a macroprudential policy in line with the design of a CCyB regulation that accounts for shadow banking activity and green credits. In contrast to the quadratic prudential cost in banks' profit function defined by Roussel (2024b), our CCyB regulation implies that the prudential cost simultaneously affects the spread rate between green and brown loans (i.e., the green premium) and the leverage of traditional banks, as in Lubello (2024).

The paper's findings suggest that the best way to achieve banking stability — specifically, minimizing the volatility of the overall credit-to-GDP ratio — is through the implementation of a CCyB regulation that accounts for both brown and green credits (i.e. prudent CCyB regulation). The rationale behind using a CCyB regulation without carbon-intensive setting is that traditional and shadow banks do not experience asymmetric leaks between green and brown loans. As a result, financial regulators prioritize managing fluctuations across all types of credit to reduce overall credit-to-GDP volatility. However, when a strict emissions tax is imposed on polluting firms, a carbon-intensive CCyB regulation better aligns with regulators' goals. This is because the tax enhances the substitution effect between brown and green credits, increasing the volatility of brown credits and requiring a CCyB regulation that targets these credits specifically. Additionally, the appropriate design of the carbon-intensive CCyB depends on the type of economic shock. For instance, during a positive Total Factor Productivity (TFP) shock, a prudent carbon-intensive CCyB approach is most suitable to maintain stability, while in the case of a negative financial shock, a more moderate carbon-intensive CCyB regulation should be adopted (i.e. a CCyB regulation indexed to brown credits of traditional banks).

Moreover, the increase of traditional banks involvement in the green credit market encourages financial regulators to implement a prudent carbon-intensive CCyB regulation. Hence, financial regulators may align a prudent carbon-intensive regulation with financial policies that incite traditional banks to be involved in financing the green transition. However, when a strict emissions tax is introduced, financial regulators may opt for a prudent non-carbon-intensive CCyB regulation in response to a TFP shock. This shift occurs because the emissions tax intensifies the substitution effect between green and brown loans. As traditional banks expand their role in the green credit market, the heightened substitution effect significantly impacts the volatility of green credits, leading regulators to adopt a non-carbon-intensive CCyB regulation to maintain banking stability.

The rest of the paper is organized as follows: Section 2 provides a literature review related to the topics of this paper. Section 3 describes the key parts of the model used in our analysis. Section 4 outlines the design of the carbon-intensive CCyB regulation, while Section 5 presents the results. Section 6 concludes.

2 Related literature

This paper is related to several strands of literature. First, it contributes to the literature on climate-related issues in DSGE models. Climate-related and E-DSGE models distinguish themselves from Integrated Assessment Models (IAMs), such as the DICE/RICE model of Nordhaus (2018), by incorporating richer economic features. The work of Fischer and Springborn (2011) and Heutel (2012) represents early contributions to the study of optimal environmental policies within a Real Business Cycle (RBC) model. Annicchiarico and Di Dio (2015) and Economides and Xepapadeas (2018) extend the analysis of these earlier works by examining the impact of price rigidities on the efficiency of environmental policies.

However, unlike our work, all the papers mentioned above do not integrate an explicit banking sector. Thus, our paper is also related to the literature that incorporates this sector into climate-related and E-DSGE models. The work of Ferrari and Nispi-Landi (2023) defines a banking sector that provides loans to both green and brown firms. The aim of their paper is to examine whether a green Quantitative Easing (QE) by a central bank helps to reduce the green investment gap created by private banks. Similar to our work, these authors assume that private banks face a costly trade-off in the green composition of their credit portfolio, which results in a spread rate between green and brown loans, i.e., a green premium.

In contrast to a costly trade-off in the green composition of banks' credit portfolios, another strand of green finance DSGE literature focuses on the evolution of the green premium when banks discriminate between insolvency risks of green and brown borrowers. For example, Grill et al.(2024) examine this discrimination when banks provide loans to different types of polluting firms (low, moderate, and high polluting). In their work, the discrimination between firms' insolvency risks is mainly driven by the emissions tax applied to high-polluting firms, as this tax erodes their profitability. In addition to emissions taxes, Giovanardi and Kaldorf (2024) and Lubello (2024) introduce green prudential regulations on the capital requirements constraints of regulated banks. Thus, in contrast to Grill et al.(2024), the works of Giovanardi and Kaldorf (2024) and Lubello (2024) imply an active role for financial regulators in promoting the green transition. The work of Roussel (2024a) extends the analysis of these authors by examining whether greening a key instrument in the Basel III RWA finalization framework—the Output Floor—can maintain banking stability while simultaneously promoting the green transition.

Nevertheless, all of these papers do not consider the shadow banking sector in their models and, as a result, overlook the risk of credit leakages toward unregulated banks that could undermine the efficiency of green prudential regulations. Our paper fills this gap by incorporating a shadow banking sector and contributes to the growing literature on shadow banks in DSGE models. The work of Fève et al.(2019) suggests that shadow banks contribute to increased credit intermediation efficiency because they are not subject to regulatory constraints. This key difference in the regulatory regime between traditional and shadow banks is also addressed in other works, such as Verona et al.(2013) and Begeneau and Landvoigt (2022). While both of these works account for regulatory arbitrage between traditional and shadow banks in calibrated models, Fève et al.(2022) assess the impact of this arbitrage in a model estimated for the U.S. economy, while Gebauer and Mazelis (2023) do the same for Euro Area economies. However, none of the shadow bank-related papers mentioned above incorporate the green transition context into their analysis. The paper by Roussel (2024b) fills this gap by examining the role of shadow banks in influencing the efficiency of two green prudential proposals: the Green Supporting Factor (GSF) and the Brown Penalizing Factor (BPF).

Our paper extends the analysis of Roussel (2024b) by incorporating a macroprudential policy aimed at reducing the accumulation of systemic risk generated by brown and green loans provided by both traditional and shadow banks. This macroprudential policy involves the application of Counter-Cyclical Buffers (CCyB) regulations on the capital requirements of traditional banks. Therefore, our paper is also related to the literature on DSGE models evaluating the efficiency of CCyB regulation. Building on the quadratic prudential cost framework designed by Gerali et al.(2010), the works of Angelini et al.(2014) and Gebauer and Mazelis (2023) introduce a CCyB regulation by applying time-varying capital requirements to banks' activities. In these papers, the CCyB regulation is formulated as a Taylor rule, where the evolution of capital requirements depends on their previous stance and a target defined by the financial regulator. This target aligns with the one set by the Basel Committee, namely the credit-to-GDP ratio gap (BCBS, 2010a).

Instead of a Taylor rule design, Badarau and Roussel (2022) define a CCyB rule that depends on the asset-to-capital ratio of banks and the maximum value of this ratio allowed by the financial regulator. While previous papers integrate CCyB regulation through a prudential quadratic cost, which allows banks to temporarily miss capital requirements, Karmakar and Lima (2023), Lubello and Rouabah (2024) and Lubello (2024) introduce the CCyB regulation by assuming that, for each period, the value of a bank must be greater than or equal to a fraction of its assets. Our paper introduces the CCyB regulation via an endogenous evolution of this fraction, which depends on the evolution of the credit-to-GDP ratio gap. However, in contrast to these papers, our framework simultaneously takes into account the role of shadow banks and the green transition in the design of the CCyB regulation.

3 The model

Our model builds on the DSGE framework of Ferrari and Nispi-Landi (2023) and integrates a shadow banking system similar to Roussel (2024b). In contrast to the latter work, we implement a macroprudential policy that simultaneously affects both the green premium rate (i.e., the spread between green and brown loans) and banks' leverage strategy. The calibration of the model is based on euro area data and follows Roussel (2024b), except for some particular parameters for which details are provided in Appendix 1 .

The economy is populated by households, the production sector, traditional banks, shadow banks, a central bank, and a prudential regulator. Households provide labor to green (non-polluting) and brown (polluting) firms, consume goods, and make deposits in both traditional and shadow banks. The production sector is composed of green and brown production sub-sectors, intermediate producers, final firms, and capital producers. In the green (brown) sub-sector, competitive firms finance their physical capital with their own net worth and loans provided by traditional and shadow banks. Monopolistic intermediate producers use the output of green and brown firms to produce intermediate goods, which are then sold to competitive final firms. Capital producers combine the output of final firms and non-depreciated capital from intermediate firms to produce physical capital, which is then purchased by green and brown firms.

The model also incorporates a negative pollution externality generated by emissions from brown firms. However, this externality simultaneously reduces the productivity of both green and brown firms. Traditional and shadow banks use household deposits and their own capital to finance loans to green and brown firms. The central bank follows a Taylor rule to set the nominal central bank rate, which also corresponds to the nominal deposit rate of traditional banks[2]. As in Roussel (2024b), green and brown firms can default on their loan repayments, which generates a risk premium in the interest rates charged by traditional and shadow banks.

[2]In line with Gebauer and Mazelis (2023) and Lubello and Rouabah (2024), the deposit rate for shadow banks is higher than that for traditional banks due to the higher risk undertaken by households in shadow bank deposits.

One key difference between traditional and shadow banks, similar to Gebauer and Mazelis (2023), is that traditional banks are subject to capital requirement constraints. Unlike Roussel (2024b), these constraints arise from depositors' strategies to prevent banks from "running away" when they engage in credit activity. Specifically, as in Lubello (2024), it is assumed that depositors will lend to a bank if the bank's value is greater than or equal to a fraction of its Risk-Weighted-Assets (RWA). The value of a bank is given by the infinite discounted sum of its net worth. When the financial regulator applies a macroprudential policy, such as a Counter-Cyclical Buffers (CCyB) regulation, depositors understand that banks must increase their capital requirements during credit booms to limit systemic risk in the banking system. The accumulation of systemic risk leads depositors to expect a higher minimum bank value to cover the additional solvency risk. Consequently, this tighter expectation leads to an increase in the fraction of a bank's RWA required to ensure that depositors continue to make deposits. Furthermore, in line with Grill et al.(2024) and Roussel (2024b), traditional banks can use the Internal Rating-Based (IRB) approach to estimate the credit risk of green and brown borrowers when calculating their capital requirements.

The rest of this section provides further explanations on entrepreneurs, the traditional and shadow banking systems, and the design of the macroprudential policy in the model. The remaining parts of the model are similar to the work of Roussel (2024b), and a full description of our model is available in the online appendix.

3.1 Entrepreneurs

Green and brown entrepreneurs finance the physical capital of green and brown firms, respectively. In period t, the green (or brown) entrepreneur e manages several heterogeneous projects with a total value of $q_t k_t^G(e)$ (or $q_t k_t^B(e)$). The green (or brown) entrepreneur uses its net wealth $N_{E,t}^G(e)$ (or $N_{E,t}^B(e)$) and aggregate loans obtained from the banking system, $b_t^G(e)$ (or $b_t^B(e)$), to finance these projects. The balance sheet of each entrepreneur is written as:

$$q_t k_t^h(e) - N_{E,t}^h(e) = b_t^h(e) \qquad \text{with } h \in \{G; B\} \tag{1}$$

For each green (or brown) entrepreneur, aggregate loans correspond to a mix of traditional and shadow bank loans, which is expressed via the following CES function:

$$b_t^h(e) = \left[\left(\gamma_h^F\right)^{1/\psi_h^F} \left(b_{h,t}^F(e)\right)^{\frac{\psi_h^F-1}{\psi_h^F}} + \left(1-\gamma_h^F\right) \left(b_{h,t}^S(e)\right)^{\frac{\psi_h^F-1}{\psi_h^F}} \right]^{\frac{\psi_h^F}{\psi_h^F-1}} \quad \text{with } h \in \{G; B\} \quad (2)$$

Where $b_{h,t}^F(e)$ and $b_{h,t}^S(e)$ are the amount of traditional and shadow banks loans for the entrepreneur e of type h, respectively. The parameter $\gamma_h^F \in [0; 1]$ denotes the bias for traditional bank loans in financing credits of type h while $\psi_h^F > 0$ is the elasticity between traditional and shadow bank loans in credit market of type h.

Properties of these CES functions allow to define the optimal traditional and shadow banks loans demand for green and brown entrepreneurs :

$$b_{h,t}^F = \gamma_h^F \left(\frac{r_{h,t+1}^F}{r_{h,t+1}^A}\right)^{-\psi_h^F} b_t^h \qquad b_{h,t}^S = (1-\gamma_h^F) \left(\frac{r_{h,t}^S}{r_{h,t}^A}\right)^{-\psi_h^F} b_t^h \quad (3)$$

Where $r_{h,t}^F$ and $r_{h,t}^S$ are interest rate charged by traditional and shadow banks for borrower of type h, respectively. Variable $r_{h,t}^A$ denotes aggregate loans interest rate for credits of type h. The CES functions for both credit types give the dynamic of these aggregate interest rates :

$$r_{h,t}^A = \left[\gamma_h^F \left(r_{h,t}^F\right)^{1-\psi_h^F} + (1-\gamma_h^F) \left(r_{h,t}^S\right)^{1-\psi_h^F}\right]^{\frac{1}{1-\gamma_h^F}} \quad (4)$$

In the same vein as Bernanke, Gertler, and Gilchrist (BGG, 1999), it is assumed that the entrepreneur's projects are risky and yield an individual return equal to $\omega_t^h R_{E,t}^h$. The variable ω_t^h denotes the idiosyncratic risk of the project's return, while $R_{E,t}^h$ reflects the aggregate gross return. Similar to Giovanardi et al.(2023), it is assumed that the idiosyncratic risk ω_t^h follows a log-normal distribution with mean $\mu_{\ln(\omega_h)}$ and standard deviation σ_M.

The variable $\omega_{h,t}$ is i.i.d. with a cumulative distribution function $F(\omega_{h,t})$, which satisfies standard regularity properties[3]. The mean of the idiosyncratic risk ω is given by $\mu_{\ln(\omega_h)} = -0.5\sigma_M^2$, ensuring that $\mathbb{E}_{h,t}(\omega_{h,t+1}) = 1$ in each period.

A project is profitable when its return exceeds a threshold $\omega_{h,t}^C$, such that the value of the profitable project is $\overline{\omega}_{h,t}(e) = E\left(\omega_{h,t}|\omega_{h,t} \geq \omega_{h,t}^C(e)\right)$. After aggregating all projects, the profit

[3]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.

function of the entrepreneur e is given by:

$$\Pi^{E}_{h,t}(e) = \mathbb{E}_t \left\{ \overline{\omega}_{h,t+1}(e) R^h_{E,t+1} q_t k^h_t(e) - r^A_{h,t+1} b^h_t(e) \right\} \qquad \text{with } h \in \{G; B\} \tag{5}$$

Where r^h_t represents interest rate on bank loans.

By assuming zero profit in the previous profit function, the *ex-post* value of $\omega^C_{i,t}$ must satisfy the condition below:

$$\omega^C_{h,t+1} R^h_{E,t+1} q_t k^h_t(e) = r^A_{h,t+1} b^h_t(e) \tag{6}$$

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

$$g\left(\overline{\omega}_{h,t+1}(e)\right) = \overline{\omega}_h(e)^{1/(1-\varkappa)} \left(\overline{\omega}_{h,t+1}(e)\right)^{\varkappa/(\varkappa-1)} \tag{7}$$

Where $\varkappa \in [0, 1[$ reflects the bias intensity and $\overline{\omega}_h(e)$ represents the steady-state value of $\overline{\omega}_{h,t}(e)$. In the long run, entrepreneurs are not subjected to a biased view of the aggregate return, such that $g(\overline{\omega}_i(e)) = \overline{\omega}_i(e)$.

Once entrepreneur e forecasts the aggregate returns of projects before the realization of ω, they are able to select profitable projects (i.e., those for which $\omega \geq \omega^C_{h,t}$) and choose the amount of capital $k^h_t(e)$ in order to maximize their *ex-ante* profit function:

$$\Pi^{h,E}_{i,t}(e) = \mathbb{E}_t \left\{ \eta^E_{h,t+1} \left[g(\overline{\omega}_{h,t+1}(e)) R^h_{E,t+1} q_t k^h_t(e) - r^A_{h,t+1} b^h_t(e) \right] \right\} \tag{8}$$

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

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

$$\frac{R^h_{E,t+1}}{r^A_{h,t+1}} = \frac{1}{g(\overline{\omega}_{h,t+1}(e))} = \overline{\omega}_h(e)^{-1/(1-\varkappa)} \left(\overline{\omega}_{h,t+1}(e)\right)^{-\varkappa/(\varkappa_-1)} \tag{9}$$

Moreover, the entrepreneur's net wealth at the beginning of period t is given by the profit obtained at the end of period $t-1$:

$$N^h_{E,t}(e) = (1-\delta^h_E)\Pi^{h,E}_{h,t-1}(e) \tag{10}$$

Where $\delta^h_E \in [0,1[$ is the net wealth decay related to the default rate of the entrepreneur[4].

3.2 The banking system

The banking system is populated by traditional and shadow banks, which provide loans to green and brown entrepreneurs. These loans are financed by households' deposits and the own net worth of both types of financial intermediaries.

3.2.1 Traditional banks

Each traditional bank j provides an amount of loans $b^F_{B,t}(j)$ to brown entrepreneurs and $b^F_{G,t}(j)$ to green ones. The traditional bank finances these loans with household deposits $d^F_t(j)$ and its own capital (or bank net worth) $n^F_t(j)$, such that the traditional bank's balance sheet is written as:

$$b^F_{B,t}(j) + b^F_{G,t}(j) = d^F_t(j) + n^F_t(j) \tag{11}$$

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

$$\begin{aligned} n^F_t(j) = &\left[1-\Phi\left(1-\eta^{F,E}_{B,t}\right)\right] r^B_{F,t} b^F_{B,t-1}(j) + \left[1-\Phi\left(1-\eta^{F,E}_{G,t}\right)\right] r^G_{F,t} b^F_{G,t-1}(j) - \frac{r_{t-1}}{\pi_t} d^F_{t-1}(j) \\ &- \frac{\kappa^{FG}}{2}\left(\frac{b^F_{G,t-1}(j)}{b^F_{t-1}(j)} - b^*_F\right)^2 n^F_{t-1}(j) \end{aligned} \tag{12}$$

With :

$$b^F_t(j) = b^F_{G,t}(j) + b^F_{B,t}(j) \tag{13}$$

Where $r^h_{F,t}$ denotes the interest rate charged by traditional banks on the loans to entrepreneur h. The variable $1-\eta^{F,E}_{h,t}$ reflects the default probability of entrepreneur h, while the parameter $\Phi \in [0,1]$ represents the additional cost that traditional banks would incur in the case of

[4]This parameter is endogenously determined at the steady state.

entrepreneurs' default[5]. In line with Ferrari and Nispi-Landi (2023), traditional banks face a quadratic cost on the green composition of their loan portfolio. The parameter κ^{FG} reflects the intensity of this cost, and b_F^* represents the share of green loans in the total loan portfolio of traditional banks at the steady state. In the absence of heterogeneous credit risk between brown and green loans, the quadratic cost ensures that traditional banks do not have free arbitrage between both loan types. This also means that traditional banks face a green premium (i.e., the spread rate between green and brown loans) that does not depend solely on borrowers' riskiness.

Furthermore, a traditional bank j can exit the market with a probability of $(1 - \chi_t^F)$ at the period t and collect funds $n_{t+1}^F(j)$ at the beginning of period $t+1$. These funds are transferred to households, as they are the bank's stockholders. Hence, with a probability χ_t^F, traditional bank j continues its activity, and the value of this bank (written recursively) is given by:

$$V_{j,t}^F\left(n_t^F(j)\right) = \max \mathbb{E}_t\left[\sum_{i=0}^{\infty}(1-\chi_{t+i}^F)[\prod_{j=0}^{t+i}\left(\chi_{t+j}^F\right)]\beta^{i+1}\frac{\lambda_{t+1+i}}{\lambda_{t+i}}n_{t+1+i}^F(j)\right] \tag{14}$$

Moreover, it is assumed that the probability of exit of banks follows a stochastic evolution:

$$\chi_t^F = \chi^F \varepsilon_t^\chi \tag{15}$$

Where χ^F is the long-run value of the probability and ε_t^χ corresponds to an exogenous auto-regressive process :

$$log\left(\varepsilon_t^\chi\right) = \rho^\chi\left(\varepsilon_{t-1}^\chi\right) + \upsilon_t^\chi \quad \text{with } \upsilon_t^{\chi^F} \sim \mathcal{N}(0,\sigma_\chi^2) \tag{16}$$

After collecting deposits and providing loans in period t, traditional bank j is able to divert a fraction θ_t^F of available funds for personal use (e.g., transferring funds to its stockholders[6]). In the same vein as Lubello and Rouabah (2024) and Lubello (2024), in order to prevent traditional banks from "running away", depositors will lend to a traditional bank if the value of the latter is higher than the fraction of RWA:

[5]This additional cost can be assimilated to the use of recovery agencies by traditional banks.
[6]This refers to households' deposits in banks other than the ones they own.

$$V_{j,t}^{F}\left(n_{t}^{F}(j)\right)\geq\theta_{t}^{F}\text{RWA}_{t}(j) \tag{17}$$

With :

$$\text{RWA}_{t}(j)=\phi_{t}^{B}(j)b_{B,t}^{F}(j)+\phi_{t}^{G}(j)b_{G,t}^{F}(j) \tag{18}$$

Where ϕ_t^G and ϕ_t^B stand for the risk-weight of green and brown loans, respectively. As in Grill et al.(2024), the risk-weight of green and brown corporate loans is estimated under the IRB approach.

While Lubello and Rouabah (2024) assume that θ_t^F corresponds to a stochastic shock on the credit supply of traditional banks, we assume that the evolution of θ_t^F is closely linked to the evolution of the CCyB regulation set by the financial regulator. Indeed, depositors are aware that an increase in the CCyB (i.e., a tighter macroprudential regulation) implies an economy more exposed to financial systemic risk. This additional risk increases the bank's insolvency risk, and depositors require banks to raise their value to cover this risk, which implies an increase in θ_t^F at equilibrium.

By taking into account equations (12) and (17), traditional banks aim to maximize the value function defined in equation (14) with respect to green and brown loans, as well as deposits. After aggregation of all traditional banks, the first-order conditions (FOCs) of the program are as follows:

$$l_t^F=\frac{\theta_t^F\left(l_{B,t}^F\phi_t^G+l_{G,t}^F\phi_t^B\right)+\mathbb{E}_t\left\{\beta\frac{\lambda_{t+1}}{\lambda_t}\nu_{t+1}^F\left[\left(\widetilde{r_{F,t+1}^G}-\widetilde{r_{F,t+1}^B}\right)l_{G,t}^F+\frac{r_t}{\pi_{t+1}}-\frac{\kappa^{FG}}{2}\left(\frac{l_{G,t}^F(j)}{l_t^F(j)}-b_F^*\right)^2\right]\right\}}{\theta_t^F\left(\phi_t^G+\phi_{B,t}^A\right)-\mathbb{E}_t\left\{\beta\frac{\lambda_{t+1}}{\lambda_t}\nu_{t+1}^F\left(\widetilde{r_{F,t+1}^B}-\frac{r_t}{\pi_{t+1}}\right)\right\}} \tag{19}$$

$$\mathbb{E}_t\left\{\beta\frac{\lambda_{t+1}}{\lambda_t}\nu_{t+1}^F\left(\widetilde{r_{F,t+1}^G}-\widetilde{r_{F,t+1}^B}\right)\right\}=\mathbb{E}_t\left\{\beta\frac{\lambda_{t+1}}{\lambda_t}\nu_{t+1}^F\frac{\kappa^{FG}}{l_t^F}\left(\frac{l_{G,t}^F(j)}{l_t^F(j)}-b_F^*\right)+\theta_t^F\frac{\lambda_t^F}{1+\lambda_t^F}\left(\phi_t^G-\phi_t^B\right)\right\} \tag{20}$$

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

$$\nu_t^F = (1-\chi_t^F)+$$
$$\chi_t^F \mathbb{E}_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \nu_{t+1}^F \left[\left(\widetilde{r_{F,t+1}^G} - \widetilde{r_{F,t+1}^B} \right) l_{G,t}^F + \left(\widetilde{r_{F,t+1}^B} - \frac{r_t}{\pi_{t+1}} \right) l_t^F + \frac{r_t}{\pi_{t+1}} - \frac{\kappa^{FG}}{2} \left(\frac{l_{G,t}^F(j)}{l_t^F(j)} - b_F^* \right)^2 \right] \right\} \tag{21}$$

The component λ_t^F corresponds to the Lagrangian multiplier of equation (17) in the maximization program of banks and is equal to:

$$\lambda_t^F = \frac{\mathbb{E}_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \nu_{t+1}^F \left(\left(\widetilde{r_{F,t+1}^B} - \frac{r_t}{\pi_{t+1}} \right) + \frac{\kappa^{FG}}{\left(l_t^F\right)^2} \left(\frac{l_{G,t-1}^F}{l_{t-1}^F} - b_F^* \right) \right) \right\}}{\theta_t^F \left(\phi_t^G + \phi_t^B \right) - \mathbb{E}_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \nu_{t+1}^F \left(\widetilde{r_{F,t+1}^B} - \frac{r_t}{\pi_{t+1}} \right) + \frac{\kappa^{FG}}{\left(l_t^F\right)^2} \left(\frac{l_{G,t}^F}{l_t^F} - b_F^* \right) \right\}} \tag{22}$$

By rearranging terms of equation (20), we can express the green premium of banks as following:

$$\begin{aligned} \mathbb{E}_t \left\{ r_{F,t+1}^G - r_{F,t+1}^B \right\} =& \mathbb{E}_t \left\{ \left[\frac{\kappa^{FG}}{l_t^F} \left(\frac{l_{G,t}^F(j)}{l_t^F(j)} - b_F^* \right) + \frac{\theta_t^F}{\beta} \frac{\lambda_t}{\lambda_{t+1}} \frac{\lambda_t^F}{1+\lambda_t^F} \left(\phi_t^G - \phi_t^B \right) \right] \frac{1}{\left[1 - \Phi \left(1 - \eta_{G,t+1}^{F,E} \right) \right]} \right. \\ & \left. + r_{F,t+1}^B \left(\frac{\left[1 - \Phi \left(1 - \eta_{B,t+1}^{F,E} \right) \right]}{\left[1 - \Phi \left(1 - \eta_{G,t+1}^{F,E} \right) \right]} - 1 \right) \right\} \end{aligned} \tag{23}$$

The equation (23) shows that the green premium of traditional banks depends on the adjustment cost of green leverage, the prudential regulation, and the riskiness of green and brown entrepreneurs (i.e., green and brown borrowers). As explained further in the next subsection, the evolution of θ_t^F can be assimilated to the evolution of the macroprudential policy. It is worth noting that similar riskiness between green and brown entrepreneurs (i.e., $\phi_t^G = \phi_t^B$) cancels out the direct effect of the macroprudential policy on the green premium. In this case, only the adjustment cost of green leverage influences the green premium, as in Ferrari and Nispi-Landi (2023). However, as indicated by equation (19), by modifying θ_t^F, the macroprudential policy influences the leverage strategy of traditional banks and thus has an impact on the adjustment cost of green leverage observed in the green premium equation (23). Therefore, equations (19) and (23) indicate that the macroprudential policy will affect both the price and quantity of loans simultaneously. When green and brown entrepreneurs have similar riskiness, equation (19) also indicates that a tighter macroprudential policy (i.e., an increase in θ_t^F) decreases the leverage decided by traditional banks[7].

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

$$n_t^F = n_{y,t}^F + n_{o,t}^F \tag{24}$$

Old traditional banks correspond to the fraction χ_t^F of traditional banks in period $t-1$ that survived into period t. Hence, the law of motion of old traditional banks' net worth is written as:

$$n_{o,t}^F = \chi_t^F \left[\left(\widetilde{r_{F,t}^G} - \widetilde{r_{F,t}^B} \right) l_{G,t-1}^F + \left(\widetilde{r_{F,t}^B} - \frac{r_{t-1}}{\pi_t} \right) l_{t-1}^F + \frac{r_{t-1}}{\pi_t} - \frac{\kappa^{FG}}{2} \left(\frac{l_{G,t}^F(j)}{l_t^F(j)} - b_F^* \right)^2 \right] n_{t-1}^F \tag{25}$$

It is also assumed that households transfer a share $\frac{\iota^F}{1-\chi_t^F}$ of the assets of surviving banks to new ones. This transfer provides enough capital to new banks to start their business:

$$n_{y,t}^F = \iota^F b_t^F \tag{26}$$

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

$$n_t^F = \chi_t^F \left[\left(\widetilde{r_{F,t}^G} - \widetilde{r_{F,t}^B} \right) l_{G,t-1}^F + \left(\widetilde{r_{F,t}^B} - \frac{r_{t-1}}{\pi_t} \right) l_{t-1}^F + \frac{r_{t-1}}{\pi_t} - \frac{\kappa^{FG}}{2} \left(\frac{l_{G,t-1}^F(j)}{l_{t-1}^F(j)} - b_F^* \right)^2 \right] n_{t-1}^F + \iota^F b_t^F \tag{27}$$

3.2.2 Shadow banks

Shadow banks exhibit the same behavior as traditional banks, except that they are not subject to capital requirements constraints and, thus, the CCyB regulation. Similar to Gebauer and

[7] When $\phi_t^G = \phi_t^B = 1$, the leverage equation of traditional banks is similar to the one obtained by Ferrari and Nispi-Landi (2023).

Mazelis (2023), shadow banks' decisions are designed *à la* Gertler and Karadi (2011), and the value of shadow banks does not depend on RWA, such that:

$$V^S_{j,t}\left(n^S_t(j)\right) \geq \theta^S b^S_t(j) \tag{28}$$

Since the micro-foundations of shadow banks' decisions are similar to those of traditional banks, shadow banks' equations are analogous to those of traditional banks, but with an index S instead of F and without the RWA setting and CCyB regulation constraint, such that:

$$b^S_{B,t}(j) + b^S_{G,t}(j) = d^S_t(j) + n^S_t(j) \tag{29}$$

$$n^S_t = \chi^S_t \left[\left(\widetilde{r^G_{S,t}} - \widetilde{r^B_{S,t}}\right) l^S_{G,t-1} + \left(\widetilde{r^B_{S,t}} - \frac{r^{d,S}_{t-1}}{\pi_t}\right) l^S_{t-1} + \frac{r^{d,S}_{t-1}}{\pi_t} - \frac{\kappa^{FG}}{2}\left(\frac{l^S_{G,t-1}(j)}{l^S_{t-1}(j)} - b^*_S\right)^2\right] n^S_{t-1} + \iota^S b^S_t \tag{30}$$

$$\chi^S_t = \chi^S \varepsilon^\chi_t \tag{31}$$

$$l^S_t = \frac{\mathbb{E}_t\left\{\beta \frac{\lambda_{t+1}}{\lambda_t} \nu^S_{t+1}\left[\left(\widetilde{r^G_{S,t+1}} - \widetilde{r^B_{S,t+1}}\right) l^S_{G,t} + \frac{r^{d,S}_t}{\pi_{t+1}} - \frac{\kappa^{FG}}{2}\left(\frac{l^S_{G,t}(j)}{l^S_t(j)} - b^*_S\right)^2\right]\right\}}{\theta^S - \mathbb{E}_t\left\{\beta \frac{\lambda_{t+1}}{\lambda_t}\nu^S_{t+1}\left(\widetilde{r^B_{S,t+1}} - \frac{r^{d,S}_t}{\pi_{t+1}}\right)\right\}} \tag{32}$$

$$\nu^S_t = (1-\chi^S_t) + \chi^S_t \beta \mathbb{E}_t\left\{\frac{\lambda_{t+1}}{\lambda_t}\nu^S_{t+1}\left[\left(\widetilde{r^G_{S,t+1}} - \widetilde{r^B_{S,t+1}}\right) l^S_{G,t} + \left(\widetilde{r^B_{S,t+1}} - \frac{r^{d,S}_t}{\pi_{t+1}}\right) l^S_t + \frac{r_t}{\pi_{t+1}} - \frac{\kappa^{FG}}{2}\left(\frac{l^S_{G,t}(j)}{l^S_t(j)} - b^*_S\right)^2\right]\right\} \tag{33}$$

$$\mathbb{E}_t\left\{r^G_{S,t+1} - r^B_{S,t+1}\right\} = \mathbb{E}_t\left\{\left[\frac{\kappa^{FG}}{l^S_t}\left(\frac{l^S_{G,t}(j)}{l^S_t(j)} - b^*_S\right)\right]\frac{1}{\left[1-\Phi\left(1-\eta^{S,E}_{G,t+1}\right)\right]} + r^B_{S,t+1}\left(\frac{\left[1-\Phi\left(1-\eta^{S,E}_{B,t+1}\right)\right]}{\left[1-\Phi\left(1-\eta^{S,E}_{G,t+1}\right)\right]} - 1\right)\right\} \tag{34}$$

As shown by the green premium condition in equation (34), the absence of capital requirements constraints for shadow banks implies that these banks only discriminate between green and brown loans with respect to the green composition in their loan portfolio and the borrower's default probability. In line with Roussel (2024b), default probabilities estimated by shadow banks evolve differently from those estimated by traditional banks because the latter incorporate credit risk regulation into their estimations.

3.3 Authorities

3.3.1 Government and central bank policy

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

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

$$\frac{r_t}{\overline{r}} = \left(\frac{r_{t-1}}{\overline{r}}\right)^{\rho_r} \left[\left(\frac{\pi_t}{\overline{\pi}}\right)^{\phi_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{\phi_Y}\right]^{1-\rho_r} \tag{35}$$

Where $\overline{r}$ and $\overline{\pi}$ stand for the steady-state central bank rate and inflation, respectively. Note that the deposit rate is directly indexed to the central bank rate. Parameter ρ_r denotes the inertia of the monetary policy, while ϕ_π and ϕ_y reflect the sensitivity of the policy to the evolution of inflation and output growth, respectively.

3.3.2 Macroprudential policy

Finally, there is a financial regulator who sets a micro and macroprudential policy to maintain financial stability in the economy. The microprudential policy consists of imposing capital requirements on traditional banks through the lens of the depositors' constraint, which is represented by the long-term value of θ_t^F in our model. The macroprudential policy takes the form of a CCyB regulation on traditional banks' capital requirements. As explained in previous subsections, in the model, the evolution of the CCyB regulation is closely linked to the evolution of the minimum fraction θ_t^F of RWA needed by traditional banks to incentivize depositors to finance their credit activity. Consequently, we assume that the macroprudential regulation influences the evolution of θ_t^F as follows:

$$\frac{\theta_t^F}{\overline{\theta^F}} = \left(\frac{\theta_{t-1}^F}{\overline{\theta^F}}\right)^{\rho_{\theta^F}} \left[\left(\frac{\mathcal{T}_t}{\overline{\mathcal{T}}}\right)^{\phi_{\mathcal{T}}}\right]^{1-\rho_{\theta^F}} \tag{36}$$

Where ρ_{θ^F} is the smoothing parameter of the macroprudential policy, while $\mathcal{T}_t$ is the systemic risk indicator targeted by the financial regulator and $\phi_{\mathcal{T}}$ denotes the sensitivity of the macroprudential policy with respect to the indicator. The components $\overline{\theta^F}$ and $\overline{\mathcal{T}}$ stand for the steady-state values of θ^F and the systemic risk indicator, respectively. Note that capital requirements are not counter-cyclical when $\phi_{\mathcal{T}} = 0$.

4 Design of the carbon-intensive CCyB regulation

According to the Basel Committee, financial regulators should set their CCyB regulations based on the credit-to-GDP ratio gap (BCBS, 2010a). The evolution of the credit-to-GDP ratio helps capture the accumulation of financial systemic risk faced by the economy. Hence, in our model, the systemic risk indicator corresponds to the evolution of the credit-to-GDP ratio.

However, as highlighted by the work of Fève et al.(2019) and Gebauer and Mazelis (2023), the definition of the credit-to-GDP ratio used in macroprudential policy may lead to two possible CCyB settings: a "prudent" CCyB regulation that accounts for fluctuations in both traditional and shadow bank loans, and a "moderate" CCyB regulation that accounts for fluctuations in traditional bank loans only. The main contribution of our paper is to extend the work of these authors by examining whether a CCyB regulation should incorporate the credit of shadow banks in the context of the green transition. As listed in Table 1, our analysis leads to the definition of four CCyB settings. The first two settings correspond to the prudent and moderate CCyB regulations defined by Gebauer and Mazelis (2023). The third and fourth CCyB settings correspond to the carbon-intensive versions of the two previous CCyB settings: brown loans provided by traditional and shadow banks (prudent carbon-intensive CCyB); brown loans provided by traditional banks only (moderate carbon-intensive CCyB)[8].

The first CCyB setting depicted in Table 1 is a "prudent" macroprudential policy, as it

[8]The carbon-intensive CCyB setting follows the one defined by D'Orazio and Popoyan (2019).

Table 1: Macroprudential policy design with respect to credit-to-GDP ratio definition

Scenario	**Target**
Standard CCyB rule	
a. Traditional and shadow banks credits	$\mathcal{T} = \left(b_t^F + b_t^S\right)/y_t$
b. Traditional banks credits	$\mathcal{T} = b_t^F/y_t$
Carbon-intensive CCyB rule	
c. Traditional and shadow banks brown credits	$\mathcal{T} = \left(b_{B,t}^F + b_{B,t}^S\right)/y_t$
d. Traditional banks brown credits	$\mathcal{T} = b_{B,t}^F/y_t$

Note : Variable y_t denotes the aggregate output computed in the model.

requires traditional banks to account for credit leakages when estimating their capital requirements (Gebauer and Mazelis, 2023). This scenario differs from the one defined by Fève et al.(2019), where shadow banks are subject to macroprudential regulation when the latter includes both traditional and shadow bank credits in the definition of the credit-to-GDP ratio. In line with Gebauer and Mazelis (2023), we prefer to keep shadow banks unregulated in order to fully capture the regulatory arbitrage effect[9]. The second CCyB setting is a "moderate" macroprudential policy since the financial regulator does not account for credit leakages to unregulated banks. In the context of the green transition, these credit leakages may increase the contribution of shadow banks in financing green loans. The third CCyB setting reflects the carbon-intensive version of the first CCyB setting. The scope of carbon-intensive credit includes brown loans provided by shadow banks, implying that the financial regulator does not account for green credit leakages to shadow banks. This third CCyB setting also represents a more moderate regulation than the first CCyB setting but a more prudent regulation than the second CCyB setting. Finally, the fourth CCyB setting does not account for either credit leakages to shadow banks or green loans provided by traditional banks. Among the four CCyB settings, this fourth scenario can be considered the most moderate regulation.

[9]Regulatory arbitrage reflects the preference of borrowers to seek loans from shadow banks, as these are unregulated and, therefore, may charge a lower interest rate.

5 Consistency of a carbon-intensive CCyB regulation over business and financial cycle

As defined in the Basel III Accords, the main objective of the CCyB regulation is to contain the procyclicality of the financial sector (BCBS, 2010a). To achieve this, the CCyB regulation aims to build up capital buffers for traditional banks when the economy experiences a period of excessive credit growth that contributes to the accumulation of systemic risk. As explained in previous sections, the Basel Committee suggests that financial regulators use the credit-to-GDP ratio gap as a leading indicator to signal the over-accumulation of systemic risk. However, the Basel III Accords' recommendations lead financial regulators to apply CCyB regulation to traditional banks, while shadow banks remain in the "grey area" of macroprudential policy. Hence, the current debate on designing a unified regulatory framework for shadow banks and the growing concerns about climate change risk highlight the potential role of macroprudential policy and shadow banks in financing the green transition.

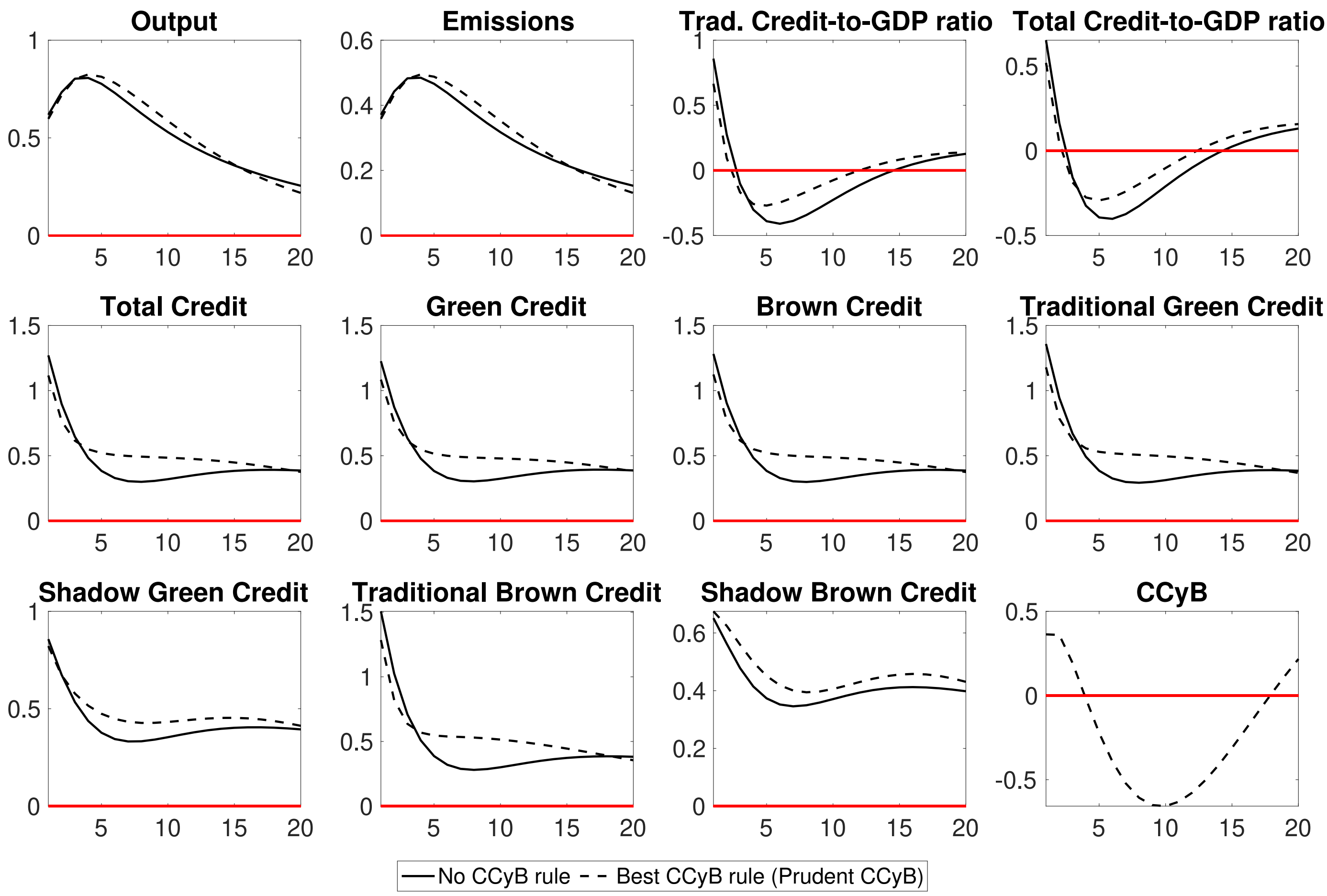
The aim of this section is to examine whether carbon-intensive CCyB settings align with the banking stability objectives of financial regulators when shadow banks operate in the credit market. To do so, we will compare the effectiveness of the four CCyB settings (defined in Table 1) in reducing the volatility of the total credit-to-GDP ratio. As highlighted by the work of Gebauer (2021), when shadow banks are integrated into the model, the volatility of shadow and traditional credit-to-GDP ratios plays a crucial role in minimizing the micro-founded loss function for the CCyB regulation. Therefore, in our work, we maintain the same banking stability objective (i.e., minimizing the volatility of the total credit-to-GDP ratio) for all four CCyB settings. As in Angelini et al.(2014) and Garcia-Revelo and Levieuge (2022), the efficiency of the four CCyB settings is examined under both economic and financial shocks. The economic shock corresponds to a 1% increase in the Total Factor Productivity (TFP) of brown and green firms. As underlined by Lubello (2024), a positive TFP shock provides important insights into the ability of macroprudential policy to curb the accumulation of banking systemic risk and limit the rise in emissions generated by the real sector. The financial shock corresponds to a 1% decrease in the survival rate of traditional and shadow banks (i.e. χ^F and χ^S). This shock allows us to examine whether the financial regulator can support the banking system after a financial recession while slowing down emissions recovery implied by expansionary macroprudential policy. In our simulations, most of the model's parameters follow the calibration of Ferrari and Nispi-Landi (2023) and a full description of this calibration is provided in Table A.2.1 .

5.1 Consistency of a carbon-intensive CCyB regulation under a positive TFP shock

To assess the efficiency of our four CCyB settings during an economic upturn, we plot the Impulse Response Functions (IRFs) of economic, environmental, and financial variables following an exogenous 1% increase in the TFP of the green and brown firm sectors. Figure 1 displays the IRFs of these variables. For now, we focus our attention on the solid black lines in each graph of the figure. These lines represent the IRFs of the variables when the financial regulator does not implement CCyB regulation and, therefore, does not integrate concerns about shadow banking and the green transition into its macroprudential policy. The positive TFP shock increases the output of green and brown firms, which, in turn, implies a similar increase in aggregate output. The rise in productivity in the firm sector allows green and brown entrepreneurs to finance less risky projects for the same level of return. In turn, less risky projects enable these entrepreneurs to issue more loans from traditional and shadow banks, which increases the amount of aggregate green and brown credit. Interestingly, despite the risk of a substitution effect between traditional and shadow banks due to regulatory arbitrage, the rise in credit demand allows both types of financial intermediaries to increase their loan supply. However, the rise in aggregate credit outweighs the stimulation of output and thus contributes to the accumulation of banking systemic risk, as shown by the increase in the total credit-to-GDP ratio following the TFP shock. Furthermore, since the brown firm sector is larger than the green sector, the rise in aggregate firm production leads to an increase in emissions.

Therefore, implementing a CCyB regulation could be useful in dampening the accumulation of systemic risk in the banking sector. Assuming that the financial regulator aims to minimize systemic risk, it is important to assess whether a carbon-intensive CCyB setting is more suitable

Figure 1: Impulse responses : Positive TFP shock - Macroprudential policy stances



Note : Variables are expressed in percentage deviation from the level of their steady-state. Variable "Trad. Credit-to-GDP ratio" corresponds to traditional bank loans over GDP while variable "Total Credit-to-GDP ratio" corresponds to traditional and shadow bank loans over GDP.

for the regulator's banking stability objectives than the standard CCyB setting.

To this end, Table 2 outlines the changes in the volatility of the total credit-to-GDP ratio implied by each macroprudential policy stance defined in Table 1. These changes are expressed as percentage deviations from the baseline scenario, in which no CCyB regulation is applied. In line with Angelini et al.(2014), Poutineau and Vermandel (2017) and Garcia-Revelo and Levieuge (2022), it is assumed that an efficient CCyB regulation should reduce the volatility of the credit-to-GDP ratio. This goal serves as a consistent proxy for reducing the accumulation of systemic banking risk. In our analysis, we assume that the optimal CCyB regulation is the one that minimizes the volatility of the total credit-to-GDP ratio, as the volatility of both traditional and shadow bank credit simultaneously affects household welfare.

Table 2: Efficiency of CCyB rules with respect to macroprudential policy stances and shocks

Scenario		Total Credit-to-GDP Volatility	
		TFP shock	Bankruptcy shock
a.	Traditional and shadow banks credits	-26.342	-28.571
b.	Traditional banks credits	-26.065	-27.008
c.	Traditional and shadow banks brown credits	-26.327	-28.505
d.	Traditional banks brown credits	-26.016	-26.731

Note: Values are expressed in percentage changes from values obtained under the baseline scenario (i.e. without CCyB regulation). As a example, the first value of the table reads as following: compared to no CCyB regulation, a CCyB regulation indexed to traditional and shadow bank loans leads to a reduction of -26.342% of the volatility of total credit-to-GDP ratio. Volatilities are obtained with the resolution of the model under a second order approximation.

Table 2 shows that, regardless of the macroprudential policy stance, the CCyB regulation reduces the volatility of the total credit-to-GDP ratio. This result confirms the usefulness of CCyB regulation in maintaining stability in the banking system. We also observe that a standard CCyB regulation, encompassing both traditional and shadow bank loans (i.e., a prudent financial regulation), is the most effective at minimizing the volatility of the total credit-to-GDP ratio and, thus, maintaining banking stability. As shown in Table 3, this outcome arises because, in the absence of asymmetries in credit leakages, a CCyB tied to both traditional and shadow bank loans minimizes fluctuations in systemic risk driven by green and brown credits. Interestingly, although this CCyB setting minimizes systemic risk for the entire banking system, it does not minimize the systemic risk posed by traditional banks alone. This suggests that the optimal CCyB regulation should focus more on mitigating systemic risk generated by shadow banks than by traditional banks. Since the CCyB regulation is only applied to traditional banks and may generate credit leakages towards shadow banks, it is crucial for the optimal CCyB to minimize fluctuations in shadow bank credit. Therefore, under a TFP shock, a carbon-intensive CCyB regulation is not the most suitable macroprudential policy to minimize banking system instability. It is preferable for the financial regulator to maintain a prudent CCyB regulation without carbon-intensive indexation. However, in the medium term, Figure 1 shows that the decline in the total credit-to-GDP ratio relaxes the CCyB constraint, stimulating credit at traditional banks and, through credit leakages, at shadow banks as well. While this credit stimulation allows both brown and green firms to increase their production, it also leads to higher emissions. This indicates that a financial regulator implementing a CCyB regulation may face potential trade-offs.

Table 3: Decomposition of volatility changes with respect to loan and lender types

Scenario		Green Credit-to-GDP Volatility	Brown Credit-to-GDP Volatility	Traditional Credit-to-GDP Volatility	Shadow Credit-to-GDP Volatility
TFP shock					
a.	Traditional and shadow banks credits	-25.006	-26.668	-31.521	-7.804
b.	Traditional banks credits	-24.667	-26.408	-31.686	-7.457
c.	Traditional and shadow banks brown credits	-24.987	-26.654	-31.532	-7.785
d.	Traditional banks brown credits	-24.608	-26.361	-31.693	-7.403
Bankruptcy shock					
a.	Traditional and shadow banks credits	-27.796	-28.752	-31.006	-15.403
b.	Traditional banks credits	-25.972	-27.26	-31.114	-12.552
c.	Traditional and shadow banks brown credits	-27.714	-28.692	-31.047	-15.245
d.	Traditional banks brown credits	-25.667	-26.991	-31.029	-12.157

Note: Values are expressed in percentage changes from values obtained under the baseline scenario (i.e. without CCyB regulation). Volatilities are obtained with the resolution of the model under a second order approximation.

5.2 Consistency of a carbon-intensive CCyB regulation under a negative bank survival rate shock

The lessons from the Great Financial Crisis (GFC) of 2007 highlight the need to implement macroprudential policies to limit the accumulation of systemic risk in the banking sector during periods of credit booms and to reinforce the resilience of the banking system during financial downturns (BCBS, 2010b).

Although banking stability is a key objective for financial regulators during a financial crisis, the recovery of both the banking and real sectors may support brown production and, consequently, dampen the reduction of emissions. Thus, for financial regulators, there remains a trade-off between banking stability and the green transition. However, reducing emissions may undermine the productivity of the real sector and slow the recovery of both output and the banking sector. Therefore, a carbon-intensive CCyB could be an effective policy to minimize banking instability during a financial recession.

To assess the consistency of the carbon-intensive CCyB with the financial regulator's objectives during a financial recession, we simulate a negative financial shock corresponding to a 1% decrease in the survival rate of traditional and shadow banks (i.e. χ^F and χ^S). This shock is well-suited to capture the sudden increase in systemic risk triggered by the unexpected bankruptcy of banks, as was the case with Lehman Brothers during the 2007 GFC, or with Silicon Valley Bank, Silvergate Bank, and Signature Bank in 2023 (Acharya et al., 2023).

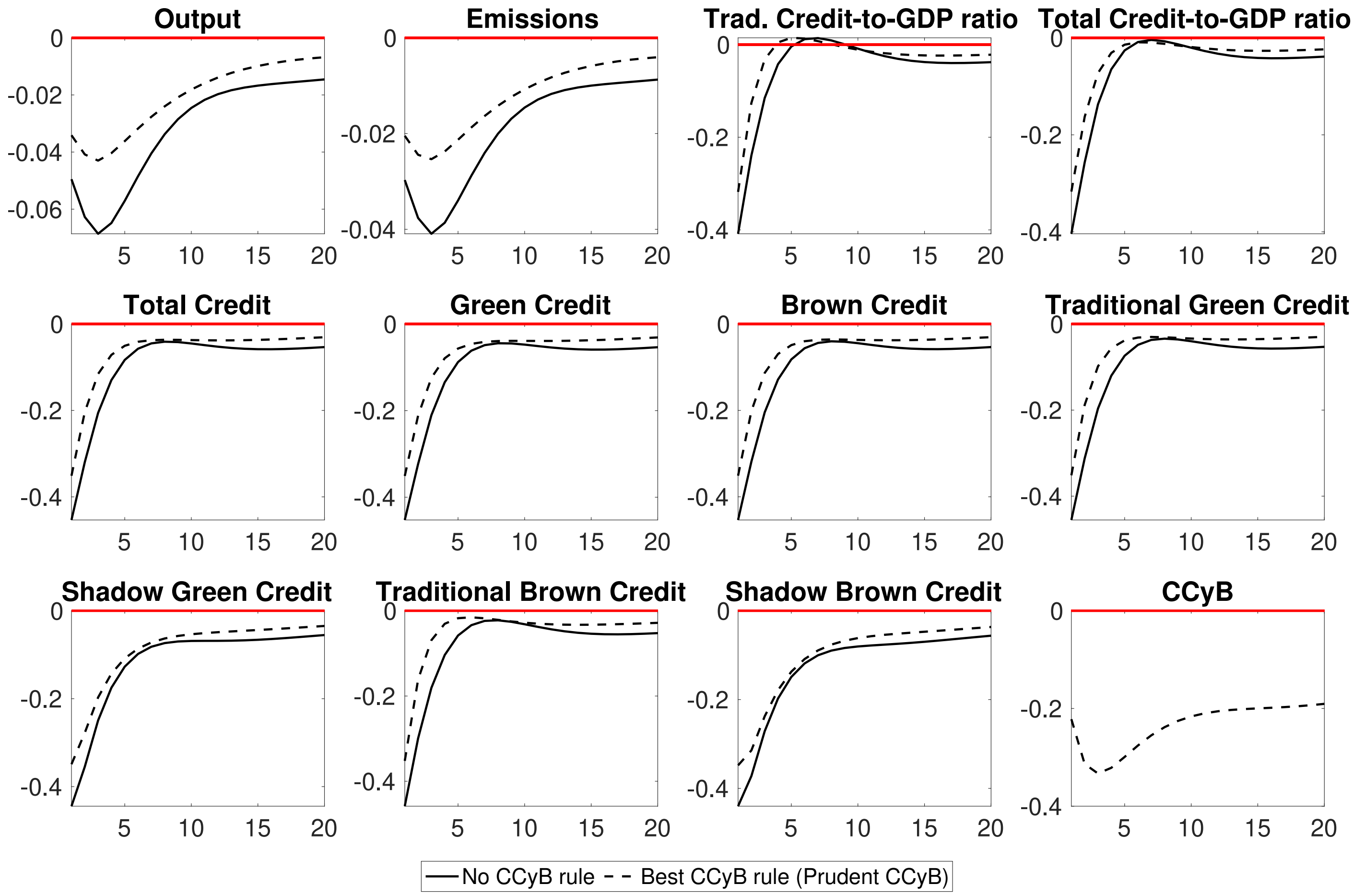
Figure 2 depicts the IRFs of macroeconomic, macrofinancial, and environmental variables under the negative banks' survival rate shock.

When the financial regulator does not implement a CCyB regulation (represented by the solid black lines in the figure), the fall in banks' net worth leads both traditional and shadow banks to reduce their credit supply to brown and green borrowers. As a result, brown and green firms are forced to cut back on their physical capital investments, which decreases both aggregate output and emissions. Despite the reduction in aggregate output, the decline in aggregate credit leads to a decrease in the credit-to-GDP ratio for both traditional and shadow banks. We observe that the recovery time for shadow banks' credit activity is longer than that for traditional banks because the latter capture a large share of the credit demand recovery.

Additionally, the riskier deposit activities of shadow banks compel them to charge higher interest rates on loans, which discourages borrowers from taking loans from them. Instead, borrowers turn to traditional banks, exacerbating shadow banks' competitiveness problem and slowing their recovery.

Similar to the positive TFP shock scenario, when the financial regulator implements a CCyB regulation, Table 2 shows that a standard and prudent CCyB regulation (i.e., rule a) is the most suitable policy for maintaining banking stability, as it results in the smallest reduction in the volatility of the credit-to-GDP ratio. Figure 2 supports this finding, as this CCyB setting fosters the recovery of both traditional and shadow banks' credit activities. This support for banking activity helps to mitigate the initial decrease in the credit supply, which finances the physical capital of both green and brown firms. Better financing conditions for these firms help dampen the initial drop in aggregate output.

Figure 2: Impulse responses : Negative bank survival rate shock (bankruptcy shock) - Macroprudential policy stances



Note : Variables are expressed in percentage deviation from the level of their steady-state. Variable "Trad. Credit-to-GDP ratio" corresponds to traditional bank loans over GDP while variable "Total Credit-to-GDP ratio" corresponds to traditional and shadow bank loans over GDP.

Moreover, similar to the TFP shock scenario, Table 3 indicates that the prudent CCyB regulation is the most suitable policy for aligning with the financial regulator's objectives, as it minimizes the volatility of the green, brown, and shadow credit-to-GDP ratios. However, the faster recovery of aggregate output leads to a quicker rebound in emissions. Thus, similar to the TFP shock, the financial regulator may face a trade-off between banking system stability and green transition objectives.

Overall, the results of this section suggest that, in the absence of asymmetric participation by traditional banks in the green and brown credit markets, a prudent CCyB regulation is the most suitable for achieving the financial regulator's banking stability goals. Nonetheless, the prudent CCyB regulation may lead the financial regulator to face a trade-off between minimizing banking instability and achieving green transition objectives.

6 Contribution of emission tax and traditional banks involvement in the consistency of a carbon-intensive CCyB regulation

The previous section highlighted that financial regulators should neither set a carbon-intensive nor a moderate CCyB regulation to achieve their goals, specifically to maintain banking stability by minimizing the volatility of the total credit-to-GDP ratio.

However, the implementation of an emissions tax on the production of polluting firms (i.e., brown firms) could affect the credit portfolio strategies of both traditional and shadow banks. Indeed, an emissions tax may decrease the profitability of brown loans, which could prompt banks to increase the funding of green loans, but at the expense of brown loans. The higher preference of banks for green loans amplifies the substitution between brown and green loans, which increases the volatility of brown loans. In turn, stronger fluctuations in the brown credit market could favor the use of a carbon-intensive CCyB regulation to maintain banking stability.

Moreover, due to the lack of granular data on green and brown loans for traditional and shadow banks, the analysis in the previous section assumed that traditional banks' involvement in the green credit market is similar to their involvement in the brown credit market (i.e., $\gamma_B^F = \gamma_G^F = 0.735$). This assumption implies the absence of asymmetric leakages between green and brown loans for both traditional and shadow banks. To provide a more comprehensive analysis of the consistency of a carbon-intensive CCyB regulation for financial regulators, it is also necessary to examine whether the conclusions about the best CCyB setting hold when traditional banks are more (or less) involved in the green credit market than the brown credit market.

Therefore, the aim of this section is to examine whether a carbon-intensive CCyB regulation may be suitable for financial regulators when an emissions tax is applied to brown firms and when traditional banks exhibit varying levels of involvement in the green credit market.

6.1 Does emission tax foster the consistency of a carbon-intensive CCyB regulation ?

In line with Heutel (2012), Minesso and Pagliari (2023) and Roussel (2024a), we assume that the government introduces an emission tax τ^b that is proportional to the volume of emissions e_t produced by the production of brown firms y_t^B. Moreover, brown firms are able to abate an endogenous fraction $\mu_t \in [0, 1]$ of their emissions. Abatement technology allows brown firms to lower the 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. In the model, the introduction of emission tax and abatement technology cost implies the following profit function for brown firms :

$$\Pi_t^B = p_t^B y_t^B - w_t h_t^B - r_{E,t}^B q_{t-1} k_{t-1}^B + (1-\delta) q_t k_{t-1}^B - \tau^B e_t - \theta_1 \mu_t^{\theta_2} y_t^B \tag{37}$$

Where p_t^B is the price of goods produced by brown firms. Hours worked h_t^B made by households are remunerated at the nominal wage w_t while q_t is the price of physical capital paid by brown firms and $r_{E,t}^B$ the return of this capital expected by brown entrepreneurs. The parameter δ denotes the depreciation rate of the physical capital. The reduction of emissions generated by the abatement technology implies the following dynamic for emissions :

$$e_t = (1 - \mu_t) \left(y_t^B\right)^{1|\psi} \tag{38}$$

Where ψ reflects the sensitivity of emissions to brown firms production.

Brown firms choose an amount of physical capital, hours worked and abatement technology that maximizes their profit function. First Order Conditions (FOC) of the program are following:

$$w_t h_t^B = (1-\alpha)\left[p_t^B y_t^B - \tau^B(1-\psi)e_t - \theta_1 \mu_t^{\theta_2} y_t^B\right] \tag{39}$$

$$k_{t-1}^B\left(r_{E,t}^B q_{t-1} - (1-\delta)q_t\right) = \alpha\left[p_t^B y_t^B - \tau^B(1-\psi)e_t - \theta_1 \mu_t^{\theta_2} y_t^B\right] \tag{40}$$

$$\mu_t = \left(\frac{\tau^B\left(y_t^B\right)^{-\psi}}{\theta_1\theta_2}\right)^{\frac{1}{\theta_2-1}} \tag{41}$$

The FOC above indicate that if $\theta_2 > 1$, then brown firms will use abatement technology when they are subjected to emissions tax (i.e. $\tau^B > 0$). The positive relationship between emissions tax and abatement cost implies that stricter fiscal policy on carbon emissions incites brown firms to use more abatement technology to reduce the pollution generated by their production. One notes also that brown firms internalize cost of emissions tax in the allocation of their input, which influences the amount of their production.

Similar to Minesso and Pagliari (2023), we set the parameters θ_1 and θ_2 to 0.056 and 2.8, respectively. To examine whether a green fiscal policy, in the form of an emissions tax, could alter the choice of the most suitable CCyB setting for financial regulators, we select three levels of emissions tax: 1%, 10%, and 15%. These levels aim to detect a potential convergence towards an alternative best CCyB setting as the emissions tax becomes progressively stricter for brown firms[10].

As depicted in Table 4, a low level of emissions tax does not affect the conclusions obtained in the previous section, as the prudent CCyB regulation remains the most suitable policy to achieve the goals of financial regulators. However, when the government implements an emissions tax of 10% or more, the most suitable CCyB corresponds to a prudent carbon-intensive regulation under the TFP shock and a moderate carbon-intensive regulation under the financial shock. The convergence towards carbon-intensive CCyB settings arises from the fact that stricter emissions taxes affect the brown credit sector more strongly than the green credit sector (see also IRFs changes for traditional and shadow banks brown loans in Figure A.3.1 and Figure A.3.2 in Appendix 3). Indeed, stricter emissions taxes significantly reduce the profitability of brown firms, which leads banks to increase the substitution between brown and green loans.

[10] We allow for the calibration of the emissions tax because we are interested in the qualitative impact of the emissions tax on the design of the CCyB regulation.

Since brown credit represents the majority of credit activity in our economy, this substitution generates higher fluctuations in the brown credit market, making brown credit volatility the main driver of the overall volatility of the total credit-to-GDP ratio.

Table 4: Impact of emission tax on the efficiency of macroprudential policy stances

		TAX=1%		TAX=10%		TAX=15%	
Scenario		Total Credit-to-GDP Volatility		Total Credit-to-GDP Volatility		Total Credit-to-GDP Volatility	
		TFP shock	Bankruptcy shock	TFP shock	Bankruptcy shock	TFP shock	Bankruptcy shock
a.	Traditional and shadow banks credits	**-26.359**	**-28.606**	-26.288	-28.852	-25.92	-28.953
b.	Traditional banks credits	-26.061	-27.294	-15.584	-29.273	3.135	-30.086
c.	Traditional and shadow banks brown credits	-26.332	-28.568	**-26.31**	-29.005	**-26.27**	-29.187
d.	Traditional banks brown credits	-25.995	-27.069	-12.631	**-29.394**	9.966	**-30.339**

Note: Values are expressed in percentage changes from values obtained under the baseline scenario (i.e. without CCyB regulation). Volatilities are obtained with the resolution of the model under a second order approximation. The best CCyB settings are reflected by the lowest volatility (displayed in bold in the table).

Interestingly, the choice of the most suitable carbon-intensive CCyB regulation varies depending on the type of shock. This result arises from the fact that, under a financial shock, the combined effect of a drop in credit supply and stricter emissions taxes leads shadow banks to substitute brown loans with those from traditional banks. As a result, in addition to the higher substitution effect between green and brown loans, the increased substitution of brown loans between shadow and traditional banks exacerbates fluctuations in the brown loans issued by traditional banks. These fluctuations become the key driver of the volatility of the total credit-to-GDP ratio, which explains why the optimal macroprudential policy converges to a moderate carbon-intensive CCyB setting (i.e., rule d.).

The results in Table A.2.2 (see Appendix 2) confirm this statement, as under the financial shock, a moderate carbon-intensive CCyB regulation minimizes the volatility of both the traditional banks' credit-to-GDP ratio and the brown credit-to-GDP ratio. Under the TFP shock, the prudent carbon-intensive CCyB regulation minimizes the volatility of the brown credit-to-GDP ratio but does not minimize the volatility of the traditional banks' credit-to-GDP ratio. These results emphasize the dominant role of the substitution effect between brown and green credits under a TFP shock.

Consequently, the introduction of a stricter emissions tax may encourage financial regulators to adopt a carbon-intensive CCyB regulation to maintain banking stability effectively. The choice between a prudent or moderate carbon-intensive regulation depends on the nature of the shock affecting the economy.

6.2 How traditional banks involvement in green credit market modifies the consistency of a carbon-intensive CCyB regulation ?

As mentioned in previous sections, a prudent CCyB regulation is the most suitable setting when traditional banks have the same level of involvement in both the green and brown credit markets. Due to the lack of granular data on green and brown loans managed by traditional and shadow banks, our baseline scenario assumes an equal degree of involvement by traditional banks in both markets (i.e., $\gamma_B^F = \gamma_G^F = 0.735$). However, it is more likely that the empirical involvement of traditional banks in the green credit market differs from their involvement in the brown credit market.

Therefore, the aim of this section is to examine whether varying levels of traditional banks' involvement in the green credit market, relative to the brown credit market, impact the choice of the most suitable CCyB regulation for financial supervisors. To do this, we analyze the effect of higher involvement of traditional banks in the green credit market by gradually increasing their green market participation[11] (i.e., $\gamma_G^F = \{0.85, 0.9, 0.95\}$). Additionally, we analyze the effect of lower involvement of traditional banks in the green credit market, relative to the brown credit market, by gradually increasing their participation in the brown credit market (i.e., $\gamma_B^F = \{0.85, 0.9, 0.95\}$).

As shown in Table 5, when traditional banks are more involved in the green credit market than in the brown one, a prudent carbon-intensive CCyB setting is the most suitable regulation for financial regulators.

[11] We assume that traditional banks' participation in one market increases gradually while their participation in the other market remains unchanged.

Figure A.3.3 and Figure A.3.4 (see Appendix 3) confirm that the prudent carbon-intensive CCyB regulation dampens fluctuations in the total credit-to-GDP ratio caused by TFP and bankruptcy shocks. It is also noteworthy that a higher involvement of traditional banks in the green credit market, relative to the brown credit market, generates permanent asymmetric leakages between green and brown loans for both traditional and shadow banks. These asymmetric leakages, in turn, change credit access for green and brown firms to finance their physical capital.

The choice of a prudent carbon-intensive CCyB setting arises from the fact that higher involvement of traditional banks in the green credit sector leads to a greater concentration of shadow banks' activities in the brown credit sector. This higher concentration increases the volatility of brown credit provided by shadow banks, contributing to greater volatility in aggregate brown credit. As a result, this volatility becomes a key driver of fluctuations in the credit-to-GDP ratio, which justifies the use of a carbon-intensive CCyB to reduce these fluctuations.

Looking at Table A.2.3 (see Appendix 2), we observe that the prudent carbon-intensive CCyB setting minimizes the volatility of the shadow credit-to-GDP ratio and brown credit-to-GDP ratio. These results highlight the crucial role of higher shadow bank concentration in the brown credit market in driving fluctuations in the total credit-to-GDP ratio.

Table 5: Volatility changes with respect to macroprudential policy stances when traditional banks are more involved in green than in brown credit market (i.e. $\gamma_G^F > \gamma_B^F$)

		$\gamma_G^F = 0.85$		$\gamma_G^F = 0.9$		$\gamma_G^F = 0.95$	
Scenario		**Total Credit-to-GDP Volatility**		**Total Credit-to-GDP Volatility**		**Total Credit-to-GDP Volatility**	
		TFP shock	**Bankruptcy shock**	**TFP shock**	**Bankruptcy shock**	**TFP shock**	**Bankruptcy shock**
a.	Traditional and shadow banks credits	-26.565	-29.24	-26.483	-29.405	-26.393	-29.526
b.	Traditional banks credits	-26.202	-27.28	-25.989	-27.097	-25.749	-26.802
c.	Traditional and shadow banks brown credits	**-26.765**	**-30.323**	**-26.937**	**-31.193**	**-27.181**	**-32.151**
d.	Traditional banks brown credits	-26.456	-28.915	-26.533	-29.844	-26.688	-30.799

When traditional banks are more involved in the brown credit market than in the green one, Table 6 indicates that a prudent CCyB setting is the most suitable regulation for financial supervisors. Figure A.3.5 and Figure A.3.6 (see Appendix 3) confirm the ability of the prudent CCyB setting to dampen the volatility of the total credit-to-GDP ratio. Higher involvement of traditional banks in one credit market relative to the other generates permanent asymmetric leakages between green and brown credits. These asymmetric leakages influence the reaction of output and credit when TFP and bankruptcy shocks occur.

Table 6: Volatility changes with respect to macroprudential policy stances when traditional banks are less involved in green than in brown credit market (i.e. $\gamma_G^F < \gamma_B^F$)

		$\gamma_B^F = 0.85$		$\gamma_B^F = 0.9$		$\gamma_B^F = 0.95$	
Scenario		**Total Credit-to-GDP Volatility**		**Total Credit-to-GDP Volatility**		**Total Credit-to-GDP Volatility**	
		TFP shock	**Bankruptcy shock**	**TFP shock**	**Bankruptcy shock**	**TFP shock**	**Bankruptcy shock**
a.	Traditional and shadow banks credits	**-28.375**	**-31.719**	**-29.116**	**-32.912**	**-29.885**	**-34.042**
b.	Traditional banks credits	-28.309	-29.787	-29.041	-30.833	-29.773	-31.847
c.	Traditional and shadow banks brown credits	-28.326	-29.32	-28.991	-28.716	-29.587	-27.574
d.	Traditional banks brown credits	-28.217	-27.354	-28.904	-27.119	-29.529	-26.642

Furthermore, the choice of a prudent CCyB setting arises from the fact that higher involvement in the brown credit sector leads to greater concentration of shadow bank activity in the green credit sector. This higher concentration results in increased fluctuations in the green credits provided by shadow banks, which in turn exacerbates the volatility of aggregate green credit. This volatility becomes one of the key drivers of fluctuations in the total credit-to-GDP ratio. Therefore, in addition to the fluctuations in traditional banks' brown credit, the optimal CCyB setting must account for the fluctuations in shadow banks' green credit in order to minimize total credit-to-GDP volatility. As a result, a prudent CCyB setting is the most appropriate regulation because it considers both traditional banks' brown credit and shadow banks' green credit fluctuations. The results in Table A.2.4 in Appendix 2 confirm this, as the prudent CCyB setting minimizes the volatility of both the shadow credit-to-GDP ratio and the green credit-to-GDP ratio.

All in all, our results indicate that when traditional banks are more involved in the green credit market than in the brown credit market, a prudent carbon-intensive CCyB setting is the most suitable regulation for financial regulators. However, when traditional banks are more involved in the brown credit market than in the green credit market, financial regulators should adopt a non-carbon-intensive CCyB regulation to achieve their banking stability objectives.

6.3 Combined effect of emissions tax and traditional banks involvement on the consistency of a carbon-intensive CCyB regulation

This last subsection examines whether the introduction of an emissions tax, when traditional banks are more (or less) involved in the green credit market, modifies the conclusions drawn in previous subsections.

As shown in Table 7, when traditional banks are more involved in the green credit market than in the brown credit market, a stricter emissions tax leads financial regulators to adopt a prudent CCyB regulation when a TFP shock hits the economy. The shift from a carbon-intensive to a non-carbon-intensive CCyB regulation can be explained as follows. A stricter emissions tax exacerbates the substitution effect between green and brown loans for both traditional and shadow banks. While the higher concentration of shadow bank activity in the brown credit sector contributes to increase volatility of aggregate brown credit, the stronger substitution effect between green and brown credits generates significant fluctuations in green credit. Since traditional banks are more concentrated in the green credit sector, these fluctuations are primarily driven by the activity of traditional banks. As a result, fluctuations in traditional banks' green credit become one of the key drivers of the total credit-to-GDP ratio's volatility, prompting financial regulators to adopt a policy that accounts for both shadow banks' credit volatility and traditional banks' green credit volatility. The use of a prudent, non-carbon-intensive CCyB regulation addresses both sources of volatility, making it the most suitable regulation for financial regulators.

Results from Table A.2.5 (see Appendix 2) confirm this explanation, as compared to its carbon-intensive version, the prudent CCyB regulation reduces the volatility of the green credit-to-GDP ratio and the traditional bank credit-to-GDP ratio more effectively.

Table 7: Impact of a 10% emissions tax on the efficiency of macroprudential policy stances with high involvement of traditional banks in green credit market (with $\gamma_G^F = 0.85$ and $\gamma_B^F = 0.735$)

Scenario	TAX=1%		TAX=10%		TAX=15%	
	Total Credit-to-GDP Volatility		**Total Credit-to-GDP Volatility**		**Total Credit-to-GDP Volatility**	
	TFP shock	**Bankruptcy shock**	**TFP shock**	**Bankruptcy shock**	**TFP shock**	**Bankruptcy shock**
a. Traditional and shadow banks credits	-26.585	-29.272	**-26.711**	-29.486	**-26.753**	-29.571
b. Traditional banks credits	-26.234	-27.305	-26.439	-27.474	-26.512	-27.54
c. Traditional and shadow banks brown credits	**-26.76**	**-30.373**	-26.701	**-30.719**	-26.663	**-30.858**
d. Traditional banks brown credits	-26.464	-28.961	-26.502	-29.279	-26.502	-29.407

Furthermore, the results in Table 8 indicate that when traditional banks are more involved in the brown credit market under a TFP shock, a stricter emissions tax leads financial regulators to adopt a moderate CCyB regulation instead of a prudent one. This shift to a moderate CCyB regulation occurs because a stricter emissions tax increases the substitution effect between brown and green loans. Since traditional banks are more concentrated in the brown credit market, this substitution effect exacerbates the volatility of the traditional credit-to-GDP ratio the green credit-to-GDP ratio and the brown credit-to-GDP ratio. The significant changes in these volatilities leads financial regulators to adopt a moderate CCyB regulation to minimize the volatility of the total credit-to-GDP ratio. These explanations are confirmed by the results in Table A.2.6 (Appendix 2) since, compared to the prudent CCyB regulation, the moderate one more effectively reduces the volatility of the traditional credit-to-GDP ratio, and the green credit-to-GDP ratio the brown credit-to-GDP ratio.

Consequently, the results of this section show that the implementation of a strict emissions tax may lead financial regulators to adopt a carbon-intensive CCyB regulation to achieve their banking stability goals. The setting of the carbon-intensive regulation depends on the nature of the shock that hits the economy. Moreover, the shift to carbon-intensive regulation occurs when traditional banks are more involved in the green credit market. This result also highlights the consistency of aligning a carbon-intensive CCyB regulation with financial policies that promote the involvement of traditional banks in green credit markets. However, the implementation of

Table 8: Impact of emission tax on the efficiency of macroprudential policy stances with low involvement of traditional banks in brown credit market (with $\gamma_G^F = 0.735$ and $\gamma_B^F = 0.85$)

		TAX=1%		TAX=10%		TAX=15%	
Scenario		**Total Credit-to-GDP Volatility**		**Total Credit-to-GDP Volatility**		**Total Credit-to-GDP Volatility**	
		TFP shock	**Bankruptcy shock**	**TFP shock**	**Bankruptcy shock**	**TFP shock**	**Bankruptcy shock**
a.	Traditional and shadow banks credits	**-28.389**	**-31.746**	-28.465	**-31.92**	-28.484	**-31.987**
b.	Traditional banks credits	-28.334	-29.813	**-28.475**	-29.986	**-28.516**	-30.052
c.	Traditional and shadow banks brown credits	-28.341	-29.36	-28.415	-29.63	-28.423	-29.738
d.	Traditional banks brown credits	-28.243	-27.395	-28.383	-27.67	-28.415	-27.779

a stricter emissions tax may disrupt this consistency when the economy faces a TFP shock.

7 Conclusion

The banking instability risk of climate change prompts financial regulators to assess whether green prudential measures could help mitigate this risk. Among the proposals for green prudential regulation, the introduction of a carbon-intensive Countercyclical Capital Buffer (CCyB) has been suggested to curb excessive credit from the polluting sector. However, the carbon-intensive CCyB would apply solely to regulated banks, which could lead to credit leakages towards shadow banks (unregulated institutions). This shift may undermine the effectiveness of the green macroprudential policy and disrupt the overall stability of the banking system.

The aim of this paper is to evaluate whether a carbon-intensive CCyB regulation is suitable for financial regulators when shadow banks are involved in financing both polluting (brown) and non-polluting (green) firms. To achieve this, the paper examines the consistency of a carbon-intensive CCyB regulation within an environmental general equilibrium framework, incorporating both polluting and non-polluting sectors, as well as traditional and shadow banks. The proposed application of the carbon-intensive CCyB regulation to traditional banks follows the suggestion made by D'Orazio and Popoyan, (2019), which recommends increasing capital requirements for these banks when the carbon-intensive (brown) credit-to-GDP ratio deviates from its trend value. In the presence of shadow banks, two potential designs for the carbon-intensive CCyB regulation may emerge: one indexed to the total brown credit-to-GDP ratio (prudent carbon-intensive) and the other indexed to the brown credit-to-GDP ratio of traditional banks (moderate carbon-intensive).

The results of this paper show that the implementation of a prudent CCyB regulation (i.e., indexed to both brown and green credits) is the most suitable approach for achieving the banking stability objective of financial regulators, namely minimizing the volatility of the total credit-to-GDP ratio. The choice to use a CCyB regulation without carbon-intensive features stems from the fact that the absence of asymmetric leakages between green and brown loans for traditional and shadow banks prompts financial regulators to focus on fluctuations across all credit types in order to reduce the volatility of the total credit-to-GDP ratio. However, when a strict emissions tax is imposed on polluting firms, a carbon-intensive CCyB regulation becomes more aligned with the goals of financial regulators. This is because a strict emissions tax amplifies the substitution effect between brown and green credits, increasing the volatility of brown credits and necessitating a CCyB regulation that is specifically indexed to these credits. Furthermore, the design of the carbon-intensive CCyB depends on the nature of the economic shock. Specifically, under a positive TFP shock, a prudent carbon-intensive CCyB setting is most appropriate for maintaining banking stability, whereas under a negative financial shock, financial regulators should adopt a moderate carbon-intensive CCyB regulation.

Furthermore, a greater involvement of traditional banks in the green credit market encourages financial regulators to adopt a prudent carbon-intensive CCyB regulation. This highlights the importance of aligning this regulation with financial policies that incentivize traditional banks to increase their participation in financing the green transition. However, the implementation of a strict emissions tax may prompt financial regulators to revert to a non-carbon-intensive prudent CCyB regulation when a TFP shock affects the economy. This shift arises because a strict emissions tax amplifies the substitution effect between green and brown loans. As traditional banks become more engaged in the green credit market, the stronger substitution effect significantly impacts the volatility of green credits for these banks, compelling financial regulators to adopt a non-carbon-intensive CCyB regulation to ensure banking stability.

Looking forward, the analysis presented in this paper highlights several areas for future research. For example, our framework could be extended by exploring the coordination of carbon-intensive CCyB regulation across different countries. Another potential extension would involve incorporating green microprudential proposals, such as the Green Supporting Factor (GSF) or the Brown Penalizing Factor (BPF), to assess whether the interactions between green microprudential and macroprudential policies influence the CCyB regulation stance adopted by financial regulators. Finally, introducing securitization for traditional bank loans would introduce an additional channel in the substitution process between shadow and traditional bank credits. This added channel could amplify fluctuations in green and brown loans for both types of financial intermediaries, potentially altering the choice of the most suitable CCyB regulation for financial regulators.

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Appendix 1 Calibration

Most of model's parameters follows values calibrated in Roussel (2024b) for Euro area. In order to take into account the green investment gap underlined by Campiglio (2016), we assume that the degree of substitution between traditional and shadow bank loans ψ^F is higher for brown credits than green credits. To do so, we set $\psi_B^F = 3$ and $\psi_G^F = 2$. Moreover, in the baseline analysis, the share of shadow banks loans in aggregated non-financial corporate loans is equal to 26.5% as in Gebauer and Mazelis (2023). Due to the lack of granular data between green and brown shadow banks loans, we assume that the share of traditional banks loans in green and brown credits market are identical[12], which implies that $\gamma_G^F = \gamma_B^F = 0.735$. Furthermore, in the baseline scenario, it is also supposed that the riskiness of green and brown entrepreneurs are similar in the long run. This means that the credit risk of both entrepreneur types are similar at the steady-state, which implies the absence of a green premium in the long run. Following the work of Grill et al.(2024) , we assume that European traditional banks estimate credit risk of green and brown entrepreneurs under the IRB approach. Moreover, we set consumption elasticity to $\sigma = 0.8$ and monetary policy parameters are calibrated to the values estimated by Gebauer and Mazelis (2023). Finally, standard deviation of bank survival rate shock is set to $\sigma_\chi = 1\%$ while its auto-regressive coefficient is set to $\rho_\chi = 0.1$ in order to reflect the low persistence of bankruptcy events.

[12] Additional analysis in the paper will relax this hypothesis by supposing scenarios where shadow banks are more and less involved in green finance.

Table A.2.1 : Calibration of parameters and shocks

Parameter	Description	Value
β	Subjective discount factor	0.995
σ	Consumption elasticity	0.8
φ	Inverse of Frisch elasticity	1
κ_D	Deposits cost in shadow banking	$0.002*$
ε	Degree of substitution in goods market	6
α	Share of capital in production	0.33
κ_P	Price adjustment cost	26.86
δ	Capital depreciation rate	0.025
ζ	Weight of brown good	0.8^*
$\varkappa$	Bias view of entrepreneurs	0.11
κ_I	Investment adjustment cost	2.48
θ^F	Divertable share of traditional banks' assets	0.223^*
θ^S	Divertable share of shadow banks' assets	0.394^*
χ^F	Long term exit rate traditional banks	0.958
χ^S	Long term exit rate shadow banks	0.944
ι^F	Wealth for new traditional banks	$4.81e-04^*$
ι^S	Wealth for new shadow banks	0.013^*
Φ	Recovery agencies costs	0.2
κ^{FG}	Intensity of green leverage adjustment constraint	0.5
LGD	Loss-Given-Default green and brown entrepreneurs	0.45
ϕ_G^{IRB}	SS IRB green risk-weight	0.52^*
ϕ_B^{IRB}	SS IRB brown risk-weight	0.52^*
$\overline{l^F}$	SS traditional banks leverage	18.31^*
$\overline{l^S}$	SS shadow banks leverage	3
γ_G^F	Share traditional banks loans in green credits	0.735
γ_B^F	Share traditional banks loans in brown credits	0.735
ψ_G^F	Elasticity between traditional and shadow banks green loans	2
ψ_B^F	Elasticity between traditional and shadow banks brown loans	3
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	5.562^*
$\overline{\pi}$	SS inflation	1.005
g	SS public spending-to-GDP ratio	0.2
ρ_r	Persistence of monetary policy	0.88
ϕ_π	Inflation weight in Taylor rule	1.75
ϕ_y	Production weight in Taylor rule	0.2
ρ_a	Persistence of productivity shock	0.9
ρ_χ	Persistence of banks survival rate shock	0.1
σ_a	Standard deviation productivity shock	1%
σ_χ	Standard deviation banks survival rate shock	1%

Note : Symbol $*$ means that the value is determined endogenously at the steady-state and depends on credit risk policies and introduction of shadow banks (in the table : without these policies and with shadow banks).

Appendix 2 Volatility decomposition

Table A.2.2 : Decomposition of volatility changes with respect to loan and lender types (with an emissions tax of 10%)

	Scenario	Green Credit-to-GDP Volatility	Brown Credit-to-GDP Volatility	Traditional Credit-to-GDP Volatility	Shadow Credit-to-GDP Volatility
		TFP shock			
a.	Traditional and shadow banks credits	-20.648	-26.398	-1.896	13.069
b.	Traditional banks credits	0.159	-19.784	-30.168	12.272
c.	Traditional and shadow banks brown credits	-19.758	-26.73	-3.8	12.801
d.	Traditional banks brown credits	3.458	-17.097	-33.322	11.905
		Bankruptcy shock			
a.	Traditional and shadow banks credits	-27.72	-29.12	-31.764	-11.969
b.	Traditional banks credits	-27.924	-29.594	-33.45	-9.596
c.	Traditional and shadow banks brown credits	-27.857	-29.276	-31.979	-11.911
d.	Traditional banks brown credits	-28.018	-29.722	-33.717	-9.357

Note: Values are expressed in percentage changes from values obtained under the baseline scenario (i.e. without CCyB regulation). Volatilities are obtained with the resolution of the model under a second order approximation. Decomposition of volatility changes under a 10% emissions tax displayed in Table 4.

Table A.2.3 : Decomposition of volatility changes with respect to loan and lender types under higher involvement of traditional banks into green credit sector (i.e., $\gamma_G^F = 0.85$ and $\gamma_B^F = 0.735$)

Scenario		Green Credit-to-GDP Volatility	Brown Credit-to-GDP Volatility	Traditional Credit-to-GDP Volatility	Shadow Credit-to-GDP Volatility
TFP shock					
a.	Traditional and shadow banks credits	-37.928	-21.406	-31.531	-6.873
b.	Traditional banks credits	-39.012	-20.922	-31.519	-6.716
c.	Traditional and shadow banks brown credits	-36.471	-21.797	-31.354	-6.98
d.	Traditional banks brown credits	-37.855	-21.337	-31.473	-6.883
Bankruptcy shock					
a.	Traditional and shadow banks credits	-28.02	-25.528	-32.096	-13.907
b.	Traditional banks credits	-33.691	-22.891	-31.623	-11.145
c.	Traditional and shadow banks brown credits	-21.314	-27.516	-31.417	-16.385
d.	Traditional banks brown credits	-29.269	-25.044	-32.102	-13.362

Note: Values are expressed in percentage changes from values obtained under the baseline scenario (i.e. without CCyB regulation). Volatilities are obtained with the resolution of the model under a second order approximation. Decomposition of volatility changes (with $\gamma_G^F = 0.85$ and $\gamma_B^F = 0.735$) displayed in Table 5.

Table A.2.4 : Decomposition of volatility changes with respect to loan and lender types under higher involvement of traditional banks into brown credit sector (i.e., $\gamma_B^F = 0.85$ and $\gamma_G^F = 0.735$)

Scenario	Green Credit-to-GDP Volatility	Brown Credit-to-GDP Volatility	Traditional Credit-to-GDP Volatility	Shadow Credit-to-GDP Volatility
TFP shock				
a. Traditional and shadow banks credits	-8.573	-32.348	-31.717	-7.637
b. Traditional banks credits	-8.558	-32.506	-31.84	-7.525
c. Traditional and shadow banks brown credits	-8.492	-32.606	-31.906	-7.474
d. Traditional banks brown credits	-8.445	-32.666	-31.941	-7.349
Bankruptcy shock				
a. Traditional and shadow banks credits	-13.16	-34.842	-34.418	-13.35
b. Traditional banks credits	-10.995	-33.955	-33.299	-11.167
c. Traditional and shadow banks brown credits	-10.528	-33.68	-32.979	-10.697
d. Traditional banks brown credits	-8.736	-32.328	-31.484	-8.89

Note: Values are expressed in percentage changes from values obtained under the baseline scenario (i.e. without CCyB regulation). Volatilities are obtained with the resolution of the model under a second order approximation. Decomposition of volatility changes (with $\gamma_B^F = 0.85$ and $\gamma_G^F = 0.735$) displayed in Table 6.

Table A.2.5 : Decomposition of volatility changes with respect to loan and lender types under higher involvement of traditional banks into green credit sector (i.e., $\gamma_G^F = 0.85$ and $\gamma_B^F = 0.735$) and a 10% emissions tax

Scenario		Green Credit-to-GDP Volatility	Brown Credit-to-GDP Volatility	Traditional Credit-to-GDP Volatility	Shadow Credit-to-GDP Volatility
TFP shock					
a.	Traditional and shadow banks credits	-36.039	-22.041	-31.417	-7.474
b.	Traditional banks credits	-37.241	-21.575	-31.544	-7.293
c.	Traditional and shadow banks brown credits	-34.155	-22.374	-30.906	-7.725
d.	Traditional banks brown credits	-35.593	-21.952	-31.175	-7.62
Bankruptcy shock					
a.	Traditional and shadow banks credits	-27.202	-25.866	-32.327	-14.239
b.	Traditional banks credits	-33.01	-23.165	-31.798	-11.432
c.	Traditional and shadow banks brown credits	-20.354	-28.019	-31.777	-16.826
d.	Traditional banks brown credits	-28.392	-25.503	-32.424	-13.778

Note: Values are expressed in percentage changes from values obtained under the baseline scenario (i.e. without CCyB regulation). Volatilities are obtained with the resolution of the model under a second order approximation. Decomposition of volatility changes (with $\gamma_G^F = 0.85$ and $\gamma_B^F = 0.735$ and a 10% emissions tax) displayed in Table 7.

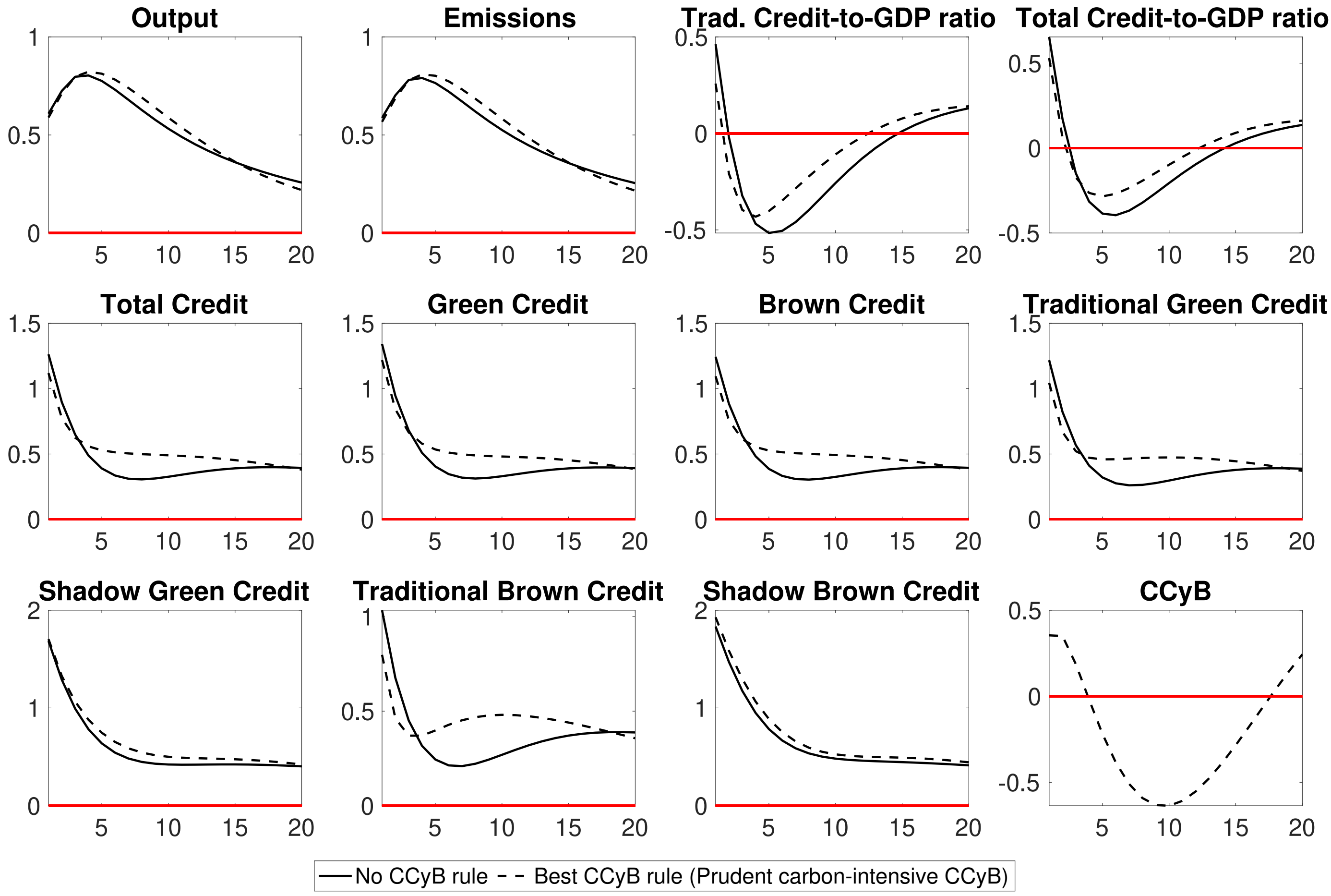
Table A.2.6 : Decomposition of volatility changes with respect to loan and lender types under higher involvement of traditional banks into brown credit sector (i.e., $\gamma_B^F = 0.85$ and $\gamma_G^F = 0.735$) and a 10% emissions tax

Scenario	Green Credit-to-GDP Volatility	Brown Credit-to-GDP Volatility	Traditional Credit-to-GDP Volatility	Shadow Credit-to-GDP Volatility
TFP shock				
a. Traditional and shadow banks credits	-7.889	-32.581	-31.677	-8.052
b. Traditional banks credits	-7.985	-32.806	-31.874	-7.964
c. Traditional and shadow banks brown credits	-8.047	-32.774	-31.82	-8.029
d. Traditional banks brown credits	-8.077	-32.909	-31.937	-7.91
Bankruptcy shock				
a. Traditional and shadow banks credits	-12.821	-35.134	-34.633	-13.447
b. Traditional banks credits	-10.728	-34.195	-33.492	-11.274
c. Traditional and shadow banks brown credits	-10.344	-34.007	-33.269	-10.877
d. Traditional banks brown credits	-8.608	-32.628	-31.77	-9.077

Note: Values are expressed in percentage changes from values obtained under the baseline scenario (i.e. without CCyB regulation). Volatilities are obtained with the resolution of the model under a second order approximation. Decomposition of volatility changes (with $\gamma_B^F = 0.85$ and $\gamma_G^F = 0.735$ and a 10% emissions tax) displayed in Table 8.

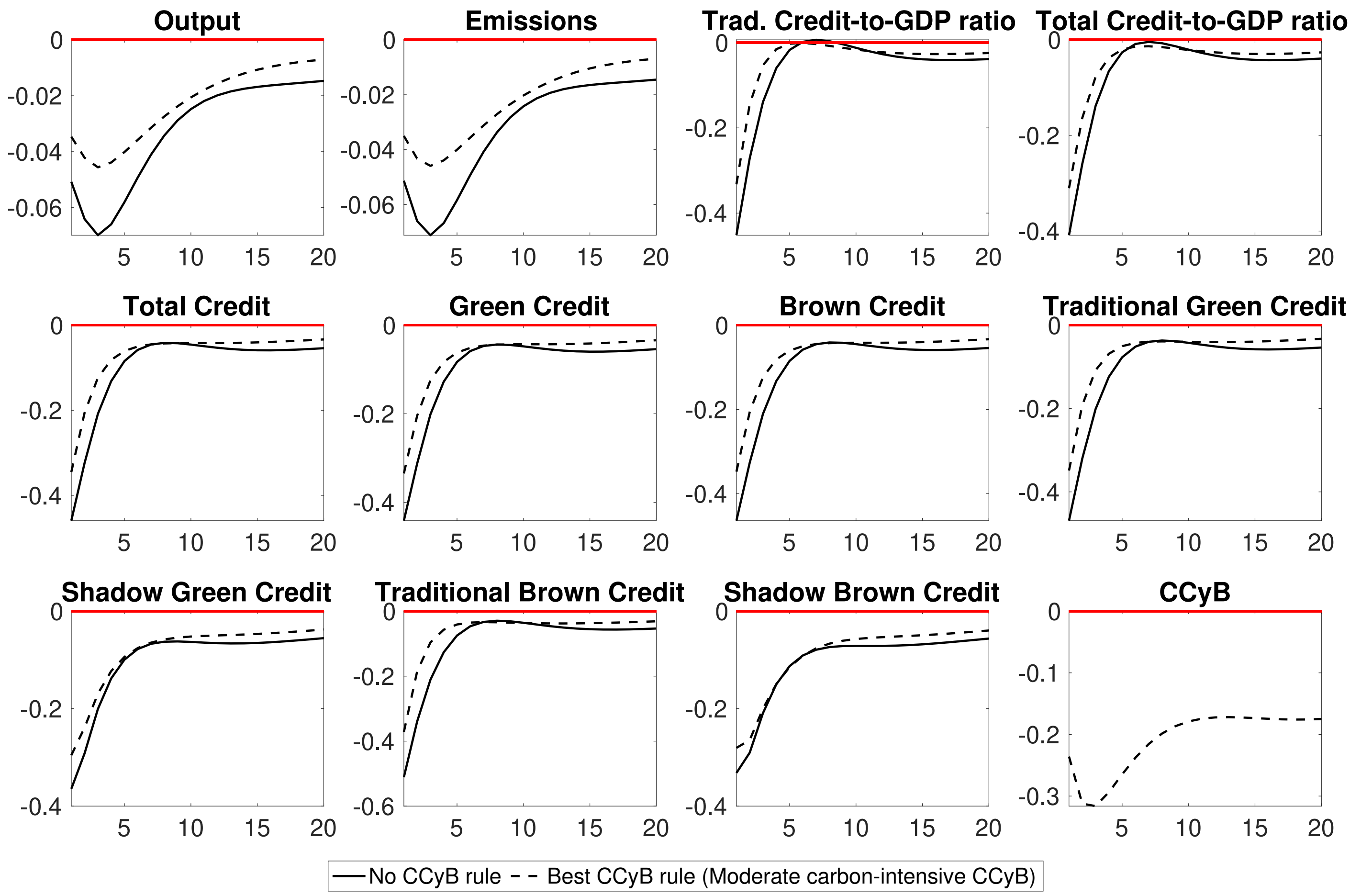
Appendix 3 Impulse response functions

Figure A.3.1 : Impulse responses : Positive TFP shock with an emissions tax of 10%



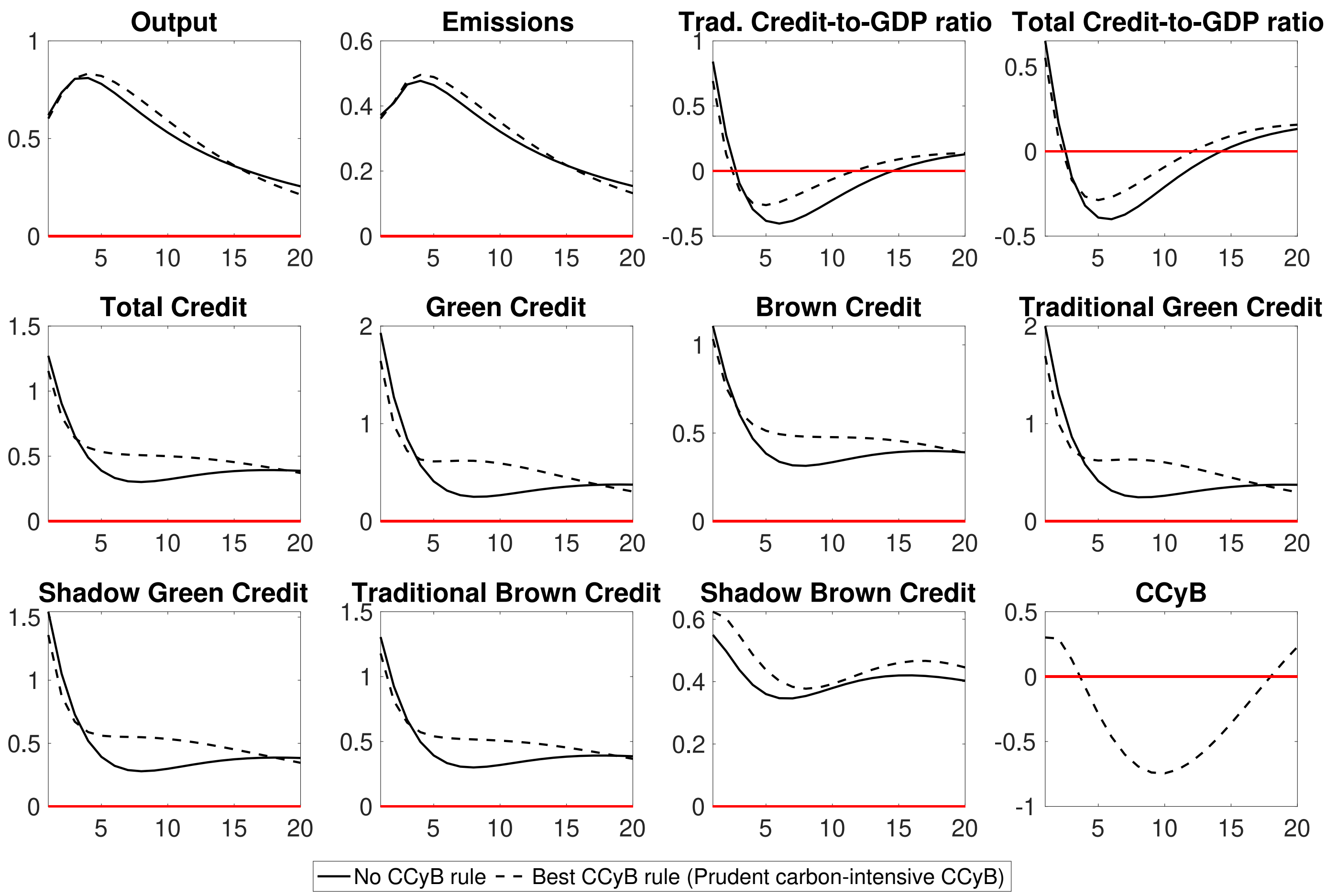
Note : Variables are expressed in percentage deviation from the level of their steady-state. Variable ”Trad. Credit-to-GDP ratio” corresponds to traditional bank loans over GDP while variable ”Total Credit-to-GDP ratio” corresponds to traditional and shadow bank loans over GDP. Volatilities estimated under a 10% emissions tax scenario are displayed in Table 4.

Figure A.3.2 : Impulse responses : Negative bank survival rate shock (bankruptcy shock) with an emissions tax of 10%



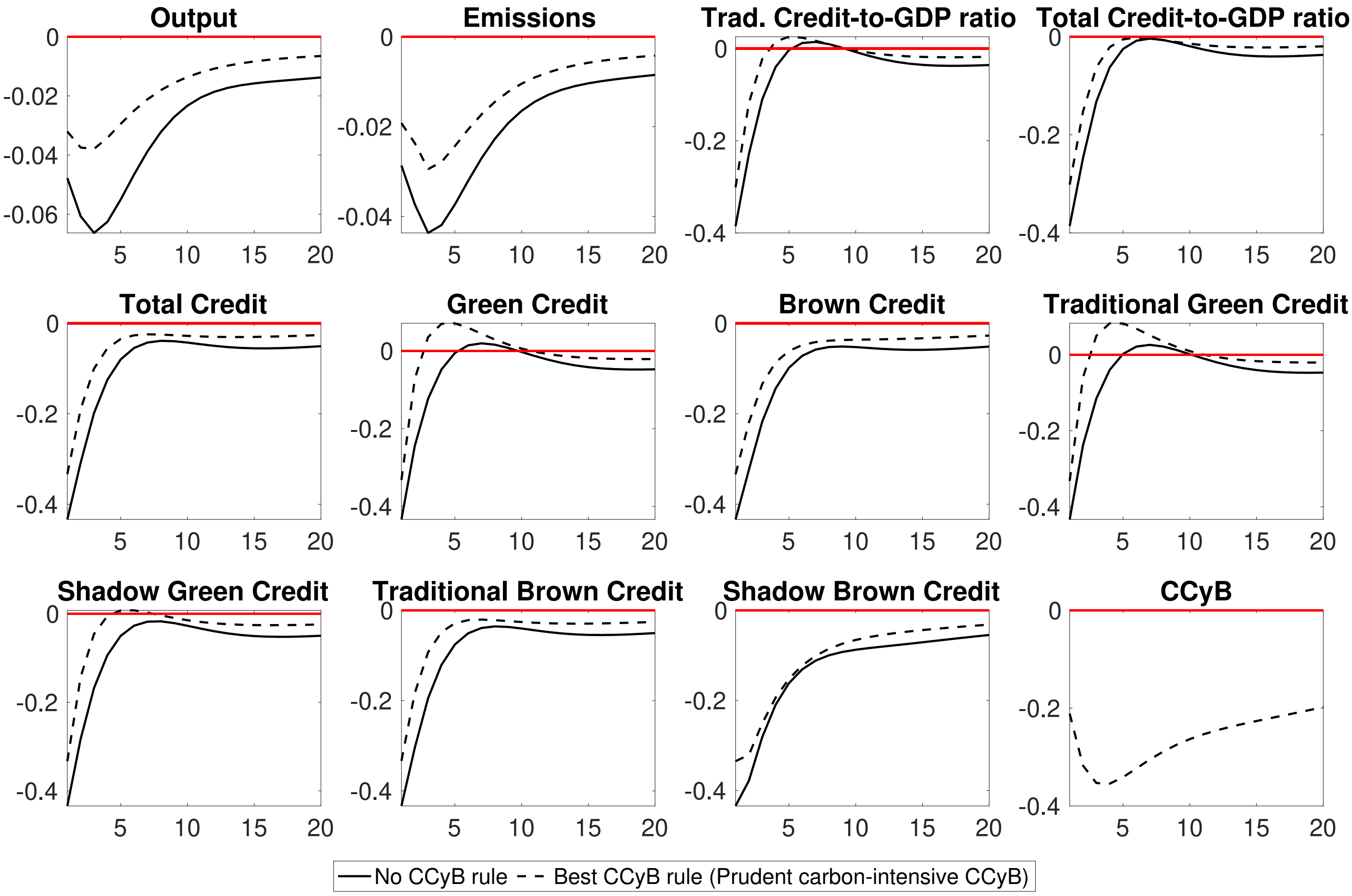
Note : Variables are expressed in percentage deviation from the level of their steady-state. Variable ”Trad. Credit-to-GDP ratio” corresponds to traditional bank loans over GDP while variable ”Total Credit-to-GDP ratio” corresponds to traditional and shadow bank loans over GDP.Volatilities estimated under a 10% emissions tax scenario are displayed in Table 4.

Figure A.3.3 : Impulse responses : Positive TFP shock - Higher green credit involvement of traditional banks (i.e., $\gamma_G^F = 0.85$ and $\gamma_B^F = 0.735$)



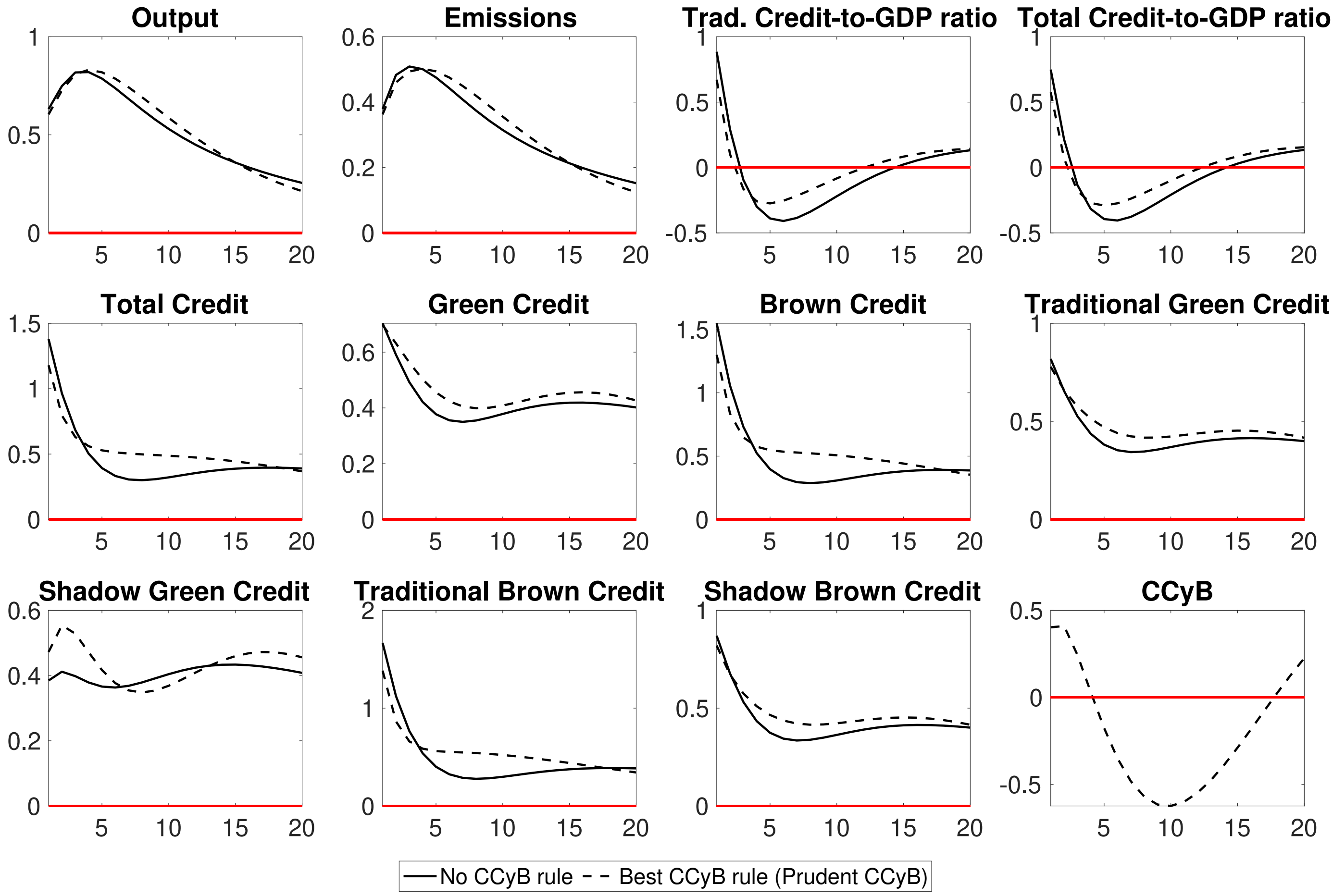
Note : All variables are expressed in percentage deviation from the level of their steady-state. Variable ”Trad. Credit-to-GDP ratio” corresponds to traditional bank loans over GDP while variable ”Total Credit-to-GDP ratio” corresponds to traditional and shadow bank loans over GDP. Volatilities estimated under higher green credit involvement of traditional banks scenario are displayed in Table 5.

Figure A.3.4 : Impulse responses : Negative bank survival rate shock (bankruptcy shock) - Higher green credit involvement of traditional banks (i.e., $\gamma_G^F = 0.85$ and $\gamma_B^F = 0.735$)



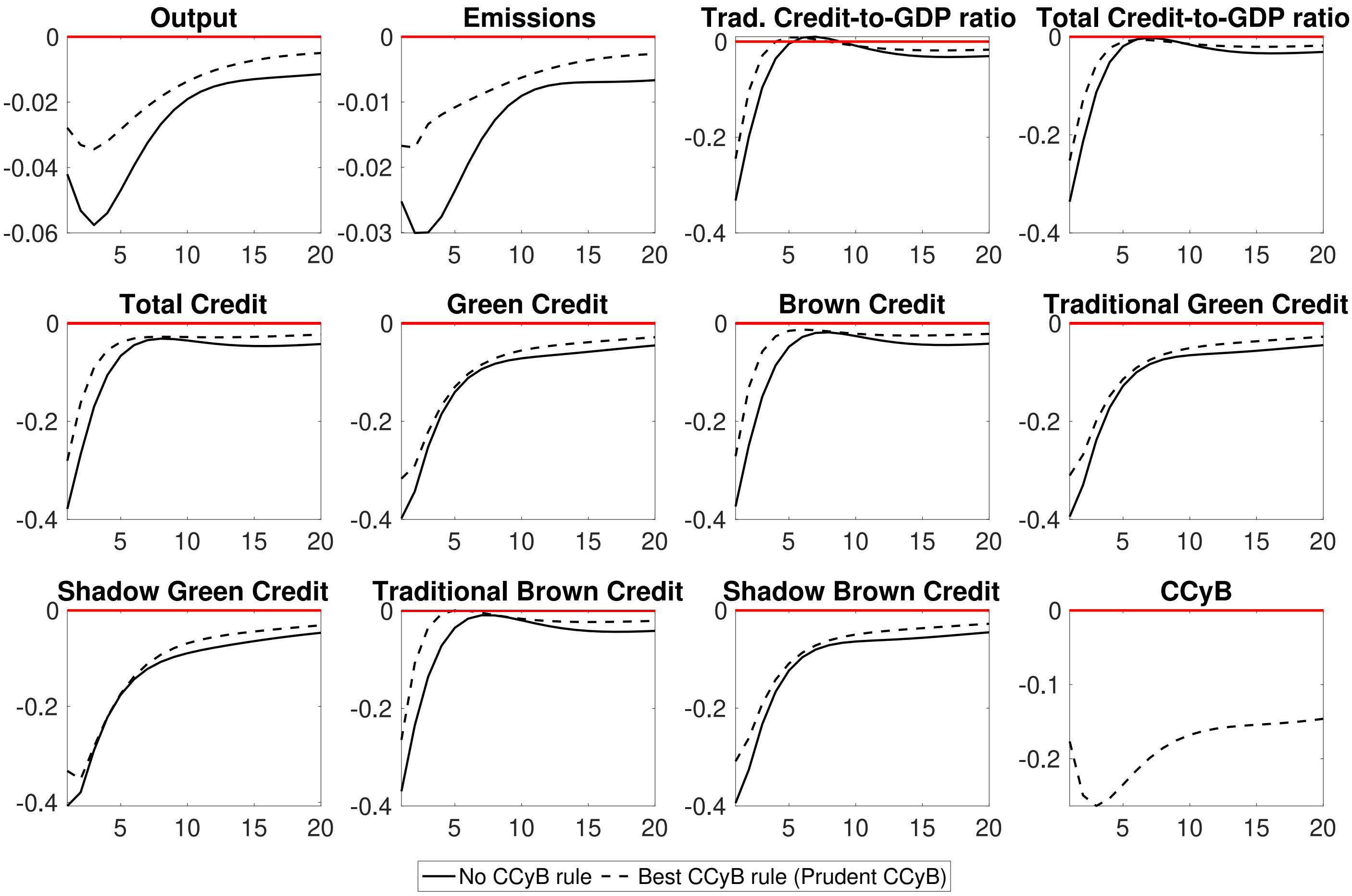
Note : All variables are expressed in percentage deviation from the level of their steady-state. Variable "Trad. Credit-to-GDP ratio" corresponds to traditional bank loans over GDP while variable "Total Credit-to-GDP ratio" corresponds to traditional and shadow bank loans over GDP. Volatilities estimated under higher green credit involvement of traditional banks scenario are displayed in Table 5.

Figure A.3.5 : Impulse responses : Positive TFP shock - Higher brown credit involvement of traditional banks (i.e., $\gamma_B^F = 0.85$ and $\gamma_G^F = 0.735$)



Note : All variables are expressed in percentage deviation from the level of their steady-state. Variable "Trad. Credit-to-GDP ratio" corresponds to traditional bank loans over GDP while variable "Total Credit-to-GDP ratio" corresponds to traditional and shadow bank loans over GDP. Volatilities estimated under higher brown credit involvement of traditional banks scenario are displayed in Table 6.

Figure A.3.6 : Impulse responses : Negative bank survival rate shock (bankruptcy shock) - Higher brown credit involvement of traditional banks (i.e., $\gamma_B^F = 0.85$ and $\gamma_G^F = 0.735$)



Note : All variables are expressed in percentage deviation from the level of their steady-state. Variable "Trad. Credit-to-GDP ratio" corresponds to traditional bank loans over GDP while variable "Total Credit-to-GDP ratio" corresponds to traditional and shadow bank loans over GDP. Volatilities estimated under higher brown credit involvement of traditional banks scenario are displayed in Table 6.