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Monetary and macroprudential policies: How to Be green? A political-economy approach

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ABSTRACT

This study examines the trade-offs that central banks would face if they began addressing climate change. The various instruments available to address climate-related risks overlap with those currently used for monetary and macroprudential purposes. However, most existing literature fails to adequately consider the political-economy aspect of this phenomenon. This creates a bias in favor of interventions by central banks. Using a political principal–agent setting that eliminates this bias, we examine the conditions under which the central bank architecture could effectively pursue this goal without compromising its core mandates. The effectiveness of central banks depends on their ability to calibrate, maintain independence and demonstrate a degree of activism.

1. Introduction

In 2015, the Paris Agreement was signed by 196 national governments amid public protests and growing climate concerns. The agreement, which depends on systemic transformations of signatories' economies, aims to limit global warming to less than 2 (preferably 1.5) degrees Celsius relative to preindustrial levels (Schoenmaker, 2021). Since the early 2000s, CO_2 emissions have increased significantly. If this trend continues, it could result in severe climate-related economic disruptions and lower economic growth Kotz et al., 2021 (Kotz et al., 2021). This may lead to a permanent annual GDP loss of 5%–20% over 20 years (Stern, 2007).

After Mike Carney's speech at Lloyd's of London in 2015, climate change was added to central banks' agenda. Carney, then governor of the Bank of England (BoE), first advocated the relevance of environmental risks for central bankers, emphasizing the potential effects of these risks on financial stability and calling for the development of "the frameworks that help the market itself to adjust efficiently" (Carney, 2015). Based on this interpretation, climate-change effects can jeopardize central banks' financial stability objective. Thus, they have started examining how and to what extent climate-related risks should be included in their monetary and macroprudential policy frameworks (Dikau et al., 2019; Vestergaard, 2024).

On the monetary side, the focus is on the so-called Green QE, i.e., a central bank's asset purchase program aimed at green activities. Currently, the European Central Bank (ECB) and the BoE are the two major central banks leading this initiative. On the prudential side, three pillars, I, II, and III, have been proposed. Pillar I measures typically raise the most concerns, which are also recognized by policymakers (EBA, 2023); as brown industries tend to be more creditworthy than green ones, at least in the short term, favoring brown industries could mean increasing systemic risk. Pillar II and III measures will be easier to implement as major central banks introduced climate stress tests in 2023 (Acharya et al., 2023).

Following this trend, both the ECB and the BoE have initiated measures to penalize (sustain) brown (green) industries (Baer et al., 2021) and their financing capacity. These proactive measures have included divesting portfolios from brown assets while continuing to analyze further interventions in capital and disclosure requirements. Alternatively, the Federal Reserve (Fed) has avoided entering the climate arena. In Jerome Powell's words, "We are not climate–change policymakers" (Reuters, 2024). In recent years, the topic of climate change has become increasingly common in speeches and declarations made by the central banks (Dikau et al., 2019; Feldkircher and Teliha, 2024); however, this focus has often been heterogeneous (Masciandaro and Tarsia, 2021; FSB, 2022; Oman et al., 2024).

The different positions of central banks worldwide indicate varying assessments of several underlying issues (DiLeo et al., 2023). Tirole (2023) effectively highlighted that central banks might suffer from a lack of legitimacy, capability, and accountability when engaging in

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climate policy. In most cases, they do not directly address climate issues (Dikau and Volz, 2021) and estimates of their effectiveness in mitigating environmental risks remain consistently low (Abiry et al., 2022; Carattini et al., 2023; Ferrari and Nispi Landi, 2023). The uncertainty surrounding climate shocks and environmental policy is unavoidable (Huang and Punzi, 2024). Furthermore, these interventions could have significant implications for distribution due to the penalization of brown sectors (Fay et al., 2015; Breckenfelder et al., 2023).

Efforts to combat climate change could also lead to trade-offs in achieving clearly defined (i.e., without environmental concerns) price and financial stability objectives, as the policy instruments across different policy dimensions (monetary, macroprudential, and environmental) often overlap (Annicchiarico et al., 2021). This final point is particularly significant because it relates to how central banks design their interventions. Given the challenges of changing mandates or explicit including climate objectives, environmental concerns are often included as "constraints" on the existing policy instruments (Monnin, 2018; De Grauwe, 2019; Dikau and Volz, 2019; Dikau et al., 2020; Bremus et al., 2021).

The following questions then arise: What characteristics make the central bank fit to assume climate responsibilities? What might be the trade-offs? We propose a principal–agent setting to analyze what central banks' interventions in climate policy regarding (i) the achievement of their "core" objectives (price and financial stability) and (ii) the potential efficacy of central banks in limiting the effects of climate events.

Meanwhile, the literature has mainly analyzed the subject from an "economic" perspective. Chan (2020) and Chen and Dongyang (2020) showed that explicit climate targets for emissions are directly included in the central bank's policy rule. Holtemöller and Sardone (2022) showed that the central bank's optimal response varies for green and brown sectors. While these approaches offer useful insights and operational models, they should be complemented by political-economy considerations that account for the institutional boundaries within which central banks must operate. Such considerations are also relevant to the overall political-economy analysis of how governments and bureaucracies in democratic societies can create and implement policies that facilitate green transitions (Besley and Persson, 2023).

On the one hand, it would be difficult for central banks to pursue explicit climate objectives that are not included in their mandates (Dikau and Volz, 2021; Boneva et al., 2022). On the other hand, penalizing or supporting specific sectors raises questions about central banks' neutrality (Bartholomew and Diggle, 2021). Given the redistributive effects of climate policies, these factors necessitate some form of "backing" from elected authorities, whether supportive or coercive (Tucker, 2019; Baer et al., 2021; Deyris, 2023; DiLeo, 2023; Moschella, 2024).

Governments define the institutional design of central banks and supervisors. They are the governments' agencies that are bound by an underlying principal–agent relationship (Chortareas and Miller, 2010). In this relationship, government agents are assigned their mandates and objectives and are held accountable to the public. Regarding climate policy, governments, which have played a historically predominant role in this domain using carbon pricing, should act as a source of central banks' legitimacy. This dimension is currently absent from the analysis. Consequently, existing approaches may underestimate the potential trade-offs arising from central banks' interventions, leading to over-optimistic results in their favor.

In our model, a central bank attempts to minimize climate risks using traditional tools and penalizing (favoring) brown (green) debt instruments. To address the neutrality concerns, the central bank should depend on the government's support or be susceptible to the government's pressures in addressing climate issues. We, therefore, implicitly assume that the government wants the central bank to take proactive measures in addressing climate change.

Whether the case is "supportive" or "coercive" depends on whether the government and the central bank agree on the need for climate actions or if the latter submits to the former's will on the issue. Our model can account for both cases as both would rely on political input. This element is measured by the central bank's dependence on the government. This analysis examines how central banks' participation in climate policy could help in "greening" the economy and whether this outcome would compromise their monetary and macroprudential targets.

This study make two key contributions: first, we develop a principal–agent setting that considers the relationship between central banks and governments; second, we model the central bank's environmental interventions in terms of constraints rather than new objectives. Overall, this framework acknowledges institutional limitations and potential backlashes of central banks' actions, ensuring a transparent and unbiased approach to economic analysis. We show that central banks' effectiveness depends on their calibration capacity, independence, and degree of activism.

The rest of this study is presented as follows. Section 2 presents a review of the relevant literature. Section 3 outlines the institutional framework, and Section 4 describes the policy implementation. Section 5 discusses the study results and draws some generalizations. Section 6 concludes.

2. Related literature

This study complements the literature on central banks' climate interventions (Chan, 2020; Chen and Dongyang, 2020; McKibbin et al., 2020; Abiry et al., 2022; Holtemöller and Sardone, 2022; Carattini et al., 2023; Ferrari and Nispi Landi, 2023) and that considering their potential trade-offs (Annicchiarico et al., 2021; Nakov and Thomas, 2023). Although these studies are becoming increasingly relevant as discussions on this subject continue, they currently lack a political-economy perspective. Most focus on the technical analysis of specific instruments that central banks could use, with little attention to how these fit within the institutional framework.

These approaches also overlook the role of political authorities in supporting central banks when extending their mandates, potentially creating a bias toward central banks' interventions. Our model, however, complements the literature that emphasizes the need for political backing for central banks to engage in the climate arena. For example, Moschella (2024) highlighted a substantial change in central banks' activism after the Global Financial Crisis. Baer et al. (2021), DiLeo (2023), DiLeo et al. (2023) and Deyris (2023) also supported this view: moving beyond the traditional interpretation of central banks' mandates is only possible when political will align with or influence that of the central bank.

Finally, this study draws from Ueda and Valencia (2012, 2014) and Smets (2014), who extend the classical Barro and Gordon (1983a,b) framework to include the effects of macroprudential policy on output and emphasize the role of macroprudential responsibilities in the central bank's loss function. Traditionally focused on the output gap and inflation. In their approach, the macroprudential objective to preserve financial stability leads to a smoothing of the leverage cycle, which is added to the other two. This innovation is particularly significant because, according to this framework, macroprudential policy plays a major role in determining firms' financing capacity. We extend their model to include climate constraints and differentiate between brown and green sectors.

3. Legislative stage

Our model outlines two stages within a democratic country that operates under a two-tier political framework (Aghion et al., 2004; Persson and Tabellini, 2004, 2024; Alesina and Tabellini, 2007). These stages consist of two consecutively occurring stages: "legislative" and "policy." In the first stage (Buchanan, 1962; Herrendorf and Lockwood, 1997; Romer and Romer, 1997; Drazen, 2002; Hefeker and Zimmer, 2011; Miller, 2019; Masciandaro, 1995, 2022a), lawmakers take a long-term approach. They decide to establish an issuer of public money with macroeconomic goals, i.e., a central bank, and establish formal rules governing its activities, degree of independence, mandates, and other institutional features (Aghion et al., 2004; Persson and Tabellini, 2004; Alesina and Tabellini, 2007). In the second stage, the nominated central banker interacts with the current government and makes policy decisions based on the legislative guidelines resulting from the previous stage, macroeconomic outcomes, and politicians' preferences. Climate change can affect these three elements.

Moreover, while in the legislative stage the lawmakers' long-term perspective is combined with standard assumptions such as rational expectations and full rationality, in the policy stage behavioral assumptions are used (Khan, 2018). We apply a standard macroeconomic approach to describe the long-term legislative stage and enhance our analysis with behavioral intuitions during the short-term policy stage. Notably, two perspectives can be considered complementary tools, considering the recent evolution of the traditional models (Branch and McGough, 2009; De Grauwe, 2012; Molnár and Santoro, 2014; Bordalo et al., 2018; Hommes et al., 2018, 2019; Jump and Levine, 2019; Woodford, 2019; De Grauwe and Ji, 2020; Gabaix, 2020; Afsar et al., 2022; Goy et al., 2022; Meggiorini, 2023; Pfauti and Syrich, 2023) and the macroecological models (Fagiolo and Roventini, 2016; Monasterolo and Raberto, 2018, 2019).

Lawmakers' choices can be modeled using a general delegation framework between citizens and politicians (Alesina and Tabellini, 2007), where choices related to central bank independence are captured by a parameter $\Omega > 0$. The intuition is that as Ω increases, the central bank's independence tends to decrease. Moreover, we assume that the design of the legislative stage allows the distinction between long-term formal (*de jure*) independence and actual (*de facto*) independence (Romelli, 2022). We review the extensive literature on central bank independence (Grilli et al., 1991; Hommes and Lustenhouwer, 2019; Bacchiocchi et al., 2024) that differentiates between legal and "more behaviorally oriented indices" (Cukierman, 1996). Independence is often influenced by politicians who use political pressures. This has been documented in both historical (Abrams, 2006) and empirical cases (Binder, 2021) that consider both citizens' wishes and politicians' personal interests (Masciandaro and Romelli, 2015; Masciandaro and Passarelli, 2020). Moreover, behavioral economics has been introduced to help explain central bankers' decisions (Favaretto and Masciandaro, 2016; Masciandaro, 2018).

The common reasoning is as follows: using the degrees of freedom that the institutional setting offers in the long run, the incumbent government, if it can do so, can exert political pressures on the central bank in the short term, thereby threatening the central banker's role. For example, if the institutional setting allows the incumbent government to override the central banker's decision during extraordinary times, the central banker may be tempted to comply with political wishes to avoid being overridden (Lohmann, 1992). The institutional design defines the setting structurally shaping the central bank's reaction function. In detail, we assume that the formal rules define the interactions between three key elements typical of any standard central bank reaction (Masciandaro, 2022a): the central banker's preferences, the incumbent government's preferences and the macroeconomic performances.

Citizens care about the effectiveness of central bank independence according to a classic well-behaved concave function $U = U(\Omega)$, where social welfare increases with optimal central bank independence. Linear preferences are used so that $U(\Omega) = \Omega$. The lawmaker is electorally rewarded based on how they perform their job. We assume that our politician wishes to please citizens, that is, the *helping-hand view* of the politician's type. Alternatively, we could assume that the politician aims to please specific constituencies (e.g., the lobbies), known as the *grabbing-hand view* (Shleifer and Vishny, 1998). This assumption helps identify under the conditions under which the level of Ω resulting from the legislative decision can differ from the socially optimal one, despite the politician's desire to please citizens.

The level of Ω is determined by the lawmaker's ability, μ, and their effort, a: $\Omega = a + \mu$. In the legislative stage, the sequence of events is as follows: (1) society decides to delegate the task of defining the central bank's independence to the lawmaker; (2) the lawmaker makes an effort, a, before knowing their ability, μ, regarding this particular task (as developing a central bank setting is not a typical task); (3) the lawmaker defines their choices, thereby revealing their ability; and (4) citizens reward the lawmaker through their vote.

The lawmaker's utility function is defined as $L = L(R, C) = R(U) - C(a)$, where $R(U)$ is the reward function and $C(a)$ is the cost function. The political reward is a function of social utility, while the political costs are a function of the effort required to implement the task. The lawmaker evaluates each task considering its political rewards and costs. Two key characteristics define the lawmaker: (1) ability: the politician's ability is a random variable that follows a normal distribution, with the mean denoted by $\overline{\mu}$; (2) political reward: the incumbent lawmaker aims to secure re-elected. The lawmaker must ensure that the majority of voters receive sufficient utility. Consequently, their utility function is associated with the social welfare function, expressed as $U = U(\Omega)$. In general, the lawmaker aims to please the voters, aligning their goals with those of the citizens.

Each delegated task can vary in convenience regarding political gains from the politician's perspective. We denote the political value they assign to the "greening" of the central bank's policies by $0 \leq \xi_L \leq 1$. Therefore, $R(U) = \xi_L U$. Aligning incentives between lawmakers and citizens is a necessary and sufficient condition for finding the politician's optimal behavior. Political rewards differ from social reward if $\xi_L \neq 1$. From the lawmaker's perspective, the political gains of a given central bank regime relate to expected consensus benefits. Moreover, the reward will be useful only if the citizens' utility exceeds the minimum threshold of utility, W, expected from an incumbent politician. The political competition condition can be defined as follows: $R_L = \xi_L \Pr(U \geq W)$. The usefulness of the political reward depends on this condition.

The lawmaker is aware of the political costs associated with designing a central bank regime as they are likely to arise when a policy position is adopted. The lawmaker's cost function can be defined as follows: $C(a) = c_L a_L^2$. This implies that the lawmaker maximizes social welfare after deducting the costs of executing the task and factoring in the political reward:

$$L = R(U) - C(a) = \xi_L U - c_L a_L^2 = \xi_L (a_L + \mu_L) - c_L a_L^2. \tag{1}$$

From the first-order condition

$$\frac{\partial L}{\partial a_L} = \xi_L - 2 c_L a_L = 0, \tag{2}$$

which implies that the optimal effort is

$$a_L = \frac{\xi_L}{2 c_L}. \tag{3}$$

Given a_L, the lawmaker's effective political reward depends on the condition of political competition: $R_L = \xi_L \Pr(U \geq W)$. Lawmakers assume that citizens are rational. They recognize that the alternative to the existing policymaker is another politician of average ability. Given their expectations for effort, a^e, it follows that $W = a^e + \overline{\mu}$. Then

$$R_L = \xi_L \Pr(a_L + \mu_L \geq a^e + \overline{\mu}) = \xi_L \Pr(\mu_L - \overline{\mu} \geq a^e - a_L). \tag{4}$$

Nature determines the ability of the incumbent μ_L. When rational expectations are matched (i.e., $a^e = a_L$), the effective political reward is positive when the incumbent lawmaker's ability is above average: $\mu_L > \overline{\mu}$.

Under this condition, the size of the central bank's institutional setting is determined by the lawmaker's ability and effort:

$$\Omega_L = a_L + \mu_L = \frac{\xi_L}{2 c_L} + \mu_L. \tag{5}$$

Clearly, given the exogenous lawmaker's ability, political preferences, which may differ from socially optimal preferences, will determine the central bank's independence.

The lawmaker's decisions determine the central bank's loss function. Following Ueda and Valencia (2012, 2014) and Smets (2014), the central bank is assigned both monetary and macroprudential mand ates (Dalla Pellegrina and Masciandaro, 2008; Masciandaro and Volpicella, 2016; Masciandaro, 2022b). Inflation and leverage are considered the respective target variables of the two policies.

$$L_{CB} = \pi^2 + \lambda(y - \widehat{y})^2 + \phi\left(c^P - \widehat{c}\right)^2, \tag{6}$$

where π is inflation, y is output with $\widehat{y}$ its natural level and c^P is the central bank's estimation of leverage with $\widehat{c}$ as its baseline value.

The parameters λ and ϕ are positive and represent the relative weight given to output and leverage stabilization, respectively, to stabilize inflation. By extending Rogoff's (1985) traditional perspective to leverage, both can be considered a measure of the central banker's conservativism, which simply reflects the assumption that committees design central bank's policies (Fry, 1998; Lybek and Morris, 2004; Pollard, 2004; Blinder and Morgan, 2005; Gerlach-Kristen, 2006; Rieder, 2022). This assumption reveals the link between collective monetary policy choices and individual board members' preferences, which can be further examined by analyzing the relationship between central bank governance and monetary policy decisions (Masciandaro, 2022a). Therefore, we can use the term "central bank(s)" or "central banker(s)" interchangeably.

There are various ways that climate-change considerations can affect this environment. One channel covers the relationship between climate change and macroeconomic performance. We assume that climate change is a source of uncertainty that increases the variance of output and jeopardizes financial stability (Carney, 2015). Another channel works through the incumbent government's preferences that can influence the central bank's decisions, given the level of its independence, and the central bankers' preferences that can be relatively conservative in terms of green sensibility.

4. Policy stage

The legislative stage defines a framework in which any incumbent government can influence the central bankers in charge because of electoral concerns, social pressures, or other short-term factors. Therefore, climate-related issues can be easily introduced when the incumbent government considers such issues as issues that the central bank should address. However, the government cannot amend the central bank's mandates established in the legislative stage. Specifically, it will compel the central bank to account for climate risks in its economic modeling despite its dependence on current preferences.

As discussed earlier, major central banks adopt strategies focused on climate-related interventions. Consistent with policymakers' suggestion, this study considers this modeling to penalize (support) brown (green) leverage and include a potential climate-induced supply shock.

This framework reflects the real world: while major central banks have established mandates legislatively defined in general terms, incumbent governments can directly or indirectly affect their behavior through political pressures (Binder, 2021). If central bankers disagreed with the government's actions, they may be forced to respond to parliamentary auditions or, in certain cases, be fired (Walsh, 1995).

We model our second-stage economy following Ueda and Valencia (2012, 2014) and Smets (2014), with the central bank managing both monetary and macroprudential policies. Inflation is the target of monetary policy, while leverage is the focus of macroprudential policy. Leverage, given by baseline conditions, is negatively affected by unexpected inflation, which reduces debt overhang, and positively affected by macroprudential accommodation, which increases debt. We also add the possibility that aggregate output is affected by an exogenous climate shock, which proxies environmental risks, and the associated real and financial risks (Bolton et al., 2022). Actual leverage is defined as

$$c = \widehat{c} - (\pi - \pi^e) + n \tag{7}$$

where π is inflation, π^e denotes the expectations for the next period, and n, set by the central bank, is the macroprudential accommodation. Macroprudential action, leverage, and bank resilience are correlated (Busies et al., 2024). Baseline leverage is given by $\widehat{c} = \widehat{c}_g + \widehat{c}_b$, with $\widehat{c}_g$ and $\widehat{c}_b$, respectively, represent the "green" and "brown" baseline leverage.[1]

We differentiate between the actual leverage c and the one the central bank considers when calibrating its instruments, we define the latter as

$$c^P = \widetilde{c} - (\pi - \pi^e) + n, \tag{8}$$

where $\widetilde{c}$ corresponds to a potentially biased value of baseline leverage. Based on the central bank's degree of dependence on the government's climate preferences, i.e., our Ω_L from the previous section, the central bank can impose a penalty factor $B > 0$ to $\widehat{c}_b$, and apply a forgiveness term $G > 0$ to $\widehat{c}_g$. This approach allows the central bank to consider the overall baseline leverage as $\widetilde{c} = \widehat{c} + \Omega_L(B - G)$.

The central bank's own (and potentially wrong) "perception" of the economy can be classified as "behavioral" (Favaretto and Masciandaro, 2016; Khan, 2018; Masciandaro, 2018; Monasterolo and Raberto, 2018, 2019; Salle et al., 2019). Consequently, it overestimates the brown baseline leverage and underestimates the green baseline leverage. Only if the central bank were fully independent of the government's preferences ($\Omega_L = 0$, which is not assumed in our model, given the result of the institutional stage), or if its calibration of B and G were perfectly balanced, making B exactly equal to G, there would be no net differentiation and thus $\widetilde{c} = \widehat{c}$.

Similar to Ueda and Valencia (2012, 2014) and Smets (2014), as well as in the traditional strands of the literature, we assume that the central bank directly determines inflation. With these models, this occurs immediately. In our model, to preserve the differentiation between target and instrument, we assume that inflation is determined by the central bank's instrument of monetary accommodation, given by m. This corresponds to

$$\pi = m. \tag{9}$$

Importantly, these last two equations suggest that the central bank can affect leverage through both the macroprudential and monetary instruments, as equation (9) is included in equation (8). This is consistent with most studies highlighting the role of monetary policy in determining financial stability (Rajan, 2010; Altunbas et al., 2014), also using augmented Taylor rule specifications that take into account financial stability issues (Borio and Lowe, 2002; Svensson, 2017; Verona et al., 2017; Zhu et al., 2021; Filardo et al., 2022).

The economy's aggregate output is determined by a macroprudential-augmented Lucas supply function, where the central bank includes an exogenous climate shock, depending on its alignment with the government's climate preferences. This supply function is given by

$$y = \widehat{y} + \alpha(\pi - \pi^e) + \beta n + \Omega_L v, \tag{10}$$

where all variables retain their earlier definitions and the parameters α and β are positive. Unless the central bank is fully independent of the

[1] The choice of leverage stabilization as the objective of macroprudential policy is consistent with the literature, which identifies "excessive" credit growth as the main factor in financial instability (Jordà et al., 2011; Claessens et al., 2012; Drehmann et al., 2012; Gourinchas and Obstfeld, 2012; Schularick and Taylor, 2012; Borio, 2014; Caruana and Shim, 2016).

government ($\Omega_L = 0$), it also factors in the exogenous climate shock $v \neq 0$. We assume this shock is well-behaved, with a null mean and a given variance.

Finally, we consider an indicator of pollution, such as emissions

$$e = f(y) - h(m, n). \tag{11}$$

Emissions depend on a positive function of output, f, with $f^{'}$ (its first derivative) > 0. The function h summarizes the effectiveness of the central bank's instruments, m and n, in reducing pollution. Consistent with the literature supporting central banks' green interventions, we assume that h is positive and $h^{'}_m > 0$ and $h^{'}_n > 0$. However, we make no assumptions regarding the size of these partial derivatives.

In this second stage[2], the central bank chooses m and n to minimize its loss function, given by equation (6),[2] subject to the economy's constraints. The output target is the natural output $\hat{y}$, and the leverage target is the actual baseline leverage $\hat{c}$. The inflation target is null. These unbiased objectives, assigned during the legislative stage, allow for any distortions arising in equilibrium due to the introduction of climate risks through the central bank's "wrong" modeling of leverage, represented in the loss function as c^P instead of c.

The central bank simultaneously sets its instruments after observing the climate shock v, which is an accommodative assumption given the uncertainty surrounding the effects of climate change (Tirole, 2023). Subsequently, the public forms its inflation expectations. Therefore, π^e is taken as given by the central bank. Solving the first-order conditions of this problem in terms of m and n, we obtain

$$m = \pi = \frac{(\phi + \alpha^2\lambda)\pi^e + (\phi - \alpha\beta\lambda)n + \phi\Omega_L(B - G) - \alpha\lambda\Omega_L v}{1 + \phi + \alpha^2\lambda}, \tag{12}$$

$$n = \frac{(\phi - \alpha\beta\lambda)(m - \pi^e) - \phi\Omega_L(B - G) - \beta\lambda\Omega_L v}{\phi + \beta^2\lambda}. \tag{13}$$

At this stage, the public rationally forms its expectations: solving the systems of equations (12) and (13), taking the expected value of the resulting monetary instrument (since $\pi = m$), and finally solving for π^e, we obtain expected inflation as $\pi^e = \Omega_L(B - G)\beta\Delta$, with

$$\Delta = (\alpha + \beta)\frac{\phi\lambda}{\phi + \beta^2\lambda}.$$

Substituting this value of expected inflation back into the solutions obtained by solving the system of equations (12) and (13) yields the equilibrium values of inflation, monetary, and macroprudential accommodation as

$$m = \pi = \Omega_L(B - G)\beta\Delta - \Omega_L\frac{\Delta}{1 + (\alpha + \beta)\Delta}v, \tag{14}$$

$$n = -\Omega_L\frac{\phi(B - G)}{\phi + \beta^2\lambda} - \Omega_L\frac{\Delta}{1 + (\alpha + \beta)\Delta}v - \Omega_L\frac{\beta\lambda}{(\phi + \beta^2\lambda)[1 + (\alpha + \beta)\Delta]}v. \tag{15}$$

The equilibrium values of leverage and output can also be determined. Substituting the equilibrium values of monetary accommodation, realized and expected inflation in equations (7) and (10) yields

$$c = \hat{c} - \Omega_L\frac{\phi(B - G)}{\phi + \beta^2\lambda} - \Omega_L\frac{\beta\lambda}{(\phi + \beta^2\lambda)[1 + (\alpha + \beta)\Delta]}v, \tag{16}$$

$$y = \hat{y} - \Omega_L\frac{\beta\phi(B - G)}{\phi + \beta^2\lambda} + \frac{\Omega_L\phi}{(\phi + \beta^2\lambda)[1 + (\alpha + \beta)\Delta]}v. \tag{17}$$

Equations (14), (16) and (17) show that the central bank's inflation, leverage, and output targets are not achieved. These target only be achieved on average if either $\Omega_L = 0$ or $B = G$.

This condition ($B = G$) is particularly relevant not only for calibration but also in terms of the central bank's perception of the economy. Specifically, this condition determines whether the central bank is behavioral, as defined in the previous section. A nonbehavioral central bank ($B = G$) would correctly model leverage as in equation (7), thus achieving its targets without discriminating against brown financing. However, this would hold true only *on average* As the effects of the climate shock v would persist and be partially mitigated by the central bank's standard tools.

Importantly, we assumed that the central bank could observe the shock before setting m and n to accommodate the more lenient view of central banks' interventionism; however, this scenario might be unlikely (Tirole, 2023). The central bank would be considered "behavioral" if $B \neq G$; however, in terms of policy effects, this is significant only for a positive degree of dependence on the government: $\Omega_L > 0$. Thus, the central bank's status, whether behavioral or not, depends on its relationship with the government, as established during the legislative stage. For a behavioral central bank, two scenarios can be envisioned: net penalization ($B > G$) or net forgiveness ($B < G$).

For $\Omega_L > 0$ and $B > G$, we find that, on average, inflation exceeds the target, while leverage falls below the baseline leverage (negative leverage gap), and output will be below its natural level (negative output gap). In this case, the penalty and forgiveness terms correspond to a net penalization, leading to a lower degree of macroprudential accommodation compared with the case of target-efficient calibration ($B = G$). The central bank attempts to offset this with larger monetary accommodation.[3] However, in this setting, the rational public sets its inflation expectations such that, on average, no unexpected inflation occurs. Consequently, negative macroprudential accommodation will be the only factor contributing to determining the average deviations of leverage from its baseline value and those of output from its natural level.

The same reason with opposite signs applies for $B < G$ (net forgiveness): on average, inflation will fall below the target, while leverage and output will exceed the target (positive leverage and output gaps). Net forgiveness results in a higher degree of macroprudential accommodation than with $B = G$, which the central bank tries to offset with lower monetary accommodation[3]. However, as there is no unexpected inflation, leverage will be greater than its baseline value, and output will exceed its natural level according to the earlier reasoning. The two scenarios, with the associated central bank's losses, are shown in Fig. 1.

Furthermore, in both cases (either net penalty or net forgiveness), a larger Ω_L (i.e., greater dependence of the central bank on the government's climate preferences) results in larger average deviations of inflation, leverage, and output from the respective targets (in one direction or the other, depending on the case). Specifically, if the central bank is not fully independent of the government's preferences and fails to effectively calibrate B and G, its dependence worsens the distorting effects of such miscalibration.

[2] This objective function does not explicitly differentiate between the time horizons of monetary and macroprudential policies. In the aftermath of the Global Financial Crisis, macroprudential policy has emerged as a tool to smooth the financial cycle, which is characterized by a lower frequency for the business cycle targeted by monetary policy (Drehmann et al., 2012). In this sense, the former would have a longer time horizon with respect to the latter. By now, though, major countries of the Basel Committee on Banking Supervision have set their macroprudential instruments (e.g., the counter-cyclical capital buffer) every quarter, making the timing of these policy decisions consistent with those of monetary policy (Russo, 2022). This approach also applies to macroprudential policy in a short horizon, as it is based on the current state of the credit (leverage) cycle. If ever one wished to preserve a time differentiation, the parameter ϕ could be assumed to incorporate a time-discount factor, in addition to the relative weight of the target per se.

[3] The term $B - G > 0$ contributes positively to equation (14) and negatively to equation (15).

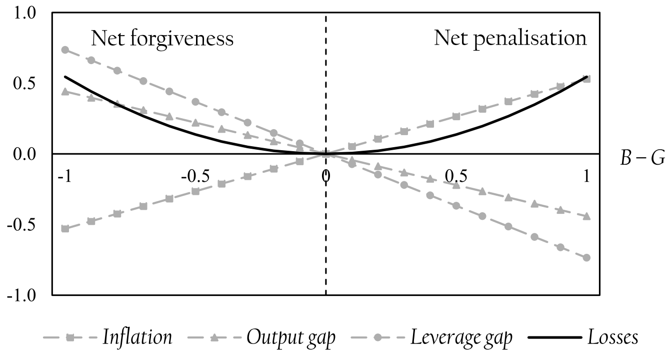

Fig. 1. Central bank's targets and losses.
Note. Output and leverage gaps, respectively, refer to the difference between realized output and its natural level and between realized leverage and its baseline value. Figures apply for the following values of the model's parameters: $\hat{y} = 10$, $\hat{c} = 10$, $\alpha = 0.6$, $\beta = 0.6$, $\lambda = 1$, $\phi = 1$, $\Omega_L = 1$.

Finally, the effect on emissions remains ambiguous. For a net penalization, on average, f from equation (11) will be lower than for $B = G$, while the sign of the change in h depends on its exact functional specification because m and n would move in opposite directions (m increases while n decreases). If a central bank is sufficiently effective in channeling monetary accommodation to reduce emissions ($h_m^{'}\, dm$ sufficiently large, where dm is the deviation of the monetary instrument from its value for $B = G$), equation (11) would decrease.

The same uncertainty would apply for net forgiveness, where, on average, f will be higher in this scenario where $B = G$, while monetary policy and macroprudential accommodation still move in opposite directions (m decreases while n increases). In this case, for (11) to decrease, the central bank should be sufficiently effective in channeling macroprudential accommodation to reduce emissions (sufficiently large $h_n^{'}\, dn$, where dn is the deviation of the macroprudential instrument from its value for $B = G$).

Fig. 2 shows the possible paths of reduction (or increase) in emissions, depending on the "strength" of the monetary or macroprudential effects and whether net forgiveness or net penalization is applied. Overall, a sufficiently strong monetary effect would reduce emissions under net penalization and increase them under net forgiveness. A sufficiently strong macroprudential effect would reduce emissions under net forgiveness and increase them under net penalization.

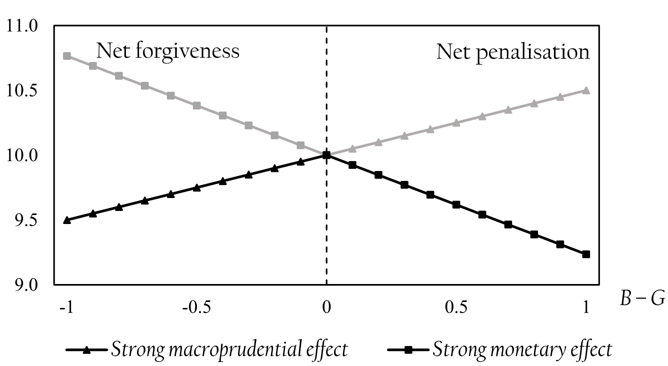

Fig. 2. Emissions.
Note. The vertical axis gives the emissions value, which for $B = G$ amounts to 10. The model parameters for which this value is estimated are assumed to be the same as in Fig. 1. Triangular marks indicate the results from a model assuming a strong *macroprudential* effect: $e = y - m - 2n$. Square marks indicate the results from a model assuming a strong *monetary* effect: $e = y - 2m - n$. Gray and black differentiate between the effect that would reduce emissions (black) and increase (gray).

5. Effectiveness and trade-offs

Our results show that a central bank would not necessarily achieve its monetary and macroprudential objectives when addressing climate risks because its dependence on the government's climate preferences would introduce the possibility of miscalibration of the penalty and forgiveness terms: if these factors balance properly, the targets will be achieved (on average); otherwise, the central bank solves its optimization problem based on a biased definition of leverage and overlooks them. This dependence also increases deviations from targets if there are miscalibrations.

Consequently, accounting for a well-behaved climate shock does not, on average, affect the central bank's ability to achieve its targets, provided the shock is fully observed before the central bank's instruments are set. This assumption can be considered accommodative; if removed, the uncertainty faced by central banks could worsen the resulting trade-offs, thereby preventing them from counterbalancing the effects of the shock through its instruments. Furthermore, this study does not propose any mechanism to structurally eliminate the economy's exposure to climate shock, which represents an interesting venue for further research.

Importantly, the central bank's dependence does not involve the government's active influence. After the institutional stage, the central bank is free to set its instruments and does not pursue biased levels of the target variables. The bias arises from the central bank's own miscalibration of G and B. Even if the central bank considers climate risks as a form of delegation by the government, this delegation is only feasible due to the central bank's sensitivity to the government's climate preferences, which are set by the legislators during the institutional stage and cannot be directly influenced by the incumbent government.

A potential extension of this setting may involve a form of government delegation that results in active influence during the policy stage. If the delegation process and the government's objectives remain consistent with those assumed in this study, this case would reasonably lead to similar but larger results: the effect of an active government's influence would add to that arising from the institutional parameters. However, identifying an explicit instrument of government's influence might highlight further distortions. Further research could also explore introducing an interest group with preferences that contradict those of the government and the central bank (Chortareas and Miller, 2003, Chortareas and Miller, 2004).

Regarding emissions, our results indicate that central banks' inclusion of climate risks in their policymaking could only be effective under stringent conditions. Their potential efficacy is proportional to deviations of monetary or macroprudential accommodation from their respective values for $B = G$, depending on whether the central bank applies net penalization or forgiveness. In other words, the central bank faces a trade-off between achieving its inflation, leverage, and output targets and its climate target: to (possibly) achieve the climate targets, the central bank must compromise the former.

Moreover, the "possibility" that the central bank could effectively reduce pollution depends on the accommodative assumption that its instruments can serve this scope (i.e., h is a positive function). While several studies support this assumption, we propose some reasons why this may not be true. First, given the innovative nature of these policies, there is no assurance that the central bank could effectively distinguish between green and brown debt instruments, which poses a taxonomy issue. Second, central banks probably lack adequate monitoring capacity beyond the financial sector.

Specifically, poor taxonomy may lead to monetary and regulatory accommodation having no or even a negative effect on pollution, such as by classifying a brown instrument as green. Furthermore, even if a given firm or industry could be classified as green, the central bank may be challenging to bind its instruments depending on the ex-post realization of a given project's green nature. As central banks have little (or no) authority to monitor nonfinancial corporations, there would be a strong incentive for these corporations to present their activity as green, even when they are not.

6. Conclusion

The existing literature on central banks' interventions in climate policy has adopted a purely economic approach, focusing on the potential efficacy of the tools they could use to support governments while ignoring the implications of these interventions in terms of central banks' traditional targets, either monetary or macroprudential, and their feasibility. Uncertainties persist regarding the scope of central banks' mandates despite the introduction of climate constraints rather than targets. Overall, this has led to mixed attitudes among central banks regarding concrete actions in climate policy.

This study proposes a principal–agent framework analyzing the benefits of central banks' incorporation of climate risks into their policymaking and how such interventions could affect their ability to pursue price and financial stability. We consider monetary and macroprudential instruments that consider both exogenous climate shocks and brown (green) penalization (forgiveness). The resulting levels of inflation, leverage, and output from our model help identify which institutional features and policy elements may hinder the central bank's monetary and macroprudential objectives while not necessarily enhancing its effectiveness in mitigating pollution.

Our results highlight the conditions under which a trade-off exists between central banks' monetary and macroprudential targets and their green effectiveness: the greater the deviation from its targets, the more powerful its climate action will be. Furthermore, the size of these deviations is positively related to the degree of the central bank's dependence on the government's climate preferences. However, our model also indicates that central banks could consider climate risks and contribute to a moderate reduction in emissions, although at the expense of their other targets.

For more effective climate actions, deviations from targets would be required. Importantly, these findings arise from a framework incorporating accommodative assumptions from the literature supporting central banks' green interventions. If these assumptions were removed, justifying central banks' interventions would become more challenging. Overall, this study suggests that only central banks with exceptional calibration capacity and high degrees of independence should consider including climate risks in their policymaking. Furthermore, the expected climate impact of such interventions would be limited. The uncertainty highlighted by this model may help explain why the Fed and the ECB have adopted different approaches to "greening" central banking.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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