An assessment of green differentiated capital requirements

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Abstract: Using the DEFINE (Dynamic Ecosystem-FINance-Economy) model, we examine the potential effects of the 'green supporting factor' and the 'brown penalising factor' on climate change, financial stability and macroeconomic activity. We identify the transmission channels of green differentiated capital requirements, focusing on the various ways via which such requirements could affect both the provision and the allocation of credit as well as the level of the interest rates. We derive four key results. First, green differentiated capital requirements can reduce the pace of climate change, but the reduction is not very likely to be quantitatively significant. Second, the brown supporting factor reduces the leverage of banks in the medium run, while the green supporting factor increases it. Third, the brown penalising factor entails some transition costs because it reduces economic growth in the short run. Fourth, the definition of brown loans matters. If a narrow definition of brown loans is adopted, the beneficial effects of the brown penalising factor on climate change are quantitatively less significant. On the contrary, a broad definition of brown loans enhances the beneficial climate change effects of the brown penalising factor. However, a broad definition increases the transition costs of the brown penalising factor.

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1. Introduction

There is a growing awareness that the targets about climate change cannot be achieved without an active role of the financial system. By facilitating the financing of low-carbon activities, a green transformation of the financial system could not only contribute to the fight against climate; it could also protect the financial system against climate-related financial risks.

The development of a climate-aligned financial system is already underway. The recent rapid expansion of green bonds is the most prominent development in this field. According to Climate Bonds Initiative (2017b), the stock of green bond increased in 2017 compared to 2016 by about 150% and there are signs that the expansion will accelerate. At the same time, various policies about central bank and financial regulation tools have been suggested which could support the development of a greener financial system (see, e.g. Campiglio, 2016; Volz, 2017; Campiglio et al., 2018).

This paper focuses on one of these suggestions linked with macroprudential regulation. We study the proposal of using capital requirements as a means to promote the transition to a low-carbon economy. Two versions of green differentiated capital requirements have been suggested in the related discussions (see European Commission, 2018). The first one is the so-called 'green supporting factor' which suggests that banks need to hold less capital for loans provided to support activities that can lead to lower greenhouse gas emissions. The second version is the so-called 'brown penalising factor'. According to this version, banks need to hold more capital against loans that finance high-carbon activities.

Although these proposals have recently received a growing interest, there is still a lack of a systematic attempt to evaluate their potential implications. Thomä and Hilke (2018) have recently estimated some potential effects of green differentiated capital requirements on credit supply and the level of interest rates in the EU. However, their analysis is partial and static: it does not rely on a complete macroeconomic framework that permits the examination of both first-round and second-round effects of such requirements. Moreover, their study does not quantify the potential effects on climate change.[1]

The aim of this paper is to provide the first quantitative dynamic assessment of the potential effects of these green differentiated capital requirements on climate change, financial stability and the macroeconomy. Our assessment is made by using the DEFINE model (see Dafermos et al., 2017, 2018). This is one of the very few climate-economy models that incorporates a detailed analysis of the interactions between climate change and the financial system and is, thereby, suitable for the evaluation of policies that intend to contribute to the development of a climate-aligned financial system.[2]

We proceed in three steps. We first introduce differentiated capital requirements in the DEFINE model and we identify the various channels through which these requirements could affect climate change, financial stability and macroeconomic activity via their impact on credit supply and the level of interest rates. The advantage of our modelling approach is that it makes a clear distinction between credit demand and credit supply and incorporates both the price and the quantity rationing of credit. Second, we identify a range of reasonable parameter values for the credit rationing and the interest rate equations, based on previous empirical studies. Finally, once the model has been calibrated and validated, we run a series of simulations in which we compare the effects of the 'green supporting factor' and the 'brown penalising factor' under different parameter values and definitions of what constitutes a brown loan.

We derive four key results. First, green differentiated capital requirements can reduce the pace of climate change. Second, the brown supporting factor reduces the leverage of banks in the medium run, while the green supporting factor increases it. Third, the brown penalising factor entails some transition costs, because it reduces economic growth in the short run; these costs are not present under the green supporting factor. Fourth, the definition of brown loans matters. If a narrow definition of brown loans is adopted, the beneficial effects of the brown penalising factor on carbon intensity are quantitatively less significant compared to the effects of the green supporting factor. On the contrary, a broad definition of brown loans makes the carbon intensity effects of

[1] Raberto et al. (2018) have investigated the potential impact of capital requirements on energy efficiency, but have not focused explicitly on the role of the green supporting and the brown penalising factor.
[2] Dafermos et al. (2018) have used the DEFINE model in order to analyse the effects of a green quantitative easing programme. Dietz et al. (2016), Bovari et al. (2018) and Lamperti et al. (2018) have also developed macroeconomic models about climate change in which finance plays a role. However, the financial system in these models is not sufficiently developed in order to allow the incorporation of capital requirements and their effects.

the brown penalising factor almost equivalent to those of the green supporting factor. However, a broad definition increases the growth transition costs of the brown penalising factor.

The paper's outline is as follows. Section 2 explains how we introduce green differentiated capital requirements in the DEFINE model and analyses the transmission channels of these requirements. Section 3 outlines how the model is overall calibrated, estimated and validated. It also describes the key features of our baseline scenario. Section 4 presents our simulation results and identifies the key factors that influence the effectiveness of green differentiated capital requirements and the trade-offs that their implementation could generate. Section 5 outlines the policy implications of our analysis and identifies the key areas for future research.

2. Modelling the effects of green differentiated capital requirements

The DEFINE 1.1 model developed in this paper introduces green differentiated capital requirements into the DEFINE 1.0 model which is described in Dafermos et al. (2018). The macroeconomy of the DEFINE 1.1 model consists of households, firms, commercial banks, the government sector and central banks. Households decide about the level of their consumption based on their income and wealth. They also take portfolio decisions since they allocate their wealth into deposits, government securities and green and conventional bonds. Firms rely on retained profits, bonds and loans in order to finance their investment expenditures. They make two types of expenditures: green and conventional investment. Commercial banks provide a proportion of loans to firms and decide about the interest rate on all types of loans. The central bank provides advances on demand to commercial banks and sets the base interest rate. The government makes expenditures and imposes taxes on households.

Regarding ecosystem processes, the model assumes that the use of fossil-fuel energy generates carbon emissions that, via a carbon cycle, affect the concentration of carbon in the atmosphere. Carbon concentration influences the atmospheric temperature and leads to climate change that has feedback effects on the economy via climate damages. For a given level of output, a higher use of renewables and a higher energy efficiency reduces carbon emissions, slowing down climate change. This can be achieved via green investment that has a non-linear impact on ecological efficiency via logistic functions that capture, amongst other, learning-by-doing and learning-by-installing processes. The DEFINE model also incorporates explicitly the material flows and takes into account the adverse effects of hazardous waste and the restrictions that exist in the long run due to the potential exhaustion of material and energy resources.

Appendices A, B, C and D report the matrices, the equations, the variables and the parameters of DEFINE 1.1. In what follows we will explain how green differentiated capital requirements are introduced in the DEFINE 1.0 model, which is the focus of this paper. More details about the DEFINE model can be found in Dafermos et al. (2018) as well as in the model's website (www.define-model.org).

The analysis of the effects of green differentiated capital requirements requires (i) a detailed modelling of the credit demand and credit supply process through which the investment of the non-financial sector is financed and (ii) a clear distinction between green and conventional (brown or non-brown) loans. Regarding (i), a considerable amount of theoretical and empirical work has been conducted over the last decade primarily as a response to the need of understanding better the role of credit in the run-up to the global financial crisis. Most Dynamic Stochastic General Equilibrium (DSGE) models have used the financial accelerator approach focusing on how the loan interest rate might affect credit. Jakab and Kumhof (2015) have departed from this approach by analysing explicitly both the quantity and the price rationing of credit and focusing on the endogenous creation of money. In addition, various empirical studies have explored the drivers of credit growth paying attention to both demand and supply factors (see, for example, Bridges et al., 2014 and Aiyar et al., 2016).

Our modelling approach draws on this literature. As Jakab and Kumhof (2015), we pay attention to both the quantity and the price rationing of credit and we assume that money is endogenously created. In line with the empirical literature, we make an explicit distinction between the demand and the supply of credit. As will be explained below, this is particularly important for the understanding of the various channels through which differentiated capital requirements affect the economy and the financial system. In addition, in line with previous agent-based and stock-flow consistent (SFC) models (see e.g. Caiani et al., 2016), we assume that agents make decisions under fundamental uncertainty in which microeconomic variables are determined via macroeconomic interactions. The complexity of the macroeconomic system does not allow the agents to optimise intertemporally. Hence, it is assumed that they are bounded rational and take decisions based on heuristics.

Regarding the distinction between loans with different environmental impact, we first differentiate between green and conventional loans as in previous version of DEFINE. Green loans are the loans which are used by firms in order to invest in capital that improves ecological efficiency, for example by being conducive to a higher use of renewables and a higher energy efficiency. In addition, we also distinguish between brown and non-brown conventional loans. Brown conventional loans are those loans that are used for investment that is considered to have significant adverse effects on the environment. Non-brown conventional loans are those loans whose adverse environmental impact is less significant. As will be shown in our simulation analysis, the way that brown/non-brown conventional loans are defined influences significantly the effectiveness of green differentiated capital requirements.

In our model, the timeline of credit-related events can be summarised as follows. Initially, firms decide about their overall desired investment based on a number of factors which are primarily related with their profitability and expected demand. A part of this investment is green. If their retained profits are not enough to cover the desired investment, firms issue bonds and apply for bank loans. Banks then decide about the level of interest rates and the proportion of loans that will be provided. If green differentiated capital requirements are in place, these bank decisions are affected by the anticipated environmental impact of the loans: banks might impose higher interest rates and higher quantity rationing on green loans compared to brown loans. The decisions of banks affect both the level of investment (and hence economic activity) and the level of carbon emissions which affects the dynamics of climate change. Banks decisions also have an impact on their own financial position. For example, a higher provision of credit might increase their leverage.

In what follows we describe the key equations linked with these events. The desired investment of firms (I^D) is as follows:

$$I^D = \left(\alpha \left(\overset{+}{u}_{-1}, \overset{+}{r}_{-1}, \overset{-}{ur}_{-1}, \overset{-}{ue}_{-1}, \overset{-}{um}_{-1} \right) K_{-1} + \varepsilon_I K_{-1} + \delta K_{-1} \right) \left(1 - D_{T-1} \right) \qquad (1)$$

where u is the rate of capacity utilisation, r is rate of (retained) profits, ur is the unemployment rate, ue is the utilisation of energy resources, um is the utilisation of material resources, K is the capital stock, δ is the depreciation rate, ε_I is a random component that follows an AR(1) process and D_T are damages that stem from climate change. The rate of capacity utilisation and the profit rate affect desired investment in a positive way since firms wish to invest more when profits and sales are high. A higher rate of unemployment leads to lower investment, but only if the unemployment rate is already close to its full employment level. The reason is that a very low unemployment rate might make firms less willing to invest due to the scarcity of available labour. Energy and material resources have a negative impact on desired investment since their scarcity might lead to high energy and raw material prices. However, this negative impact might materialise only in the very long run once these resources become scarce.

Most of the parameters of this investment equation are estimated econometrically and the signs of the independent variables are as expected. For a more detailed description of the investment function, see Dafermos et al. (2018).

A proportion, β, of desired investment takes the form of green investment (I_G^D):

$$I_G^D = \beta I^D \tag{2}$$

The rest is conventional investment (I_C^D):

$$I_C^D = I^D - I_G^D \tag{3}$$

β depends on some exogenous factors that reflect technological changes and policy developments (these are reflected in parameters β_0 and β_1). It also depends on the cost of external funding. There are two sources of external funding: bonds and bank loans. Thus, when firms decide about their desired green investment they compare the interest rate on green loans with the interest rate on conventional loans and the yield of green bonds with the yield of conventional bonds. This is shown in equation (4):

$$\beta = \beta_0 + \beta_1 - \beta_2 \left[sh_{L-1} \left(int_{G-1} - int_{C-1} \right) + \left(1 - sh_{L-1}\right)\left(yield_{G-1} - yield_{C-1} \right) \right] \tag{4}$$

where int_G is the interest rate on green loans, int_C is the interest rate on conventional loans, $yield_G$ is the yield on green bonds, $yield_C$ is the yield on conventional bonds and sh_L is the share of loans in the total liabilities of firms (loans plus bonds). The interest rate on conventional loans is the weighted sum of the interest rate on brown conventional loans and the interest rate on non-brown conventional loans:

$$int_C = sh_B\, int_B - \left(1 - sh_B\right) int_{NBC} \tag{5}$$

where int_B is the interest rate on brown conventional loans, int_{NBC} is the interest rate on non-brown conventional loans and sh_B is the share on brown loans in conventional loans.

Once firms have decided about their desired green and conventional investment, they have to specify the amount of loans that they will demand from banks. This is done via their budget constraint:

$$NL_G^D = I_G^D - \beta RP + repL_{G-1} - \delta K_{G-1} - \bar{p}_G \Delta b_G \tag{6}$$

$$NL_C^D = I_C^D - \left(1-\beta\right) RP + repL_{C-1} - \delta K_{C-1} - \bar{p}_C \Delta b_C \tag{7}$$

Equations (6) and (7) say that firms ask from banks to finance the desired investment that cannot be funded by their retained profits and bond emission. NL_G^D is the desired new green loans, NL_C^D is the desired new conventional loans, RP is firms' retained profits, rep is the principal repayment ratio, L_C is the amount of conventional loans, L_G is the amount of green loans, K_C is the conventional capital, K_G is green capital, $\bar{p}_C$ is the par value of conventional bonds, $\bar{p}_G$ is the par value of green bonds, b_C is the number of conventional bonds and b_G is the number of green bonds.

Banks impose both price and quantity credit rationing. This means that they supply only a fraction of demanded loans. In addition, the loan interest rates are affected by their own financial position and the creditworthiness of the potential borrowers.

The capital adequacy ratio is one of the factors that affect quantity credit rationing. This is in line with the recent empirical literature that has documented a negative effect of capital requirements on bank lending (see e.g. Bridges et al., 2014; Martynova, 2015, Aiyar et al., 2016 and the references therein). There is still no consensus in this literature on whether the effect is strong or weak. Therefore, in our simulations we experiment with a range of parameter values that represent a different amplitude of this effect. The other two factors that affect credit rationing are (i) the debt service ratio of firms which is a proxy of their financial position and (ii) the leverage ratio of banks that is not affected by risk weights and is of growing importance for bank decisions because of Basel III. Overall, the credit rationing function is as follows:

$$CR = f\left(\overset{+}{dsr_{-1}}, \left(lev_{B-1} \overset{+}{-} lev_B^{max}\right), \left(CAR_{-1} \overset{-}{-} CAR^{min}\right)\right) + \varepsilon_{CR} \tag{8}$$

where CR is the degree of total credit rationing on loans (which lies between 0 and 1), dsr is the debt service ratio of firms, lev_B is the bank leverage, lev_B^{max} is the maximum acceptable value of the leverage of banks, CAR is the capital adequacy ratio, CAR^{min} is the minimum acceptable value of the capital adequacy ratio, ε_{CR} is a random component that follows a stochastic AR(1) process. The credit rationing function is non-linear, which reflects that fact that credit rationing is bounded. In addition, the non-linear effect of the capital adequacy ratio on credit rationing is in line with the empirical evidence provided by Deli and Hasan (2017), which shows that capital adequacy requirements do not affect lending when banks have high levels of capital.

The assets of banks consist of green loans, brown conventional loans, non-brown conventional loans, government securities and high-powered money. The capital adequacy ratio is equal to the capital of banks over the risk-weighted assets:

$$CAR = K_B \Big/ \left[w_G L_G + w_B sh_B L_C + w_{NBC} \left(1 - sh_B\right) L_C + w_S SEC_B \right] \tag{9}$$

where w_G is the risk weight on green loans, w_B is the risk weight on brown loans, w_{NBC} is the risk weight on non-brown conventional loans, w_S is the risk weight on government securities, K_B is the capital of banks and SEC_B is the government securities held by banks. By definition, high-powered money has a risk weight equal to one. Under the current financial regulation framework, $w_G = w_B = w_{NBC}$. However, the introduction of green differentiated capital requirements would make w_G lower than w_B and w_{NBC}.

The weight on total loans is defined as:

$$w_{LT} = sh_G w_G + \left(1 - sh_G\right)\left[sh_B w_B + \left(1 - sh_B\right) w_{NBC} \right] \tag{10}$$

where sh_G is the share of desired green loans in total desired loans given by:

$$sh_G = NL_G^D \Big/ \left(NL_G^D + NL_C^D \right)$$

When banks decide about the way that the overall credit rationing will be allocated between green loans and conventional loans, they take into account the relative risk factors. When $w_B = w_{LT}$ and $w_G = w_{LT}$, the credit rationing on green loans and brown loans is the same with the total credit rationing. When $w_G < w_{LT}$, the credit rationing on green loans is more likely to be lower than the total credit rationing and when $w_B > w_{LT}$, the credit rationing on brown loans is more likely to be higher than the total credit rationing.

This is captured by the following equations:

$$CR_B = \left[1 - l_{02} + l_{12}\left(w_B - w_{LT}\right)\right]CR \tag{11}$$

$$CR_G = \left[1 + l_{01} + l_{11}\left(w_G - w_{LT}\right)\right]CR \tag{12}$$

where l_{02}, l_{12}, l_{01} and l_{11} are parameters.

By definition, the total credit rationing is given by:

$$CR = sh_G CR_G + \left(1 - sh_G\right)\left[sh_B CR_B + \left(1 - sh_B\right)CR_{NBC}\right] \tag{13}$$

Solving for CR_{NBC}, yields:

$$CR_{NBC} = \frac{CR - sh_G CR_G - \left(1 - sh_G\right)sh_B CR_B}{\left(1 - sh_G\right)\left(1 - sh_B\right)} \tag{14}$$

The lending interest rate (int) is set as a spread over the base interest rate which is determined by the central banks. This interest rate depends on similar factors as those that affect quantity credit rationing:

$$int = int_A + int_0 + int_1\, dsr_{-1} + int_2\left(lev_{B-1} - lev_B^{max}\right) - int_3\left(CAR_{-1} - CAR^{min}\right) \tag{15}$$

For the effects of capital requirements on interest rates see King (2010), Slovik and Cournede (2011), Hanson et al. (2011) and Akram (2014).

Banks impose a lower interest rate on green loans (int_G) compared to the total interest rate if $w_G < w_{LT}$:

$$int_G = \left[int_{G0} + int_{G1}\left(w_G - w_{LT}\right)\right] int \tag{16}$$

They also impose a higher interest rate on brown loans (int_B) compared to the total interest rate if $w_B > w_{LT}$:

$$int_B = \left[int_{B0} + int_{B1}\left(w_B - w_{LT}\right)\right] int \tag{17}$$

By definition, the interest rate on non-brown conventional loans is equal to:

$$int_{NBC} = \frac{int - sh_{LG}\, int_G - \left(1 - sh_{LG}\right) sh_B\, int_B}{\left(1 - sh_{LG}\right)\left(1 - sh_B\right)} \tag{18}$$

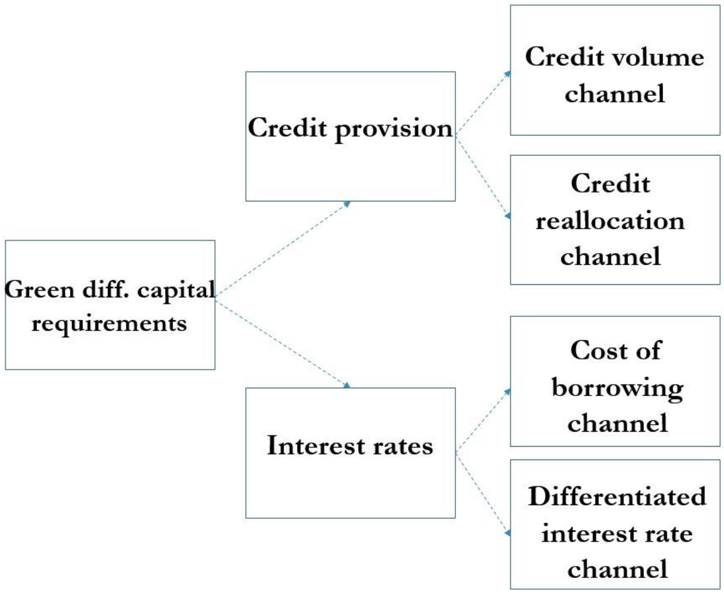
where $sh_{LG} = L_G / L$ is the share of green loans in total loans.

Let us now summarise the channels through which green differentiated capital requirements can affect the credit process in our model (see Fig. 1). There are two channels related with the provision of credit. The first one is what we call the *credit volume channel* and refers to the impact that a change in the way that the capital adequacy ratio is estimated affects total credit rationing. In particular, if a green supporting factor is introduced, w_G declines and this increases the capital adequacy ratio (according to eq. 9), causing a decline in credit rationing, according to eq. (8). On the contrary, under a brown penalising factor, w_B increases causing a decline in capital adequacy ratio and thereby a rise in credit rationing. The significance of the credit volume channel depends on the parameter that captures the responsiveness of credit rationing to the capital adequacy ratio in eq. (8).

The second channel is the *credit reallocation channel*. This channel reflects the impact of relative risk factors on the allocation of credit between green loans and brown loans. With everything else given, both a green supporting factor and a brown penalising factor induce banks to support green loans more compared to brown loans (see eqs. 8, 11 and 12). Quantitatively, the credit reallocation channel is stronger when the responsiveness of green and brown credit to their relative risk weights is high. This responsiveness is captured by the parameters l_{12} and l_{12} in eqs. (11) and (12).

Interestingly, the impact of a green supporting factor on brown loans cannot be determined a priori. If the credit reallocation channel is less significant that the volume channel, brown credit will be positively affected. Otherwise, brown credit might increase. Likewise, the effect of a brown penalising factor on green loans is ambiguous. However, a brown penalising factor will always reduce brown credit since both the volume and the reallocation operate in the same direction.

Fig. 1. Transmission channels of green differentiated capital requirements



There are two additional channels that refer to the impact of green differentiated capital requirements on the interest rates: the *cost of borrowing channel* and the *differentiated interest rate channel*. The cost of borrowing channel is straightforward: any change in the risk weights that leads to a lower (higher) capital adequacy ratio causes a rise (decline) in the overall interest rate; this in turn affects the profits of firms and thus their desired investment which determines the demand for credit. Therefore, a green supporting factor reduces the interest rates and tends to increase the demand for credit. A brown penalising factor does the opposite. The strength of this channel depends on the responsiveness of the interest rate to the capital adequacy ratio.

The differentiated interest rate channel operates via eqs. (16) and (17). Any change in financial regulation that makes w_G lower than w_B leads to a lower interest rate on green loans than the interest rate on brown loans. Why is this important? According to eq. (4), firms wish to invest more in green loans if the cost of borrowing on green loans compared to conventional loans declines. Hence, a green supporting and a brown penalising factor increase the demand for green credit compared to conventional credit. This channel is more significant when the parameters int_{G1}, int_{B1} and int_{G2} in eqs. (15, (16) and (17) are high as well as when b_2 in eq. (4) is high.

3. Calibration, estimation and validation of the model

Our model has been calibrated and validated by using data at the global level. The parameter values have been determined via a variety of ways. First, some of them have been estimated via econometric equations using panel data. This is the case with our investment, consumption and labour productivity functions. Second, some other parameter values have been calibrated based on previous studies or related data. If we cannot directly rely on previous studies or related data, we select values from a reasonable range and we conduct a sensitivity analysis for those that have a more crucial role for our results. Third, a few parameters have been indirectly calibrated such that the model produces the baseline scenario described below or matches the initial values obtained from the data. The related details are reported in Appendix D. Concerning the parameter values that affect the transmission channels of green differentiated capital requirements, these have been selected based broadly on previous empirical studies.[3]

We run our model for the period 2016-2120. We perform 200 Monte Carlo simulations and we report the across-run averages. In our baseline scenario the transition to a low-carbon economy is very slow and the global economy continues to expand in broad line with recent trends. Table 5 shows some of the main features of this scenario. The slow transition to a low-carbon economy is reflected in the fact that the improvement in CO_2 intensity (industrial emissions per unit of fossil-fuel energy), energy efficiency and in the use of renewables is very gradual. Consequently, carbon emissions continue to increase, causing severe global warming.

[3] The next versions of the paper will provide more details about the way that these parameter values have been selected and will conduct a thorough sensitivity analysis.

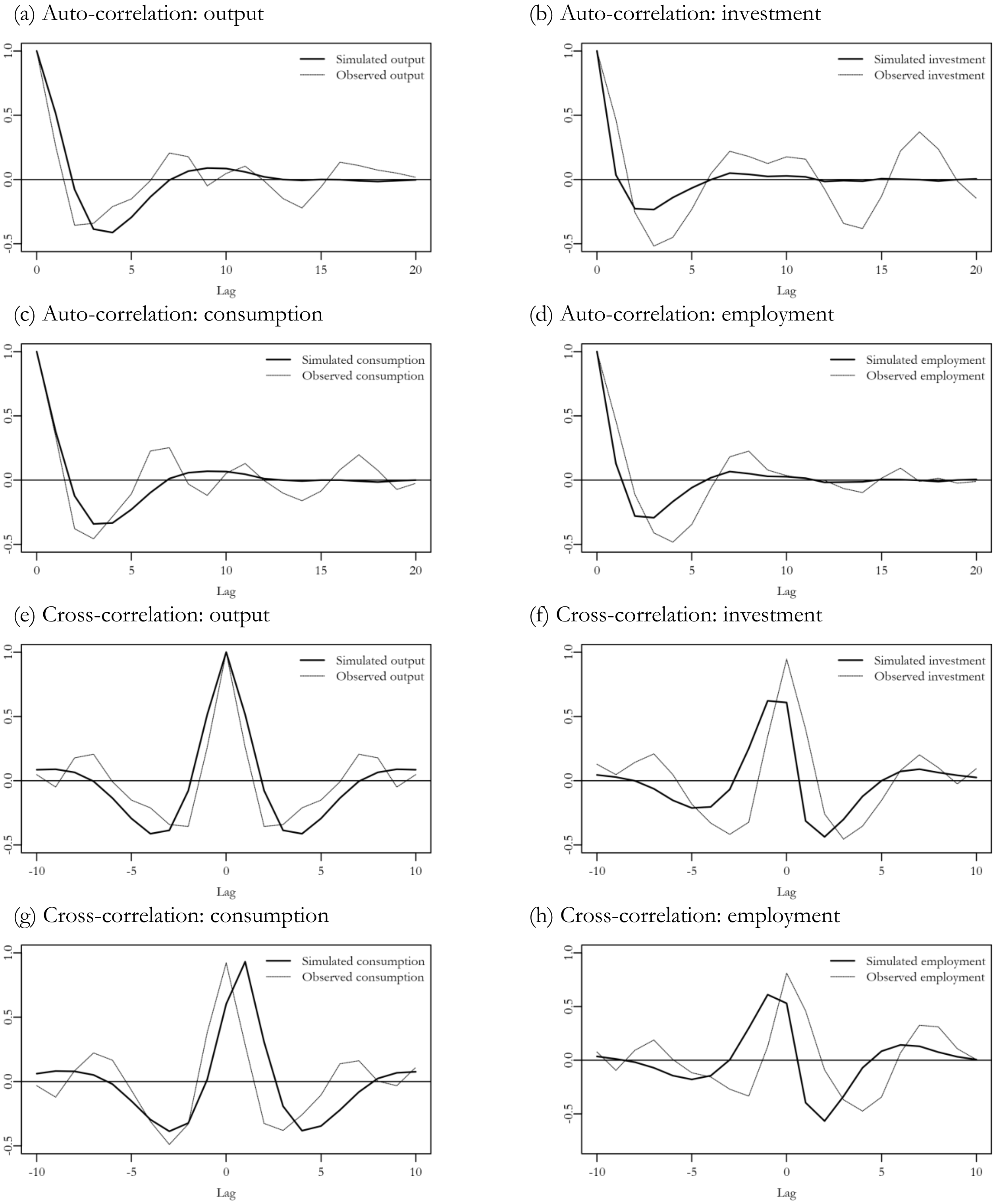
Table 5: Key features of the baseline scenario

Variable	Value/trend
Economic growth till 2050	slightly lower than 2.7% (on average)
Unemployment rate till 2050	slightly lower than 6% (on average)
Population in 2050	9.77bn
Labour force-to-population ratio in 2050	0.45
Default rate till 2050	slightly higher than 4% (on average)
CO_2 intensity in 2050 as a ratio of CO_2 intensity in 2016	around 0.9
Share of renewable energy in total energy in 2050	around 25%
Energy intensity in 2050 as a ratio of energy intensity in 2016	around 0.7
Annual green investment in the period 2016-2040	around US$1.1tn
Energy use in 2040 as a ratio of energy use in 2016	around 1.4

In order to validate the model we compare the auto- and cross-correlation structure of our simulated data with the observed ones. This allows us to check whether the model produces data with reasonable time-series properties. The results are shown in Fig. 1. Figs. 1a-1d report the auto-correlation structure of the cyclical component of the simulated and observed time series for output, consumption, investment and employment up to 20 lags. Figs. 1e-1h show the correlation between the cyclical component of output at time *t* and of output, investment, consumption and employment at time *t-lag*. The series are expressed in logs and the Hodrick-Prescott filter has been used to isolate the cyclical component. The simulated data refer to the baseline scenario.

It can be observed that the auto-correlation structure of our simulated data is similar to the auto-correlation structure of the observed data. Moreover, simulated investment, consumption and employment are pro-cyclical as in the empirical data, and their overall cross-correlation with output is similar to the cross-correlation observed in the real data. Hence, it can be argued that our model generates data with empirically reasonable properties.

Fig. 1: Auto-correlations and cross-correlations of observed and simulated data



Note: The series are expressed in logs and the Hodrick-Prescott filter has been used to isolate the cyclical component. For the simulated data, the across-run average autocorrelations and cross-correlations have been reported. The data for the observed variables have been taken from World Bank and refer to the global economy. Real output is available for the period 1960-2016, real consumption and real investment are available for the period 1970-2016 and employment is available for the period 1991-2016.

4. Effects of green differentiated capital requirements

As shown in Fig. 2, in the baseline scenario climate change reduces long-run economic growth and causes financial instability after a few decades. In particular, since the transition to a low-carbon economy is slow, the reliance of economic activity on fossil fuels results in a continuous increase in carbon emissions (Fig. 2c) that brings about a global warming of about 4°C in 2100. The resulting climate damages reduce economic activity (Fig. 2a) and lead to a decline in the profitability of firms (Fig. 2e) that increases their default rate (Fig. 2f). This rise in the default rate harms the profits of banks and thereby their leverage ratio (Fig. 2g).

How can green differentiated capital requirements affect financial stability, climate change and economic growth? We consider two policy scenarios according to which green differentiated capital requirements are introduced in 2020. In the first policy scenario a green supporting factor is implemented: the risk weight on green loans declines by 25 percentage points. In the second policy scenario financial regulators adopt a brown penalising factor: the risk weight on brown loans increases by 25 percentage points. Fig. 2 depicts the effects of these policies. For the brown penalising factor we present a range that refers to the way that brown loans are defined by policy makers. We have made a distinction between a 'narrow' and a 'broad' definition of brown loans. Brown loans are narrowly defined when they capture only these loans that are provided to investment projects that are directly linked with generation of fossil-fuel energy. On the contrary, under a broad definition, brown loans are those loans that lead to a higher generation of fossil-fuel energy not only directly, but also indirectly (for example, because they lead to the production of capital that relies on the consumption of brown energy). In our simulations the narrow definition corresponds to the case in which $sh_B = 0.2$; under the broad definition, $sh_B = 0.9$.

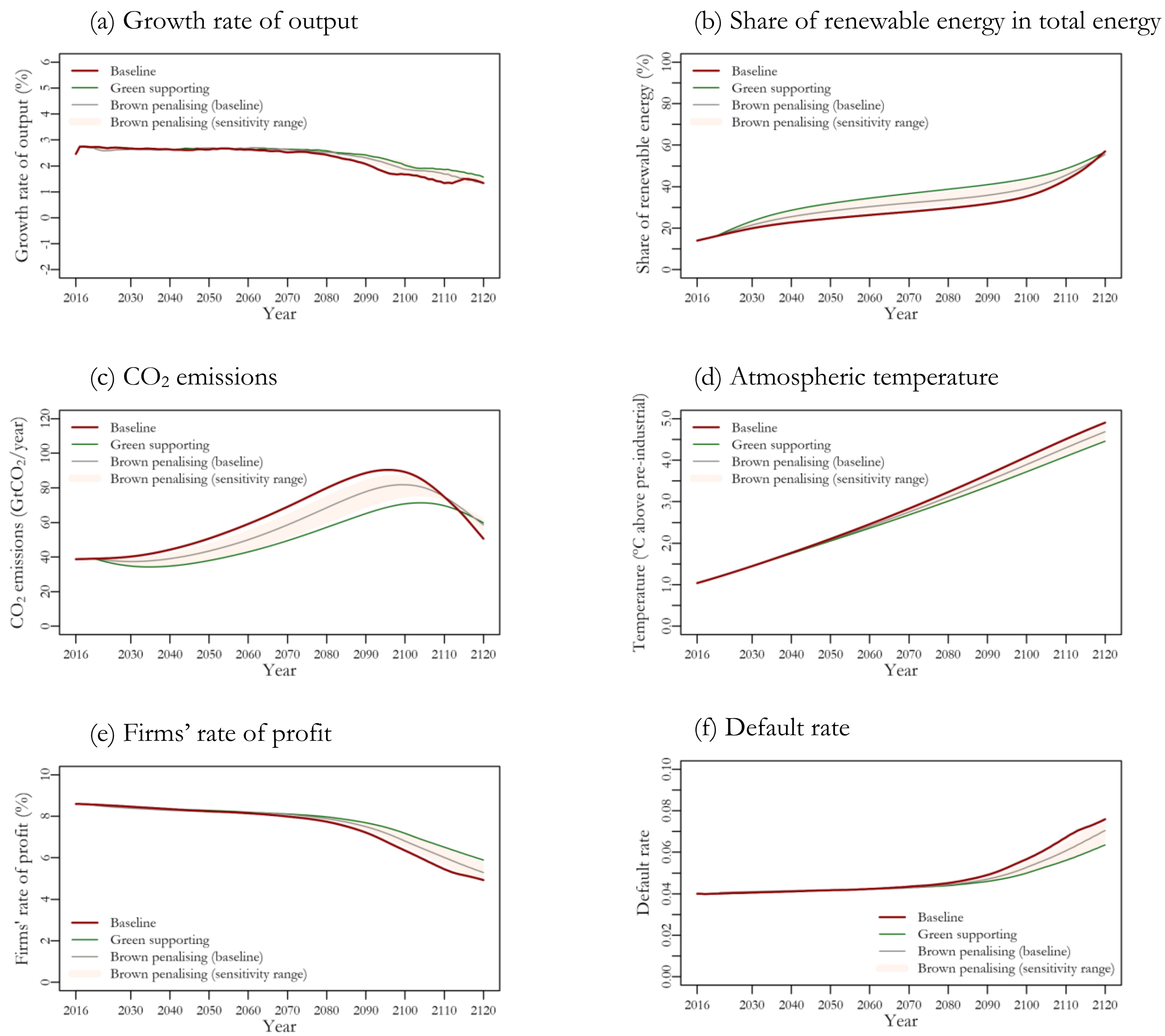
Let us first focus on the overall effects of green differentiated capital requirements. Under both the green supporting and the brown penalising factor, green investment is boosted compared to brown investment. This is so because of the *credit reallocation channel* and the *differentiated interest rate channel*. With the introduction of green differentiated capital requirements, green loans become more attractive for banks compared to conventional loans, inducing them to reduce credit rationing on green loans (Fig. 2i), increase credit rationing on brown loans (Fig. 2j), reduce the interest rate on green loans (Fig 2k) and increase the interest rate on brown loans (Fig. 2l). As a result, the share of renewable energy increases (Fig. 2b) and energy efficiency improves, making climate change slightly less severe compared to the baseline scenario (Fig. 2d). The lower atmospheric temperature reduces climate damages and this results in higher economic growth (Fig. 1a), lower defaults (Fig. 1f) and lower bank leverage (Fig. 1g) in comparison with the baseline scenario.

How does the impact of the brown penalising factor differ from the impact of the green supporting factor? Table 1 summarises the main differences in the effects of the green supporting and the brown penalising factor. A first issue to consider is the effects of these policies on bank leverage, which is a proxy of the fragility of the banking system. Due to the *credit volume channel*, the brown penalising factor increases overall credit rationing. A higher credit rationing reduces the leverage of banks (Fig. 2g). This effect is more significant when a broad definition of brown loans is adopted by policy makers. In that case, the capital adequacy ratio is reduced more since the change in capital requirements affects a higher proportion of bank loans (see Fig. 2h). On the contrary, under the green supporting factor, the capital adequacy ratio increases, this leads to higher credit rationing and thus to a higher bank leverage. Note, though, that the rise in bank leverage is quantitatively small since green loans constitute a small proportion of total loans.

Table 1. Key differences in the impact of the green supporting and the brown penalising factor

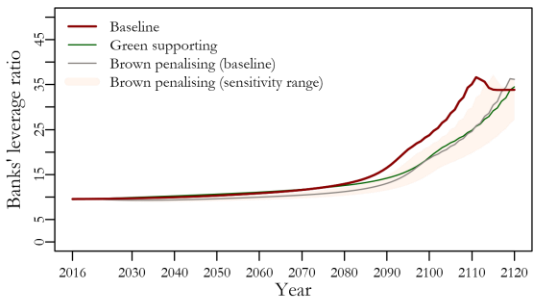
	Green supporting factor	**Brown penalising factor (narrow definition of 'brown' loans)**	**Brown penalising factor (broad definition of 'brown' loans)**
Bank leverage	Increases	Decreases	Decreases
Renewables/energy efficiency	Improves	Improves slightly	Improves
Transition macro costs	No	Low	Relatively high

Fig. 2: Effects of the implementation of green differentiated capital requirements

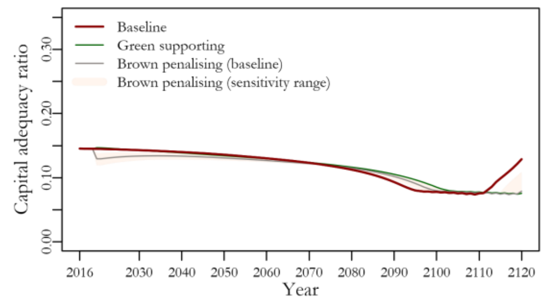


(continued from the previous page)

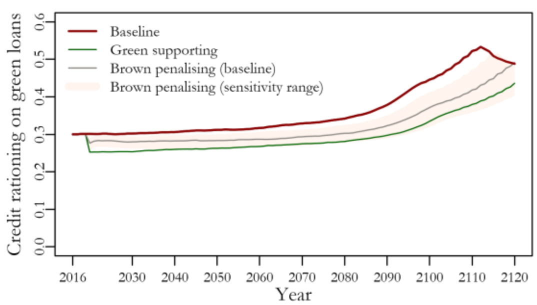
(g) Banks' leverage ratio



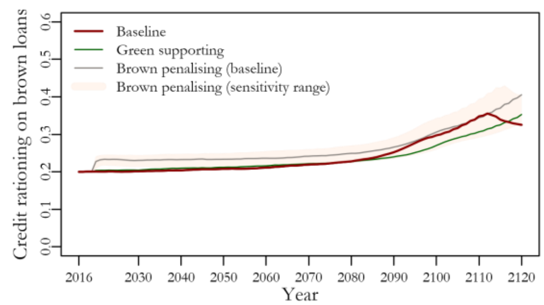
(h) Capital adequacy ratio



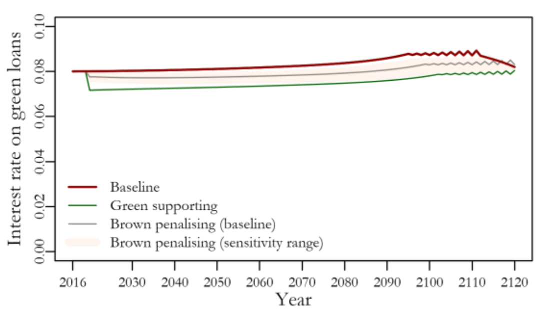
(i) Credit rationing on green loans



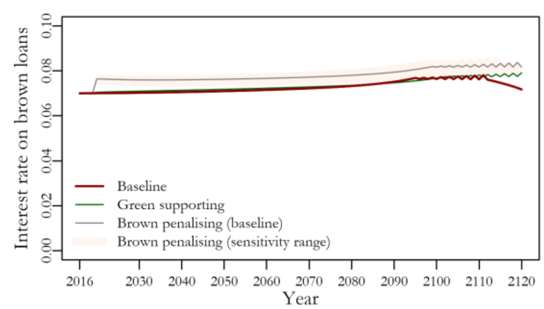
(j) Credit rationing on brown loans



(k) Interest rate on green loans



(l) Interest rate on brown loans



Note: The figure reports across-run averages from 100 Monte Carlo simulations. The values used in the simulations are reported in Appendix C and Appendix D (baseline scenario). In the sensitivity range for the brown penalising factor sh_B *(the share of brown loans in total loans) takes values between 0.2 and 0.9.*

Overall, it can be argued that the brown penalising factor is more conducive to the stability of banks than the green supporting factor, at least in the initial period of the implementation of green differentiated capital requirements. The difference between the two measures is higher the broader is the definition of brown loans.

Regarding climate change, the green supporting factor turns out to be more effective in reducing global warming. The reason is twofold. First, the green supporting factor does not lead to higher overall credit rationing, as it is the case with the brown penalising factor. At the same time, it reduces more the difference between w_G and w_{LT}. Based on eq. (11), this implies that credit rationing on green loans declines more compared to the case in which a brown penalising factor is implemented (see Fig. 2i). Second, the difference between the interest rate on green loans and the interest rate on conventional loans changes more when the green supporting factor is implemented. Thus, the green supporting factor has a more positive impact on desired green investment. However, the difference between the two policies is reduced when policy makers adopt a broader definition of brown loans. If the definition is broad enough, the impact of the two policies on atmospheric temperature is almost identical (see Fig. 2d).

An additional difference between the green supporting and the brown penalising factor is their transition costs. Since the brown penalising factor affects a higher proportion of brown loans, it leads to an increase in overall credit rationing. As shown in Fig 2a, this initially leads to lower economic growth. This decline in growth is higher the broader is the definition of brown loans. Under the green supporting factor, there is almost no transition cost.

5. Conclusion

Financial regulation can play a crucial role in supporting the transition to a low-carbon economy. Yet our understanding of the potential effects of green financial regulation is still limited. This paper has developed a model that has analysed the dynamic effects of the brown penalising and the green supporting factor on climate change, financial stability and economic growth, providing the first integrated analysis of the potential impact of these policies.

We have shown that the implementation of the brown penalising factor or the green supporting factor at the global level could reduce the pace of climate change, contributing to financial stability in the long run. The comparison between the two alternative policies reveals that the brown penalising factor is a preferable policy when emphasis is placed on the stability of the banking system: our simulations show that the leverage of banks is lower compared to the case in which the green supporting factor is in place. However, the differences between the two policies are more complicated when we focus on climate change and transition costs. Since brown loans constitute a significant part of the existing bank loans, the implementation of the brown penalising factor could reduce credit to a significant part of the firm sector. This would have some recession effects at least in the short run. The magnitude of these effects is larger when a broad definition of brown loans is adopted. Regarding climate change, the green supporting factor has more beneficial effects than the brown penalising factor, but the difference between the two policies is negligible when a broad definition of brown loans is used by policy maker.

Overall, if financial regulators wish to promote a low-leverage banking sector in the next years, the brown-penalising factor turns out to be the appropriate policy. However, there is a trade-off. If brown loans are defined in a broad way so as to include loans that contribute both directly and indirectly to carbon emissions, the transition macro costs will be larger. If, on the other hand, brown loans are defined in a narrow way, the beneficial effects of the brown penalising factor on climate will be lower compared to the effects of the green supporting factor.

The model developed in this paper could be extended in a number of ways in order to address additional issues about the implementation of green differentiated capital requirements. For example, a housing market could be introduced in order to capture the impact on green and brown housing loans. Moreover, an explicit distinction could be made between a 'green' and a 'brown' firm sector. This would permit the analysis of some additional transition costs of green differentiated capital requirement and would also allow a more detailed examination of the possibility of a green bubble. These extensions are left for future research.

References

Aiyar, S., Calomiris, C.W. and Wieladek, T., 2016. How does credit supply respond to monetary policy and bank minimum capital requirements?. European Economic Review, 82, 142-165.

Akram, Q.F., 2014. Macro effects of capital requirements and macroprudential policy. Economic Modelling, 42, 77-93.

Alli Abbas, S.M., Blattner, L., De Broeck, M., El-Ganainy, A., Huet, M., 2014. Sovereign debt composition in advanced economies: a historical perspective. IMF Working Paper 14-162.

Allianz, 2017. Global Wealth Report 2017. Allianz Economic Research.

Bovari, E., Giraud, G., Mc Isaac, F., 2018. Coping with collapse: a stock-flow consistent monetary macrodynamics of global warming. Ecological Economics 147, 383-398.

BGR, 2016. Energy Study 2016: Reserves, Resources and Availability of Energy Resources. Federal Institute for Geosciences and Natural Resources (BGR).

Bridges, J., Gregory, D., Nielsen, M., Pezzini, S., Radia, A. and Spaltro, M., 2014. The impact of capital requirements on bank lending. Bank of England Working Paper No. 486.

Caiani, A., Godin, A., Caverzasi, E., Gallegati, M., Kinsella, S., Stiglitz, J.E., 2016. Agent based-stock flow consistent macroeconomics: towards a benchmark model. Journal of Economic Dynamics and Control, 69, 375-408.

Campiglio, E., 2016. Beyond carbon pricing: the role of banking and monetary policy in financing the transition to a low-carbon economy. Ecological Economics, 121, 220-230.

Climate Bonds Initiative, 2017a. Green Bonds Highlights 2016, CBI, London.

Climate Bonds Initiative, 2017b. Bonds and climate change: the state of the market in 2017, available at: https://www.climatebonds.net/resources/reports/bonds-and-climate-change-state-market-2017.

Dafermos, Y., Nikolaidi, M., Galanis, G., 2017. A stock-flow-fund ecological macroeconomic model. Ecological Economics, 131, 191-207.

Dafermos, Y., Nikolaidi, M., Galanis, G., 2018. Climate change, financial stability and monetary policy. Ecological Economics, 152, 219-234.

Deli, Y.D. and Hasan, I., 2017. Real effects of bank capital regulations: Global evidence. Journal of Banking and Finance, 82, pp.217-228.

Dietz, S. Bowen, A., Dixon, C., Gradwell, P., 2016. 'Climate value at risk' of global financial assets. Nature Climate Change, published online: 4 April 2016, doi: 10.1038/NCLIMATE2972.

EEA, 2012. Material Resources and Waste – 2012 Update: The European Environment State and Outlook 2010. EEA, Copenhagen.

European Commission, 2018. Financing a Sustainable European Economy, Final Report 2018 by the High Level Expert Group on Sustainable Finance Final Report, European Commission.

FTSE Russell, 2016. FTSE Global Bond Index Series.

Haas, W., Krausmann, F., Wiedenhofer, D., Heinz, M., 2015. How circular is the global economy? An assessment of material flows, waste production, and recycling in the European Union and the world in 2005. Journal of Industrial Ecology, 19 (5), 765-777.

Hanson, S.G., Kashyap, A.K. and Stein, J.C., 2011. A macroprudential approach to financial regulation. Journal of economic Perspectives, 25 (1), pp.3-28.

IEA, 2016. World Energy Outlook 2016. International Energy Agency.

Jakab, J., Kumhof, M., 2015. Banks are not intermediaries of loanable funds - and why this matters. Bank of England Working Paper No. 529.

King, M., 2010. Mapping capital and liquidity requirements to bank lending spreads. BIS Working Papers No. 324.

Lamperti, F., Dosi, G., Napoletano, M., Roventini, A. and Sapio, A., 2018. Faraway, so close: coupled climate and economic dynamics in an agent-based integrated assessment model. Ecological Economics, 150, 315-339.

Martynova, N., 2015. Effect of bank capital requirements on economic growth: a survey. DNB Working Paper No. 467.

Nordhaus, W., 2016. Projections and uncertainties about climate change in an era of minimal climate policies. Cowles Foundation Discussion Paper 2057.

OECD, 2017. Mobilising Bond Markets for a Low-Carbon Transition. OECD, Paris.

Raberto, M., Ozel, B., Ponta, L., Teglio, A. and Cincotti, S., 2018. From financial instability to green finance: the role of banking and credit market regulation in the Eurace model. Journal of Evolutionary Economics, 1-37.

Slovik, P. and B. Cournède (2011), Macroeconomic Impact of Basel III. OECD Economics Department Working Papers, No. 844, OECD Publishing.

Thomä, J., and Hilke, A., 2018. The Green Supporting Factor: Quantifying the Impact on European Banks and Green Finance. 2 Degrees Investing Initiative.

UNEP, 2011. Estimating long-run geological stocks of metals. UNEP Working Paper April 6.

Volz, U., 2017. On the Role of Central Banks in Enhancing Green Financing. UN Environment Inquiry Working Paper No. 17/01, Geneva.

Weitzman, M.L., 2012. GHG targets as insurance against catastrophic climate damages. Journal of Public Economic Theory, 14 (2), 221-244.

Appendix A

Table 1: Physical flow matrix

	Material balance	Energy balance
Inputs		
Extracted matter	$+M$	
Renewable energy		$+ER$
Non-renewable energy	$+CEN$	$+EN$
Oxygen used for fossil fuel combustion	$+O2$	
Outputs		
Industrial CO_2 emissions	$-EMIS_{IN}$	
Waste	$-W$	
Dissipated energy		$-ED$
Change in socio-economic stock	$-\Delta SES$	
Total	0	0

Note: The table refers to annual global flows. Matter is measured in Gt and energy is measured in EJ. A detailed description of the symbols can be found in Appendix C and Appendix D.

Table 2: Physical stock-flow matrix

	Material reserves	Non-renewable energy reserves	Atmospheric CO_2 concentration	Socio-economic stock	Hazardous waste
Opening stock	$REV_{M\text{-}1}$	$REV_{E\text{-}1}$	$CO2_{AT\text{-}1}$	$SES_{\text{-}1}$	$HWS_{\text{-}1}$
Additions to stock					
Resources converted into reserves	$+CON_M$	$+CON_E$			
CO_2 emissions			$+EMIS$		
Production of material goods				$+MY$	
Non-recycled hazardous waste					$+hazW$
Reductions of stock					
Extraction/use of matter or energy	$-M$	$-EN$			
Net transfer of CO_2 to oceans/biosphere			$+(\phi_{11}-1)CO2_{AT-1}+\phi_{21}CO2_{UP-1}$		
Demolished/disposed socio-economic stock				$-DEM$	
Closing stock	REV_M	REV_E	$CO2_{AT}$	SES	HWS

Note: The table refers to annual global stocks and flows. Matter is measured in Gt and energy is measured in EJ. A detailed description of the symbols can be found in Appendix C and Appendix D.

Table 3: Transactions flow matrix

	Households		Firms		Commercial banks		Government sector	Central banks		Total
	Current	Capital	Current	Capital	Current	Capital		Current	Capital	
Consumption		$-C$	$+C$							0
Government expenditures			$+G$				$-G$			0
Conventional investment			$+I_C$	$-I_C$						0
Green investment			$+I_G$	$-I_G$						0
Household disposable income net of depreciation	$-Y_{HD}$	$+Y_{HD}$								0
Wages	$+wN$		$-wN$							0
Taxes	$-T_H$		$-T_F$				$+T$			0
Firms' profits	$+DP$		$-TP$	$+RP$						0
Commercial banks' profits	$+BP_D$				$-BP$	$+BP_U$				0
Interest on deposits	$+int_D D_{-1}$				$-int_D D_{-1}$					0
Depreciation of green capital			$-\delta K_{G-1}$	$+\delta K_{G-1}$						0
Depreciation of conventional capital			$-\delta K_{C-1}$	$+\delta K_{C-1}$						0
Interest on conventional loans			$-int_C L_{C-1}$		$+int_C L_{C-1}$					0
Interest on green loans			$-int_G L_{G-1}$		$+int_G L_{G-1}$					0
Interest on conventional bonds	$+coupon_C b_{CH-1}$		$-coupon_C b_{C-1}$					$+coupon_C b_{CCB-1}$		0
Interest on green bonds	$+coupon_G b_{GH-1}$		$-coupon_G b_{G-1}$					$+coupon_G b_{GCB-1}$		0
Interest on government securities	$+int_S SEC_{H-1}$				$+int_S SEC_{B-1}$		$-int_S SEC_{-1}$	$+int_S SEC_{CB-1}$		0
Interest on advances					$-int_A A_{-1}$			$+int_A A_{-1}$		0
Depreciation of durable consumption goods	$-\xi DC_{-1}$	$+\xi DC_{-1}$								0
Central bank's profits							$+CBP$	$-CBP$		0
Bailout of banks						$+BAILOUT$	$-BAILOUT$			0
Δdeposits		$-\Delta D$				$+\Delta D$				0
Δconventional loans				$+\Delta L_C$		$-\Delta L_C$				0
Δgreen loans				$+\Delta L_G$		$-\Delta L_G$				0
Δconventional bonds		$-\bar{p}_C \Delta b_{CH}$		$+\bar{p}_C \Delta b_C$					$-\bar{p}_C \Delta b_{CCB}$	0
Δgreen bonds		$-\bar{p}_G \Delta b_{GH}$		$+\bar{p}_G \Delta b_G$					$-\bar{p}_G \Delta b_{GCB}$	0
Δgovernment securities		$-\Delta SEC_H$				$-\Delta SEC_B$	$+\Delta SEC$		$-\Delta SEC_{CB}$	0
Δadvances						$+\Delta A$			$-\Delta A$	0
Δhigh-powered money						$-\Delta HPM$			$+\Delta HPM$	0
Defaulted loans				$+DL$		$-DL$				0
Total	0	0	0	0	0	0	0	0	0	0

Note: The table refers to annual global flows in trillion US$. A detailed description of the symbols can be found in Appendix C and Appendix D.

Table 4: Balance sheet matrix

	Households	Firms	Commercial banks	Government sector	Central banks	Total
Conventional capital		$+K_C$				$+K_C$
Green capital		$+K_G$				$+K_G$
Durable consumption goods	$+DC$					$+DC$
Deposits	$+D$		$-D$			0
Conventional loans		$-L_C$	$+L_C$			0
Green loans		$-L_G$	$+L_G$			0
Conventional bonds	$+p_C b_{CH}$	$-p_C b_C$			$+p_C b_{CCB}$	0
Green bonds	$+p_G b_{GH}$	$-p_G b_G$			$+p_G b_{GCB}$	0
Government securities	$+SEC_H$		$+SEC_B$	$-SEC$	$+SEC_{CB}$	0
High-powered money			$+HPM$		$-HPM$	0
Advances			$-A$		$+A$	0
Total (net worth)	$+V_H$	$+V_F$	$+K_B$	$-SEC$	$+V_{CB}$	$+K_C + K_G + DC$

Note: The table refers to annual global stocks in trillion US$. A detailed description of the symbols can be found in Appendix C and Appendix D.

Appendix B

1 Ecosystem

1.1 Matter, recycling and waste

$$MY = \mu(Y - G) \tag{B1}$$

$$M = MY - REC \tag{B2}$$

$$REC = \rho DEM \tag{B3}$$

$$DEM = \mu(\delta K_{-1} + \xi DC_{-1}) \tag{B4}$$

$$SES = SES_{-1} + MY - DEM \tag{B5}$$

$$W = M + CEN + O2 - EMIS_{IN} - \Delta SES \tag{B6}$$

$$CEN = \frac{EMIS_{IN}}{car} \tag{B7}$$

$$O2 = EMIS_{IN} - CEN \tag{B8}$$

$$HWS = HWS_{-1} + hazW \tag{B9}$$

$$hazratio = \frac{HWS}{POP} \tag{B10}$$

$$REV_M = REV_{M-1} + CON_M - M \tag{B11}$$

$$CON_M = con_M RES_{M-1} \tag{B12}$$

$$RES_M = RES_{M-1} - CON_M \tag{B13}$$

$$dep_M = \frac{M}{REV_{M-1}} \tag{B14}$$

1.2 Energy

$$E = \varepsilon Y \tag{B15}$$

$$ER = \theta E \tag{B16}$$

$$EN = E - ER \tag{B17}$$

$$ED = EN + ER \tag{B18}$$

$$REV_E = REV_{E-1} + CON_E - EN \tag{B19}$$

$$CON_E = con_E RES_{E-1} \tag{B20}$$

$$RES_E = RES_{E-1} - CON_E \tag{B21}$$

$$dep_E = \frac{EN}{REV_{E-1}} \tag{B22}$$

1.3 Emissions and climate change

$$EMIS_{IN} = \omega EN \tag{B23}$$

$$EMIS_{L} = EMIS_{L-1}(1 - lr) \tag{B24}$$

$$EMIS = EMIS_{IN} + EMIS_{L} \tag{B25}$$

$$CO2_{AT} = EMIS + \phi_{11}CO2_{AT-1} + \phi_{21}CO2_{UP-1} \tag{B26}$$

$$CO2_{UP} = \phi_{12}CO2_{AT-1} + \phi_{22}CO2_{UP-1} + \phi_{32}CO2_{LO-1} \tag{B27}$$

$$CO2_{LO} = \phi_{23}CO2_{UP-1} + \phi_{33}CO2_{LO-1} \tag{B28}$$

$$F = F_{2\times CO2}\, log_{2} \frac{CO2_{AT}}{CO2_{AT-PRE}} + F_{EX} \tag{B29}$$

$$F_{EX} = F_{EX-1} + fex \tag{B30}$$

$$T_{AT} = T_{AT-1} + t_{1}\left(F - \frac{F_{2\times CO2}}{S} T_{AT-1} - t_{2}(T_{AT-1} - T_{LO-1})\right) \tag{B31}$$

$$T_{LO} = T_{LO-1} + t_{3}(T_{AT-1} - T_{LO-1}) \tag{B32}$$

1.4 Ecological efficiency and technology

$$\omega = \omega_{-1}(1 + g_{\omega}) \tag{B33}$$

$$g_{\omega} = g_{\omega-1}(1 - \zeta_{1}) \tag{B34}$$

$$\mu = \mu^{max} - \frac{\mu^{max} - \mu^{min}}{1 + \pi_{1} e^{-\pi_{2}(K_{G-1}/K_{C-1})}} \tag{B35}$$

$$\rho = \frac{\rho^{max}}{1 + \pi_{3} e^{-\pi_{4}(K_{G-1}/K_{C-1})}} \tag{B36}$$

$$\varepsilon = \varepsilon^{max} - \frac{\varepsilon^{max} - \varepsilon^{min}}{1 + \pi_{5} e^{-\pi_{6}(K_{G-1}/K_{C-1})}} \tag{B37}$$

$$\theta = \frac{1}{1 + \pi_{7} e^{-\pi_{8}(K_{G-1}/K_{C-1})}} \tag{B38}$$

2 Macroeconomy and financial system

2.1 Output determination and damages

$$Y_{M}^{*} = \frac{REV_{M-1} + REC}{\mu} \tag{B39}$$

$$Y_E^* = \frac{REV_{E-1}}{(1-\theta)\varepsilon} \tag{B40}$$

$$Y_K^* = vK \tag{B41}$$

$$Y_N^* = \lambda hLF \tag{B42}$$

$$Y^* = min\left(Y_M^*, Y_E^*, Y_K^*, Y_N^*\right) \tag{B43}$$

$$Y = C + I + G \tag{B44}$$

$$um = \frac{Y-G}{Y_M^*} \tag{B45}$$

$$ue = \frac{Y}{Y_E^*} \tag{B46}$$

$$u = \frac{Y}{Y_K^*} \tag{B47}$$

$$re = \frac{Y}{Y_N^*} \tag{B48}$$

$$D_T = 1 - \frac{1}{1+\eta_1 T_{AT} + \eta_2 {T_{AT}}^2 + \eta_3 {T_{AT}}^{6.754}} \tag{B49}$$

$$D_{TP} = pD_T \tag{B50}$$

$$D_{TF} = 1 - \frac{1-D_T}{1-D_{TP}} \tag{B51}$$

2.2 Firms

$$TP_G = Y - wN - int_C\, L_{C-1} - int_G\, L_{G-1} - \delta K_{-1} - coupon_C b_{C-1} - coupon_G b_{G-1} \tag{B52}$$

$$TP = TP_G - T_F \tag{B53}$$

$$RP = s_F TP_{-1} \tag{B54}$$

$$DP = TP - RP \tag{B55}$$

$$r = RP/K \tag{B56}$$

$$I^D = \left(\frac{\alpha_{00}}{1+exp\left(\alpha_{01} - \alpha_1 u_{-1} - \alpha_2 r_{-1} + \alpha_{31} ur_{-1}^{-\alpha_{32}} + \alpha_{41}\left(1-ue_{-1}\right)^{-\alpha_{42}} + \alpha_{51}\left(1-um_{-1}\right)^{-\alpha_{52}}\right)} K_{-1} + \varepsilon_I K_{-1} + \delta K_{-1}\right)\left(1-D_{T-1}\right) \tag{B57}$$

$$I_G^D = \beta I^D \tag{B58}$$

$$I_C^D = I^D - I_G^D \tag{B59}$$

$$\beta = \beta_0 + \beta_1 - \beta_2\left[sh_{L-1}\left(int_{G-1} - int_{C-1}\right) + \left(1-sh_{L-1}\right)\left(yield_{G-1} - yield_{C-1}\right)\right] \tag{B60}$$

$$\beta_0 = \beta_{0-1}(1+g_{\beta 0}) \tag{B61}$$

$$g_{\beta 0} = g_{\beta 0-1}\left(1-\zeta_2\right) \tag{B62}$$

$$NL_G^D = I_G^D - \beta RP + repL_{G-1} - \delta K_{G-1} - \bar{p}_G \Delta b_G \quad \text{(B63)}$$

$$NL_C^D = I_C^D - (1-\beta) RP + repL_{C-1} - \delta K_{C-1} - \bar{p}_C \Delta b_C \quad \text{(B64)}$$

$$I_G = \beta RP + \Delta L_G + \delta K_{G-1} + \bar{p}_G \Delta b_G + defL_{G-1} \quad \text{(B65)}$$

$$I_C = RP + \Delta L_C + \Delta L_G + \delta K_{-1} - I_G + \bar{p}_G \Delta b_G + \bar{p}_C \Delta b_C + DL \quad \text{(B66)}$$

$$I = I_C + I_G \quad \text{(B67)}$$

$$L = L_C + L_G \quad \text{(B68)}$$

$$K_G = K_{G-1} + I_G - \delta K_{G-1} \quad \text{(B69)}$$

$$K_C = K_{C-1} + I_C - \delta K_{C-1} \quad \text{(B70)}$$

$$K = K_C + K_G \quad \text{(B71)}$$

$$\kappa = K_G / K \quad \text{(B72)}$$

$$\delta = \delta_0 + (1-\delta_0)(1-ad_K) D_{TF-1} \quad \text{(B73)}$$

$$v = v_{-1}\left[1-(1-ad_P) D_{TP-1}\right] \quad \text{(B74)}$$

$$g_\lambda = \sigma_0 + \sigma_1 + \sigma_2 g_{Y-1} \quad \text{(B75)}$$

$$\sigma_0 = \sigma_{0-1}(1-\zeta_3) \quad \text{(B76)}$$

$$\lambda = \lambda_{-1}(1+g_\lambda)\left[1-(1-ad_P) D_{TP-1}\right] \quad \text{(B77)}$$

$$w = s_W \lambda h \quad \text{(B78)}$$

$$N = \frac{Y}{h\lambda} \quad \text{(B79)}$$

$$ur = 1 - re \quad \text{(B80)}$$

$$b_C = b_{C-1} + \frac{x_1 I_C^D}{\bar{p}_C} \quad \text{(B81)}$$

$$b_G = b_{G-1} + \frac{x_2 I_G^D}{\bar{p}_G} \quad \text{(B82)}$$

$$x_1 = x_{10} - x_{11} yield_{C-1} \quad \text{(B83)}$$

$$x_2 = x_{20} - x_{21} yield_{G-1} \quad \text{(B84)}$$

$$x_{20} = x_{20-1}(1+g_{x20}) \quad \text{(B85)}$$

$$g_{x20} = g_{x20-1}(1-\zeta_4) \quad \text{(B86)}$$

$$yield_C = \frac{coupon_C}{p_C} \quad \text{(B87)}$$

$$yield_G = \frac{coupon_G}{p_G} \quad \text{(B88)}$$

$$coupon_C = yield_{C-1} \bar{p}_C \quad \text{(B89)}$$

$$coupon_G = yield_{G-1} \bar{p}_G \quad \text{(B90)}$$

$$B_C = B_{CH} + B_{CCB} \tag{B91}$$

$$B_G = B_{GH} + B_{GCB} \tag{B92}$$

$$p_C = \frac{B_C}{b_C} \tag{B93}$$

$$p_G = \frac{B_G}{b_G} \tag{B94}$$

$$B = B_C + B_G \tag{B95}$$

$$DL = defL_{-1} \tag{B96}$$

$$def = \frac{def^{max}}{1 + def_0\, exp\left(def_1 - def_2 illiq_{-1}\right)} \tag{B97}$$

$$illiq = \frac{\left(int_C + rep\right)L_{C-1} + \left(int_G + rep\right)L_{G-1} + coupon_C b_{C-1} + coupon_G b_{G-1} + wN + T_F + \delta K_{-1}}{Y + \left[\left(1 - CR_{NBC}\right)\left(1 - sh_B\right) + \left(1 - CR_B\right)sh_B\right]NL_C^D + \left(1 - CR_G\right)NL_G^D + p_C \Delta b_C + p_G \Delta b_G} \tag{B98}$$

$$dsr = \frac{\left(int_C + rep\right)L_{C-1} + \left(int_G + rep\right)L_{G-1} + coupon_C b_{C-1} + coupon_G b_{G-1}}{TP + int_C\, L_{C-1} + int_G\, L_{G-1} + coupon_C b_{C-1} + coupon_G b_{G-1}} \tag{B99}$$

2.2 Households

$$Y_{HG} = wN + DP + BP_D + int_D\, D_{-1} + int_S\, SEC_{H-1} + coupon_C b_{CH-1} + coupon_G b_{GH-1} \tag{B100}$$

$$Y_H = Y_{HG} - T_H \tag{B101}$$

$$C_N = \left(c_1 Y_{H-1} + c_2 V_{HF-1}\right)\left(1 - D_{T-1}\right) \tag{B102}$$

$$C = C_N \text{ if } C_N + I + G < Y^*\text{; otherwise } C = pr\left(Y^* - G - I\right) \tag{B103}$$

$$V_{HF} = V_{HF-1} + Y_H - C + b_{CH-1}\Delta p_C + b_{GH-1}\Delta p_G \tag{B104}$$

$$\frac{SEC_H}{V_{HF-1}} = \lambda_{10} + \lambda'_{10} D_{T-1} + \lambda_{11} int_S + \lambda_{12} yield_{C-1} + \lambda_{13} yield_{G-1} + \lambda_{14} int_D + \lambda_{15}\frac{Y_{H-1}}{V_{HF-1}} \tag{B105}$$

$$\frac{B_{CH}}{V_{HF-1}} = \lambda_{20} + \lambda'_{20} D_{T-1} + \lambda_{21} int_S + \lambda_{22} yield_{C-1} + \lambda_{23} yield_{G-1} + \lambda_{24} int_D + \lambda_{25}\frac{Y_{H-1}}{V_{HF-1}} \tag{B106}$$

$$\frac{B_{GH}}{V_{HF-1}} = \lambda_{30} + \lambda'_{30} D_{T-1} + \lambda_{31} int_S + \lambda_{32} yield_{C-1} + \lambda_{33} yield_{G-1} + \lambda_{34} int_D + \lambda_{35}\frac{Y_{H-1}}{V_{HF-1}} \tag{B107}$$

$$\frac{D}{V_{HF-1}} = \lambda_{40} + \lambda'_{40} D_{T-1} + \lambda_{41} int_S + \lambda_{42} yield_{C-1} + \lambda_{43} yield_{G-1} + \lambda_{44} int_D + \lambda_{45}\frac{Y_{H-1}}{V_{HF-1}} \tag{B108n}$$

$$D = D_{-1} + Y_H - C - \Delta SEC_H - \bar{p}_C \Delta b_{CH} - \bar{p}_G \Delta b_{GH} \tag{B108}$$

$$\lambda_{30} = \lambda_{30-1}\left(1 + g_{\lambda 30}\right) \tag{B109}$$

$$g_{\lambda 30} = g_{\lambda 30-1}\left(1 - \zeta_4\right) \tag{B110}$$

$$b_{CH} = \frac{B_{CH}}{p_C} \tag{B111}$$

$$b_{GH} = \frac{B_{GH}}{p_G} \tag{B112}$$

$$DC = DC_{-1} + C - \xi DC_{-1} \tag{B113}$$

$$g_{POP} = g_{POP-1}(1 - \zeta_5) \tag{B114}$$

$$POP = POP_{-1}(1 + g_{POP}) \tag{B115}$$

$$LF = (lf_1 - lf_2 hazratio_{-1})(1 - (1 - ad_{LF})D_{TF-1})POP \tag{B116}$$

$$lf_1 = lf_{1-1}(1 - \zeta_6) \tag{B117}$$

2.3 Banks

$$BP = int_C\ L_{C-1} + int_G\ L_{G-1} + int_S\ SEC_{B-1} - int_D\ D_{-1} - int_A\ A_{-1} \tag{B118}$$

$$K_B = K_{B-1} + BP_U - DL + BAILOUT \tag{B119}$$

$$BP_U = s_B BP_{-1} \tag{B120}$$

$$BP_D = BP - BP_U \tag{B121}$$

$$HPM = h_1 D \tag{B122}$$

$$SEC_B = h_2 D \tag{B123}$$

$$A = A_{-1} + \Delta HPM + \Delta L_G + \Delta L_C + \Delta SEC_B + DL - \Delta D - BP_U - BAILOUT \tag{B124}$$

$$CR = \frac{CR^{max}}{1 + r_0\ exp\left(r_1 - r_2 dsr_{-1} - r_3\left(lev_{B-1} - lev_B^{max}\right) + r_4\left(CAR_{-1} - CAR^{min}\right)\right)} + \varepsilon_{CR} \tag{B125}$$

$$CR_B = \left[1 - l_{02} + l_{12}\left(w_B - w_{LT}\right)\right]CR \tag{B126}$$

$$CR_G = \left[1 + l_{01} + l_{11}\left(w_G - w_{LT}\right)\right]CR \tag{B127}$$

$$CR_{NBC} = \frac{CR - sh_G CR_G - \left(1 - sh_G\right)sh_B CR_B}{\left(1 - sh_G\right)\left(1 - sh_B\right)} \tag{B128}$$

$$L_C = L_{C-1} + \left[\left(1 - CR_{NBC}\right)\left(1 - sh_B\right) + \left(1 - CR_B\right)sh_B\right]NL_C^D - repL_{C-1} - defL_{C-1} \tag{B129}$$

$$L_G = L_{G-1} + \left(1 - CR_G\right)NL_G^D - repL_{G-1} - defL_{G-1} \tag{B130}$$

$$lev_B = \left(L_C + L_G + SEC_B + HPM\right)/K_B \tag{B131}$$

$$CAR = K_B/\left[w_G L_G + w_B sh_B L_C + w_{BNC}\left(1 - sh_B\right)L_C + w_S SEC_B\right] \tag{B132}$$

$$w_{LT} = sh_G w_G + \left(1 - sh_G\right)\left[sh_B w_B + \left(1 - sh_B\right)w_{NBC}\right] \tag{B133}$$

$$int = int_A + int_0 + int_1\ dsr_{-1} + int_2\left(lev_{B-1} - lev_B^{max}\right) - int_3\left(CAR_{-1} - CAR^{min}\right) \tag{B134}$$

$$int_B = \left[int_{B0} + int_{B1}\left(w_B - w_{LT}\right)\right]int \tag{B135}$$

$$int_G = \left[int_{G0} + int_{G1}\left(w_G - w_{LT}\right)\right]int \tag{B136}$$

$$int_{NBC} = \frac{int - sh_{LG}\, int_G - (1 - sh_{LG})\, sh_B\, int_B}{(1 - sh_{LG})(1 - sh_B)} \tag{B137}$$

$$int_C = sh_B\, int_B - (1 - sh_B)\, int_{NBC} \tag{B138}$$

2.4 Government sector

$$SEC = SEC_{-1} + G - T + int_S\, SEC_{-1} - CBP + BAILOUT \tag{B139}$$

$$G = gov Y_{-1} \tag{B140}$$

$$T_H = \tau_H Y_{HG-1} \tag{B141}$$

$$T_F = \tau_F TP_{G-1} \tag{B142}$$

$$T = T_H + T_F \tag{B143}$$

2.5 Central banks

$$CBP = coupon_C b_{CCB-1} + coupon_G b_{GCB-1} + int_A\, A_{-1} + int_S\, SEC_{CB-1} \tag{B144}$$

$$B_{GCB} = s_G\, B_{G-1} \tag{B145}$$

$$B_{CCB} = s_C\, B_{C-1} \tag{B146}$$

$$b_{CCB} = \frac{B_{CCB}}{p_C} \tag{B147}$$

$$b_{GCB} = \frac{B_{GCB}}{p_G} \tag{B148}$$

$$SEC_{CB} = SEC - SEC_H - SEC_B \tag{B149}$$

$$SEC_{CB} = SEC_{CB-1} + \Delta HPM - \Delta A - \bar{p}_C \Delta b_{CCB} - \bar{p}_G \Delta b_{GGB} \tag{B150-red}$$

Appendix C. Initial values for endogenous variables

Symbol	Description	Value	Remarks/sources
A	Advances (trillion US$)	6.8	Calculated from the identity $K_B=L_C+L_G+HPM+SEC_B-A-D$ using the initial values of K_B, L_C, L_G, HPM, SEC_B and D
B	Value of total corporate bonds (trillion US$)	12.0	Based on OECD (2017, p. 21); we use the figure for the debt securities issued by non-financial corporations
$BAILOUT$	Bailout funds provided to the banking system from the government sector	0	No bailout is assumed in 2016 since $lev_B<lev_B^{max}$ and $CAR>CAR^{min}$
B_C	Value of conventional corporate bonds (trillion US$)	11.8	Calculated from Eq. (B95) using the initial values of B and B_G
b_C	Number of conventional corporate bonds (trillions)	0.118	Calculated from Eq. (B93) using the initial values of p_C and B_C
B_{CCB}	Value of conventional corporate bonds held by central banks (trillion US$)	0.1	Based on the recent holdings of central banks as part of their corporate sector purchase programmes
b_{CCB}	Number of conventional corporate bonds held by central banks (trillions)	0.001	Calculated from Eq. (B147) using the initial values of p_C and B_{CCB}
B_{CH}	Value of conventional corporate bonds held by households (trillion US$)	11.7	Calculated from Eq. (B91) using the initial values of B_{CCB} and B_C
b_{CH}	Number of conventional corporate bonds held by households (trillions)	0.1	Calculated from Eq. (B111) using the initial values of p_C and B_{CH}
B_G	Value of green corporate bonds (trillion US$)	0.25	Based on Climate Bonds Initiative (2017a); we use the value of the climate-alligned bonds that has been issued by the financial and the non-financial corporate sector
b_G	Number of green corporate bonds (trillions)	0.003	Calculated from Eq. (B94) using the initial values of p_G and B_G
B_{GCB}	Value of green corporate bonds held by central banks (trillion US$)	0	There was no green QE programme in 2016
b_{GCB}	Number of green corporate bonds held by central banks (trillions)	0	Calculated from Eq. (B140) using the initial values of p_G and B_{GCB}
B_{GH}	Value of green corporate bonds held by households (trillion US$)	0.25	Calculated from Eq. (B92) using the initial values of B_G and B_{GCB}
b_{GH}	Number of green corporate bonds held by households (trillions)	0.0025	Calculated from Eq. (B112) using the initial values of p_G and B_{GH}
BP	Profits of banks (trillion US$)	3.01	Calculated from Eq. (B118) using the initial values of int_B, int_{NBC}, int_G, L_C, L_G, SEC_B, D and A
BP_D	Distributed profits of banks (trillion US$)	0.54	Calculated from Eq. (B121) using the initial values of BP and BP_U
BP_U	Retained profits of banks (trillion US$)	2.47	Calculated from Eq. (B120) using the initial value of BP
C	Consumption (trillion US$)	48.3	No supply-side constraints are assumed in 2016 since $C_N+I+G<Y^*$; therefore $C=C_N$
C_N	Consumption when no supply-side constraints exist (trillion US$)	48.3	Calculated from Eq. (B44) using the initial values of Y, G and I (since $C=C_N$)
CAR	Capital adequacy ratio	0.1	Calculated from Eq. (B131) using the initial values of K_B, L_C, L_G and SEC_B
CBP	Central banks' profits (trillion US$)	0.2	Calculated from Eq. (B144) using the initial values of $coupon_C$, b_{CCB}, $coupon_G$, b_{GCB}, A and SEC_{CB}
CEN	Carbon mass of the non-renewable energy sources (Gt)	9.9	Calculated from Eq. (B7) using the initial value of $EMIS_{IN}$
$CO2_{AT}$	Atmospheric CO_2 concentration ($GtCO_2$)	3146	Taken from NOAA/ESRL (National Oceanic & Atmospheric Administration/Earth System Research Laboratory)
$CO2_{LO}$	Lower ocean CO_2 concentration ($GtCO_2$)	6380.6	Based on the DICE-2016R model (Nordhaus, 2016); GtC have been transformed into $GtCO_2$
$CO2_{UP}$	Upper ocean/biosphere CO_2 concentration ($GtCO_2$)	1694.2	Based on the DICE-2016R model (Nordhaus, 2016); GtC have been transformed into $GtCO_2$
CON_E	Amount of non-renewable energy resources converted into non-renewable energy reserves (EJ)	1629.0	Calculated from Eq. (B20) using the initial value of RES_E
CON_M	Amount of material resources converted into material reserves (Gt)	209	Calculated from Eq. (B12) using the initial value of RES_M
$coupon_C$	Fixed coupon paid per conventional corporate bond (US$)	5	Calculated from Eq. (B87) using the initial values of p_C and $yield_C$
$coupon_G$	Fixed coupon paid per green corporate bond (US$)	5	Calculated from Eq. (B88) using the initial values of p_G and $yield_G$
CR	Degree of total credit rationing on loans	0.2	Calculated from Eq. (B125) using the initial values of dsr, lev_B and CAR
CR_B	Degree of credit rationing on brown conventional loans	0.2	Calculated from Eq. (B126) using the initial values of w_{LT} and CR
CR_G	Degree of credit rationing on green loans	0.3	Calculated from Eq. (B127) using the initial values of w_{LT} and CR
CR_{NBC}	Degree of credit rationing on non-brown conventional loans	0.2	Calculated from Eq. (B128) using the initial values of w_{LT}, sh_G, CR, CR_G and CR_B
D	Deposits (trillion US$)	65.0	Based on Allianz (2017)
DC	Stock of durable consumption goods (trillion US$)	1456	Calculated from Eq. (B4) using the initial values of K, DEM, δ and μ
def	Rate of default	0.040	Based on World Bank
DEM	Demolished/discarded socio-economic stock (Gt)	17.0	Based on Haas et al. (2015)
dep_E	Energy depletion ratio	0.013	Calculated from Eq. (B22) using the initial values of EN and REV_E
dep_M	Matter depletion ratio	0.008	Selected from a reasonable range of values
DL	Amount of defaulted loans (trillion US$)	2.2	Calculated from Eq. (B96) using the initial values of L and def
DP	Distributed profits of firms (trillion US$)	17.5	Calculated from Eq. (B55) using the initial values of TP and RP
dsr	Debt service ratio of firms	0.42	Calculated from Eq. (B99) using the initial values of int_C, int_G, L_C, L_G, $coupon_C$, b_C, $coupon_G$, b_G and TP
D_T	Total proportional damage caused by global warming	0.0031	Calculated from Eq. (B49) using the initial value of T_{AT}
D_{TF}	Part of damage that affects directly the fund-service resources	0.0028	Calculated from Eq. (B51) using the initial values of D_T and D_{TP}
D_{TP}	Part of damage that reduces the productivities of fund-service resources	0.0003	Calculated from Eq. (B50) using the initial value of D_T
E	Energy used for the production of output (EJ)	580.0	Based on IEA (International Energy Agency); total primary energy supply is used
ED	Dissipated energy (EJ)	580.0	Calculated from Eq. (B18) using the initial values of EN and ER
$EMIS$	Total CO_2 emissions ($GtCO_2$)	38.8	Calculated from Eq. (B25) using the initial values of $EMIS_{IN}$ and $EMIS_L$
$EMIS_{IN}$	Industrial CO_2 emissions ($GtCO_2$)	36.2	Taken from CDIAC (Carbon Dioxide Information Analysis Center)
$EMIS_L$	Land-use CO_2 emissions ($GtCO_2$)	2.5	Taken from the DICE-2016R model (Nordhaus, 2016)
EN	Energy produced from non-renewable sources (EJ)	498.8	Calculated from Eq. (B17) using the initial values of E and ER
ER	Energy produced from renewable sources (EJ)	81.2	Calculated from Eq. (B16) using the initial values of θ and E
F	Radiative forcing over pre-industrial levels (W/m^2)	2.52	Calculated from Eq. (B29) using the initial values of $CO2_{AT}$ and F_{EX}
F_{EX}	Radiative forcing, over pre-industrial levels, due to non-CO_2 greenhouse gases (W/m^2)	0.51	Based on the DICE-2016R model (Nordhaus, 2016)
G	Government expenditures (trillion US$)	12.5	Calculated from Eq. (B140) using the initial value of Y

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Symbol	Description	Value	Remarks/sources
g_{POP}	Growth rate of population	0.014	Taken from United Nations (medium fertility variant)
g_{x20}	Growth rate of the autonomous proportion of desired green investment funded via bonds	0.040	Calibrated such that the model generates the baseline scenario
g_Y	Growth rate of output	0.025	Based on World Bank
$g_{\beta 0}$	Growth rate of the autonomous share of green investment in total investment	0.003	Calibrated such that the model generates the baseline scenario
g_{λ}	Growth rate of labour productivity	0.012	Calculated from Eq. (B75) using the initial values of g_Y and σ_0
$g_{\lambda 30}$	Growth rate of the households' portoflio choice parameter related to the autonomous demand for green bonds	0.040	Calibrated such that the model generates the baseline scenario
g_{ω}	Growth rate of CO_2 intensity	-0.003	Calibrated such that the model generates the baseline scenario
$hazratio$	Hazardous waste accumulation ratio (tonnes per person)	1.87	Calculated from Eq. (B10) using the initial values of HWS and POP
HPM	High-powered money	13.00	Calculated from Eq. (B122) using the initial value of D
HWS	Stock of hazardous waste (Gt)	14.0	Calculated assuming a constant ratio of hazardous waste to GDP since 1960
I	Total investment (trillion US$)	15.0	Calibrated such that the model generates the baseline scenario
I_C	Conventional investment (trillion US$)	14.3	Calculated from Eq. (B67) using the initial values of I and I_G
I_C^D	Desired conventional investment (trillion US$)	16.6	Calculated from the identity $I_C^D=I^D-I_G^D$; we use the initial values of I^D and I_G^D
I^D	Desired total investment (trillion US$)	17.5	Calibrated such that the model generates the baseline scenario
I_G	Green investment (trillion US$)	0.7	Based on IEA (2016); we use a higher value than the one reported in IEA (2016) since green investment in our model is not confined to investment in energy efficiency and renewables (it also includes investment in recycling and material efficiency)
I_G^D	Desired green investment (trillion US$)	0.9	Calculated such that it is reasonably higher than I_G
$illiq$	Illiquidity ratio	0.73	Calculated from Eq. (B98) using the initial values of int_C, int_G, L_C, L_G, $coupon_C$, b_C, $coupon_G$, b_G, w, N, T_F, δ, K, Y, CR_B, CR_{NBC}, NL_C^D, CR_G, NL_G^D, p_C and p_G
int	Interest rate on total loans	0.07	Calculated from Eq. (B134) using the initial values of dsr, lev_B and CAR
int_B	Interest rate on brown conventional loans	0.07	Calculated from Eq. (B135) using the initial values of w_{LT} and int
int_C	Interest rate on conventional loans	0.07	Calculated from Eq. (B138) using the initial values of int_B and int_{NBC}
int_G	Interest rate on green loans	0.08	Calculated from Eq. (B136) using the initial values of w_{LT} and int
int_{NBC}	Interest rate on non-brown conventional loans	0.07	Calculated from Eq. (B137) using the initial values of sh_{LG}, int, int_G and int_B
K	Total capital stock of firms (trillion US$)	227.4	Calculated from the identity $K=(K/Y)*Y$ using the initial value of Y and assuming that $K/Y=3$ (based on Penn World Table 9.0)
K_B	Capital of banks (trillion US$)	8.4	Calculated from Eq. (B129) using the initial values of lev_B, L_C, L_G, SEC_B and HPM
K_C	Conventional capital stock (trillion US$)	219.0	Calculated from Eq. (B71) using the initial values of K and K_G
K_G	Green capital stock (trillion US$)	8.4	Calculated from Eq. (B72) using the initial values of K and $\varkappa$
L	Total loans of firms (trillion US$)	57.7	Calculated from the identity $L=(credit-B/Y)*Y$; $credit$ is the credit to the non-financial corporations in percent of GDP taken from BIS (Bank for International Settlements); it is assumed that $credit$ includes both loans and bonds
L_C	Conventional loans (trillion US$)	55.5	Calculated from Eq. (B68) using the initial values of L and L_G
L_G	Green loans (trillion US$)	2.1	Calculated by assuming that $L_G/L=K_G/K=\varkappa$; we use the initial values of $\varkappa$ and L
lev_B	Banks' leverage ratio	9.6	Taken from World Bank
LF	Labour force (billion people)	3.42	Taken from World Bank
lf_1	Autonomous labour force-to-population ratio	0.460	Calculated from Eq. (B116) using the initial values of LF, POP, $hazratio$ and D_{TF}
M	Extraction of new matter from the ground, excluding the matter included in non-renewable energy sources (Gt)	51.5	Taken from UN Environment International Resource Panel Global Material Flows Database; the figure refers to non-metallic minerals plus metal ores
MY	Output in material terms (Gt)	56.6	Calculated from Eq. (B2) using the initial values of M and REC
N	Number of employees (billion people)	3.2	Calculated from the definition of the rate of employment ($re=N/LF$) using the initial values of re and LF
NL_C^D	Desired new amount of conventional loans (trillion US$)	11.1	Calculated from Eq. (B64) using the initial values of I_C^D, β, RP, L_C, δ, K_C and b_C
NL_G^D	Desired new amount of green loans (trillion US$)	0.7	Calculated from Eq. (B63) using the initial values of I_G^D, β, RP, L_G, δ, K_G and b_G
$O2$	Oxygen used for the combustion of fossil fuels (Gt)	26.3	Calculated from Eq. (B8) using the initial values of $EMIS_{IN}$ and CEN
p_C	Market price of conventional corporate bonds (US$)	100	The price has been normalised such that it is equal to US$100 (the par value of bonds) in 2016
p_G	Market price of green corporate bonds (US$)	100	The price has been normalised such that it is equal to US$100 (the par value of bonds) in 2016
POP	Population (billions)	7.47	Taken from United Nations (medium fertility variant)
r	Rate of retained profits	0.009	Calculated from Eq. (B56) using the initial values of RP and K
re	Rate of employment	0.94	Calculated from Eq. (B80) using the initial value of ur
REC	Recycled socio-economic stock (Gt)	5.1	Calculated from Eq. (B3) using the initial values of ρ and DEM
RES_E	Non-renewable energy resources (EJ)	543000	Based on BGR (2016, p. 36)
RES_M	Material resources (Gt)	417245	Calculated by assuming $RES_M/REV_M=64.8$ (based on UNEP, 2011)
REV_E	Non-renewable energy reserves (EJ)	38000	Based on BGR (2016, p. 36)
REV_M	Material reserves (Gt)	6438	Calculated from Eq. (B14) using the initial values of M and dep_M
RP	Retained profits of firms (trillion US$)	2.0	Calculated from Eq. (B54) using the initial value of TP
SEC	Total amount of government securities	63.4	Calculated from the identity $general\ government\ debt\text{-}to\text{-}GDP=SEC/Y$ using the initial value of Y and the value of the $general\ government\ debt\text{-}to\text{-}GDP$ ratio (taken from IMF)
SEC_B	Government securities held by banks (trillion US$)	9.5	Calculated by assuming that $SEC_B/SEC=0.2$ based on Alli Abbas et al. (2014)

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Symbol	Description	Value	Remarks/sources
SEC_{CB}	Government securities held by central banks (trillion US$)	6.1	Calculated from the identity $SEC_{CB}=HPM+V_{CB}-\bar{p}_C b_{CCB}-\bar{p}_G b_{GCB}-A$ using the initial values of V_{CB}, b_{CCB}, b_{GCB}, A and HPM
SEC_H	Government securities held by households (trillion US$)	47.7	Calculated from Eq. (B149) using the initial values of SEC, SEC_{CB} and SEC_B
SES	Socio-economic stock (Gt)	1506.3	Calculated from the identity $SES=\mu(K+DC)$ using the initial values of μ, K and DC
sh_G	Share of desired green loans in total desired loans	0.05	Calculated from the formula $sh_G=NL_G^D/(NL_G^D+NL_C^D)$ using the initial values of NL_G^D and NL_C^D
sh_L	Share of loans in total firm liabilities	0.83	Calculated from the formula $sh_L=L/(L+B)$ using the initial values of L and B
sh_{LG}	Share of green loans in total loans	0.04	Calculated from the formula $sh_{LG}=L_G/L$ using the initial values of L and L_G
T	Total taxes (trillion US$)	11.6	Calculated from Eq. (B135) using the initial values of T_H and T_F
T_{AT}	Atmospheric temperature over pre-industrial levels (^oC)	1.04	Based on Met Office
T_F	Taxes on firms' profits (trillion US$)	3.3	Calculated from Eq. (B134) using the initial value of TP_G
T_H	Taxes on households' disposable income	8.2	Calculated from Eq. (B133) using the initial value Y_{HG}
T_{LO}	Lower ocean temperature over pre-industrial levels (^oC)	0.0112	Based on the DICE-2016R model (Nordhaus, 2016)
TP	Total profits of firms (trillion US$)	19.5	Calculated from Eq. (B53) using the initial values of TP_G and T_F
TP_G	Total gross profits of firms (trillion US$)	22.9	Calculated from Eq. (B52) using the initial values of Y, w, N, L_C, L_G, int_C, int_G, δ, K, $coupon_C$, b_C, $coupon_G$ and b_G
u	Rate of capacity utilisation	0.72	Based on World Bank, Enterprise Surveys
ue	Rate of energy utilisation	0.01	Calculated from Eq. (B46) using the initial values of Y and Y_E^*
um	Rate of matter utilisation	0.01	Calculated from Eq. (B45) using the initial values of Y, G and Y_M^*
ur	Unemployment rate	0.06	Based on World Bank
v	Capital productivity	0.46	Calculated from Eqs. (B41) and (B47) using the initial values of Y, u and K
V_{CB}	Wealth of central banks (trillion US$)	0	It is assumed that there are no accumulated capital gains for the central banks
V_H	Wealth of households (trillion US$)	1580.6	Calculated from the identity $V_H=DC+D+p_C b_{CH}+p_G b_{GH}+SEC_H$ using the initial values of SEC_H, p_C, b_{CH}, p_G, b_{GH}, DC and D
V_{HF}	Financial wealth of households (trillion US$)	124.6	Calculated from the identity $V_{HF}=D+p_C b_{CH}+p_G b_{GH}+SEC_H$ using the initial values of SEC_H, p_C, b_{CH}, p_G, b_{GH} and D
w	Annual wage rate (trillion US$/billions of employees)	12.26	Calculated from Eq. (B78) using the initial value of λ
W	Waste (Gt)	11.90	Calculated from the identity $W=DEM-REC$ using the initial values of DEM and REC
w_{LT}	Risk weight on total loans	1.0	Calculated from Eq. (B133) using the initial value of sh_G
x_1	Proportion of desired conventional investment funded via bonds	0.02	Calibrated such that the model generates the baseline scenario
x_2	Proportion of desired green investment funded via bonds	0.01	Calibrated such that the model generates the baseline scenario
x_{20}	Autonomous proportion of desired green investment funded via bonds	0.01	Calculated from Eq. (B84) using the initial values of $yield_G$ and x_{20}
Y	Output (trillion US$)	75.8	Taken from World Bank (current prices)
Y^*	Potential output (trillion US$)	80.6	Calculated from Eq. (B43) using the initial values of Y_M^*, Y_E^*, Y_K^* and Y_N^*
Y_E^*	Energy-determined potential output (trillion US$)	5774.7	Calculated from Eq. (B40) using the initial values of REV_E, θ and ε
Y_H	Disposable income of households (trillion US$)	51.5	Calculated from Eq. (B101) using the initial values of Y_{HG} and T_H
Y_{HD}	Household disposable income net of depreciation (trillion US$)	57.9	Calculated from the identity $Y_{HD}=Y_H-\xi DC_{-1}$ using the initial values of Y_H and DC
Y_{HG}	Gross disposable income of households (trillion US$)	59.7	Calculated from Eq. (B100) using the initial values of w, N, DP, BP_D, D, SEC_H, $coupon_C$, b_{CH}, $coupon_G$ and b_{GH}
$yield_C$	Yield on conventional corporate bonds	0.05	Based on FTSE Russell (2016)
$yield_G$	Yield on green corporate bonds	0.05	Based on FTSE Russell (2016)
Y_K^*	Capital-determined potential output (trillion US$)	105.3	Calculated from Eq. (B41) using the initial values of v and K
Y_M^*	Matter-determined potential output (trillion US$)	7199.9	Calculated from Eq. (B39) using the initial values of REV_M, REC and μ
Y_N^*	Labour-determined potential output (trillion US$)	80.6	Calculated from Eq. (B42) using the initial values of λ and LF
β	Share of desired green investment in total investment	0.05	Calculated from Eq. (B58) using the initial values of I_G^D and I^D
β_0	Autonomous share of desired green investment in total investment	0.04	Calculated from Eq. (B60) using the initial values of β, sh_L, $yield_G$ and $yield_C$
δ	Depreciation rate of capital stock	0.04	Calculated from Eq. (B73) using the initial value D_{TF}
ε	Energy intensity (EJ/trillion US$)	7.65	Calculated from Eq. (B15) using the initial values of E and Y
θ	Share of renewable energy in total energy	0.14	Based on IEA (International Energy Agency); total primary energy supply is used
$\varkappa$	Ratio of green capital to total capital	0.04	Selected such that it is reasonably lower than I_G/I
λ	Hourly labour productivity (trillion US$/(billions of employees*annual hours worked per employee))	0.01	Calculated from Eq. (B79) using the initial values of Y and N
λ_{30}	Households' portfolio choice parameter related to the autonomous demand for green bonds	0.01	Calculated from Eq. (B107) using the initial values of B_{GH}, V_{HF}, D_T, $yield_C$, $yield_G$ and Y_H
μ	Material intensity (kg/$)	0.89	Calculated from Eq. (B1) using the initial values of MY, G and Y
ϱ	Recycling rate	0.30	Based on Haas et al. (2015)
σ_0	Autonomous growth rate of labour productivity	-0.02	Calibrated such that the model generates the baseline scenario
ω	CO_2 intensity of non-renewable energy ($GtCO_2$/EJ)	0.07	Calculated from Eq. (B23) using the initial values of $EMIS_{IN}$ and EN

Appendix D. Values for parameters and exogenous variables (baseline scenario)

Symbol	Description	Value	Remarks/sources
ad_K	Fraction of gross damages to capital stock avoided through adaptation	0.80	Selected from a reasonable range of values
ad_{LF}	Fraction of gross damages to labour force avoided through adaptation	0.70	Selected from a reasonable range of values
ad_P	Fraction of gross damages to productivity avoided through adaptation	0.70	Selected from a reasonable range of values
c_1	Propensity to consume out of disposable income	0.65	Calibrated such that the model generates the baseline scenario
c_2	Propensity to consume out of financial wealth	0.13	Empirically estimated using data for a panel of countries over the period 1995-2016 (the econometric estimations are available upon request)
car	Coefficient for the conversion of GtC into $GtCO_2$	3.67	Taken from CDIAC (Carbon Dioxide Information Analysis Center)
CAR^{min}	Minimum capital adequacy ratio	0.08	Based on the Basel III regulatory framework
$CO2_{AT\text{-}PRE}$	Pre-industrial CO_2 concentration in atmosphere ($GtCO_2$)	2156.2	Taken from DICE-2016R model (Nordhaus, 2016); GtC have been transformed into $GtCO_2$
$CO2_{LO\text{-}PRE}$	Pre-industrial CO_2 concentration in upper ocean/biosphere ($GtCO_2$)	6307.2	Taken from DICE-2016R model (Nordhaus, 2016); GtC have been transformed into $GtCO_2$
$CO2_{UP\text{-}PRE}$	Pre-industrial CO_2 concentration in lower ocean ($GtCO_2$)	1320.1	Taken from DICE-2016R model (Nordhaus, 2016); GtC have been transformed into $GtCO_2$
con_E	Conversion rate of non-renewable energy resources into reserves	0.003	Selected from a reasonable range of values
con_M	Conversion rate of material resources into reserves	0.0005	Selected from a reasonable range of values
CR^{max}	Maximum degree of credit rationing	0.5	Selected from a reasonable range of values
def^{max}	Maximum default rate of loans	0.2	Selected from a reasonable range of values
def_0	Parameter of the default rate function	4.00	Calculated from Eq. (B97) using the initial value of *illiq*
def_1	Parameter of the default rate function	5.69	Calibrated such that the model generates the baseline scenario
def_2	Parameter of the default rate function (related to the sensitivity of the default rate to the illiquidity ratio of firms)	7.81	Selected from a reasonable range of values
F_{2xCO2}	Increase in radiative forcing (since the pre-industrial period) due to doubling of CO_2 concentration from pre-industrial levels (W/m^2)	3.7	Taken from the DICE-2016R model (Nordhaus, 2016)
fex	Annual increase in radiative forcing (since the pre-industrial period) due to non-CO_2 agents (W/m^2)	0.006	Based on the DICE-2016R model (Nordhaus, 2016)
gov	Share of government expenditures in output	0.17	Based on World Bank; the figure includes only the consumption government expenditures
h	Annual working hours per employee	1850	Based on Penn World Table 9.0
h_1	Banks' reserve ratio	0.2	Based on World Bank
h_2	Banks' government securities-to-deposits ratio	0.15	Calculated from Eq. (B123) using the initial values of SEC_B and D
haz	Proportion of hazardous waste in total waste	0.04	EEA (2012, p. 22) reports a figure equal to 3.7% for EU-27
int_0	Parameter in the function of the interest rate on total loans	0.08	Calculated from Eq. (B134) using the initial values of dsr, CAR and lev_B
int_1	Parameter in the function of the interest rate on total loans (related to the sensitivity of credit rationing to the debt service ratio)	0.10	Selected from a reasonable range of values
int_2	Parameter in the function of the interest rate on total loans (related to the sensitivity of credit rationing to the leverage ratio of banks)	0.10	Selected from a reasonable range of values
int_3	Parameter in the function of the interest rate on total loans (related to the sensitivity of credit rationing to the capital adequacy ratio of banks)	0.10	Selected from a reasonable range of values
int_A	Interest rate on advances	0.02	Based on Global Interest Rate Monitor
int_{B0}	Parameter in the function of the interest rate on brown loans	0.99	Calculated from Eq. (B135) using the initial values of int and w_{LT}
int_{B1}	Parameter in the function of the interest rate on brown loans (related to the sensitivity of interest rate on brown loans to the difference between the weight on brown loans and total loans)	0.50	Selected from a reasonable range of values
int_D	Interest rate on deposits	0.015	Based on World Bank
int_{G0}	Parameter in the function of the interest rate on green loans	1.14	Calculated from Eq. (B136) using the initial values of int and w_{LT}
int_{G1}	Parameter in the function of the interest rate on green loans (related to the sensitivity of interest rate on green loans to the difference between the weight on green loans and total loans)	0.50	Selected from a reasonable range of values
int_S	Interest rate on government securities	0.015	Based on FTSE Russell (2016)
l_{01}	Parameter in the function of the credit rationing on green loans	0.46	Calculated from Eq. (B127) using the initial values of CR and w_{LT}
l_{02}	Parameter in the function of the credit rationing on brown loans	0.02	Calculated from Eq. (B126) using the initial values of CR and w_{LT}
l_{11}	Parameter in the function of the credit rationing on green loans (related to the sensitivity of credit rationing to the difference between the weight on green loans and total loans)	1.00	Selected from a reasonable range of values
l_{12}	Parameter in the function of the credit rationing on brown loans (related to the sensitivity of credit rationing to the difference between the weight on brown loans and total loans)	1.00	Selected from a reasonable range of values
lev_B^{max}	Maximum leverage ratio	33.33	Based on the Basel III regulatory framework (the Basel III bank leverage can be proxied by the capital-to-assets ratio and its minimum value is 3%; since in our model the bank leverage is defined as the assets-to-capital ratio, the maximum value used is equal to 1/0.03)
lf_2	Sensitivity of the labour force-to-population ratio to hazardous waste	0.001	Selected from a reasonable range of values
lr	Rate of decline of land-use CO_2 emissions	0.024	Taken from the DICE-2016R model (Nordhaus, 2016); has been adjusted to reflect a 1-year time step
p	Share of productivity damage in total damage caused by global warming	0.1	Selected from a reasonable range of values
$\bar{p}_C$	Par value of conventional corporate bonds (US$)	100	The par value of bonds is assumed to be always equal to US$100
$\bar{p}_G$	Par value of green corporate bonds (US$)	100	The par value of bonds is assumed to be always equal to US$100
pr	Ratio of demand-determined output to supply-determined output under the existence of supply-side constraints	0.99	Selected such that it is reasonably close to 1

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Symbol	Description	Value	Remarks/sources
r_0	Parameter in the function of the credit rationing on total loans	1.44	Calculated from Eq. (B125) using the initial values of dsr, CAR and lev_B
r_1	Parameter in the function of the credit rationing on total loans	-0.25	Calibrated such that the model generates the baseline scenario
r_2	Parameter in the function of the credit rationing on total loans (related to the sensitivity of credit rationing to the debt service ratio)	2.07	Selected from a reasonable range of values
r_3	Parameter in the function of the credit rationing on total loans (related to the sensitivity of credit rationing to the leverage ratio of banks)	0.04	Selected from a reasonable range of values
r_4	Parameter in the function of the credit rationing on total loans (related to the sensitivity of credit rationing to the capital adequacy ratio of banks)	2.07	Selected from a reasonable range of values
rep	Loan repayment ratio	0.1	Selected from a reasonable range of values
S	Equilibrium climate sensitivity, i.e. increase in equilibrium temperature due to doubling of CO_2 concentration from pre-industrial levels (^oC)	3.1	Taken from then DICE-2016R model (Nordhaus, 2016)
s_B	Banks' retention rate	0.84	Calibrated such that the model generates the baseline scenario
s_C	Share of conventional corporate bonds held by central banks (trillion US$)	0.01	Calculated from Eq. (B138) using the initial values of B_{CCB} and B_C
s_F	Firms' retention rate	0.11	Calibrated such that the model generates the baseline scenario
s_G	Share of green corporate bonds held by central banks (trillion US$)	0.00	Calculated from Eq. (B137) using the initial values of B_{GCB} and B_G
s_W	Wage income share	0.52	Based on Penn World Table 9.0
sh_B	Share of brown convnentional loans	0.50	Selected from a reasonable range of values
t_1	Speed of adjustment parameter in the atmospheric temperature equation	0.020	Taken from the DICE-2016R model (Nordhaus, 2016); has been adjusted to reflect a 1-year time step
t_2	Coefficient of heat loss from the atmosphere to the lower ocean (atmospheric temperature equation)	0.018	Taken from the DICE-2016R model (Nordhaus, 2016); has been adjusted to reflect a 1-year time step
t_3	Coefficient of heat loss from the atmosphere to the lower ocean (lower ocean temperature equation)	0.005	Taken from the DICE-2016R model (Nordhaus, 2016); has been adjusted to reflect a 1-year time step
w_B	Risk weight on brown conventional loans	1.0	Based on BCBS (2006)
w_G	Risk weight on green loans	1.0	Based on BCBS (2006)
w_{NBC}	Risk weight on non-brown conventional loans	1.0	Based on BCBS (2006)
w_S	Risk weight on government securities	0.0	Based on BCBS (2006)
x_{10}	Autonomous proportion of desired conventional investment funded via bonds	0.02	Calculated from Eq. (B83) using the initial values of $yield_C$ and x_1
x_{11}	Sensitivity of the proportion of desired conventional investment funded via bonds to the conventional bond yield	0.10	Selected from a reasonable range of values
x_{21}	Sensitivity of the proportion of desired green investment funded via bonds to the green bond yield	0.10	Selected from a reasonable range of values
a_{00}	Parameter in the desired investment function	0.16	Calibrated such that the model generates the baseline scenario
a_{01}	Parameter in the desired investment function	1.18	Calibrated such that the model generates the baseline scenario
a_1	Parameter in the desired investment function (related to the sensitivity of investment to the capacity utilisation)	2.00	Based on econometric estimations for a panel of countries over the period 1950-2014 (available upon request)
a_2	Parameter in the desired investment function (related to the sensitivity of investment to the rate of profit)	1.66	Based on econometric estimations for a panel of countries over the period 1950-2014 (available upon request)
a_{31}	Parameter in the desired investment function (related to the sensitivity of investment to the unemployment rate)	0.02	Based on econometric estimations for a panel of countries over the period 1950-2014 (available upon request)
a_{32}	Parameter in the desired investment function (related to the sensitivity of investment to the unemployment rate)	0.5	Selected from a reasonable range of values
a_{41}	Parameter in the desired investment function (related to the sensitivity of investment to the energy utilisation rate)	0.1	Selected from a reasonable range of values
a_{42}	Parameter in the desired investment function (related to the sensitivity of investment to the energy utilisation rate)	0.99	Selected from a reasonable range of values
a_{51}	Parameter in the desired investment function (related to the sensitivity of investment to the matter utilisation rate)	0.1	Selected from a reasonable range of values
a_{52}	Parameter in the desired investment function (related to the sensitivity of investment to the matter utilisation rate)	0.99	Selected from a reasonable range of values
β_1	Autonomous share of desired green investment in total investment	0.02	Calibrated such that the model generates the baseline scenario
β_2	Sensitivity of the desired green investment share to the interest rate differential between green loans/bonds and conventional loans/bonds	1	Selected from a reasonable range of values
δ_0	Depreciation rate of capital stock when there are no global warming damages	0.04	Based on Penn World Table 9.0
ε^{max}	Maximum potential value of energy intensity (EJ/trillion US$)	12	Selected such that it is reasonably higher than initial ε
ε^{min}	Minimum potential value of energy intensity (EJ/trillion US$)	2	Selected such that it is reasonably higher than 0
ζ_1	Rate of decline of the (absolute) growth rate of CO_2 intensity	0.0005	Calibrated such that the model generates the baseline scenario
ζ_2	Rate of decline of the growth rate of β_0	0.005	Calibrated such that the model generates the baseline scenario
ζ_3	Rate of decline of the autonomous (absolute) growth rate of labour productivity	0.02	Calibrated such that the model generates the baseline scenario
ζ_4	Rate of decline of the growth rates of x_{20} and λ_{30}	0.20	Calibrated such that the model generates the baseline scenario
ζ_5	Rate of decline of the growth rate of population	0.04	Calibrated such that the model generates the baseline scenario
ζ_6	Rate of decline of the autonomous labour force-to-population ratio	0.0006	Calibrated such that the model generates the baseline scenario
η_1	Parameter of damage function	0	Based on Weitzmann (2012); D_T=50% when T_{AT}=6^{o}C
η_2	Parameter of damage function	0.00284	Based on Weitzmann (2012); D_T=50% when T_{AT}=6^{o}C
η_3	Parameter of damage function	0.000005	Based on Weitzmann (2012); D_T=50% when T_{AT}=6^{o}C
λ_{10}	Parameter of households' portfolio choice	0.40	Calculated from Eq. (B105) using the initial values of SEC_H, V_{HF}, D_T, $yield_C$, $yield_G$ and Y_H
$\lambda_{10}{'}$	Parameter of households' portfolio choice	0.10	Selected from a reasonable range of values
λ_{11}	Parameter of households' portfolio choice	0.03	Calculated from the constraint λ_{11}=-λ_{21}-λ_{31}-λ_{41}
λ_{12}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{13}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values

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Symbol	Description	Value	Remarks/sources
λ_{14}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{15}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{20}	Parameter of households' portfolio choice	0.10	Calculated from Eq. (B106) using the initial values of B_{CH}, V_{HF}, D_T, $yield_C$, $yield_G$ and Y_H
λ_{20}'	Parameter of households' portfolio choice	-0.20	Selected from a reasonable range of values
λ_{21}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{21}=\lambda_{12}$
λ_{22}	Parameter of households' portfolio choice	0.03	Calculated from the constraint $\lambda_{22}=-\lambda_{12}-\lambda_{32}-\lambda_{42}$
λ_{23}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{24}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{25}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{30}'	Parameter of households' portfolio choice	0.00	Global warming damages are assumed to have no impact on the holdings of green bonds
λ_{31}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{31}=\lambda_{13}$
λ_{32}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{32}=\lambda_{23}$
λ_{33}	Parameter of households' portfolio choice	0.03	Calculated from the constraint $\lambda_{33}=-\lambda_{13}-\lambda_{23}-\lambda_{43}$
λ_{34}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{35}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{40}	Parameter of households' portfolio choice	0.50	Calculated from the constraint $\lambda_{40}=1-\lambda_{10}-\lambda_{20}-\lambda_{30}$
λ_{40}'	Parameter of households' portfolio choice	0.10	Calculated from the constraint $\lambda_{40}'=-\lambda_{10}'-\lambda_{20}'-\lambda_{30}'$
λ_{41}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{41}=\lambda_{14}$
λ_{42}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{42}=\lambda_{24}$
λ_{43}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{43}=\lambda_{34}$
λ_{44}	Parameter of households' portfolio choice	0.03	Calculated from the constraint $\lambda_{44}=-\lambda_{14}-\lambda_{24}-\lambda_{34}$
λ_{45}	Parameter of households' portfolio choice	0.03	Calculated from the constraint $\lambda_{45}=-\lambda_{15}-\lambda_{25}-\lambda_{35}$
μ^{max}	Maximum potential value of material intensity (kg/US$)	1.5	Selected such that it is reasonably higher than initial μ
μ^{min}	Minimum potential value of material intensity (kg/US$)	0.3	Selected such that it is reasonably higher than 0
ξ	Proportion of durable consumption goods discarded every year	0.007	Selected such that the initial growth of DC is equal to the growth rate of output
π_1	Parameter linking the green capital-conventional capital ratio with material intensity	2.08	Calibrated such that initial μ corresponds to initial $\varkappa$ and $\mu(2050)=0.9\mu(2015)$ in line with the baseline scenario
π_2	Parameter linking the green capital-conventional capital ratio with material intensity	19.98	Calibrated such that initial μ corresponds to initial $\varkappa$ and $\mu(2050)=0.9\mu(2015)$ in line with the baseline scenario
π_3	Parameter linking the green capital-conventional capital ratio with recycling rate	7.61	Calibrated such that initial ρ corresponds to initial $\varkappa$ and $\rho(2050)=1.4\rho(2015)$ in line with the baseline scenario
π_4	Parameter linking the green capital-conventional capital ratio with recycling rate	40.55	Calibrated such that initial ρ corresponds to initial $\varkappa$ and $\rho(2050)=1.4\rho(2015)$ in line with the baseline scenario
π_5	Parameter linking the green capital-conventional capital ratio with energy intensity	13.63	Calibrated such that initial ε corresponds to initial $\varkappa$ and $\varepsilon(2050)=0.7\varepsilon(2015)$ in line with the baseline scenario
π_6	Parameter linking the green capital-conventional capital ratio with energy intensity	62.74	Calibrated such that initial ε corresponds to initial $\varkappa$ and $\varepsilon(2050)=0.7\varepsilon(2015)$ in line with the baseline scenario
π_7	Parameter linking the green capital-conventional capital ratio with the share of renewable energy	36.50	Calibrated such that initial θ corresponds to initial $\varkappa$ and $\theta(2050)=0.25$ in line with the baseline scenario
π_8	Parameter linking the green capital-conventional capital ratio with the share of renewable energy	47.58	Calibrated such that initial θ corresponds to initial $\varkappa$ and $\theta(2050)=0.25$ in line with the baseline scenario
ρ^{max}	Maximum potential value of recycling rate	0.8	Selected such that it is reasonably lower than 1
σ_1	Autonomous growth rate of labour productivity	0.0108	Calibrated such that the model generates the baseline scenario
σ_2	Sensitivity of labour productivity growth to the growth rate of output	0.92	Empirically estimated using data for a panel of countries over the period 1991-2016 (the econometric estimations are available upon request)
τ_F	Firms' tax rate	0.15	Selected from a reasonable range of values
τ_H	Households' tax rate	0.14	Calibrated such that the model generates the baseline scenario
φ_{11}	Transfer coefficient for carbon from the atmosphere to the atmosphere	0.9760	Calculated from the formula $\varphi_{11}=1-\varphi_{12}$ (see the DICE-2016R model, Nordhaus, 2016)
φ_{12}	Transfer coefficient for carbon from the atmosphere to the upper ocean/biosphere	0.0240	Taken from the DICE-2016R model (Nordhaus, 2016); has been adjusted to reflect a 1-year time step
φ_{21}	Transfer coefficient for carbon from the upper ocean/biosphere to the atmosphere	0.0392	Calculated from the formula $\varphi_{21}=\varphi_{12}(CO2_{AT\text{-}PRE}/CO2_{UP\text{-}PRE})$ (see the DICE-2016R model, Nordhaus, 2016)
φ_{22}	Transfer coefficient for carbon from the upper ocean/biosphere to the upper ocean/biosphere	0.9595	Calculated from the formula $\varphi_{22}=1-\varphi_{21}-\varphi_{23}$ (see the DICE-2016R model, Nordhaus, 2016)
φ_{23}	Transfer coefficient for carbon from the upper ocean/biosphere to the lower ocean	0.0013	Taken from the DICE-2016R model (Nordhaus, 2016); has been adjusted to reflect a 1-year time step
φ_{32}	Transfer coefficient for carbon from the lower ocean to the upper ocean/biosphere	0.0003	Calculated from the formula $\varphi_{32}=\varphi_{23}(CO2_{UP\text{-}PRE}/CO2_{LO\text{-}PRE})$ (see the DICE-2016R model, Nordhaus, 2016)
φ_{33}	Transfer coefficient for carbon from the lower ocean to the lower ocean	0.9997	Calculated from the formula $\varphi_{33}=1-\varphi_{32}$ (see the DICE-2016R model, Nordhaus, 2016)