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Cross-Border Financial Flows and Global Warming In a Two-Area Ecological SFC Model

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Abstract. We develop an ecological open-economy stock-flow consistent model that enables testing cross-area interactions among productive sectors, financial markets, social groups and the ecosystem. We argue that green financial investments can bring about unwanted ecological implications. Besides, the unequal diffusion of green technologies and assets across areas can lead the governments of less ecologically efficient areas to move further away from low-carbon policies. Mission-oriented green policies can smooth the side effects of traditional fiscal policies. However, their effectiveness depends crucially on the impact of cross-border financial flows (and growth rate differentials) on exchange rates. Lacking a cross-area policy coordination plan, currency fluctuations may well counteract green behaviours and policies.

Keywords: Stock-Flow Consistent Models, Climate Change, Financial Stability

JEL codes: D53, E44, F37, G17, Q54

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1. Introduction

Domestic and cross-border financial stability is paramount for promoting low-carbon transition. In order to achieve Paris Agreement's goals, low-carbon or green investments are required worldwide (e.g. UNFCCC 2015). According to the *International Energy Agency* (IEA), the current level of low-carbon investment is inadequate. Additional 48 trillion USD are required over the period 2020-2035 (IEA 2011). The energy sector needs 3.5 trillion USD investment per year up to 2050 (IEA, 2017). This means that the current level of green investment should be nearly doubled. In addition, appropriate policies to allocate private and public funds are required to boost green investment and trigger synergies between sectors and institutions. Several policies are to be implemented to promote low-carbon assets and share investment risks between private and government institutions. Some programmes have been already undertaken to align the financial system with climate goals (e.g. UNEP 2014). These policies are expected to guide private investors' behaviour in the next decades (e.g. Ameli et al. 2017; Boissinot et al. 2016; EC 2016). However, the volume of scientific studies on the effect of financial flows and low-carbon investment on climate change is still limited (IPCC 2018).

In the attempt to contribute to this debate, we have developed an ecological open-economy stock-flow consistent (SFC) model. The model reproduces global trends and enables us to test cross-area interactions among the productive sector, the financial markets, the society and the broader ecosystem. We aim at studying the impact of (both productive and financial) green investments on climate change, and vice versa. We also assess potential implications of fiscal policies that directly promote a low-carbon transition. We show that green financial investments can bring about unwanted ecological implications. Besides, the unequal diffusion of green technologies and assets across areas can make it profitable for the governments of less ecologically efficient areas to reduce cross-border transactions, while moving further away from low-carbon technologies. In principle, mission-oriented fiscal policies can help counter these tendencies. However, possible side effects, linked with the impact of cross-border financial flows (and growth rate differentials) on the exchange rates, must be carefully considered and addressed. Looking at the theoretical foundations, our contribution builds upon the most recent literature on ecological macroeconomics. While there are several methodological affinities, we depart from the existing literature in that we focus on cross-border (or cross-area) effects and interactions. We do so by using a model in which the world economy is defined as *two quasi-independent but interacting systems*. We show that the exchange rate is a crucial variable, as it transmits the impulses from the international transaction-flows to the domestic economy and the broad ecosystem.

The rest of the paper is organised as follows. In section 2, we provide a short review of the most recent literature on ecological macroeconomics modelling. In section 3, we present the main theoretical and methodological aspects of our contribution. We discuss the key features of our ecological open-economy model, equation by equation. We then use the model to analyse the impact of several global warming-related shocks and policy changes on key economic, financial, social and ecological variables. Our findings and the related policy implications are presented and discussed in depth in sections 4 and 5. We show that, lacking macroeconomic coordination across areas, international financial flows and exchange rate adjustments can counteract green behaviours and policies.

2. Literature review

Our work builds upon two strands of literature: macro and financial ecological models; and open-economy SFC models. Starting from the former, an increasing number of ecological and climate finance models have been developed in the last decade. These models aim at:

a) Detecting sustainable growth conditions and questioning the growth imperative (e.g. Jackson and Victor 2015, 2016 and Richters and Siemoneit 2017);
b) Studying the energy sector (e.g. Naqvic 2015, Berg et al. 2015);
c) Investigating the trajectories of key environmental, macroeconomic and financial variables (e.g. Dafermos et al. 2017, 2018);
d) Examining the interaction between climate change and financial stability (e.g. Dafermos et al. 2018);
e) Assessing the impact of State-led innovation policies on climate change and other ecological variables (e.g. Mazzucato 2015; Mazzucato and Semieniuk 2018; Deleidi et al. 2019; 2020);
f) Analysing the impact of green fiscal policies and green sovereign bonds on the ecosystem (Monasterolo and Raberto 2018 and Bovari et al. 2018);
g) Addressing the questions of how to finance the transition towards a ‘greener’ economy (e.g. Campiglio 2016; Ameli et al. 2017; Rademaekers et al. 2017) and how to tackle climate risks (e.g. Aglietta and Espagne 2016; Bardoscia et al. 2017; Battiston et al. 2017; Bovari et al. 2018; Dafermos et al. 2018).

More precisely, Jackson and Victor (2015, 2016) raise the question whether growth is necessary for capitalist economies to survive. They also argue that government countercyclical spending can promote the transition by smoothing and dampening the oscillations associated with it. The growth imperative is questioned also by Richters and Siemoneit (2017).

Naqvic (2015) proposes a multi-sectoral demand-led SFC model for a closed economy that interacts with the environment. It aims at evaluating the effectiveness of alternative environmental economic policies. He finds that the investment in innovative technologies is the only option that supports output and fosters employment (and wage growth), while reducing CO_2 emissions.

Berg et al. (2015) develop a multi-sectoral ecological SFC model that integrates the stock-flow analysis with the input-output methodology. Their main findings can be summarised as follows: (i) a non-growing economy can be associated with positive interest rates; (ii) an increase in energy prices can affect negatively the economic system by lowering real wages and aggregate demand, thus triggering a recession.

Dafermos et al. (2017) develop a stock-flow-fund ecological demand-led macroeconomic model calibrated using global data. The model combines a standard SFC framework with the flow-fund approach developed by Georgescu-Roegen (1971, 1979, 1984). Output is demand-led and finance is non-neutral. The authors focus on the channels through which the monetary system, the real economy and the ecosystem interact. Supply constraints are determined by the exhaustion of natural resources and by environmental damages. Climate change is included in the analysis. It affects aggregate demand through the influence of catastrophes, global warming and health issues on the desired level of investment, savings, consumption and potential output. Two types of green finance policy are analysed: (i) a reduction in the interest rate and the relaxing of credit rationing criteria on green loans; (ii) easier green credit requirements combined with tighter conditions on conventional types of loans. The latter generates better environmental results than the former, as it is associated with a lower economic growth combined with a larger share of green investment, lower CO_2 emissions, and lower atmospheric temperature.

More recently, Dafermos et al. (2018) have assessed and investigated the links between climate change and financial instability. The authors argue that an increase in the average temperature can be detrimental for firms' profitability and financial stability, possibly leading to a higher default rate and increasing the risk of systemic bank losses. A green quantitative easing program (regarded as a long-term industrial policy) is proposed and discussed, to tackle the financial instability triggered by climate change. The authors analyse a hypothetical scenario where central banks decide to buy a quarter of total green bonds worldwide. It is shown that green QE policies help counter financial instability. Investment financing becomes less dependent on bank credit, hence less subject to credit crunch risks. Moreover, a slower climate change implies lower economic damages. As a result, firms' profitability is restored, liquidity problems are dampened, and the default ratio decreases.

The ecological model developed by Deleidi et al. (2019) is based on four different theoretical approaches: (i) the Sraffian supermultiplier model; (ii) the Neo-Schumpeterian framework that emphasises the entrepreneurial role of the State; (iii) the SFC approach to macro-economic modelling; and (iv) recent developments in ecological economics literature aiming at crossbreeding post-Keynesian theories with ecological topics. The model aims at examining: (i) the impact of innovation on economic growth and the ecosystem; and (ii) the impact of ecological feedbacks on economic growth and government spending effectiveness. The authors find that, in principle, the government can be successful in supporting innovation and growth, while slowing down natural reserves' depletion rates and tackling climate change. However, ecological feedbacks affect government policies. Furthermore, the policy-makers are likely to be facing a conundrum in the next decade: green innovation allows for lower matter-, energy- and CO2-intensity coefficients, but the higher investment and production levels may well frustrate these efficiency gains (rebound effect).

Monasterolo and Raberto (2018) propose a mix of fiscal and monetary policies (green sovereign bonds) that aim at tackling climate change. Simulations show that green sovereign bonds contribute significantly to green investment and reduce the import of raw materials. However, the implementation of this monetary policy can imply a short-run trade-off between positive effects in terms of green transition and the risk of wealth concentration. Focusing on green fiscal policies (incentives and taxes), climate change mitigation can be associated with an increase in the unemployment rate.

Bovari et al. (2018) combine a SFC approach with a dynamic predator-prey (or Lotka-Volterra) model. They analyse the challenges posed by climate change in combination with private indebtedness, which can co-cause financial instability. The proposed policy approach consists in pricing carbon emissions through a carbon tax, which would make convenient for firms to reduce emissions.

Campiglio (2016) analyses the mechanisms through which banking and macro-prudential policies can support low-carbon investments through selective funding. Other authors (e.g. Ameli et al. 2017, and Rademaekers et al. 2017) focus on the role played by different classes of investors, notably, institutional investors, pension funds and insurance companies. The effects of *transition* and *physical risks* on the stability of the financial system are considered, among others, by Aglietta and Espagne (2016), Bardoscia et al. (2017), Battiston et al. (2017), Bovari et al. (2018) and Dafermos et al. (2018). Overall, it is argued that climate change is likely to bring about severe implications for the stability of the financial system in the next decades, by increasing bankruptcy rates, leading to *flight to safety* behaviours, and worsening credit conditions. There is a general agreement that green monetary policies (e.g. green QE programmes) can slow down global warming and smooth climate-induced financial instability.

Turning to the second strand of literature, our main reference is Godley and Lavoie (2007b). who developed three benchmark models for the open economy: *a*) the REG model, which is the simplest two-region model; *b*) the OPEN model, which is a two-country model with fixed exchange rates, gold as *international currency* and no foreign assets held by agents; *c*) an advanced version of the OPEN model, featuring a two-country model with four different closures, which engenders four different sub-models (OPENFIX, OPENFIXR, OPENFIXG and OPENFLEX). These prototypes, incorporating the main insights from the first generation of open-economy SFC models (Nikiforos and Zezza, 2017: 1221), have paved the way for a second wave of models. Plenty of them have been proposed ever since and we only mention some of the most significant.

Lavoie and Daigle (2011) use behavioural finance insights into an OPENFLEX model. They find that chartist expectations (based on the idea that the current trend will continue) can affect exchange rate regime properties. Mazier and Tiou-Tagba Aliti (2012) analyse world-wide imbalances using a three-country SFC model (including the US, the Euro Area and China). Building upon an earlier model by Lavoie and Zhao (2010), they show that a more flexible dollar-yuan exchange rate is powerful adjustment mechanism. Valdecantos and Zezza (2015) also focus on world imbalances. They consider four blocs: the US, the Euro Area, China and the rest of the world. The model is then used to test alternative international monetary systems, including the well-known Keynes' plan. Bortz (2014) uses an OPENFLEX-like model to study the interactions between a financially dependent economy (that needs to borrow in foreign currency) and a financially dominant economy (issuing the international money). Experiments' findings support an active management of the exchange rate. Dezter (2018) shows that increasing inequality can generate different growth regimes, depending on country-specific institutional structures and regulatory frameworks. Finally, Raza et al. (2019) analyse how financial flows can contribute to destabilise a small economy and propose a mix of policy measures that can help taming the ensuing financial and economic instability.

3. Theory and method

3.1 Model features and key assumptions

Our contribution innovates relative to the existing literature in that it focuses on (side) effects of cross-border financial flows. The formal model we have developed belongs to the class of SFC dynamic macroeconomic models (e.g. Godley and Lavoie 2007; see also Nikiforos and Zezza 2017; Carnevali et al. 2019). While some ecological SFC models have been developed in the last decade, they usually focus on a single-area economy. However, local impacts of climate change and the depletion of natural resources are likely to be unequal across regions and countries. Besides, when a climate change-related shock hits an area, it may well bring about indirect effects for other areas. To shed light on this yet-unexplored aspect, we have developed an ecological two-area SFC model. Its basic structure is made up of 228 difference equations and 2 redundant equations. Exogenous variables and coefficients are more than one hundred.[1]

The key features of our model can be summarised as follows:

a) We divide the world economy in two main areas. For the sake of simplicity, we name them Greenland and Brownland, respectively.

b) Each domestic household sector is made up of two social groups: the recipients of labour incomes (the workers) and the recipients of entrepreneurial and financial incomes (the capitalists).

c) While the workers can only hold their savings in form of cash (domestic currency) and bank deposits, capitalists can diversify their portfolios by purchasing domestic and foreign government bills and/or firms' shares (see Fig. 1, charts *g* and *h*).

d) Initial values of economic and financial stocks, and the related parameter values, are identical across areas (e.g. GDPs, wealth stocks, propensities to consume, interest rates, etc.).

e) Both economies are demand-led in the short- and long-run. There is no constraint on the supply side, except for the availability of natural reserves and the impact of global warming. Variables are expressed at constant prices if not otherwise specified. Unit prices of products are fixed.

f) Productive firms can undertake both conventional investment and low-carbon (or green) investment. Green capital entails lower CO_2-, energy and matter-intensity ratios, relative to conventional capital.

g) Current accounts are balanced in the baseline scenario, while government deficits are in line with world data (i.e. 4.5% of GDP ca).

h) There is a floating exchange rate regime. As a result, current account and financial account variables determine the relative price of the currencies.

i) Natural resources' endowments (matter and energy stocks) are identical across areas. Each area can only access its own reserves. However, ecological shocks hitting one area can affect the other area through changes in the average temperature and the related damages.

[1] Notice that the dynamic equations of the model are 89, of which 28 are the driving behavioural equations (notably, 17, 18, 20, 21, 43, 44, 46, 54, 55, 57, 61, 62, 89, 93, 123, 124, 144, 145, 171, 173, 174, 175, 177, 178, 179, 194, 195, 208). Consequently, the key coefficients for the model dynamics are *only* 56. Notice also that the model we simulated is slightly bigger, because it includes some checks and additional calculations. It amounts to 249 endogenous variables and 145 exogenous variables and parameters, overall. The model was coded and run using *EViews*. The list of coefficient values and data sources are shown by Table 6 in the Appendix. The complete program file is available online at *sfc-models.net* and *marcopassarella.it/en*.

j) Unlike economic, financial and social coefficients, the techniques of production are different across areas in terms of ecological efficiency. Given the labour to capital ratio, the ecological efficiency is defined by the capital composition. Besides, given both the labour to capital ratio and the capital composition, Greenland output is marked by lower CO_2-, energy- and matter-intensity ratios, and a higher share of renewable energy to total energy (see Table 6 in the Appendix).

For the sake of simplicity, model equations can be grouped and subdivided into seventeen theoretical blocks, based on the human life sphere the relate to.

I. *Disposable income, wealth and taxes*. Disposable income of both capitalists and workers in Brownland is defined as total income net of taxes:[2]

$$YD_r^B = Y_r^B \cdot (1 - \theta_B) \tag{1}$$

$$YD_w^B = Y_w^B \cdot (1 - \theta_B) \tag{2}$$

where θ_B is the average tax rate on both labour non-labour incomes. For the sake of simplicity, we assume that capital gains are tax-free. As a result, the so-called Haig-Simons disposable income of capitalists is:

$$YD_{hs,r}^B = YD_r^B + CG_b^B + CG_e^B \tag{3}$$

where:

$$CG_b^B = d(xr_G) \cdot B_{s,-1}^{BG} \tag{4}$$

and

$$CG_e^B = d(xr_G) \cdot E_{s,-1}^{BG} \tag{5}$$

are the revaluation effects on foreign bills (B_s^{BG}) and foreign shares (E_s^{BG}) held by Brownland capitalists, while xr_G is the exchange rate (defined as the quantity of foreign currency per one unit of domestic currency).[3] Household saving (that is, the excess of disposable income over consumption) is accumulated over time as a stock of financial assets. Each area's stock of net wealth is therefore:

$$V_r^B = V_{r,-1}^B + YD_{hs,r}^B - C_r^B \tag{6}$$

$$V_w^B = V_{w,-1}^B + YD_w^B - C_w^B \tag{7}$$

[2] Notice that uppercase letters are usually associated with nominal variables (even when expressed at constant prices). Lowercase letters are used for real variables (physical quantities) and coefficients instead. When possible, coefficients are expressed using Greek letters. The superscript/superscript B stands for Brownland, while G marks Greenland's variables and parameters. Similarly, w refers to working class households, whereas r stands for rentiers or capitalist households.

[3] For the sake of simplicity, product prices are taken as fixed. Adjustments are all made through quantities. We recognise this is a simplification. However, it is in line with a long-standing Keynesian tradition in economic modelling. If firms are price setter (monopoly power), production conditions across countries are similar (apart from ecological coefficient values), and inputs are not fully employed, it can be assumed that price levels are insensitive to the ebb and flow of the market. Since product prices are fixed (unity), there is no difference between the nominal exchange rate and the real exchange rate in the model.

We assume that there are no differences in economic, social and financial motives and behaviours in Greenland relative to Brownland. As a result, equations (1) to (7) are replicated for Greenland:

$$YD_r^G = Y_r^G \cdot (1-\theta_G) \quad (8)$$

$$YD_w^G = Y_w^G \cdot (1-\theta_G) \quad (9)$$

$$YD_{hs,r}^G = YD_r^G + CG_b^G + CG_e^G \quad (10)$$

$$CG_b^G = d(xr_B) \cdot B_{s,-1}^{GB} \quad (11)$$

$$CG_e^G = d(xr_B) \cdot E_{s,-1}^{GB} \quad (12)$$

$$V_r^G = V_{r,-1}^G + YD_{hs,r}^G - C_r^G \quad (13)$$

$$V_w^G = V_{w,-1}^G + YD_w^G - C_w^G \quad (14)$$

We can now calculate the total tax revenues in Brownland and Greenland, respectively:

$$T_B = (Y_r^B + Y_w^B) \cdot \theta_B \quad (15)$$

$$T_G = (Y_r^G + Y_w^G) \cdot \theta_G \quad (16)$$

Indirect taxation (e.g. VAT) is assumed away, instead.

II. *Consumption and income shares*. Household consumption is driven by disposable income and net wealth:

$$C_r^B = \left(\alpha_{1r}^B \cdot YD_r^B + \alpha_{2r}^B \cdot V_{r,-1}^B\right) \cdot \left(1 - d_{T,-1}^B\right) \quad (17)$$

$$C_w^B = \left(\alpha_{1w}^B \cdot YD_w^B + \alpha_{2w}^B \cdot V_{w,-1}^B\right) \cdot \left(1 - d_{T,-1}^B\right) \quad (18)$$

where α_{1r}^B and α_{1w}^B are the propensities to consume out of income of capitalists and workers, respectively, while α_{2r}^B and α_{2w}^B are their propensities to consume out of wealth. Household consumption plans are also affected by climate change-related damages, captured by the coefficient d_T^B.[4] Brownland total income (or gross domestic product) is defined by the standard macroeconomic identity:

$$Y_B = C_r^B + C_w^B + GOV_{tot}^B + X_B - IM_B + INV_B \quad (19)$$

where GOV_{tot}^B is total government spending, X_B is gross export, IM_B is gross import and INV_B is total private investment. Greenland equations mirror Brownland's, that is:

$$C_r^G = \left(\alpha_{1r}^G \cdot YD_r^G + \alpha_{2r}^G \cdot V_{r,-1}^G\right) \cdot \left(1 - d_{T,-1}^G\right) \quad (20)$$

$$C_w^G = \left(\alpha_{1w}^G \cdot YD_w^G + \alpha_{2w}^G \cdot V_{w,-1}^G\right) \cdot \left(1 - d_{T,-1}^G\right) \quad (21)$$

$$Y_G = C_r^G + C_w^G + GOV_{tot}^G + X_G - IM_G + INV_G \quad (22)$$

Wage bills in the two areas are simply defined as shares of total income:

$$Y_w^B = \omega_B \cdot Y_B \quad (23)$$

$$Y_w^G = \omega_G \cdot Y_G \quad (24)$$

As a result, the gross profit earned by private production firms in Brownland is defined as:

[4] We discuss thoroughly this aspect in the next sections.

$$F_f^B = Y_B - Y_w^B - DA_B - r_{l,-1}^B \cdot L_{f,-1}^B \tag{25}$$

This accounting identity can be derived from the second column of the transactions-flow matrix[5]. Retained profits are a percentage of total profits:

$$F_u^B = F_f^B \cdot ret_B \tag{26}$$

Distributed profits (or dividends) are based on the return rate on equity and shares:

$$F_d^B = r_{e,-1}^B \cdot (E_{s,-1}^{BB} + E_{s,-1}^{GB}) \tag{27}$$

The residual component is the compensations of Brownland firms' managers:

$$F_m^B = F_f^B - F_u^B - F_d^B \tag{28}$$

While the definition of managers' income as a residual variable is not common in the SFC literature, it allows reproducing the effects of incentive schemes for the managers (e.g. the distribution of stock options). These schemes aim at inducing the managers to pursue profit maximisation. If the shareholders compete to hire the best managers, the latter are expected to capture the entire shareholder's *surplus* (i.e. the difference between the actual return rate and the normal rate on financial assets in the medium run). Notice that our modelling choice also stabilises the flow of dividends over time, hence the return rate on equity and shares – which, once again, can be thought as a policy pursued by the managers to assure a high but stable market value of the firms over time. Incidentally, this brings about stabilising implications for the model dynamics.

We can now calculate the total income earned by Brownland capitalist households:

$$Y_r^B = F_m^B + F_b^B + r_{b,-1}^B \cdot B_{s,-1}^{BB} + xr_{G,-1} \cdot r_{b,-1}^G \cdot B_{s,-1}^{BG} + F_{d,-1}^{BB} + F_{d,-1}^{BG} \tag{29}$$

where:

$$F_d^{BG} = xr_G \cdot r_e^G \cdot E_s^{BG} \tag{30}$$

and

$$F_d^{BB} = r_e^G \cdot E_s^{BB} \tag{31}$$

is the flow of dividends paid by Greenland firms to Brownland shareholders, and by Brownland firms to Brownland shareholders, respectively.

As usual, Greenland equations are in line with Brownland's:

$$F_f^G = Y_G - Y_w^G - DA_G - r_{l,-1}^G \cdot L_{f,-1}^G \tag{32}$$

$$F_u^G = F_f^G \cdot ret_G \tag{33}$$

$$F_d^G = r_{e,-1}^G \cdot (E_{s,-1}^{GG} + E_{s,-1}^{BG}) \tag{34}$$

$$F_m^G = F_f^G - F_u^G - F_d^G \tag{35}$$

$$Y_r^G = F_m^G + F_b^G + r_{b,-1}^G \cdot B_{s,-1}^{GG} + xr_{B,-1} \cdot r_{b,-1}^B \cdot B_{s,-1}^{GB} + F_{d,-1}^{GB} + F_{d,-1}^{GG} \tag{36}$$

$$F_d^{GB} = xr_B \cdot r_e^B \cdot E_s^{GB} \tag{37}$$

[5] See Table 2, where square brackets define production firms' capital account.

$$F_d^{GG} = r_e^G \cdot E_s^{GG} \quad (38)$$

III. *Firms' investment plans*. Production firms purchase two different types of capital goods, conventional and green. Capital accumulation in Brownland is defined by the subsystem:

$$K_B = K_{gr}^B + K_{con}^B \quad (39)$$

$$K_{gr}^B = K_{gr,-1}^B + INV_{gr}^B - DA_{gr}^B \quad (40)$$

$$K_{con}^B = K_{con,-1}^B + INV_{con}^B - DA_{con}^B \quad (41)$$

$$DA_B = DA_{gr}^B + DA_{con}^B \quad (42)$$

$$DA_{gr}^B = \delta_B \cdot K_{gr,-1}^B \quad (43)$$

$$DA_{con}^B = \delta_B \cdot K_{con,-1}^B \quad (44)$$

$$AF_B = DA_B \quad (45)$$

$$INV_B = \left(\gamma_0^B + \gamma_1^B \cdot INV_{B,-1} + \gamma_2^B \cdot GOV_{tot,-1}^B\right) \cdot \left(1 - d_{T,-1}^B\right) \quad (46)$$

$$INV_{gr}^B = \min[(\chi_1^B \cdot GOV_{gr}^B + \chi_2^B \cdot Y_B + \chi_3^B \cdot d_T^B), INV_B) \quad (47)$$

$$INV_{con}^B = INV_B - INV_{gr}^B \quad (48)$$

Equation (39) defines the total stock of capital in Brownland as the summation of green and conventional capital. Equations (40) and (41) show that the capital stock increases as the gross investment increases and reduces as depreciation allowances increase. The latter are defined by equations (42) to (44), based on the average capital depreciation rate (δ_B). In equation (45), it is assumed that private firms' amortisation funds match capital depreciation. Equation (46) shows that the benchmark level of the gross *aggregate* investment is defined by three components: an autonomous part; an autoregressive mechanism; and an additional component that depends positively on government spending in the past period. The third component captures the private investment-enhancing role that government intervention plays in fields such as the provision of infrastructures and the support to private innovation. Besides, like consumption, investment is affected by climate change-related damages. Equation (47) defines green investment as a share of output *plus* two additional components, which depend on government green spending and damages, respectively. In line with Deleidi and Mazzucato (2019a, b) and Deleidi et al. (2019), we posit that mission-oriented government spending (MOIS) plays a crucial role in shaping private firms' plans. The reason is that green MOIS can foster low-carbon transition by establishing the direction of the technical progress. It creates new technological opportunities for the private sector by reducing the risk to undertake green investments (e.g. Mazzucato 2018).[6] Although MOIS does not necessarily increase productive capacity, we assume that green MOIS contributes to define *the composition of the (private)*

[6] A well-known example of green MOIS is the *Energiewende Programme* (e.g. EC 2018; Mazzucato 2015, 2018).

capital stock.[7] Green capital accumulation improves the ecological efficiency of the productive system (lower matter-, energy and CO_2-intensity ratios and higher recycling rate). It is implicitly assumed that, first, the firms choose the amount of desired investment; second, they set the share of it to be devoted to green investment (which cannot exceed total investment); third, they calculate the amount of conventional investment as a residual level. Notice that production firms can fund their investment plans through internal funds (retained profits plus amortisation funds) and equity issues. The change in loans demanded by firms is defined residually:

$$L_f^B = L_{f,-1}^B + INV_B - AF_B - F_u^B - d(E_s^{GB}) - d(E_s^{BB}) \quad (49)$$

Similarly, the capital accumulation equations for Greenland are:

$$K^G = K_{gr}^G + K_{con}^G \quad (50)$$

$$K_{gr}^G = K_{gr,-1}^G + INV_{gr}^G - DA_{gr}^G \quad (51)$$

$$K_{con}^G = K_{con,-1}^G + INV_{con}^G - DA_{con}^G \quad (52)$$

$$DA_G = DA_{gr}^G + DA_{con}^G \quad (53)$$

$$DA_{gr}^G = \delta_G \cdot K_{gr,-1}^G \quad (54)$$

$$DA_{con}^G = \delta_G \cdot K_{con,-1}^G \quad (55)$$

$$AF_G = DA_G \quad (56)$$

$$INV_G = \left(\gamma_0^G + \gamma_1^G \cdot INV_{G,-1} + \gamma_2^G \cdot GOV_{tot,-1}^G\right) \cdot \left(1 - d_{T,-1}^G\right) \quad (57)$$

$$INV_{gr}^G = \min[(\chi_1^G \cdot GOV_{gr}^G + \chi_2^G \cdot Y_G + \chi_3^G \cdot d_T^G), INV_G) \quad (58)$$

$$INV_{con}^G = INV_G - INV_{gr}^G \quad (59)$$

$$L_f^G = L_{f,-1}^G + INV_G - AF_G - F_u^G - d(E_s^{BG}) - d(E_s^{GG}) \quad (60)$$

IV. *International trade*. Borrowing from the literature on international trade, we define both import and export as nonlinear functions of the exchange rate and the income level in the other area. However, we amend the standard formulation to account for climate change-related damages, which can possibly affect consumption of foreign products in the two areas. The rationale here is that a higher ecological awareness, associated with climate change, can favour Greenland products over Brownland's. Therefore, gross export *from* and *to* Brownland is defined, respectively, as:

$$X_B = \exp\left[\varepsilon_0 - \varepsilon_1 \cdot log\left(xr_{B,-1}\right) + \varepsilon_2 \cdot log(Y_G)\right] \cdot \left(1 - att_X \cdot d_{T,-1}^B\right) \quad (61)$$

$$IM_B = \exp\left[\mu_0 + \mu_1 \cdot log\left(xr_{B,-1}\right) + \mu_2 \cdot log(Y_B)\right] \cdot \left(1 + att_{IM} \cdot d_{T,-1}^G\right) \quad (62)$$

where ε_1 captures the elasticity of Brownland export to the exchange rate and ε_2 captures Brownland elasticity to total income of Greenland, whereas μ_1 and μ_2 refer to Brownland

[7] As a result, the second component of equation (47) can be regarded as defining the share of green investment that private firms would not be undertaking if they were not supported by the State.

import. It is assumed that global warming affects international trade, damaging Brownland exports while supporting Greenland's. Attenuation policies are put in place by Brownland firms to reduce the economic impact of climate change. Coefficients att_X and att_{IM} are meant to capture this effect. Besides, since we subdivided the world economy in two areas, Greenland export and import must match Brownland import and export, respectively:

$$X_G = IM_B \cdot xr_B \tag{63}$$

$$IM_G = X_B \cdot xr_B \tag{64}$$

V. *Demand for financial assets*. Six types of financial instruments are considered: (domestic) cash, (domestic) bank deposits, domestic government bills, foreign bills, shares issued by domestic firms and foreign shares. For the sake of simplicity, we assume that the workers can only hold cash and deposits, while the capitalists are also allowed to hold domestic and foreign bills and/or shares.[8] Portfolio equations are modelled in line with Tobinesque principles. This means that the capitalists hold a share of each asset (to total net wealth) that depends on its return rate relative to the return rates on other assets:[9]

$$\frac{B_d^{BB}}{V_r^B} = \lambda_{10} + \lambda_{11} \cdot r_{b,-1}^B - \lambda_{12} \cdot r_{b,-1}^G - \lambda_{13} \cdot r_{e,-1}^B - \lambda_{14} \cdot r_{e,-1}^G \tag{65}$$

$$\frac{B_d^{BG}}{V_r^B} = \lambda_{20} - \lambda_{21} \cdot r_{b,-1}^B + \lambda_{22} \cdot r_{b.-1}^G - \lambda_{23} \cdot r_{e,-1}^B - \lambda_{24} \cdot r_{e,-1}^G \tag{66}$$

$$\frac{E_d^{BG}}{V_r^B} = \lambda_{70} - \lambda_{71} \cdot r_{b,-1}^B - \lambda_{72} \cdot r_{b,-1}^G - \lambda_{73} \cdot r_{e,-1}^B + \lambda_{74} \cdot r_{e,-1}^G \tag{67}$$

$$\frac{E_d^{BB}}{V_r^B} = \lambda_{90} - \lambda_{91} \cdot r_{b,-1}^B - \lambda_{92} \cdot r_{b,-1}^G + \lambda_{93} \cdot r_{e,-1}^B - \lambda_{94} \cdot r_{e,-1}^G \tag{68}$$

Equations (65) to (68) define the nominal demand for Brownland bills by Brownland capitalists, Greenland bills by Brownland capitalists, Greenland shares by Brownland capitalists, and Brownland shares by Brownland capitalists, respectively.

Bank deposits bear no interests. The amount held by Brownland capitalists is defined as a share of their residual net wealth:

$$M_r^B = (V_r^B - B_S^{BB} - E_S^{BB} - (B_S^{BG} + E_S^{BG}) \cdot xr_G) \cdot \nu_B \tag{69}$$

The remaining portion of net wealth is held as cash:

$$H_r^B = V_r^B - B_S^{BB} - E_S^{BB} - (B_S^{BG} + E_S^{BG}) \cdot xr_G - M_r^B \tag{70}$$

Turning to workers, they can just choose the share of wealth they wish to hold in form of bank deposits, while the residual share is held as cash:

$$M_w^B = V_W^B \cdot \nu_B \tag{71}$$

[8] Notice that every household can only hold cash and deposits denominated in domestic currency, but the capitalists can buy foreign bills and shares too.

[9] For the sake of simplicity, we do not consider the expected variation of the exchange rate in portfolio equations. If investors follow a conventionalist behaviour (meaning that they expect the exchange rate to move towards a conventional value in the long run), qualitative properties of a floating regime are unaffected by exchange rate expectations (Lavoie and Daigle 2011).

$$H_w^B = V_w^B - M_w^B \quad (72)$$

Total holdings of cash in Brownland are therefore:

$$H_h^B = H_w^B + H_r^B \quad (73)$$

As usual, Greenland equations match Brownland's:

$$\frac{B_d^{GG}}{V_r^G} = \lambda_{40} - \lambda_{41} \cdot r_{b,-1}^B + \lambda_{42} \cdot r_{b,-1}^G - \lambda_{43} \cdot r_{e,-1}^B - \lambda_{44} \cdot r_{e,-1}^G \quad (74)$$

$$\frac{B_d^{GB}}{V_r^G} = \lambda_{50} + \lambda_{51} \cdot r_{b,-1}^B - \lambda_{52} \cdot r_{b,-1}^G - \lambda_{53} \cdot r_{e,-1}^B - \lambda_{54} \cdot r_{e,-1}^G \quad (75)$$

$$\frac{E_d^{GB}}{V_r^G} = \lambda_{80} - \lambda_{81} \cdot r_{b,-1}^B - \lambda_{82} \cdot r_{b,-1}^G + \lambda_{83} \cdot r_{e,-1}^B - \lambda_{84} \cdot r_{e,-1}^G \quad (76)$$

$$\frac{E_d^{GG}}{V_r^G} = \lambda_{100} - \lambda_{101} \cdot r_{b,-1}^B - \lambda_{102} \cdot r_{b,-1}^G - \lambda_{103} \cdot r_{e,-1}^B + \lambda_{104} \cdot r_{e,-1}^G \quad (77)$$

$$M_r^G = (V_r^G - B_s^{GG} - E_s^{GG} - (B_s^{GB} + E_s^{GB}) \cdot xr_B) \cdot \nu_G \quad (78)$$

$$H_r^G = V_r^G - B_s^{GG} - E_s^{GG} - (B_s^{GB} + E_s^{GB}) \cdot xr_B - M_r^G \quad (79)$$

$$M_w^G = V_W^G \cdot \nu_G \quad (80)$$

$$H_w^G = V_w^G - M_w^G \quad (81)$$

$$H_h^G = H_w^G + H_r^G \quad (82)$$

VI. *Supplies and prices of financial assets*. The market equilibrium conditions for the (nominal) supplies of Brownland bills to Brownland capitalists, Greenland bills to Greenland capitalists, Brownland bills to Greenland capitalists, Greenland bills to Brownland capitalists, Greenland shares to Brownland capitalists, Greenland shares to Greenland capitalists, Brownland shares to Greenland capitalists and Brownland shares to Brownland capitalists, respectively, are:

$$B_s^{BB} = B_d^{BB} \quad (83)$$

$$B_s^{GG} = B_d^{GG} \quad (84)$$

$$B_s^{GB} = B_d^{GB} \cdot xr_G \quad (85)$$

$$B_s^{BG} = B_d^{BG} \cdot xr_B \quad (86)$$

$$E_s^{BG} = E_d^{BG} \cdot xr_B \quad (87)$$

$$E_s^{GG} = E_d^{GG} \quad (88)$$

$$E_s^{GB} = E_d^{GB} \cdot xr_G \quad (89)$$

$$E_s^{BB} = E_d^{BB} \quad (90)$$

Unlike other financial assets (and products), the equity market adjusts through prices (p_e^B), rather than quantities. The quantity of shares issued by Brownland firms is:

$$e_s^B = e_{s,-1}^B + \xi_B \cdot \frac{INV_{B,-1}}{p_{e,-1}^B} \quad (91)$$

where ξ_B is the desired new equity to investment ratio of Brownland firms. As a result, the unit price of shares issued by Brownland firms is:

$$p_e^B = \frac{E_d^{BB} + E_d^{GB}}{e_s^B} \tag{92}$$

We assume that the dividend yield accruing on shares is linked with the average return rate on other financial assets, while the managers are the recipients of (non-retained) extra profits – see equations (25) to (28) and (32) to (35). The dividend yield is calculated as a weighted average of the return rate on bonds and the target or maximum return rate on equity:

$$r_e^B = \left(1 - \pi_{dy}^B\right) \cdot r_b^B + \pi_{dy}^B \cdot r_e^{BT} \tag{93}$$

$$r_e^{BT} = \frac{F_f^B}{e_{s,-1}^B \cdot p_{e,-1}^B} \tag{94}$$

Equation (94) shows the return rate that the shareholders would realise if there were no salaries for the managers.

As usual, Greenland equations mirror Brownland's:

$$e_s^G = e_{s,-1}^G + \xi_G \cdot \frac{INV_{G,-1}}{p_{e,-1}^G} \tag{95}$$

$$p_e^G = \frac{E_d^{GG} + E_d^{BG}}{e_s^G} \tag{96}$$

$$r_e^G = \left(1 - \pi_{dy}^G\right) \cdot r_b^G + \pi_{dy}^G \cdot r_e^{GT} \tag{97}$$

$$r_e^{GT} = \frac{F_f^G}{e_{s,-1}^G \cdot p_{e,-1}^G} \tag{98}$$

VII. *The banking sector*. Capitalists and workers hold a share of their liquidity in terms of bank deposits. The supply of deposits in Brownland simply adjusts to demand:

$$M_s^B = M_w^B + M_r^B \tag{99}$$

Loans, and hence deposits, are created by banks *out of thin air*. This occurs every time banks credit firm's accounts to fund production and investment plans. We assume that banks are always willing to lend, so that credit supply adjusts smoothly to demand:

$$L_s^B = L_f^B \tag{100}$$

The notional stock of bills held by Brownland banks equals the difference between deposits and loans:

$$B_{b,not}^B = M_s^B - L_s^B \tag{101}$$

However, Brownland banks do actually buy bills only if they have enough reserves to do so. This condition holds only if the deposits they collect at the end of the period exceed the loans they granted. Therefore:

$$B_b^B = B_{b,not}^B \cdot \zeta_B \tag{103}$$

where:

$$\zeta_B = 1 \ iff \ B_{b,not}^B > 0; otherwise \ \zeta_B = 0 \tag{102}$$

is the trigger for notional Brownland bills bought by Brownland banks. As a result, the advances demanded by Brownland banks are:

$$A_d^B = -B_{b,not}^B \cdot (1 - \zeta_B) \quad (104)$$

We assume that the central bank acts as the lenders of last resort for the banking sector. Consequently, the supply of advances always adjusts passively to banks' demand:

$$A_s^B = A_d^B \quad (105)$$

Bank profits are calculated as the difference between the interest payments received on banks' financial assets and the interests paid on bank's liabilities. The interest rate accruing on advances, reserves and deposits is negligible. Production costs are also assumed away. Therefore, the equation for bank profits is:

$$F_b^B = r_{b,-1}^B \cdot B_{b,-1}^B + r_l^B \cdot L_{s,-1}^B \quad (106)$$

As usual, Greenland equations match Brownland's:

$$M_s^G = M_w^G + M_r^G \quad (107)$$

$$L_s^G = L_f^G \quad (108)$$

$$B_{b,not}^G = M_s^G - L_s^G \quad (109)$$

$$\zeta_G = 1 \ iff \ B_{b,not}^G > 0; otherwise \ \zeta_G = 0 \quad (110)$$

$$B_b^G = B_{b,not}^G \cdot \zeta_G \quad (111)$$

$$A_d^G = -B_{b,not}^G \cdot (1 - \zeta_G) \quad (112)$$

$$A_s^G = A_d^G \quad (113)$$

$$F_b^G = r_{b,-1}^G \cdot B_{b,-1}^G + r_l^G \cdot L_{s,-1}^G \quad (114)$$

VIII. *The central bank and the government sector*. Monetary policy is assumed to support fiscal policy. Consequently, the central bank is always available to purchase all the Treasury bills that are not subscribed by private investors:

$$B_{cb}^{BB} = B_s^B - B_s^{BB} - B_s^{GB} - B_b^B \quad (115)$$

Cash is supplied as long as Treasury bills are purchased by the central bank and advances are granted to the banking sector:

$$H_s^B = B_{cb}^{BB} + A_s^B \quad (116)$$

The amount of profits realised by Brownland central bank is therefore:[10]

$$F_{cb}^B = r_{b,-1}^B \cdot B_{cb,-1}^{BB} \quad (117)$$

Analogously, the following subsystem of equations holds for Greenland:

$$B_{cb}^{GG} = B_s^G - B_s^{GG} - B_s^{BG} - B_b^G \quad (118)$$

$$H_s^G = B_{cb}^{GG} + A_s^G \quad (119)$$

$$F_{cb}^G = r_{b,-1}^G \cdot B_{cb,-1}^{GG} \quad (120)$$

[10] Central bank profits realised on domestic bills are forwarded to the government (see equations 198 and 199). Under the floating exchange rate setting, international reserves of central banks are not modelled. As a result, there are no profit accruing on foreign bills.

Turning to the government sector, the policy makers can opt for two types of government spending: conventional (or routine) spending and green MOIS. Total government expenditures in the two countries are:

$$GOV_{tot}^{B} = GOV_{con}^{B} + GOV_{gr}^{B} \tag{121}$$

$$GOV_{tot}^{G} = GOV_{con}^{G} + GOV_{gr}^{G} \tag{122}$$

Like conventional spending, green MOIS does not have a direct effect on ecological efficiency. However, unlike conventional spending, green MOIS specifically promotes private green investment. Its amount is defined exogenously, whereas routine spending is modelled as an AR(1) process:

$$GOV_{con}^{B} = \gamma_{GOV0}^{B} + \gamma_{GOV1}^{B} \cdot GOV_{con,-1}^{B} \tag{123}$$

$$GOV_{con}^{G} = \gamma_{GOV0}^{G} + \gamma_{GOV1}^{G} \cdot GOV_{con,-1}^{G} \tag{124}$$

Supplies of bills are derived from government budget constraints:

$$B_{s}^{B} = B_{s,-1}^{B} + GOV_{tot}^{B} + r_{B,-1} \cdot B_{s,-1}^{B} - T_{B} - F_{cb}^{B} \tag{125}$$

$$B_{s}^{G} = B_{s,-1}^{G} + GOV_{tot}^{G} + r_{G,-1} \cdot B_{s,-1}^{G} - T_{G} - F_{cb}^{G} \tag{126}$$

IX. *The exchange rates*. A floating exchange rate is used in the baseline scenario. It is determined by demand and supply forces, considering both the real side (the trade balance) and the financial side (financial incomes in the current account and the financial account). We assume perfect capital mobility, but not perfect capital substitutability. Economic agents make their portfolio choices based on the relative return rates on financial assets. However, differences in return rates are persistent, because financial assets are not perfect substitutes. There is no tendency for their return rates to equalise.

The exchange rate for Greenland is defined as the quantity of Brownland currency in exchange for one unit of Greenland currency. We define it by using the equilibrium condition for the balance of payments:

$$xr_{G} = \frac{r_{b,-1}^{B} \cdot B_{S,-1}^{GB} + r_{e,-1}^{B} \cdot E_{S,-1}^{GB} - d(B_{S}^{GB}) - d(E_{S}^{GB}) - X_{B} + IM_{B}}{r_{b,-1}^{G} \cdot B_{S,-1}^{BG} + r_{e,-1}^{G} \cdot E_{S,-1}^{BG} - d(B_{S}^{BG}) - d(E_{S}^{BG})} \tag{127}$$

Clearly, the exchange rate for Brownland is:

$$xr_{B} = \frac{1}{xr_{G}} \tag{128}$$

As we show in the next section, the adjustment of the exchange rate is one of the key mechanisms through which the two areas and the ecosystem interact.[11]

X. *The ecosystem: material resources and reserves*. The next four blocks of equations are based on Dafermos et al. (2017, 2018) and Carnevali et al. (2019). We first track the evolution over time of material reserves:

[11] A thorough discussion of the exchange rate is provided online at *sfc-models.net* and *marcopassarella.it/en* (see Extra Contents).

$$y^B_{mat} = \mu_B \cdot Y_B \tag{129}$$

$$y^G_{mat} = \mu_G \cdot Y_G \tag{130}$$

$$mat_B = y^B_{mat} - rec_B \tag{131}$$

$$mat_G = y^G_{mat} - rec_G \tag{132}$$

$$rec_B = \rho_B \cdot dis_B \tag{133}$$

$$rec_G = \rho_G \cdot dis_G \tag{134}$$

$$dis_B = \mu_B \cdot (DA_B + \xi_B \cdot DC^B_{-1}) \tag{135}$$

$$dis_G = \mu_G \cdot (DA_G + \xi_B \cdot DC^G_{-1}) \tag{136}$$

$$DC^B = DC^B_{-1} + C^B_r + C^B_w - TB_{B,-1} - \zeta_B \cdot DC^B_{-1} \tag{137}$$

$$DC^G = DC^G_{-1} + C^G_r + C^G_w - TB_{G,-1} - \zeta_G \cdot DC^G_{-1} \tag{138}$$

$$k^B_{se} = k^B_{se,-1} + y^B_{mat} - dis_B \tag{139}$$

$$k^G_{se} = k^G_{se,-1} + y^G_{mat} - dis_G \tag{140}$$

$$wa_B = mat_B - d(k^B_{se}) \tag{141}$$

$$wa_G = mat_G - d(k^G_{se}) \tag{142}$$

$$k^B_m = k^B_{m,-1} + conv^B_m - mat_B \tag{143}$$

$$k^G_m = k^G_{m,-1} + conv^G_m - mat_G \tag{144}$$

$$k_m = k^B_m + k^G_m \tag{145}$$

$$conv^B_m = \sigma^B_m \cdot res^B_{m,-1} \tag{146}$$

$$conv^G_m = \sigma^G_m \cdot res^G_{m,-1} \tag{147}$$

$$res^B_m = res^B_{m,-1} - conv^B_m \tag{148}$$

$$res^G_m = res^G_{m,-1} - conv^G_m \tag{149}$$

$$res_m = res^B_m + res^G_m \tag{150}$$

$$cen_B = \frac{emis_B}{car} \tag{151}$$

$$cen_G = \frac{emis_G}{car} \tag{152}$$

$$o2_B = emis_B - cen_B \tag{153}$$

$$o2_G = emis_G - cen_G \tag{154}$$

Equations (129)-(130) define the production of material goods in the two areas, based on area-specific matter-intensity coefficients. Equations (131)-(132) define the extraction of matter from the ground as the difference between the matter used in the production process and the recycled socio-economic stock.[12] The latter is calculated by equations (133)-(134). The amount of goods discarded or demolished every year is defined by equations (135)-(136). It includes depleted capital goods and the portion of consumption goods that are thrown away

[12] The socio-economic stock of an area can be defined as the stock of material things (measured in Gt) that are necessary or desirable for human life, such as fixed capital, dwellings and other durable goods.

every year (based on the exogenous rates ζ_B and ζ_G). Equations (137)-(138) define each area's stock of durable goods, meaning the stock of goods that last more than one year. Notice that imports increase the stock, while exports reduce it. We can now calculate the total socio-economic stocks in the two areas, which are defined by equations (139)-(140). The two stocks increase as additional goods are produced, and reduce as goods are discarded. Equations (141)-(142) calculate the waste generated by production activities. Equations (143) to (145) show that net stocks of material reserves grow as resources are converted into reserves and reduce as matter is extracted from the ground. Equations (146)-(147) show that material resources are converted into reserves based on exogenous rates (σ_m^G and σ_m^G). Available stocks of material resources are not limitless. Equations (148) to (150) show that resources decrease over time, depending on the pace of conversion. Equations (151)-(152) define the carbon mass of (non-renewable) energy, while equations (153)-(154) define the mass of oxygen used for production purposes in the two areas (see first column of Table 3).

XI. *The ecosystem: energy resources and reserves*. This block resembles the previous one, for it tracks the evolution over time of energy reserves:

$$e_B = \epsilon_B \cdot Y_B \tag{155}$$

$$er_B = \eta_B \cdot e_B \tag{156}$$

$$en_B = e_B - er_B \tag{157}$$

$$ed_B = er_B + en_B \tag{158}$$

$$e_G = \epsilon_G \cdot Y_G \tag{159}$$

$$er_G = \eta_G \cdot e_G \tag{160}$$

$$en_G = e_G - er_G \tag{161}$$

$$ed_G = er_G + en_G \tag{162}$$

$$k_e^B = k_{e,-1}^B + conv_e^B - en_B \tag{163}$$

$$k_e^G = k_{e,-1}^G + conv_e^G - en_G \tag{164}$$

$$k_e = k_e^B + k_e^G \tag{165}$$

$$conv_e^B = \sigma_e^B \cdot res_e^B \tag{166}$$

$$conv_e^G = \sigma_e^G \cdot res_e^G \tag{167}$$

$$res_e^B = res_{e,-1}^B - conv_e^B \tag{168}$$

$$res_e^G = res_{e,-1}^G - conv_e^G \tag{169}$$

$$res_e = res_e^B + res_e^G \tag{170}$$

Equations (155) to (158) define the total amount of energy required for production, renewable energy, non-renewable energy, and dissipated energy at the end of each period in Brownland. Equations (159) to (162) define the same variables for Greenland. Equations (163) to (165) show that the total stock of energy reserves increases as the conversion of resources increases, and reduces as non-renewable energy sources are used. Equations (166)-(167)

show that energy resources are converted into reserves based on exogenous conversion rates. Total stocks of energy worldwide and for the two areas are defined by equations (168) to (170).

XII. *The ecosystem: emissions and climate change*. While the amount of natural reserves is still (relatively) abundant, the use of non-renewable energy in the production process is associated with CO_2 emissions:

$$emis_B = \beta_0^B + \beta_1^B \cdot en_B \tag{171}$$

$$emis_G = \beta_0^G + \beta_1^G \cdot en_G \tag{172}$$

$$emis_l = emis_{l,-1} \cdot (1 - g_l) \tag{173}$$

$$emis = emis_b + emis_g + emis_l \tag{174}$$

$$co2_{AT} = emis + \phi_{11} \cdot co2_{AT,-1} + \phi_{21} \cdot co2_{UP,-1} \tag{175}$$

$$co2_{UP} = \phi_{12} \cdot co2_{AT,-1} + \phi_{22} \cdot co2_{UP,-1} + \phi_{32} \cdot co2_{LO,-1} \tag{176}$$

$$co2_{LO} = \phi_{23} \cdot co2_{UP,-1} + \phi_{33} \cdot co2_{LO,-1} \tag{177}$$

$$F = F_2 \cdot \log_2\left(\frac{co2_{AT}}{co2_{AT}^{PRE}}\right) + F_{EX} \tag{178}$$

$$F_{EX} = F_{EX,-1} + fex \tag{179}$$

$$T_{AT} = T_{AT,-1} + \tau_1 \cdot \left[F - \frac{F_2}{s} \cdot T_{AT,-1} - \tau_2 \cdot (T_{AT,-1} - T_{LO,-1})\right] \tag{180}$$

$$T_{LO} = T_{LO,-1} + \tau_3 \cdot (T_{AT,-1} - T_{LO,-1}) \tag{181}$$

Equations (171)-(172) define industrial emissions of CO_2 as linear functions of non-renewable energy sources used in each area. Land emissions (declining according to an exogenous rate, g_l) are also considered, as shown by equation (173). Equation (174) defines global CO_2 emissions as the summation of worldwide industrial emissions and land emissions. Equations (175) to (177) define the carbon cycle, calculating the atmospheric CO_2 concentration, the upper ocean/biosphere CO_2 concentration and the lower ocean CO_2 concentration, respectively. Equations (178) and (179) calculate the radiative forcing due to CO_2 emissions over the pre-industrial levels (W/m^2) and the radiative forcing due to non-CO_2 greenhouse gases, respectively. This is necessary to define (the change in) the average atmospheric temperature as a non-linear function of the past temperature and the radiating forcing – equation (180). Equation (181) defines (the change in) the lower ocean temperature as a function of the past temperature levels.[13]

XIII. *The ecosystem: ecological efficiency*. This block of equations defines ecological efficiency endogenously:

$$\mu_B = \mu_{gr}^B \cdot \frac{k_{gr}^B}{k_B} + \mu_{con}^B \cdot \frac{k_{con}^B}{k_B} \tag{182}$$

[13] An intuitive representation of the relationships defined by equation blocks X to XII is provided by Fig. 11 in the Appendix.

$$\mu_B = \mu_{gr}^G \cdot \frac{k_{gr}^G}{k_G} + \mu_{con}^G \cdot \frac{k_{con}^G}{k_G} \tag{183}$$

$$\epsilon_B = \epsilon_{gr}^B \cdot \frac{k_{gr}^B}{k_B} + \epsilon_{con}^B \cdot \frac{k_{con}^B}{k_B} \tag{184}$$

$$\epsilon_G = \epsilon_{gr}^G \cdot \frac{k_{gr}^G}{k_G} + \epsilon_{con}^G \cdot \frac{k_{con}^G}{k_G} \tag{185}$$

$$\beta_B = \beta_{gr}^B \cdot \frac{k_{gr}^B}{k_B} + \beta_{con}^B \cdot \frac{k_{con}^B}{k_B} \tag{186}$$

$$\beta_G = \beta_{gr}^G \cdot \frac{k_{gr}^G}{k_G} + \beta_{con}^G \cdot \frac{k_{con}^G}{k_G} \tag{187}$$

$$\eta_B = \eta_{gr}^B \cdot \frac{k_{gr}^B}{k_B} + \eta_{con}^B \cdot \frac{k_{con}^B}{k_B} \tag{188}$$

$$\eta_G = \eta_{gr}^G \cdot \frac{k_{gr}^G}{k_G} + \eta_{con}^G \cdot \frac{k_{con}^G}{k_G} \tag{189}$$

$$dep_m^B = \frac{mat_B}{k_{m,-1}^B} \tag{190}$$

$$dep_m^G = \frac{mat_G}{k_{m,-1}^G} \tag{191}$$

$$dep_e^B = \frac{en_B}{k_{e,-1}^B} \tag{192}$$

$$dep_e^G = \frac{en_G}{k_{e,-1}^G} \tag{193}$$

Equations (182) to (187) show that matter-, energy- and CO_2-intensity coefficients of each area reduce as the share of green capital to total capital stock increases. Similarly, the share of renewable energy grows as the share of green capital stock grows – equations (188) and (189). Depletion ratios of natural resources are also calculated by equations (190) to (193).

XIV. *The ecosystem: damages and feedbacks*. Climate change-related gross damages are defined as nonlinear functions of the average atmospheric temperature. Extreme weather conditions, catastrophes and uncertainty affect capital depreciation rates. In addition, uncertainty and rising ecological awareness modify consumption patterns, foster hoarding behaviours and depress investment. Damages equations are:

$$d_T^B = 1 - \left(1 + d_1^B \cdot T_{AT} + d_2^B \cdot T_{AT}^2 + d_3^B \cdot T_{AT}^{x_B}\right)^{-1} \tag{194}$$

$$d_T^G = 1 - \left(1 + d_1^G \cdot T_{AT} + d_2^G \cdot T_{AT}^2 + d_3^G \cdot T_{AT}^{x_G}\right)^{-1} \tag{195}$$

$$\delta_B = \delta_0^B + (1 - \delta_0^B) \cdot (1 - ad_K^B) \cdot d_{T,-1}^B \tag{196}$$

$$\delta_G = \delta_0^G + \left(1 - \delta_0^G\right) \cdot \left(1 - ad_K^G\right) \cdot d_{T,-1}^G \tag{197}$$

Equations (194)-(195) define the total percentage of gross damages due to changes in temperature.[14] Equations (196)-(197) define the area-specific effect of climate change on capital depreciation rates, considering also adaptation strategies of the firms (captured by

[14] Notice that d_i^j and x_j (with $i = 1,2,3$ and $j = B, G$) are positive coefficients, such that: $0 < d_T^j < 1$ and $T_{AT} = 6 \rightarrow \frac{d_T^B + d_T^G}{2} = 0.5$ (see Table 6 in the Appendix).

coefficients ad_K^B and ad_K^G, which accounts for the higher resilience of new investments in fixed capital). The other channels through which climate change affects the economy are: by dampening household consumption; by favouring green export; and by modifying investment plans of the firms. Notice that total investment reduces – recall equations (46) and (57) – but the share of green investment to total investment increases as damages increase – equations (47) and (58).

XV. *Auxiliary equations for domestic and foreign balances*. The standard macroeconomic identities for domestic and foreign balances are defined as follows:

$$DEF_B = GOV_{tot}^B + r_{b,-1}^B \cdot B_{s,-1}^B - T_B - F_{cb,-1}^B \quad (198)$$

$$DEF_G = GOV_{tot}^G + r_{b,-1}^G \cdot B_{s,-1}^G - T_G - F_{cb,-1}^G \quad (199)$$

$$NAFA_B = DEF_B + CAB_B \quad (200)$$

$$NAFA_G = DEF_G + CAB_G \quad (201)$$

$$CAB_B = TB_B + xr_{G,-1} \cdot \left(r_{b,-1}^G \cdot B_{s,-1}^{BG} + r_{e,-1}^G \cdot E_{s,-1}^{BG}\right) - r_{b,-1}^B \cdot B_{s,-1}^{GB} - r_{e,-1}^B \cdot E_{s,-1}^{GB} \quad (202)$$

$$CAB_G = TB_G + xr_{B,-1} \cdot \left(r_{b,-1}^B \cdot B_{s,-1}^{GB} + r_{e,-1}^B \cdot E_{s,-1}^{GB}\right) - r_{b,-1}^G \cdot B_{s,-1}^{BG} - r_{e,-1}^G \cdot E_{s,-1}^{BG} \quad (203)$$

$$KAB_B = -d(B_s^{BG}) \cdot xr_G + d(B_s^{GB}) - d(E_s^{BG}) \cdot xr_G + d(E_s^{GB}) \quad (204)$$

$$KAB_G = -d(B_s^{GB}) \cdot xr_B + d(B_s^{BG}) - d(E_s^{GB}) \cdot xr_B + d(E_s^{BG}) \quad (205)$$

$$TB_B = X_B - IM_B \quad (206)$$

$$TB_G = X_G - IM_G \quad (207)$$

$$BP_B = CAB_B + KAB_B \quad (208)$$

$$BP_G = CAB_G + KAB_G \quad (209)$$

$$GNP_B = Y_B + xr_{G,-1} \cdot (r_{b,-1}^G \cdot B_{s,-1}^{BG} + r_{e,-1}^G \cdot E_{s,-1}^{BG}) - r_{b,-1}^B \cdot B_{s,-1}^{GB} - r_{e,-1}^B \cdot E_{s,-1}^{GB} \quad (210)$$

$$GNP_G = Y_G + xr_{B,-1} \cdot (r_{b,-1}^B \cdot B_{s,-1}^{GB} + r_{e,-1}^B \cdot E_{s,-1}^{GB}) - r_{b,-1}^G \cdot B_{s,-1}^{BG} - r_{e,-1}^G \cdot E_{s,-1}^{BG} \quad (211)$$

$$\mu_2 = \mu_{2,-1} + \gamma_\mu \cdot d(GOV_{gr}^B) \quad (212)$$

Equations (198)-(199) define government deficits in the two areas. Equation (200)-(201) show the net accumulation of financial assets. Equations (202)-(203) define the current account of each area. Equations (204)-(205) display their financial accounts. Equations (206)-(207) calculate the trade balances. Equations (208)-(209) define the related balance of payment identities. Equations (210)-(211) define the gross national products of the two areas. Finally, we link the propensity to import of Brownland (from Greenland) to Brownland government's green spending, as the policy makers can foster low-carbon consumption through green incentives – equation (212).

XVI. *Inequality indices*. We define the inequality indices for the two areas:

$$YD_{tot}^B = YD_w^B + YD_{hs,r}^B \quad (213)$$

$$YD_{tot}^G = YD_w^G + YD_{hs,r}^G \quad (214)$$

$$gini_{YD}^{B} = \frac{YD_{hs,r}^{B}}{YD_{tot}^{B}} \quad (215)$$

$$gini_{YD}^{G} = \frac{YD_{hs,r}^{G}}{YD_{tot}^{G}} \quad (216)$$

$$V_{tot}^{B} = V_{r}^{B} + V_{w}^{B} \quad (217)$$

$$V_{tot}^{G} = V_{r}^{G} + V_{w}^{G} \quad (218)$$

$$gini_{V}^{B} = \frac{V_{r}^{B}}{V_{tot}^{B}} \quad (219)$$

$$gini_{V}^{G} = \frac{V_{r}^{G}}{V_{tot}^{G}} \quad (220)$$

Equations (213) to (216) determine the income inequality index for each area as the ratio of capitalists' disposable income (including capital gains) to total disposable income. Equations (217) to (220) define the wealth inequality index for each area as the ratio of capitalists' net wealth to total net wealth.

XVII. *Financial indices*. Leverage ratios, valuation ratios of firms, stock market indices and liquidity ratios of banks are also monitored:

$$q_{G} = \frac{e_{s,-1}^{G} \cdot p_{e,-1}^{G} + L_{f}^{G}}{K_{G}} \quad (221)$$

$$q_{B} = \frac{e_{s,-1}^{B} \cdot p_{e,-1}^{B} + L_{f}^{B}}{K_{B}} \quad (222)$$

$$lev_{f}^{G} = \frac{L_{f}^{G}}{K^{G}} \quad (223)$$

$$lev_{f}^{B} = \frac{L_{f}^{B}}{K^{B}} \quad (224)$$

$$per_{G} = \frac{p_{e}^{G}}{F_{G}/e_{s,-1}^{G}} \quad (225)$$

$$per_{B} = \frac{p_{e}^{B}}{F_{B}/e_{s,-1}^{B}} \quad (226)$$

$$liq_{b}^{G} = \frac{A_{s}^{G} + M_{s}^{G} - L_{s}^{G}}{M_{s}^{G}} \quad (227)$$

$$liq_{b}^{B} = \frac{A_{s}^{B} + M_{s}^{B} - L_{s}^{B}}{M_{s}^{B}} \quad (228)$$

Equations (221)-(222) define the so-called Tobin's q for the corporate sector. It is the ratio between the market value of firms and its replacement cost (meaning, the value of the capital stock in our model). Equations (223)-(224) define the firms' leverage ratios, that is, their debt to capital ratio. Another interesting financial index is the price-earnings ratio of firms' shares, which is calculated by equations (225) and (226). Finally, we use the commercial banks' balance sheets to calculate their liquidity ratios and monitor the liquidity of their balance sheets – equation (227)-(228).

Redundant equations. Since we developed an interacting two-area model, there are two redundant equations, in the sense that they are logically implied by the other equations:

$$H_s^B = H_h^B \quad (116B)$$

$$H_s^G = H_h^G \quad (119B)$$

The two equations above hold that the supply of cash (from central banks) must match the demand for cash (arising from the private sector) in each area, despite the two variables being determined independently – see equations (73), (82), (116) and (119). This is, in fact, the twofold equilibrium condition that we used to check the accounting consistency of the model.

3.2 Model calibration and experiments

Coefficients are given realistic or reasonable values that allow to model to reproduce global trends. Initial values of output components are based on *World Bank* time series. The coefficients for the related equations are usually calculated as average values throughout the period 1960-2018. Other economic parameters are calibrated in such a way to obtain a realistic baseline. Initial values and coefficients for temperature and CO_2 emissions are based on data from GISTEMP (2019) and Lenssen et al. (2019), and from Ritchie and Roser (2019), respectively. Additional ecological parameters and initial values of variables are taken from, or based on, Dafermos et al. (2017, 2018) and IPCC (2018).[15] We obtain a gross world output equal to 81 trillion ca of currency units in 2018. The average growth rate in 1960-2018 is 3.40%. Under the baseline, total financial assets (including cash and deposits) held by households are 4.7 times the gross world output (i.e. more than 380 trillion) in 2018. If banks' holdings are also considered, the amount is as high as 6 times world output. Turning to ecological variables, annual worldwide industrial CO_2 emissions are 40 billion Gt ca in 2018 baseline (from 10 billion GT ca in 1960). Despite producing the same output, Brownland emissions are almost three times as many as Greenland's. Global CO_2 emissions decline after 2020, thanks to ecological efficiency gains taking place in both areas. Consequently, global CO_2 concentration in the atmosphere is expected to stabilise at around 3,600 billion Gt ca in 2060. The average atmospheric temperature in 2020 is +1C ca above the pre-industrial level. It is expected to keep growing in the subsequent decade, reaching +2C in 2050. A *business as usual* scenario (no ecological efficiency gains) is also considered, in which the average temperature is expected to grow even faster. Parameter values for matter resources are not estimated from data. However, they are tuned in such a way for resources to match 390,000 Gt ca in 2018, while matter reserves are 6,300 Gt ca in the same year. Energy resources are

[15] See Table 6 in the Appendix for the full set of coefficient values, initial values of stocks and lagged endogenous variables. The balance sheet and the transactions-flow matrix for the two areas are displayed by Table 1 and Table 2, respectively. The physical flow and stock-flow matrices are displayed by Table 3 and Table 4. The material and energy balances under the baseline scenario are displayed by Fig. 9 in the Appendix.

550,000 Ej ca, whereas energy reserves are 40,000 Ej ca. The socio-economic stock for the world economy is 1,180 Gt ca in the baseline.

Fig. 1 displays baseline values and trends for selected variables. The baseline scenario is obtained by running the model from 1960 to 2060 on an annual basis. Observed series are used up to 2018, while model simulations (or out-of-sample predictions) are plotted afterwards. While the aim of our contribution is mainly theoretical, a basic validation of the model has been performed by comparing auto- and cross-correlations of simulated macroeconomic series with those of observed series.[16]

We use the model to test the reaction of selected economic, financial, social and ecological variables to six events or shocks linked with global warming. Experiments are all run starting from 2025. This allows key variables to achieve a stable baseline before we trigger the shocks. Experiments are defined as follows:

1. *Preference for 'safer' financial assets*. Higher risk aversion and hoarding behaviours can result from the increase in the frequency of natural catastrophes. We test the effect of investors' flight to safety on selected variables.
2. *Preference for 'greener' financial assets*. This can result from a higher ecological awareness of the population. We test the effect of investors reducing their holdings of Brownland's assets, while increasing Greenland's.
3. *Preference for 'greener' products*. A higher ecological awareness can lead consumers to turn to low-impact products. We test the effect of the decision of households to reduce their consumption of goods made in Brownland, while increasing Greenland's.
4. *Brownland's austerity (and autarchy) measures*. Green policies – particularly green incentives – lead Brownland's private sector to import low-carbon goods from Greenland. This affects Brownland's trade balance and therefore the government budget balance. Hence the decision of Brownland's policy-makers to address the twin deficit by cutting green incentives. We test the effect of this policy reaction.
5. *Increase of green government spending*. Another, more direct, way to boost low-carbon investment is to support it through active fiscal policies, aiming at generating a green innovation cascade. We test the effect of these policies in Greenland.
6. *Coordinated government spending*. We test the effect of the policy above when both countries opt for it.

[16] Fig. 10 in the Appendix shows that patterns of the simulated series in the baseline scenario are reasonably coherent with past patterns of the observed series.

4. Results and discussion

4.1 Key findings

We used our model to analyse the effects of the above shocks on the economy, the financial sector, the society and the ecosystem. All in all, we show that unintended results occur when cross-border financial flows are considered. The main reason is that they modify the relative price of currencies (i.e. the exchange rate), thereby affecting the economy and the ecosystem. Our findings for selected variables under different scenarios are summarised by Table 5 in the Appendix. As mentioned, some unintentional effects and trade-offs linked to green behaviours and policies show up, which we discuss thoroughly in the next paragraphs.

Preference for safer financial assets (Fig. 2). The decision of the investors to move from risky to safer financial assets is one of the most frequently reported effects of uncertainty. It is usually associated with the higher frequency of adverse climate conditions. The resulting flight to safety may bring about unintended implications though. For instance, both Greenland's and Brownland's investors (the capitalists, in our model) may want to reduce the portion of shares held in their portfolios. They can replace firms' shares with liquidity and/or government bills. Whatever the specific mix they choose, regional and global outputs benefit from that change *if the portion of idle balances (including both cash and deposits) reduces*, despite the lower amount of equity. By contrast, output is negatively affected *if the overall portion of liquidity increases*. This is the case displayed by Fig. 2a, where investors are assumed to increase their holdings of bills (crowding shares out) and cash (crowding deposits out). The point is that financial assets are not perfect substitutes. Consequently, nonlinear effects are possible when economic agents redefine their portfolios.[17] If households' behaviour is symmetrical across areas, balance of payments' entries are not affected, neither is the exchange rate – Fig. 2b, 2i and 2l. This is the only circumstance where international financial flows play no role. Looking at the ecosystem, a lower output entails lower industrial CO_2 emissions and thus a lower atmospheric temperature relative to the baseline – Fig. 2c and 2e. As shown by Fig. 2d, this occurs despite a lower ecological efficiency at the global level. The reason is that ecological efficiency ratios improve as the accumulation of green capital proceeds, thus moving pro-cyclically. Financial effects are not univocal. Fig. 2f and Fig. 2g show that firms are better off in the new scenario. Their valuation ratios (as expressed by Tobin's q) improve, and so do the price-earnings ratios of equity. However, firms' leverage ratios increase (Minsky effect) and

[17] Notice that the lower output does not necessarily harm government budget. In fact, it can bring about an improvement of it if central banks act as lenders of last resort – Fig. 2b. The reason is that a higher portion of bills is now held by the central banks, whose profits (i.e. seigniorage incomes, which are transferred to the government sector) offset the fall in tax revenues. In addition, the lower absolute level of asset holdings (including bills) held by households help reducing the interest burden for the government.

banks' liquidity ratios are worse off in the new scenario, because bank deposits fall more rapidly than loans – Fig. 2h. In short, a flight to safety can improve ecological indices, but affects both economic growth and private sector's financial condition. The net impact on the government sector depends on the role played by the central bank. If the latter acts as a lender of last resort, the government budget improves (because the fall in interest payments outstrips the fall in tax revenues), otherwise it gets worse. Finally, both areas record an increase in their socio-economic stocks, but it is the capitalists the only group who benefit from it – Fig. 8.

Preference for greener assets (Fig. 3). Climate change can induce investors of both areas to reduce their holdings of Brownland's financial assets, while increasing Greenland's – Fig. 3j and 3k. Our experiments show that both Greenland's economy and the environment might not benefit from that. The adjustment in the exchange rate is the key variable. Under a floating regime, the higher flows of capital from Brownland to Greenland result in an appreciation of Greenland's currency – see Fig. 3b and 3i. Greenland's current account (i.e. the opposite of Brownland's current account displayed by Fig. 3b) worsens, because of the fall in net export coupled with the fall in net incomes (dividends and interest payments) – Fig. 3b and 3l. This affects Greenland's GDP – Fig. 3a. The increase in Brownland's output offsets the reduction in Greenland's. Unfortunately, this goes along with higher industrial CO_2 emissions worldwide. There can be some ecological efficiency gain in Brownland, due to higher green investments. However, this is not enough to compensate for the greater production at the global level and the lower share of Greenland output (rebound effect). This leads to an increase in atmospheric temperature (relative to the baseline) in the medium run – Fig. 3c, 3d and 3e. Looking at the domestic financial side, Brownland's firms increase their leverage ratio, while Greenland's firms are forced to deleverage – Fig. 3f and 3g. This is reflected in Brownland banks' liquidity ratio, which falls sharply in the long run. Greenland banks face liquidity problems in the short to medium run too – Fig. 3h. Summing up, under a floating exchange rate regime, a higher preference for green financial assets can harm, rather than safeguard, the ecosystem, while boosting financial imbalances. In addition, socio-economic stocks reduce and inequality worsens in both areas (Fig. 8). It can be shown that this paradoxical effect of greener portfolios is quite insensitive to the chosen set of values for portfolio parameters *under a floating exchange rate regime*.[18] In fact, Greenland GDP would be unaffected or even boosted by capital in-flows under a fixed exchange rate regime. The reason is that its financial account surplus would result in the accumulation of international reserves, not in the appreciation of

[18] The aim of our work is to show that counterintuitive effects are possible, not necessary. This is the reason we do not include here a sensitivity analysis. However, all the experiments can be easily replicated by using our program file and the related dataset. The robustness of the findings above can be checked by using alternative values for key parameters and exogenous variables.

Greenland currency.[19] Nevertheless, our model warns us that unwanted implications are *possible* under a floating regime.

Preference for greener products (Fig. 4). The impact of consumers reducing their demand for *made in Brownland* (and/or increasing their demand for *made in Greenland*) is far more intuitive. Both Greenland's economy and the ecosystem benefit from greener consumption habits worldwide – Fig. 4a, 4b, 4c, 4d and 4e. The aggregate liquidity ratio of Greenland's banks worsens in the medium- to long-run, but this is due to their higher lending activity. The leverage ratio of Greenland's productive sector is also higher, but the increase in firms' valuation ratio outstrips the former – Fig. 4g and 4h. Looking at their portfolios, households now hold more liquid assets, because of the increase in money demand for transactions and precautionary motives – Fig. 4j and 4k. A higher socio-economic stock is accumulated in Greenland, but it is the capitalist class who benefits from it. The opposite occurs in Brownland (fig. 8). It is worth stressing that Brownland's economy is expected to recover in the medium to long run, despite the initial negative impact. For the strong depreciation of Brownland currency ends up boosting its net export to Greenland – Fig. 4a, 4b, 4i and 4l.[20] However, Brownland records a twin deficit in the short run when consumers turn to green products.

Brownland's austerity (and autarchy) measures (Fig. 5). A possible way to counter Brownland's twin deficit is to pursue a contractionary fiscal policy. This intervention is more effective if Brownland's policy makers target green incentives and/or other types of green spending, as most goods are made in Greenland.[21] Austerity measures in Brownland can be associated with an increase in Brownland output *if* the fall in import outstrips the fall in domestic demand. Both the sign and the strength of this effect depend on the sensitivity of Brownland import to government spending. Fig. 5a shows that Greenland's economy is affected, because of the reduction in export. Both government budget and current account balance of Brownland benefit from government cuts, whereas Greenland balances worsen – Fig. 5b. However, as shown by Fig. 5i and 5l, the appreciation of the currency undermines Brownland products' competiveness, thus reducing the output growth rate in the medium run.[22] Despite the lower world output, global CO_2 emissions and the temperature can increase relative to the baseline, due to ecological efficiency losses – Fig. 5c, 5d and 5e. Looking at the financial side, Brownland's firms record both a higher valuation ratio and a higher leverage ratio. Brownland banks can face liquidity issues in the new scenario. Household holdings of financial assets

[19] Fig. 3B in the Appendix displays the same shock under a fixed exchange rate regime, where central banks stabilise exchange rates by accumulating or reducing gold reserves (or the *anchor currency*). All in all, the role of exchange rate adjustments can be appreciated by looking at Fig. 8.

[20] Compare Fig. 4 to Fig. 4B in the Appendix, displaying the same shock under a fixed exchange rate regime.

[21] The link between Brownland's green government spending and the propensity to import is captured by equation (212) in our model.

[22] Compare Fig. 5 to Fig. 5B in the Appendix, displaying the same shock under a fixed exchange rate regime.

reduce relative to the baseline, but the socio-economic stock is higher – Fig. 5f, 5g, 5h, 5j, 5k and 8. Notice, however, that these results depend on the high sensitivity of import to government spending that we assumed in our experiment ($\gamma_\mu = 0.50$, associated with a 20% cut of government green spending). Should import sensitivity be negligible ($\gamma_\mu < 0.03$ ca in our model), Brownland output would collapse, along with world output. Austerity always cures the disease (the twin deficit) in our model, but it may well kill the patient.

Increase of green government spending (Fig. 6). In principle, green MOIS can help Greenland boost ecological efficiency and foster low-carbon transition. Fig. 6a shows that Brownland's economy can also benefit from it. The effect is only temporary though, for it is progressively counterbalanced by the appreciation of Brownland currency. This, in turn, is due to the higher deficit (or lower surplus) recorded by Greenland's current account balance (because of the increase in import) – Fig. 6b, 6i and 6l. In addition, Fig. 6c reminds us that the reduction in CO_2 emissions is anything but trivial. Despite the higher green investment, global economic growth may well outstrip any efficiency gain (Fig. 6d). This is the well-known *rebound effect* (e.g. Greening et al. 2000). As a result, the average temperature increases relative to the baseline – Fig. 6e. Looking at the financial side, balance sheets of both banks and firms are quite sound in Greenland. Paradoxically, Brownland households' wealth is gradually reduced by the appreciation of their currency, which affects income (via capital lossess on foreign currency-denominated financial assets) and hence saving.[23] Brownland's banks are also slightly affected – see Fig. 6f, 6g, 6h, 6j and 6k. The only way to take full advantage from government green-oriented spending is for the two areas to pursue coordinated green expansionary policies. This is especially appropriate when green policies synergies allow improving ecological efficiency ratios (see Fig. 7, where we assume a 10% ecological efficiency gain). However, inequality indices within areas worsen, while the *absolute* impact on temperature is mostly eroded by the higher growth rate of global output.

4.2 Policy implications and use of the model for planning purposes

Our experiments show that the effectiveness of green individual behaviours and low-carbon policies depends crucially on cross-border financial flows and their impacts on the exchange rates. Currency fluctuations bring about unintended implications from uncoordinated green actions, thus possibly making the final net effects on the economy, the financial sector, the society, and the broader ecosystem, unpredictable. In principle, a fixed (or a band) exchange rate regime can help counter those implications. However, it does not eliminate the perverse incentives for financially-distressed governments to cut green spending and import. In fact, it is likely to exacerbate them. Therefore, a strong macroeconomic and monetary coordination

[23] Compare Fig. 6 to Fig. 6B in the Appendix, displaying the same shock under a fixed exchange rate regime.

across countries seems paramount to tackle climate change and inequality, while assuring financial stability. Yet, our two-area economy model is only a simplification of the real world economy, where a fully coordinated fiscal intervention can be hardly implemented, due to political disputes and lack of general consensus. As a result, a second best solution – at the individual country or region level – can be put in place by smoothing the effects of cross-area financial flows through selective capital controls. More precisely, the most volatile components of the international capital flows should be targeted, meaning the speculative and portfolio investments. This would allow the governments to smooth any downward pressure on their currencies, thus limiting losses of foreign reserves and reducing unwanted effects from green policies and behaviours.[24]

The main strength of our model is that it allows the policy-makers to monitor all the phenomena discussed above, by verifying whether the current trends can be sustained (or not) from a variety of angles.[25] Although the aim of this paper is mainly theoretical, the model can be customised and recalibrated to match the available data for other regions, countries or areas. Alternative scenarios can then be created to test the effects that each policy option generates on different spheres of interest (production, finance, society, and environment), given the implications for, and the reaction of, other areas (e.g. the rest of the world). In other words, while our model warns against possible coordination issues affecting green and redistributive policies, it can help the policy-makers to address them by designing and testing new options on an international scale.

5. Conclusions

We have developed an ecological open-economy SFC model that enables testing the impact of cross-area financial flows on the economy, the financial sector, the society and the ecosystem. We have shown that, while some well-known empirical facts are replicated by the model (e.g. the rebound effect), additional counter-intuitive effects are found (e.g. green finance worsening, rather than countering, climate change). Our main findings can be listed as follows:

a) The search for safe financial assets (brought about by climate-related uncertainty) can affect economic growth and financial stability *if the portion of idle balances increases*.

[24] Notice that the central bank can always neutralise upward movements by selling financial assets that are denominated in the domestic currency.

[25] The very possibility to model and account for interconnections across different spheres is the main advantage of SFC models relative to other macroeconomic models, like dynamic stochastic general equilibrium models and empirical models (e.g. vector autoregression models).

b) The search for green financial assets can exacerbate climate change *if capitals are free to move and exchange rates are fully floating* (reacting to cross-area transactions and financial flows).

c) Green consumption affects the current account*, hence the government budget*, of less ecologically-efficient areas.

d) If governments of 'brown' areas react by cutting (green) spending, the net effect on regional output *depends on the sensitivity of imports to government (green) spending*. Global output and financial stability are always affected instead.

e) Lacking a strong coordination, green innovation-oriented government policies are likely to generate negative *side effects for other areas*. In addition, ecological efficiency gains are likely to be offset by the higher growth rate of the economy (*rebound effect*).

Summing up, the effectiveness of green behaviours and policies depends crucially on the *impact of cross-border financial flows* (and the differential in output growth rates) *on the exchange rates*. On the one hand, currency fluctuations can undermine the beneficial effects of low-carbon transition plans on the ecosystem and the society. On the other hand, a fixed exchange regime requires strong coordination (or a selective capital control mechanism) to cope with external imbalances and financial instability, while tackling climate change and inequality. This is one of the key issues that the policy makers are likely to face in the next few years.

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Tables and charts

Table 1. Balance-sheet of the two-area economy

	GREENLAND (G)						BROWNLAND (B)					
	Households (capitalists + workers)	Firms	Commercial banks	Government	Central bank		Households (capitalists + workers)	Firms	Commercial banks	Government	Central bank	Σ
Money (cash)	$+H_h^G$				$-H_s^G$		$+H_h^B$				$-H_s^B$	0
CB advances			$-A_d^G$		$+A_d^G$				$-A_d^B$		$+A_d^B$	0
Deposits	$+M_h^G$		$-M_s^G$				$+M_h^B$		$-M_s^B$			0
Loans		$-L_f^G$	$+L_s^G$					$-L_f^B$	$+L_s^B$			0
G gov. bills	$+B_d^{GG}$		$+B_b^G$	$-B_s^G$	$+B_{cb}^{GG}$	$\cdot xr_G$	$+B_d^{BG} \cdot xr_G$					0
B gov. bills	$+B_d^{GB} \cdot xr_B$						$+B_d^{BB}$		$+B_b^B$	$-B_s^B$	$+B_{cb}^{BB}$	0
G firms' shares	$+p_e^G \cdot e_d^{GG}$	$-p_e^G \cdot e_s^{GG}$					$+p_e^G \cdot e_d^{BG} \cdot xr_G$					0
B firms' shares	$+p_e^B \cdot e_d^{GB} \cdot xr_B$						$+p_e^B \cdot e_d^{BB}$	$-p_e^B \cdot e_s^{BB}$				0
Conv. capital		$+K_{con}^G$						$+K_{con}^B$				$+K_{con}^G \cdot xr_G + K_{con}^B$
Green capital		$+K_{gr}^G$						$+K_{gr}^B$				$+K_{gr}^G \cdot xr_G + K_{gr}^B$
Balance (net worth)	$-V_h^G$	$-NW_f^G$	0	$-NW_g^G$	0		$-V_h^B$	$-NW_f^B$	0	$-NW_g^B$	0	$-(K_{con} + K_{gr})$
Σ	0	0	0	0	0		0	0	0	0	0	0

Notes: A '+' before a magnitude denotes an asset, whereas '–' denotes a liability (except for Balance's entries, where signs are reversed). Floating exchange rates are assumed. Capitalists and workers are aggregated and consolidated in the household sector.

Table 2. Transactions-flow matrix of the two-area economy

	GREENLAND (G)						**BROWNLAND (B)**					
	Households (capitalists + workers)	**Firms**	**Commercial banks**	**Government**	**Central bank**		**Households (capitalists + workers)**	**Firms**	**Commercial banks**	**Government**	**Central bank**	**Σ**
Consumption	$-C_G$	$+C_G$					$-C_B$	$+C_B$				0
Conv. investment		$+INV^G_{con}$ $[-INV^G_{con}]$						$+INV^B_{con}$ $[-INV^B_{con}]$				0
Green investment		$+INV^G_{con}$ $[-INV^G_{con}]$						$+INV^B_{con}$ $[-INV^B_{con}]$				0
Conv. gov. spend.		$+GOV^G_{con}$		$-GOV^G_{con}$				$+GOV^B_{con}$		$-GOV^B_{con}$		0
Green gov. spend.		$+GOV^G_{gr}$		$-GOV^G_{gr}$				$+GOV^B_{gr}$		$-GOV^B_{gr}$		0
G exports to B		$+X_G$						$+X_B$				0
B exports to G		$-IM_G$						$-IM_B$				0
Wages	$+\omega_G \cdot Y^G$	$-\omega_G \cdot Y^G$					$+\omega_B \cdot Y^B$	$-\omega_G \cdot Y^B$				0
Taxes	$-T_G$			$+T_G$			$-T_B$			$+T_B$		0
Deprec. allowances		$-DA_G$ $[+AF_G]$				$\cdot\, xr_G$		$-DA_B$ $[+AF_B]$				0
Interests on loans		$-r^G_{l,-1} \cdot L^G_{f,-1}$	$+r^G_{l,-1} \cdot L^G_{s,-1}$					$-r^B_{l,-1} \cdot L^B_{f,-1}$	$+r^B_{l,-1} \cdot L^B_{s,-1}$			0
Interests on G bills	$+r^G_{b,-1} \cdot B^{GG}_{d,-1}$		$+r^G_{b,-1} \cdot B^G_{b,-1}$	$-r^G_{b,-1} \cdot B^G_{s,-1}$	$+r^G_{b,-1} \cdot B^{GG}_{cb,-1}$		$+r^G_{b,-1} \cdot B^{BG}_{d,-1} \cdot xr_G$					0
Interests on B bills	$+r^B_{b,-1} \cdot B^{GB}_{d,-1} \cdot xr_B$						$+r^B_{b,-1} \cdot B^{BB}_{d,-1}$		$+r^B_{b,-1} \cdot B^B_{b,-1}$	$-r^B_{b,-1} \cdot B^B_{s,-1}$	$+r^B_{b,-1} \cdot B^{BB}_{cb,-1}$	0
G firms' dividends	$+F^{GG}_d$	$-F^G_f$					$+F^{BG}_d \cdot xr_G$					0
B firms' dividends	$+F^{GB}_d \cdot xr_B$						$+F^{BB}_d$	$-F^B_d$				0
Retained profits		$[+F^G_u]$						$[+F^B_u]$				0
Managers' compens.	$+F^G_m$	$-F^G_m$					$+F^B_m$	$-F^B_m$				0
Banks' profit (distrib.)	$+F^G_b$		$-F^G_b$				$+F^B_b$		$-F^B_b$			0
CB profits				$+F^G_{cb}$	$-F^G_{cb}$					$+F^B_{cb}$	$-F^B_{cb}$	0
Δ in cash	$-\Delta H^G_h$				$+\Delta H^G_s$		$-\Delta H^B_h$				$+\Delta H^B_s$	0
Δ in CB advances			$+\Delta A^G_d$		$-\Delta A^G_s$	$\cdot\, xr_G$			$+\Delta A^B_d$		$-\Delta A^B_s$	0
Δ in deposits	$-\Delta M^G_h$		$+\Delta M^G_s$				$-\Delta M^B_h$		$+\Delta M^B_s$			0
Δ in loans		$+\Delta L^G_f$	$-\Delta L^G_s$					$+\Delta L^B_f$	$-\Delta L^B_s$			0

Δ in G bills	$-\Delta B_d^{GG}$		$-\Delta B_b^G$	$+\Delta B_s^G$	$-\Delta B_{cb}^{GG}$		$-\Delta B_d^{BG} \cdot xr_G$					0
Δ in B bills	$-\Delta B_d^{GB} \cdot xr_B$						$-\Delta B_d^{BB}$		$-\Delta B_b^B$	$+\Delta B_s^B$	$-\Delta B_{cb}^{BB}$	0
Σ	0	0	0	0	0		0	0	0	0	0	0
Memo: capital gains	$-CG_b^G - CG_e^G$	$+CG_{eG}^G$		$+CG_{bG}^G$			$-CG_b^B - CG_e^B$	$+CG_{eB}^B$		$+CG_{bB}^B$		

Notes: A '+' before a magnitude denotes a receipt or a source of funds, whereas '–' denotes a payment or a use of funds. Floating exchange rates are assumed. Capitalists and workers are aggregated and consolidated in the household sector. [·] = capital account entry. Subscript 'eG' marks capital gains accruing on all shares issued by Greenland firms, regardless of the nationality of investors (similar considerations go for 'bG', 'eB' and 'Bb').

Table 3. Physical flow matrix of the two-area economy (consolidated)

	Worldwide material balance	**Worldwide energy balance**
Inputs		
Extracted matter	$+mat_G + mat_B$	
Renewable energy		$+er_G + er_B$
Non-renewable energy	$+cen_G + cen_B$	$+en_G + en_B$
Oxygen	$+o2_G + o2_B$	
Outputs		
Industrial CO_2 emissions	$-(emis_G + emis_B)$	
Waste	$-(wa_G + wa_B)$	
Dissipated energy		$-(ed_G + ed_B)$
Change in s.e.s.	$-(\Delta k_{se}^G + \Delta k_{se}^B)$	
Σ	0	0

Notes: Matter is measured in Gt while energy is measure in EJ. A '+' sign denotes additions to the opening stock, whereas '–' denotes reduction. G = Greenland; B = Brownland.

Table 4. Physical stock-flow matrix of the two-area economy (consolidated)

	Global material reserves	**Global non-renewable energy reserves**	**Global atmospheric CO2 concentration**	**Global socio-economic stock**
Initial stock	$+k_{m,-1}^G + k_{m,-1}^B$	$+k_{e,-1}^G + k_{e,-1}^B$	$+co2_{AT,-1}$	$+k_{se,-1}^G + k_{se,-1}^B$
Resources converted into reserves	$+conv_{m,}^G + conv_m^B$	$+conv_e^G + conv_e^B$		
CO_2 emissions (global)			$+emis_G + emis_B + emis_l$	
Production of material goods				$+y_{mat}^G + y_{mat}^B$
Extraction/use of matter/energy	$-(mat_G + mat_B)$	$-(en_G + en_B)$		
Net transfer to oceans/biosphere			$+(\phi_{11} - 1) \cdot co2_{AT,-1} + \phi_{21} \cdot co2_{UP,-1}$	
Destruction of socio-economic stock				$-(dis_G + dis_B)$
Final stock	$+k_m^G + k_m^B$	$+k_e^G + k_e^B$	$+co2_{AT}$	$+k_{se}^G + k_{se}^B$

Notes: Matter is measured in Gt while energy is measure in EJ. A '+' sign denotes inputs in the socio-economic system, whereas '–' denotes outputs. G = Greenland; B = Brownland.

Fig. 1. Baseline: selected variables

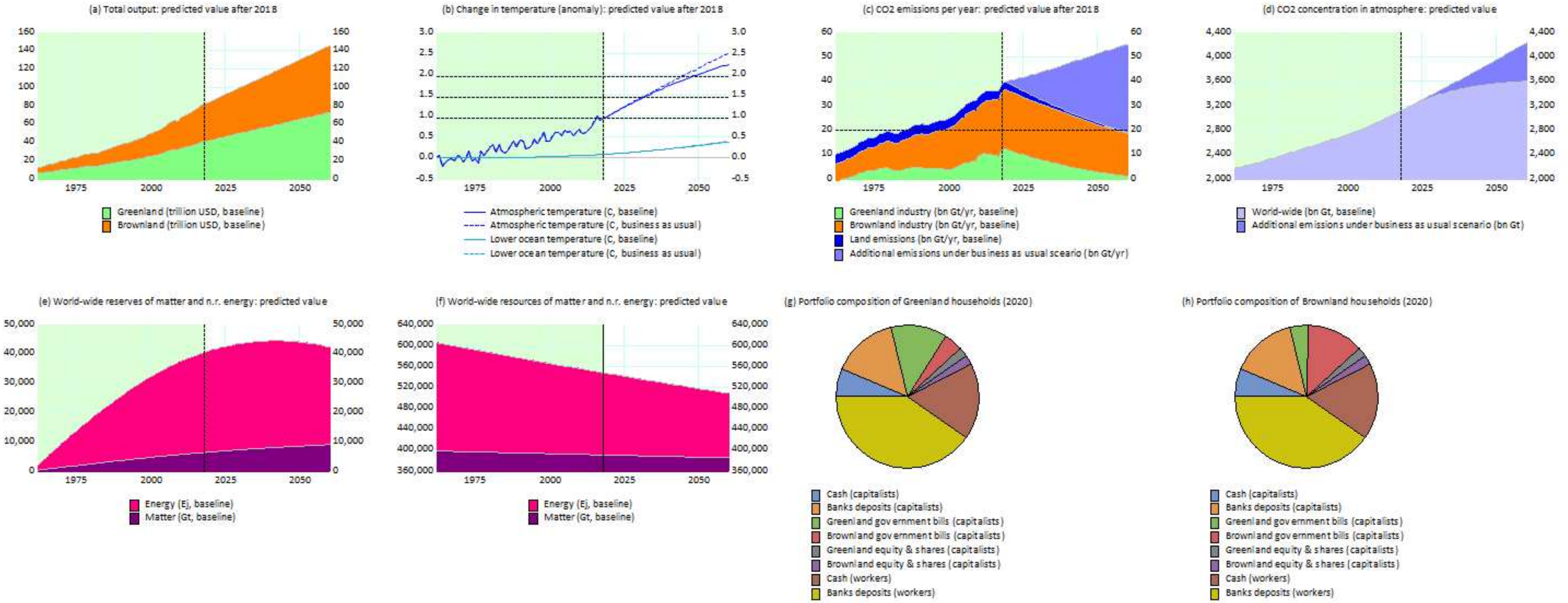


Fig. 2. Increase in risk aversion in both areas

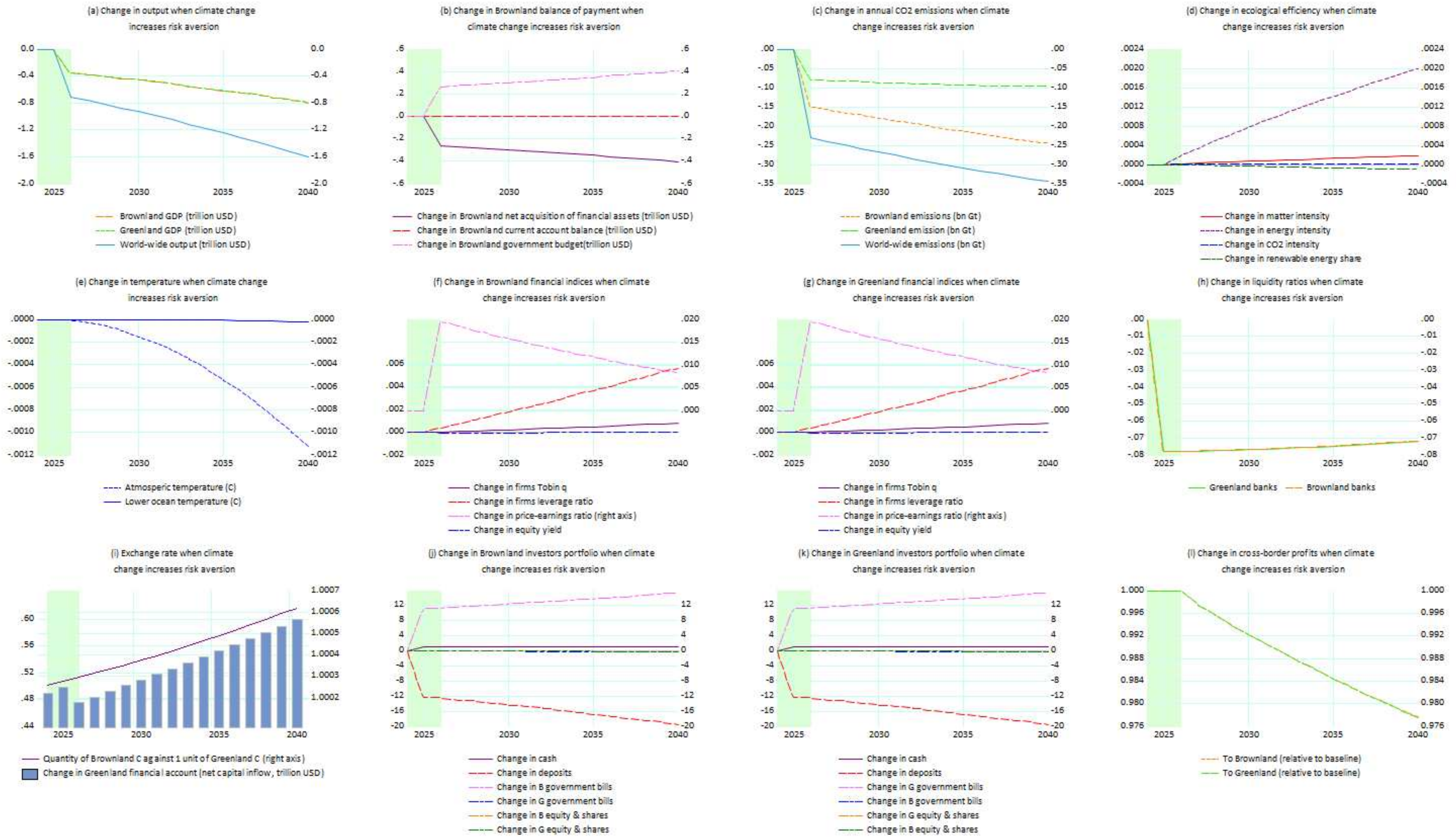


Fig. 3. Preference for greener financial assets

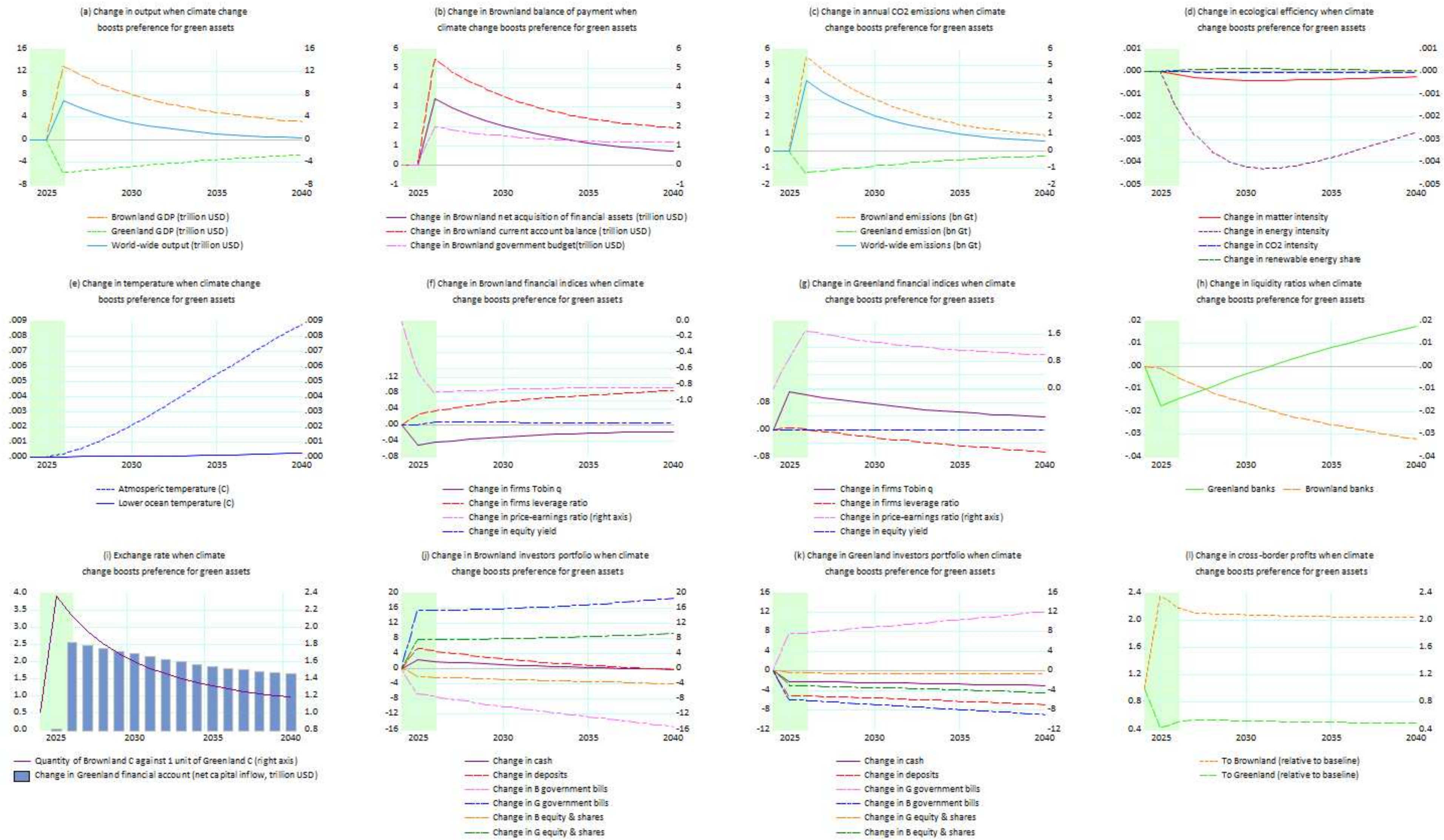


Fig. 4. Preference for greener products

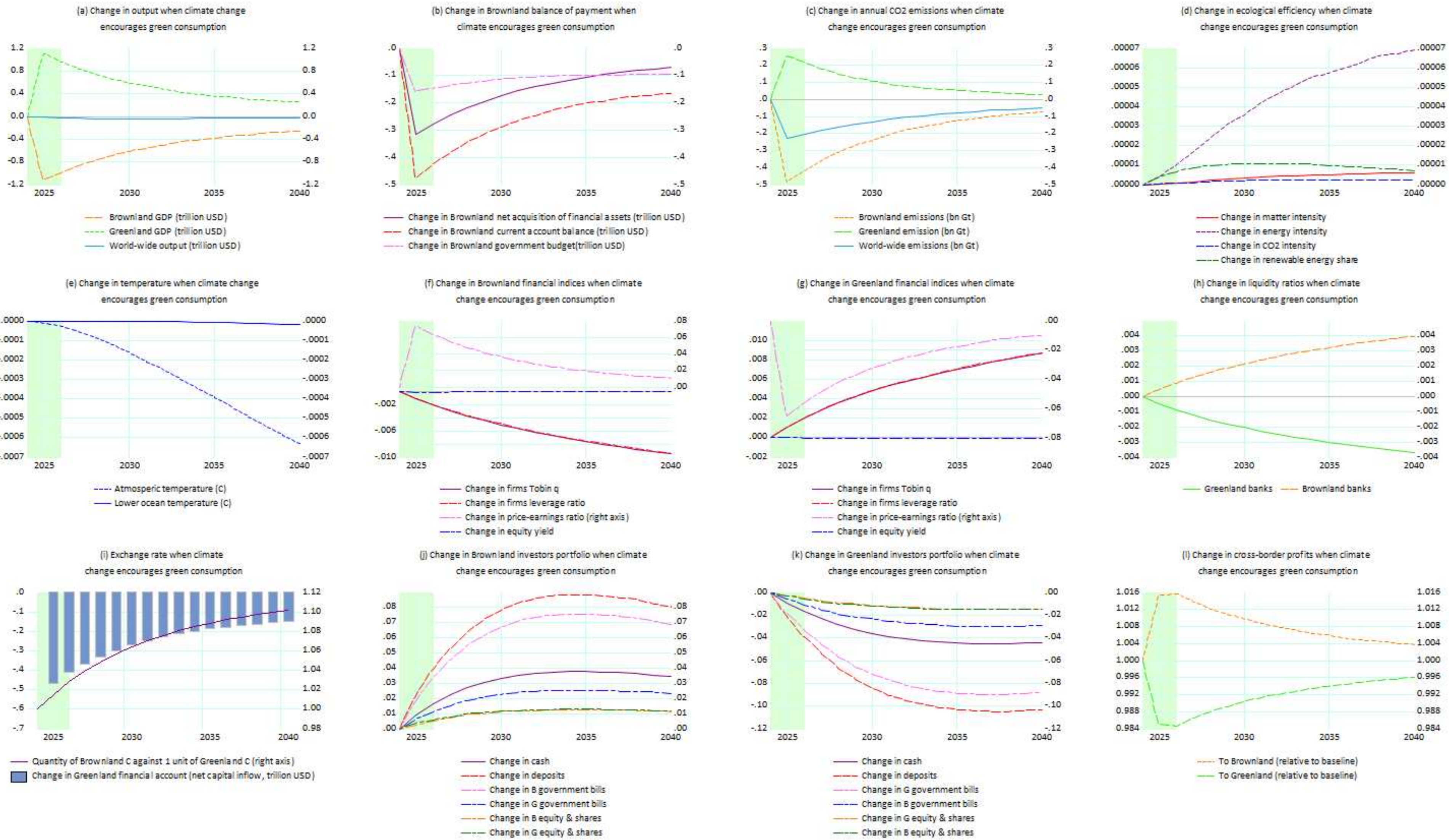


Fig. 5. Brownland government cuts green incentives, affecting import from Greenland

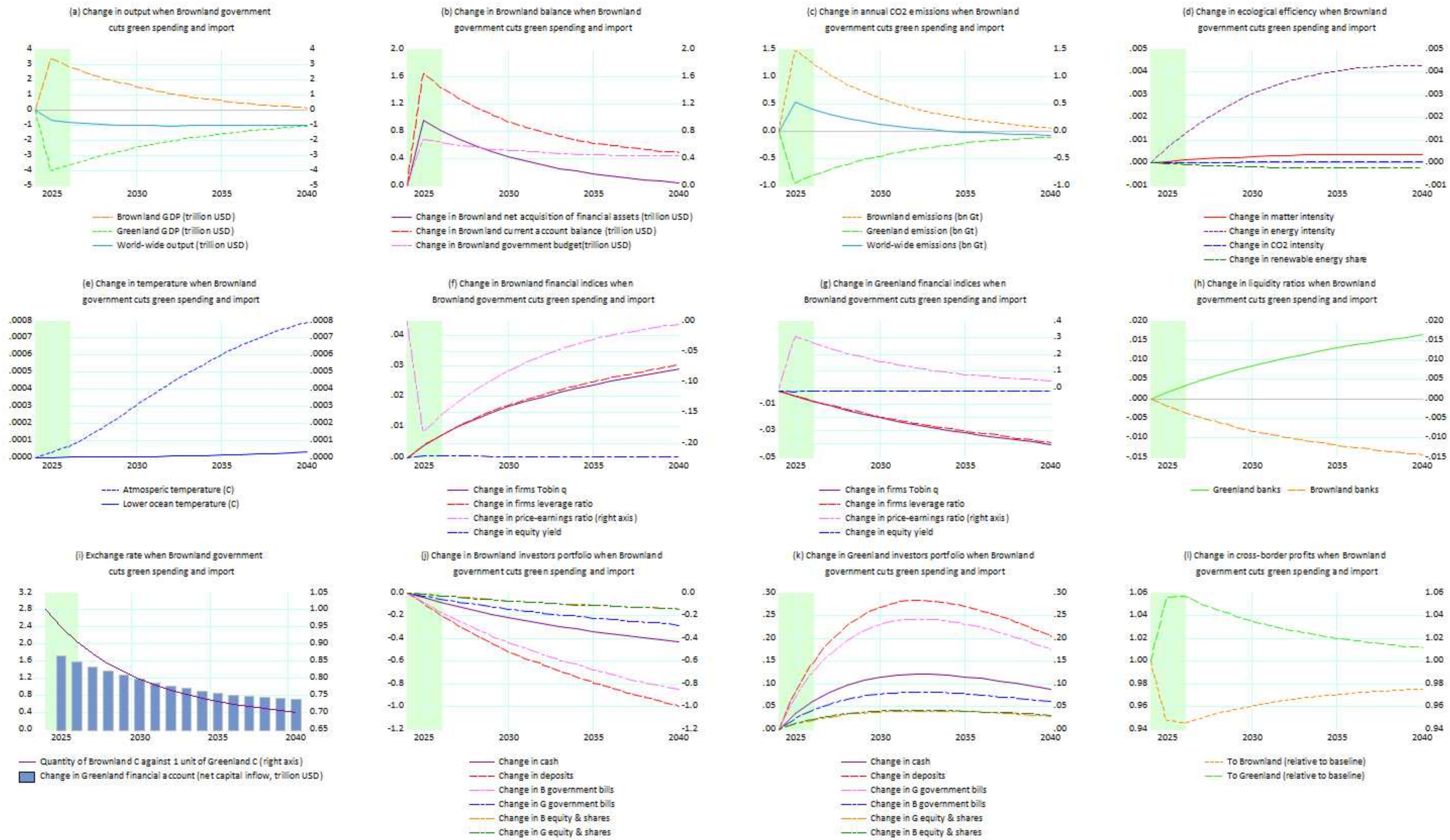


Fig. 6. Greenland government undertakes green MOIS

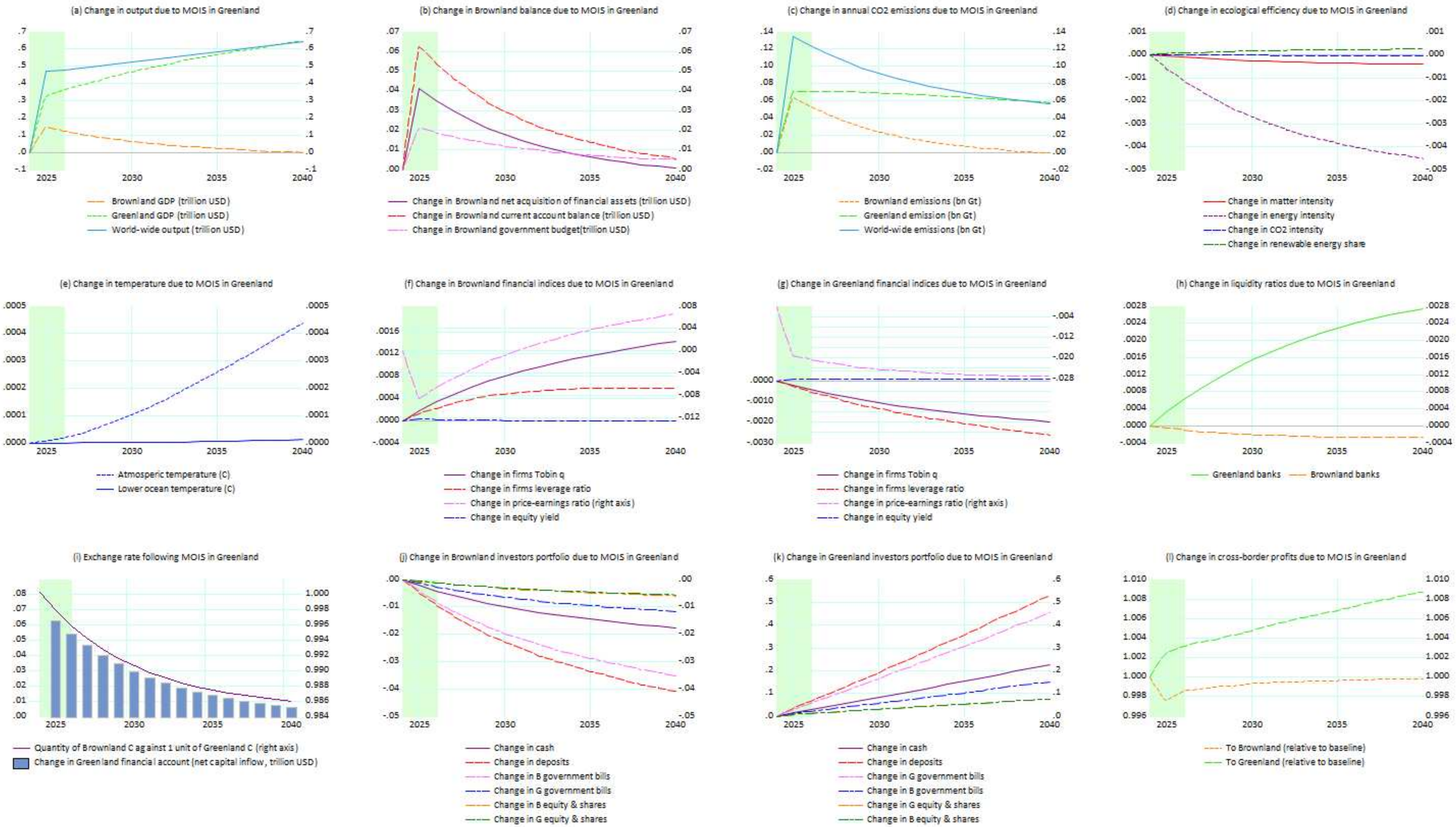


Fig. 7. Coordinated green MOIS, assuming ecological efficiency synergies

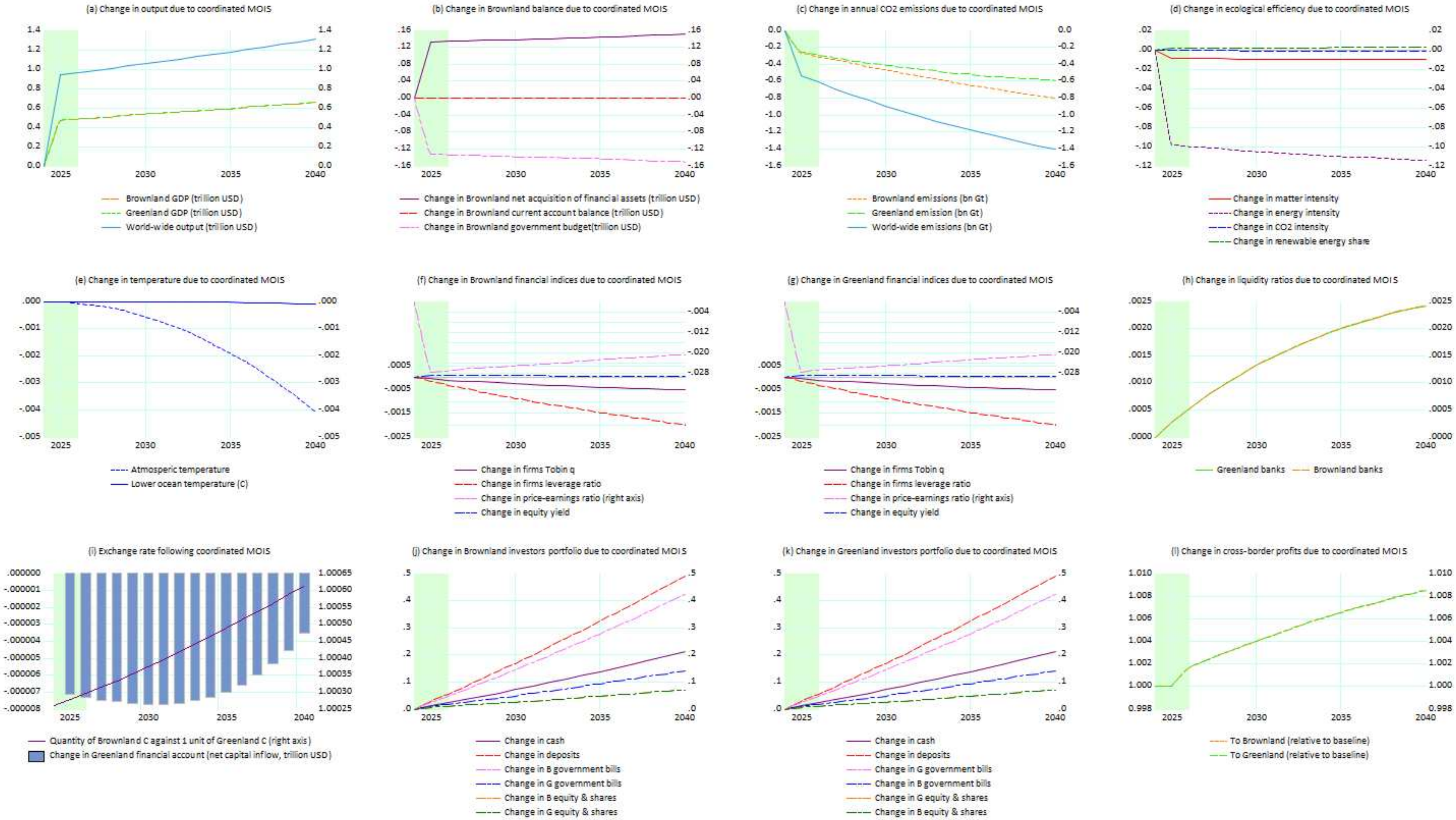
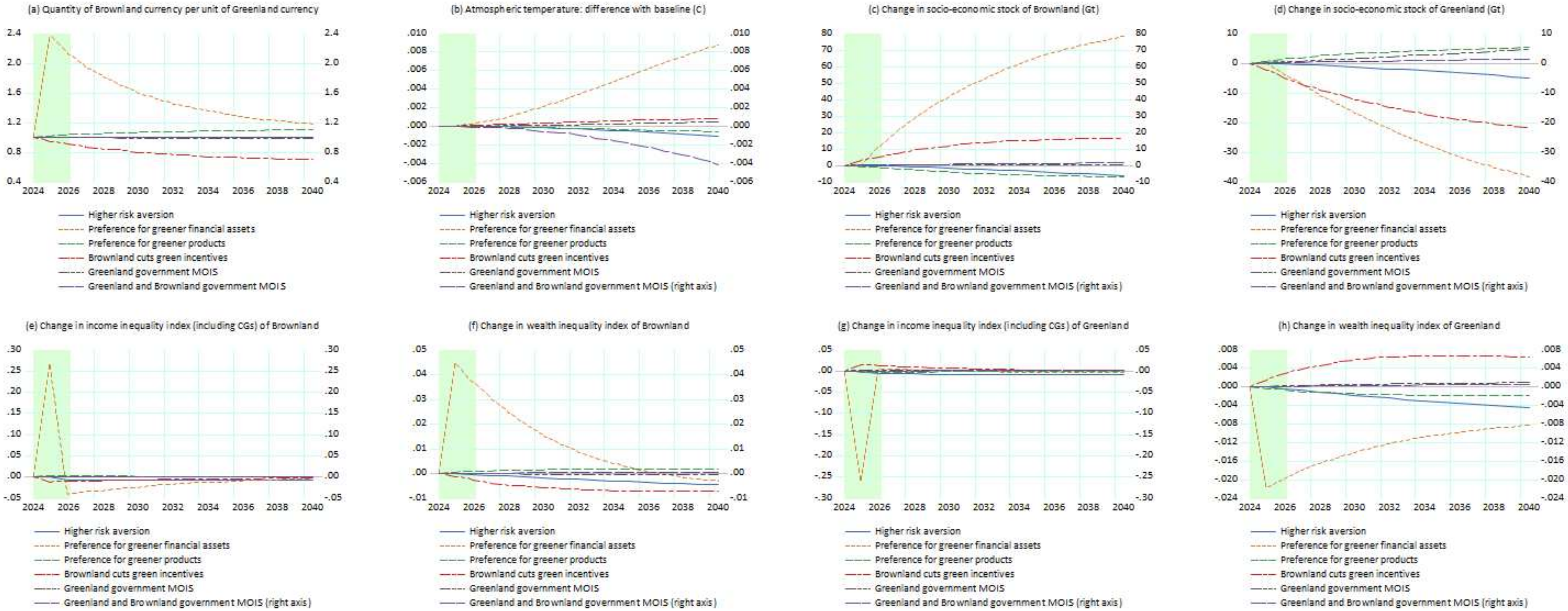


Fig. 8. Additional charts: exchange rates, temperature changes, socio-economic stocks and inequality indices (all scenarios)



Appendix: additional charts and tables

Fig. 3B. Preference for greener financial assets under a fixed exchange rate regime

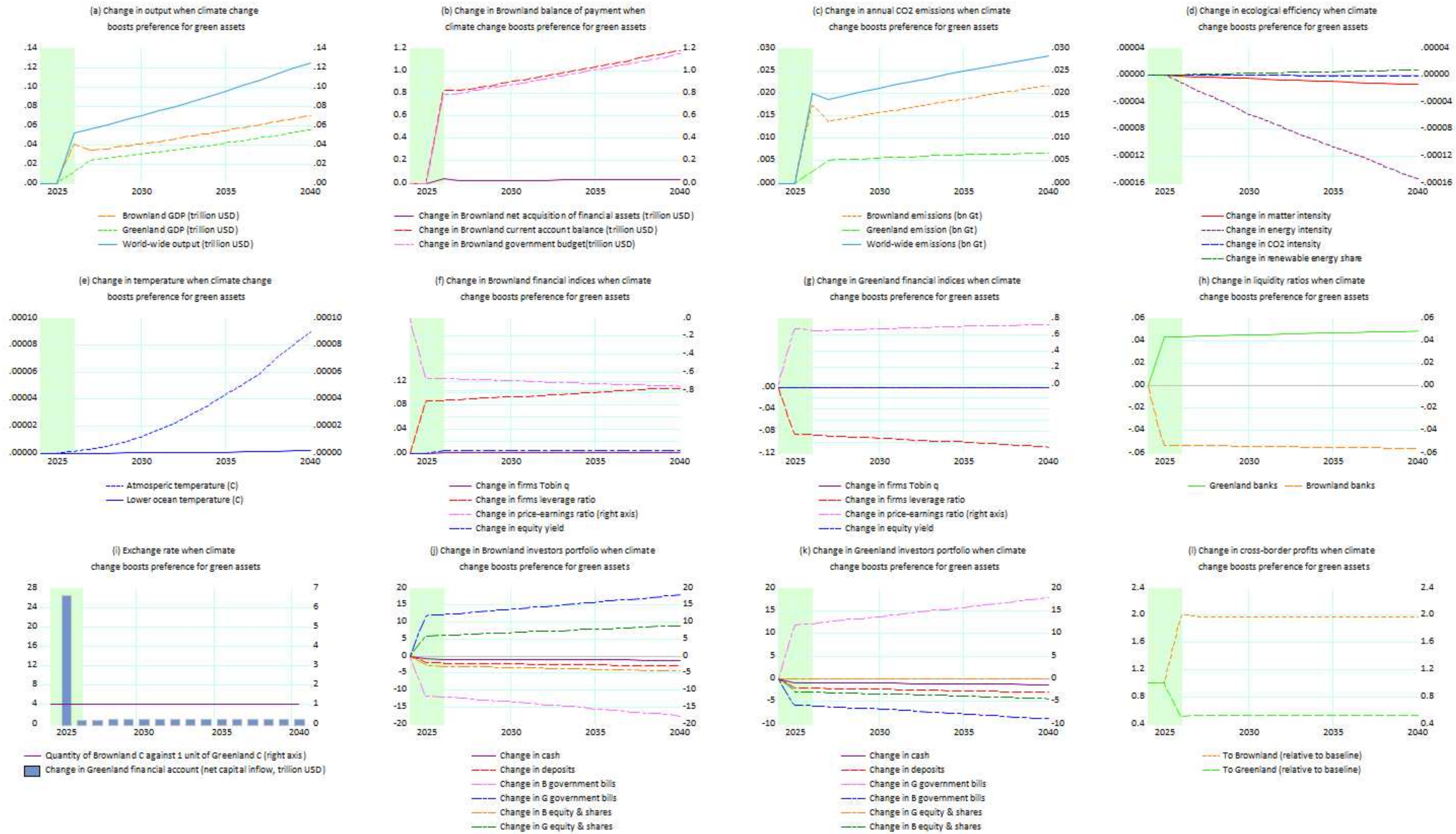


Fig. 4B. Preference for greener products under a fixed exchange rate regime

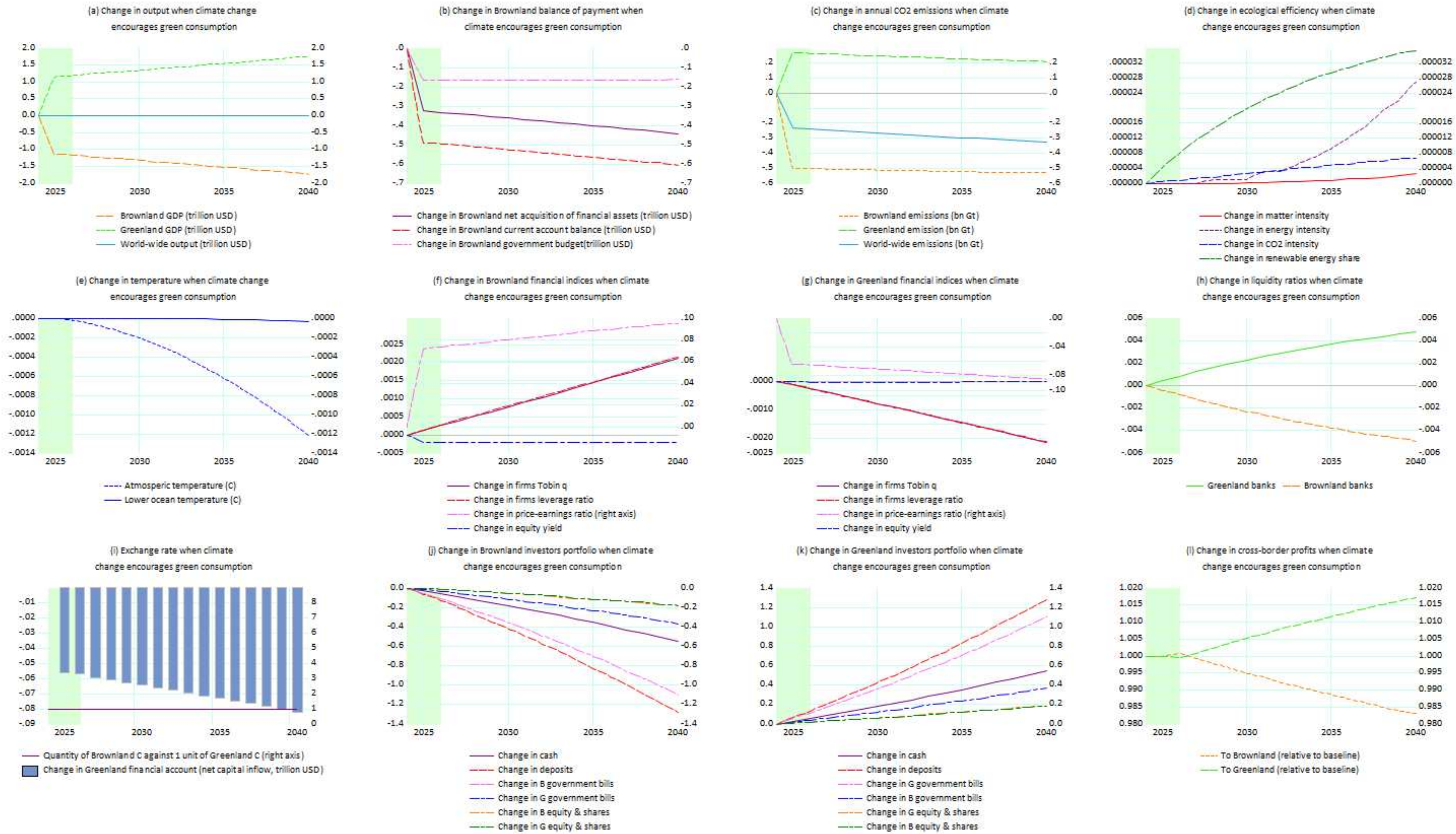


Fig. 5B. Brownland government cuts green incentives, affecting import from Greenland under a fixed exchange rate regime

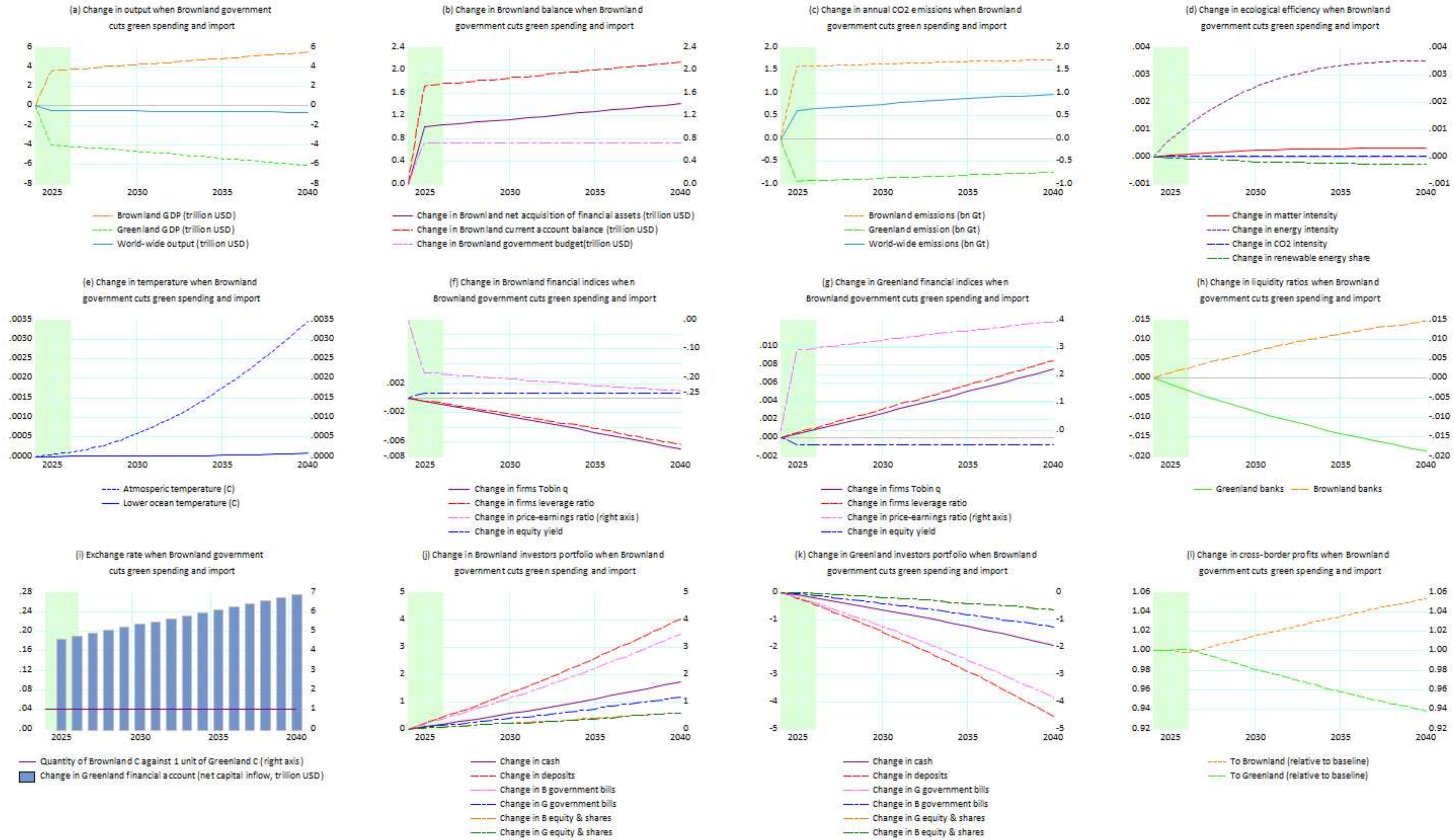


Fig. 6B. Greenland government undertakes green MOIS under a fixed exchange rate regime

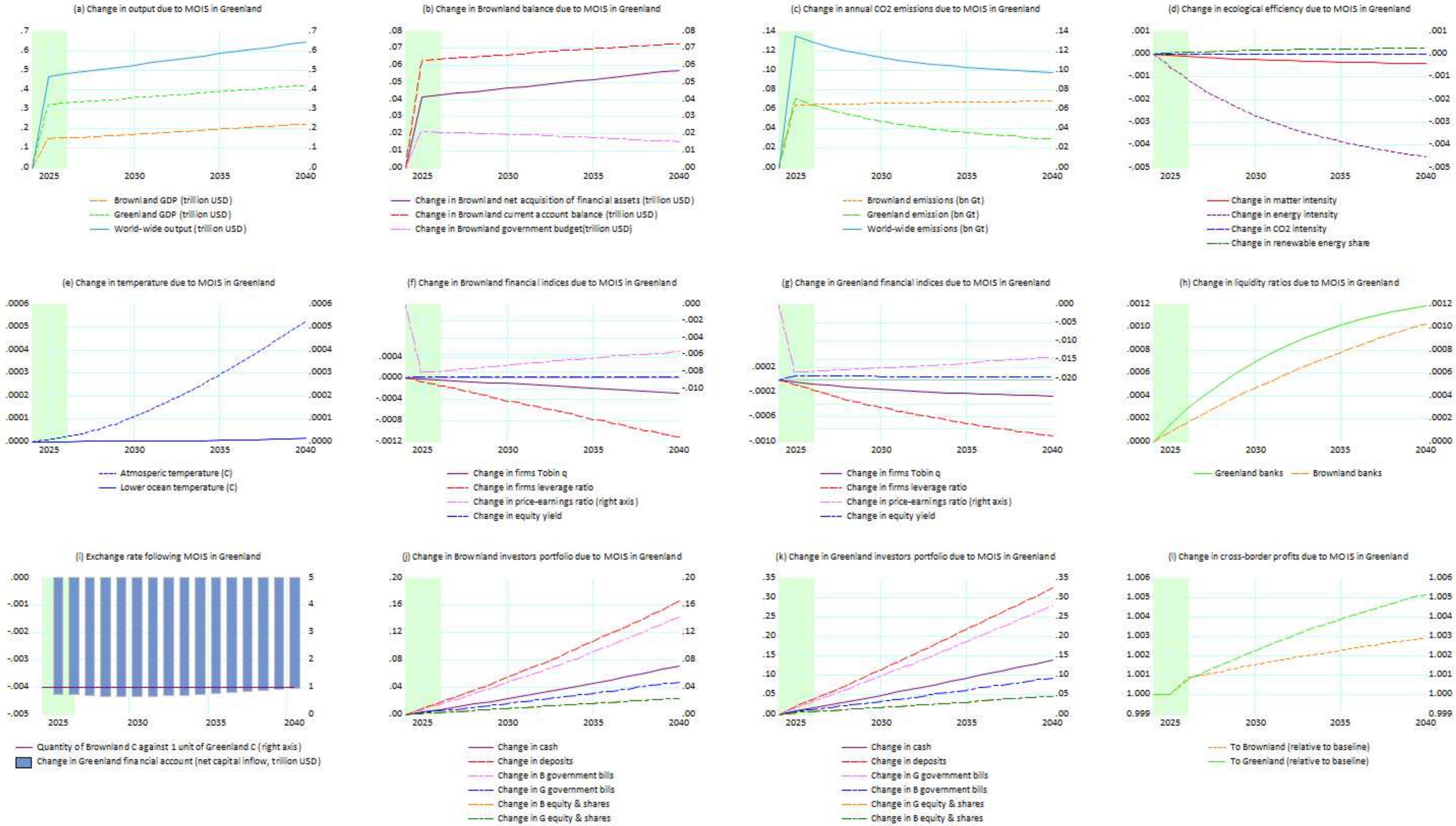
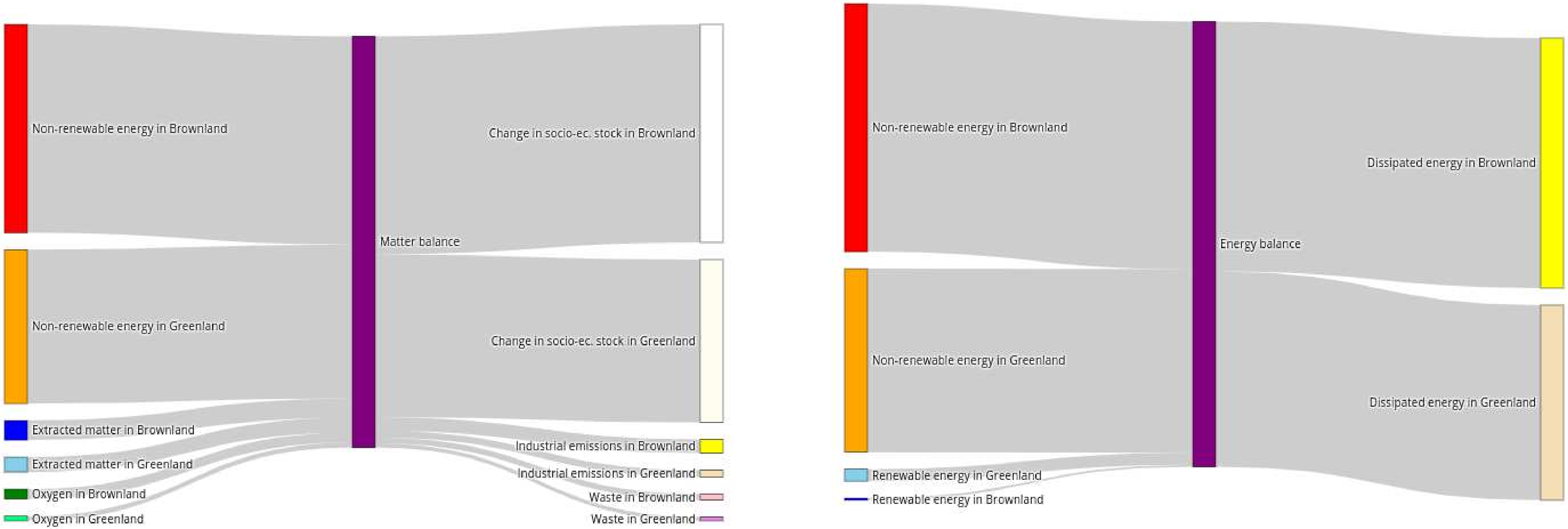
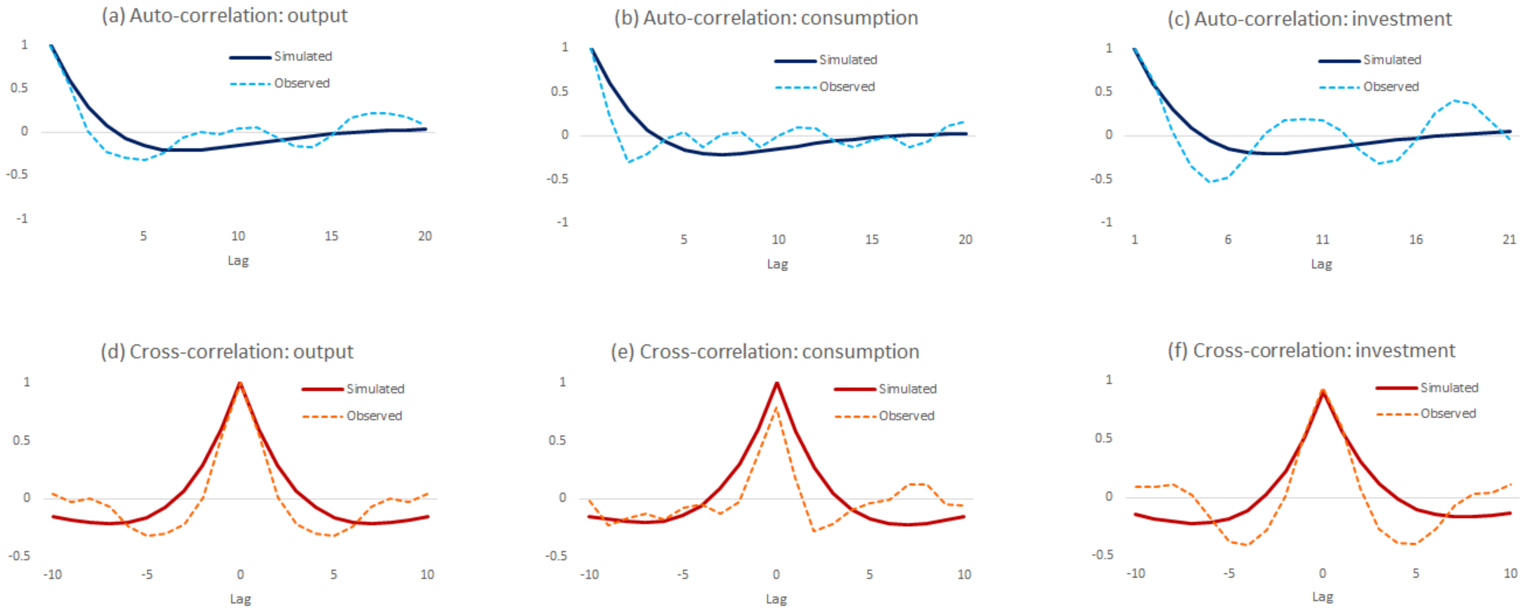


Fig. 9. Global matter and energy balances under the baseline scenario in 2018



Notes: Matter is measured in Gt while energy is measure in EJ.

Fig. 10. Auto- and cross-correlations: simulated vs. observed series



Note: Series are all expressed in logarithms. A Hodrick-Prescott filter was used to separate the cyclical component of each series from its trend. Only the former is considered. Observed data refer to the period 1960-2017. Simulated series refer to the period 2018-2060 (out-of-sample predictions).

Fig. 11. Structure of model equation blocks X to XII for each area

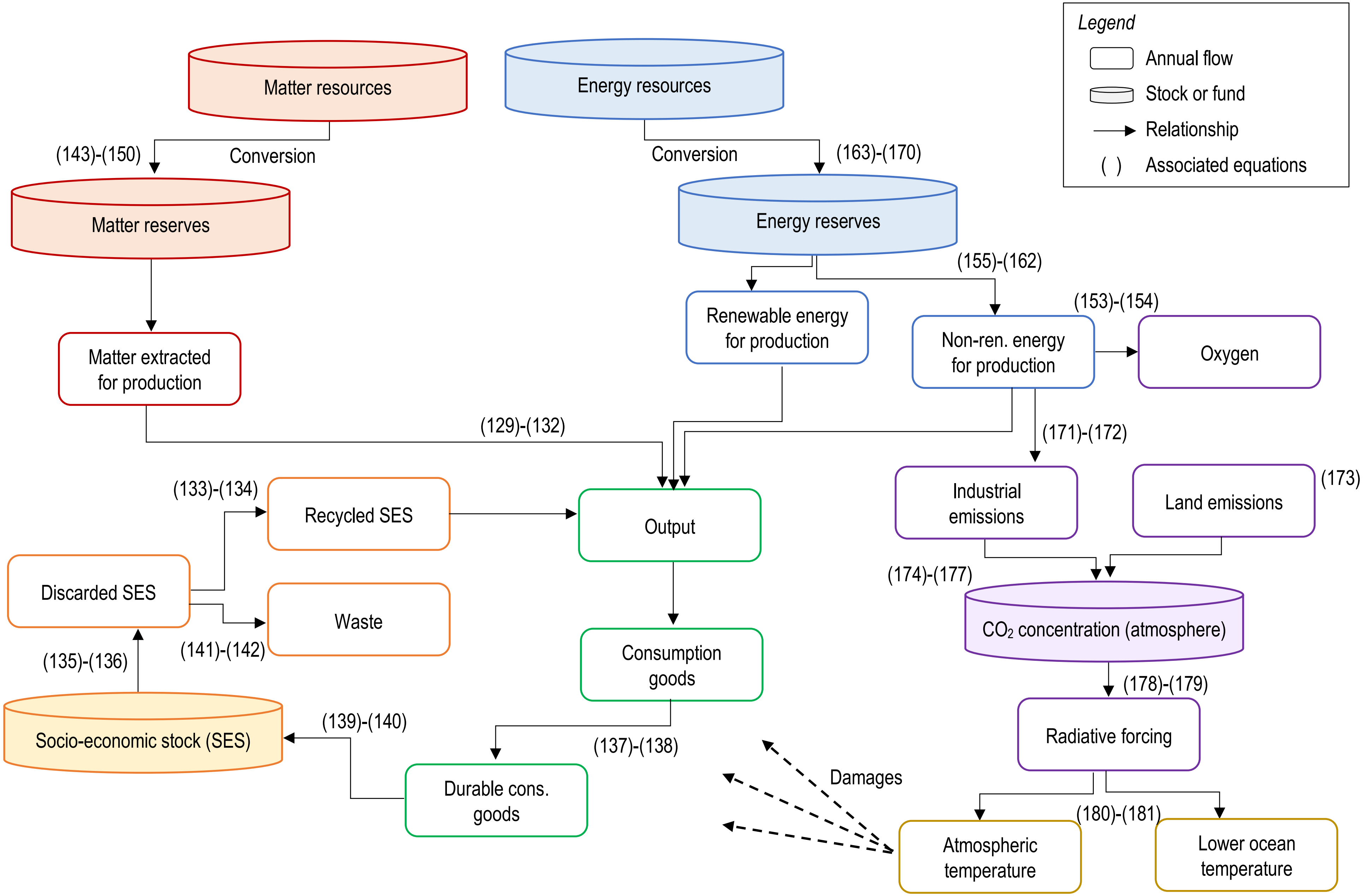


Table 5. Changes in selected variables: 2024-2050 (under a floating exchange rate regime)

	Scenario 1. Safer financial assets			Scenario 2. Greener financial assets			Scenario 3. Greener consumption			Scenario 4. Austerity in Brownland			Scenario 5. MOIS in Greenland			Scenario 6. Coordinated MOIS		
	B	G	W	B	G	W	B	G	W	B	G	W	B	G	W	B	G	W
Economy																		
Total output*	19.7809	19.7861	39.5534	22.4654	19.2220	40.4480	20.8493	21.1346	39.9536	20.5666	20.3669	50.6370	20.9773	21.7880	43.0675	21.7998	21.8054	43.5916
Exchange rate	-0.0006	0.0006	NA	-0.0629	0.0671	NA	-0.1039	0.1160	NA	0.4987	-0.3329	NA	0.0155	-0.0153	NA	-0.0006	0.0006	NA
Current account*	-0.0017	0.0017	NA	1.6148	-1.5042	NA	-0.1533	0.1374	NA	0.4139	-0.6184	NA	-0.0022	0.0022	NA	-0.0018	0.0018	NA
Government budget*	-2.6745	-2.6725	-5.3470	-1.8958	-4.4405	-6.3363	-3.3207	-3.1008	-6.4215	-2.7139	-3.6734	-6.3873	-3.2041	-3.3757	-6.5799	-3.3690	-3.3670	-6.7360
Society																		
Socio-economic stock (Gt)	664.8498	506.0621	1170.9119	769.2848	466.6481	1235.9329	669.7148	522.3921	1192.1069	693.2888	489.9761	1183.2649	678.8658	524.4741	1203.3399	680.6828	518.3581	1199.0409
Waste (Gt)	7.1963	4.9185	12.1148	7.6858	4.8234	12.5092	7.3266	5.0280	12.3547	7.3078	4.9697	12.2775	7.3431	5.0685	12.4116	7.1674	4.9039	12.0713
Income inequality	0.0217	0.0217	NA	0.0315	0.0266	NA	0.0313	0.0311	NA	0.0294	0.0313	NA	0.0312	0.0323	NA	0.0322	0.0322	NA
Wealth inequality	0.0289	0.0289	NA	0.0300	0.0291	NA	0.0369	0.0342	NA	0.0294	0.0404	NA	0.0353	0.0366	NA	0.0364	0.0364	NA
Finance																		
Tobin's q of firms	0.0233	0.0234	NA	0.0087	0.0432	NA	0.0088	0.0333	NA	0.0596	-0.0333	NA	0.0235	0.0191	NA	0.0210	0.0211	NA
Firms' leverage ratio	-0.0451	-0.0450	NA	0.0522	-0.1522	NA	-0.0681	-0.0435	NA	-0.0156	-0.1081	NA	-0.0548	-0.0587	NA	-0.0581	-0.0579	NA
Return on equity	-0.0008	-0.0008	NA	0.0029	-0.0020	NA	-0.0008	-0.0008	NA	-0.0008	-0.0008	NA	-0.0008	-0.0007	NA	-0.0008	-0.0008	NA
Bank liquidity ratio	0.0410	0.0409	NA	0.0647	0.1374	NA	0.1109	0.1011	NA	0.0881	0.1270	NA	0.1056	0.1089	NA	0.1085	0.1084	NA
Ecosystem																		
CO_2 emissions (Gt)	-3.6559	-6.6802	-12.0950	-3.0306	-6.7180	-11.5074	-3.3866	-6.5724	-11.7179	-3.4304	-6.6284	-11.8177	-3.3586	-6.5355	-11.6531	-4.4252	-7.2320	-13.4161
Atm. temperature (C)	NA	NA	0.7927	NA	NA	0.8095	NA	NA	0.7945	NA	NA	0.7963	NA	NA	0.7963	NA	NA	0.7847
Matter intensity (Kg/USD)	-0.0029	-0.0029	-0.0029	-0.0041	-0.0025	-0.0033	-0.0031	-0.0033	-0.0032	-0.0027	-0.0029	-0.0028	-0.0032	-0.0039	-0.0037	-0.0161	-0.0126	-0.0143
Energy intensity (Ej/trillion USD)	-0.0323	-0.0323	-0.0323	-0.0460	-0.0277	-0.0368	-0.0346	-0.0362	-0.0354	-0.0295	-0.0319	-0.0316	-0.0355	-0.0440	-0.0406	-0.1744	-0.1402	-0.1573

Notes: B = Brownland; G = Greenland; W = Worldwide. * Constant prices, trillion USD (Greenland currency).

Table 6. Initial values of variables and coefficient values for the baseline and the experiments

Starting values of variables and parameters of the two open economies	**Symbols and baseline values**	**Values under alternative scenarios**					
		Scenario 1. Safer financial assets	Scenario 2. Greener financial assets	Scenario 3. Greener consumption	Scenario 4. Austerity in Brownland	Scenario 5. MOIS in Greenland	Scenario 6. Coordinated MOIS
Brownland capitalists' propensity to consume out of income*	$\alpha_{1r}^{B} \approx 0.49$						
Brownland workers' propensity to consume out of income*	$\alpha_{1w}^{B} \approx 0.79$						
Greenland capitalists' propensity to consume out of income*	$\alpha_{1r}^{G} \approx 0.49$						
Greenland workers' propensity to consume out of income*	$\alpha_{1w}^{G} \approx 0.79$						
Brownland capitalists' propensity to consume out of wealth*	$\alpha_{2r}^{B} \approx 0.02$						
Brownland workers' propensity to consume out of wealth*	$\alpha_{2w}^{B} \approx 0.02$						
Greenland capitalists' propensity to consume out of wealth*	$\alpha_{2r}^{G} \approx 0.02$						
Greenland workers' propensity to consume out of wealth*	$\alpha_{2w}^{G} \approx 0.02$						
Parameter in Brownland export equation	$\varepsilon_0 = -2.1$						
Parameter in Brownland export equation	$\varepsilon_1 = 0.5$						
Parameter in Brownland export equation	$\varepsilon_2 = 1.228$			1.20			
Portfolio parameter of demand for Brownland bills by Brownland capitalists	$\lambda_{10} = 0.3$	0.40	0.20				
Portfolio parameter of demand for Brownland bills by Brownland capitalists	$\lambda_{11} = 1$						
Portfolio parameter of demand for Brownland bills by Brownland capitalists	$\lambda_{12} = 1$						
Portfolio parameter of demand for Brownland bills by Brownland capitalists	$\lambda_{13} = 0$						
Portfolio parameter of demand for Brownland bills by Brownland capitalists	$\lambda_{14} = 0$						
Portfolio parameter of demand for Greenland bills by Brownland capitalists	$\lambda_{20} = 0.1$		0.20				
Portfolio parameter of demand for Greenland bills by Brownland capitalists	$\lambda_{21} = 1$						
Portfolio parameter of demand for Greenland bills by Brownland capitalists	$\lambda_{22} = 1$						
Portfolio parameter of demand for Greenland bills by Brownland capitalists	$\lambda_{23} = 0$						
Portfolio parameter of demand for Greenland bills by Brownland capitalists	$\lambda_{24} = 0$						
Portfolio parameter of demand for Greenland bills by Greenland capitalists	$\lambda_{40} = 0.3$	0.40	0.40				
Portfolio parameter of demand for Greenland bills by Greenland capitalists	$\lambda_{41} = 1$						
Portfolio parameter of demand for Greenland bills by Greenland capitalists	$\lambda_{42} = 1$						
Portfolio parameter of demand for Greenland bills by Greenland capitalists	$\lambda_{43} = 0$						
Portfolio parameter of demand for Greenland bills by Greenland capitalists	$\lambda_{44} = 0$						
Portfolio parameter of demand for Brownland bills by Greenland capitalists	$\lambda_{50} = 0.1$		0.05				
Portfolio parameter of demand for Brownland bills by Greenland capitalists	$\lambda_{51} = 1$						
Portfolio parameter of demand for Brownland bills by Greenland capitalists	$\lambda_{52} = 1$						
Portfolio parameter of demand for Brownland bills by Greenland capitalists	$\lambda_{53} = 0$						
Portfolio parameter of demand for Brownland bills by Greenland capitalists	$\lambda_{54} = 0$						
Portfolio parameter of demand for Greenland shares by Brownland capitalists	$\lambda_{70} = 0.05$	0	0.10				

Portfolio parameter of demand for Greenland shares by Brownland capitalists	$\lambda_{71} = 0$					
Portfolio parameter of demand for Greenland shares by Brownland capitalists	$\lambda_{72} = 0$					
Portfolio parameter of demand for Greenland shares by Brownland capitalists	$\lambda_{73} = 0.01$					
Portfolio parameter of demand for Greenland shares by Brownland capitalists	$\lambda_{74} = 0.01$					
Portfolio parameter of demand for Greenland shares by Brownland capitalists	$\lambda_{75} = 0$					
Portfolio parameter of demand for Brownland shares by Greenland capitalists	$\lambda_{80} = 0.05$	0	0.025			
Portfolio parameter of demand for Brownland shares by Greenland capitalists	$\lambda_{81} = 0$					
Portfolio parameter of demand for Brownland shares by Greenland capitalists	$\lambda_{82} = 0$					
Portfolio parameter of demand for Brownland shares by Greenland capitalists	$\lambda_{83} = 0.01$					
Portfolio parameter of demand for Brownland shares by Greenland capitalists	$\lambda_{84} = 0.01$					
Portfolio parameter of demand for Brownland shares by Brownland capitalists	$\lambda_{90} = 0.05$	0	0.025			
Portfolio parameter of demand for Brownland shares by Brownland capitalists	$\lambda_{91} = 0$					
Portfolio parameter of demand for Brownland shares by Brownland capitalists	$\lambda_{92} = 0$					
Portfolio parameter of demand for Brownland shares by Brownland capitalists	$\lambda_{93} = 0.01$					
Portfolio parameter of demand for Brownland shares by Brownland capitalists	$\lambda_{94} = 0.01$					
Portfolio parameter of demand for Greenland shares by Greenland capitalists	$\lambda_{100} = 0.05$	0	0.10			
Portfolio parameter of demand for Brownland shares by Brownland capitalists	$\lambda_{101} = 0$					
Portfolio parameter of demand for Brownland shares by Brownland capitalists	$\lambda_{102} = 0$					
Portfolio parameter of demand for Brownland shares by Brownland capitalists	$\lambda_{103} = 0.01$					
Portfolio parameter of demand for Brownland shares by Brownland capitalists	$\lambda_{104} = 0.01$					
Shares issues to investment ratio in Greenland	$\xi_G = 0.01$					
Shares issues to investment ratio in Brownland	$\xi_B = 0.01$					
Real supply of shares in Brownland	$e_s^B = 1$					
Real supply of shares in Greenland	$e_s^G = 1$					
Unit price of shares in Brownland	$p_e^B = 1$					
Unit price of shares in Greenland	$p_e^G = 1$					
Parameter in Brownland import equation	$\mu_0 = -2.1$					
Parameter in Brownland import equation	$\mu_1 = 0.5$					
Parameter in Brownland import equation	$\mu_2 = 1.228$			1.256		
Parameter in Brownland import equation	$\gamma_\mu = 0$				0.5	
Average tax rate on income in Brownland*	$\theta_B \approx 0.144$					
Average tax rate on income in Greenland*	$\theta_G \approx 0.144$					
Initial value of depreciation rate in Brownland*	$\delta_0^B = 0.079$					
Initial value of depreciation rate in Greenland*	$\delta_0^G = 0.079$					
Capital adaptation coefficient in Brownland*	$ad_K^B = 0.75$					
Capital adaptation coefficient in Greenland*	$ad_K^G = 0.75$					
Export adaptation coefficient of Brownland	$ad_X = 0.05$					
Import adaptation coefficient of Brownland	$ad_{IM} = 0.05$					

Parameter of total investment function in Greenland*	$\gamma_0^G \approx 0.043$						
Parameter of total investment function in Greenland*	$\gamma_1^G \approx 1.008$						
Parameter of total investment function in Greenland	$\gamma_2^G = 0.005$						
Parameter of total investment function in Brownland*	$\gamma_0^B \approx 0.043$						
Parameter of total investment function in Brownland*	$\gamma_1^B \approx 1.008$						
Parameter of total investment function in Brownland	$\gamma_2^B = 0.005$						
Parameter of Brownland green investment function	$\chi_1^B = 0.2$						
Parameter of Brownland green investment function	$\chi_2^B = 0.02$						
Parameter of Brownland green investment function	$\chi_3^B = 10$						
Parameter of Greenland green investment function	$\chi_1^G = 0.2$						
Parameter of Greenland green investment function	$\chi_2^G = 0.02$						
Parameter of Greenland green investment function	$\chi_3^G = 10$						
Wage share to total income in Brownland	$\omega_B = 0.62$						
Wage share to total income in Greenland	$\omega_G = 0.62$						
Profit retention rate of Brownland firms	$ret_B = 0.02$						
Profit retention rate of Greenland firms	$ret_G = 0.02$						
Percentage of money held in Brownland deposits	$\nu_B = 0.7$	0.60					
Percentage of money held in Greenland deposits	$\nu_G = 0.7$	0.60					
Parameter of dividend yield in Greenland	$\pi_{dy}^G \approx 0.005$						
Parameter of dividend yield in Brownland	$\pi_{dy}^B \approx 0.005$						
Starting values of variables and parameter values for the ecosystem							
Material intensity of green capital in Brownland (Kg/USD)	$\mu_{gr}^B = 0.71$						-10%
Material intensity of green capital in Greenland (Kg/USD)	$\mu_{gr}^G = 0.51$						-10%
Material intensity of conventional capital in Brownland (Kg/USD)	$\mu_{con}^B = 0.86$						
Material intensity of conventional capital in Greenland (Kg/USD)	$\mu_{con}^G = 0.66$						
Energy intensity of green capital in Brownland (Ej/USD)	$\epsilon_{gr}^B = 7.65$						-10%
Energy intensity of green capital in Greenland (Ej/USD)	$\epsilon_{gr}^G = 5.65$						-10%
Energy intensity of conventional capital in Brownland (Ej/USD)	$\epsilon_{con}^B = 9.32$						
Energy intensity of conventional capital in Greenland (Ej/USD)	$\epsilon_{con}^G = 7.32$						
CO_2 intensity of green capital in Brownland (Gt/Ej)**	$\beta_{gr}^B \approx 0.038$						
CO_2 intensity of green capital in Greenland (Gt/Ej)**	$\beta_{gr}^G \approx 0.028$						
CO_2 intensity of conventional capital in Brownland (Gt/Ej)**	$\beta_{con}^B \approx 0.058$						
CO_2 intensity of conventional capital in Greenland (Gt/Ej)**	$\beta_{con}^G \approx 0.048$						
Rate of decline of CO_2 intensity in Brownland after 2020	$g_\beta^B = 0.02$						$+10\%$
Rate of decline of CO_2 intensity in Greenland after 2020	$g_\beta^G = 0.04$						$+10\%$

Coefficient of CO_2 annual emissions in Brownland**	$\beta_0^B \approx 3.45$
Coefficient of CO_2 annual emissions in Greenland**	$\beta_0^G \approx 3.45$
Approximate value of cum. CO_2 emissions of Brownland in 1960 (bn CO_2, Gt)**	$co2_B \approx 306$
Approximate value of cum. CO_2 emissions of Greenland in 1960 (bn CO_2, Gt)**	$co2_G \approx 306$
Temperature at the lower-ocean level	$T_{LO} = 0$
Speed of adjustment parameter in atmospheric temperature function	$\tau_1 = 0.012$
Heat loss from the atmosphere to the lower ocean in atmospheric temperature	$\tau_2 = 0.038$
Heat loss from the atmosphere to the lower ocean in lower ocean temperature	$\tau_3 = 0.005$
Equilibrium climate sensitivity	$s = 3$
Pre-industrial CO_2 concentration in atmosphere	$co2_{AT}^{PRE} = 1078.21$
Pre-industrial CO_2 concentration in upper ocean/biosphere	$co2_{UP}^{PRE} = 2475.25$
Pre-industrial CO_2 concentration in lower ocean	$co2_{LO}^{PRE} = 18335$
CO_2 transfer coefficient	$\phi_{11} = 0.9817$
CO_2 transfer coefficient	$\phi_{12} = 0.0183$
CO_2 transfer coefficient	$\phi_{21} = 0.0080$
CO_2 transfer coefficient	$\phi_{22} = 0.9915$
CO_2 transfer coefficient	$\phi_{23} = 0.0005$
CO_2 transfer coefficient	$\phi_{32} = 0.0001$
CO_2 transfer coefficient	$\phi_{33} = 0.9999$
Land-use CO_2 emissions	$emis_l = 4$
Rate of decline of land-use CO_2 emissions (after 2020)	$g_l = 0.044$
Radiative forcing over pre-industrial levels (W/m^2)	$F = 2.3$
Increase in radiative forcing due to doubling of CO2 concentraton	$F_2 = 3.8$
Radiative forcing due to non-CO_2 greenhouse gases	$F_{EX} = 0.28$
Annual increase in radiative forcing due to non-CO_2 greenhouse gases	$fex = 0.005$
Waste generated by production activities in Brownland (Gt)	$wa_B = 5.5$
Waste generated by production activities in Greenland (Gt)	$wa_G = 5.5$
Recycling rate in Brownland	$\rho_B = 0.2$
Recycling rate in Greenland	$\rho_G = 0.28$
Conversion rate of material resources into reserves in Brownland	$\sigma_m^B = 0.00034$
Conversion rate of material resources into reserves in Greenland	$\sigma_m^G = 0.00034$
Conversion rate of non-ren. energy resources into reserves in Brownland	$\sigma_e^B = 0.00177$
Conversion rate of non-ren. energy resources into reserves in Greenland	$\sigma_e^G = 0.00177$
Initial value of matter resources of Brownland (Gt)	$res_m^B \approx 199{,}290$
Initial value of matter resources of Greenland (Gt)	$res_m^G \approx 199{,}290$
Initial value of non-renewable energy resources of Brownland (Ej)	$res_e^B \approx 303{,}535$
Initial value of non-renewable energy resources of Greenland (Ej)	$res_e^G \approx 303{,}535$
Initial value of socio-economic stock of Brownland (Gt)	$k_{se}^B = 0$

Initial value of socio-economic stock of Brownland (Gt)	$k_{se}^{G} = 0$						
Coefficient converting Gt of carbon into Gt of CO_2	$car = 3.67$						
Parameter of damage function in Brownland	$d_1^B = 0$						
Parameter of damage function in Brownland	$d_2^B = 0.00284$						
Parameter of damage function in Brownland	$d_3^B = 0.000005$						
Parameter of damage function in Brownland	$x^B = 6.6754$						
Percentage of damages in Brownland	$d_T^B = 0.0028$						
Parameter of damage function in Greenland	$d_1^G = 0$						
Parameter of damage function in Greenland	$d_2^G = 0.00284$						
Parameter of damage function in Greenland	$d_3^G = 0.000005$						
Parameter of damage function in Greenland	$x^G = 6.6754$						
Percentage of damages in Greenland	$d_T^G = 0.0028$						
Brownland export damage activation coefficient	$ad_X = 0$						
Brownland import damage activation coefficient	$ad_{IM} = 0$						
Proportion of durable discarded in Brownland every year	$\zeta_B = 0.015$						
Proportion of durable discarded in Greenland every year	$\zeta_G = 0.015$						
Share of renewable energy to total energy in Brownland, conventional capital	$\eta_{con}^B = 0$						
Share of renewable energy to total energy in Greenland, conventional capital	$\eta_{con}^G = 0.05$						
Share of renewable energy to total energy in Brownland, green capital	$\eta_{gr}^B = 0.075$						$+10\%$
Share of renewable energy to total energy in Greenland, green capital	$\eta_{gr}^G = 0.15$						$+10\%$
Starting values of exogenous variables for the two open economies							
Government green spending in Brownland	$GOV_{gr}^B = 1$				0.80		1.20
Government green spending in Greenland	$GOV_{gr}^G = 1$					1.20	1.20
Government conventional spending in Brownland*	$GOV_{con}^B \approx 0.24$						
Government conventional spending in Greenland*	$GOV_{con}^G \approx 0.24$						
Coefficient of government conventional spending function in Brownland*	$\gamma_{GOV0}^B \approx 0.76$						
Coefficient of government conventional spending in Brownland*	$\gamma_{GOV1}^B \approx 1$						
Coefficient of government conventional spending function in Greenland*	$\gamma_{GOV0}^G \approx 0.76$						
Coefficient of government conventional spending in Greenland*	$\gamma_{GOV1}^G \approx 1$						
Return rate on government bonds in Brownland	$r_b^B = 0.03$						
Return rate on government bonds in Greenland	$r_b^G = 0.03$						
Interest rate on loans in Brownland	$r_l^B = 0.035$						
Interest rate on loans in Greenland	$r_l^G = 0.035$						
Starting values for endog. variables with lag for the two open economies							
Exchange rate	$xr_B = xr_G = 1$						

Return rate on equity & shares in Brownland	$r_e^G = 0.03$			
Return rate on equity & shares in Greenland	$r_e^B = 0.03$			

Notes: * based on World Bank data (accessed: February 2019); ** based on data on CO_2 emissions and atmospheric temperature anomalies provided by Ritchie and Roser (2019) and by GISTEMP (2019) and Lenssen et al. (2019), respectively. Remaining values are calculated in such a way to obtain the baseline scenario presented in Section 3.2. Starting values of financial stocks and all remaining lagged endogenous variables are set to zero. Scenario 6 is based on the assumption that a coordinated green spending plan (undertaken by both governments) is associated with a 10% improvement in ecological efficiency ratios.

Extra contents (online): the exchange rate mechanism

Our model is geographically symmetrical. Demands and supplies of financial assets are identical for the two areas. However, the way the exchange rate mechanism is modelled in the SFC literature usually departs from this symmetry (e.g. Godley and Lavoie 2007, chapter 12). The burden of the adjustment is put on one of the two areas. This requires replacing equations (85), (115), (116) and (127) with the following subset:

$$B_s^{GB} = B_s^B - B_s^{BB} - B_{cb}^{BB} - B_b^B \tag{85B}$$

$$B_{cb}^{BB} = H_s^B - A_s^B \tag{115B}$$

$$H_s^B = H_h^B \tag{116B}$$

$$xr_G = B_s^{GB} / B_d^{GB} \tag{127B}$$

While the aggregate portfolio of Brownland investors is always defined by their relative demands for financial assets, the portfolio of Greenland investors is not. Equation (85B) holds that the amount of Brownland bills held by Greenland investors is a residual. Equations (115B) and (116B) show that the amount of domestic bills purchased by Brownland central bank must match the difference between the cash issued on demand and the advances received by the commercial banks. The alternative exchange rate mechanism is defined by equation (127B). It holds that Greenland exchange rate equals the supply/demand ratio of Brownland bills to Greenland investors. This mechanism assures the stock-flow consistency of the model. It is also quite resilient to shocks. However, it brings about an undesirable asymmetry in the way portfolio decisions are made (or modelled) across areas. This lack of symmetry is the reason we used a different mechanism to define the baseline scenario in our model. Equation (127) allows preserving the symmetry of portfolio behaviours across areas. Besides, it explicitly links the exchange rate with the balances of payments of the two areas. Under a pure flexible exchange rate regime, the exchange rate is the price of a currency. It is determined by the supply and the demand for that currency in the foreign exchange market, where both real and financial forces must be considered. More precisely, the *notional* balance of payment of, say, Brownland is the summation of its current account (CAB_B) and its financial account balance (KAB_B):

$$CAB_B = TB_B + xr_{G,-1} \cdot \left(r_{G,-1} \cdot B_{s,-1}^{BG} + r_{e,-1}^{G} \cdot E_{s,-1}^{BG}\right) - r_{B,-1} \cdot B_{s,-1}^{GB} - r_{e,-1}^{B} \cdot E_{s,-1}^{GB} \tag{202}$$

$$KAB_B = -d(B_s^{BG}) \cdot xr_G + d(B_s^{GB}) - d(E_s^{BG}) \cdot xr_G + d(E_s^{GB}) \tag{204}$$

$$BP_B = CAB_B + KAB_B \tag{208}$$

The current account balance, in turn, is the summation of the trade balance ($TB_B = X_B - IM_B$) and the factor income. The former mirrors the net demand of Brownland currency for the purchase of goods (and services). The latter amounts to the financial flows to Brownland associated with net interest payments and dividends on foreign financial assets. The financial account records the net purchase of Brownland financial assets made by Greenland investors. Notice that the balance of payment shown by equation (208) is only a *notional* variable, as the summation of CAB_B and KAB_B is always zero, apart from statistical discrepancies. Should Brownland current account balance turn positive (for instance, because of Brownland export exceeding import), the demand for Brownland currency would exceed its supply. As a result, Brownland currency would appreciate. This would not affect the trade balance in the current period, as the exchange rate enters import-export equations with a lag in equations (61) and (62). However, the financial account would be affected. Greenland investors would be happy to hold a lower amount of Brownland financial assets (expressed in

Brownland currency). By contrast, Brownland investors would increase their holdings of Greenland financial assets (to meet their target level, which is expressed in their own domestic currency). Consequently, Brownland financial account would turn negative, meaning that Brownland would be a net lender to Greenland. The adjustment process, driven by a modification in the exchange rate, would only stop when the equality between the current account balance and the (opposite of the) financial account balance were restored. This is the reason the exchange rate mechanism defined by equation (127) is derived by using equation (203) and (205) in the equilibrium condition '$CAB_G + KAB_G = 0$', and then solving for xr_G. Finally, notice that we tested the model by using either (floating) exchange rate mechanism. While results are unaffected by the specific mechanism chosen, equation (127) allows for a more intuitive and theoretically-sound interpretation. However, a drawback of (127), relative to the traditional exchange rate mechanism, is that the former brings about a higher degree of simultaneity in model equations compared to the latter. Therefore, we used the traditional mechanism to study model reaction to large shocks.