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Sustainable economic policies: exploring the effects of ecosystemic macroprudential regulations.

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ABSTRACT

This paper explores the implications of ecosystemic macroprudential regulations on sustainability in an ecological PK-SFC framework. We first discuss the link between banks and global warming; and present the case for connecting prudential regulation with planetary boundaries. We then report a set of simulations suggesting that in the short run, such ecosystemic prudential regulations could effectively green banks' balance sheets, credit flows, and curtail brown investment, at the cost, however, of significant short-run losses. In the longer run, the induced green transition appears to set the economy on a more sustainable pathway, to decrease inflationary pressures, and to maintain real GDP at the baseline level, with distributional effects favourable to wage-earners. These results highlight the relevance of ecosystemic prudential regulation to tackle climate change and call for adopting a holistic approach to sustainability policies.

KEYWORDS: SDG financing, ecological finance, SFC modeling.

JEL classification: G00, G28

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1. Introduction

Re-embedding the economy and the financial systems into the constraints of climate viability is the rationale behind the article 2.1(c) of the Paris Climate Agreement. The latter calls on governments to "*make financial flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient*". The objective of reallocating financial flows to the green sector is intertwined with the main concern of the Network for Greening the Financial System (NGFS), i.e. controlling climate-related financial risks.

The key objective of global climate transition policies is to reduce greenhouse gas emissions below a critical threshold known as the planet's carbon budget. The latter corresponds to the maximum volume of hydrocarbons that could be burned while remaining below the warming threshold of +1.5° or +2° compared with the pre-industrial era. Given the current rate of global emissions, our carbon budget will be exhausted in the 2030-2040 decade. The required shift is substantial: in order to comply with a carbon budget of + 1.5° with a 50% probability by 2050, almost 60% of fossil oil and methane (the main component of natural gas), and 90% of coal, must remain in the ground (Welsby et al., 2021). Yet some of these unusable reserves have already been prospected and are already being valued on the balance sheets of the extractive industries. The stranding of these fossil-based assets, i.e. their massive depreciation, is therefore unavoidable, even if the timing of its realization is very difficult to predict precisely.

Unfortunately, financial markets have no reason to spontaneously comply with the carbon budget. The latter is indeed a physical reference linked to the materiality of our production and consumption, i.e. the flow of materials and energy. Such notions are alien to market benchmarks that are only concerned with prices. In other words, no market mechanism would lead to decisions that would limit the lucrative extraction of resources, thus abandoning in the ground fossil reserves that are highly profitable to exploit. In the same vein, both standard macroeconomic modelling and prudential policies, which assume a probabilistic world, are unable to provide relevant frameworks to deal with this issue - which has not only an economic, but also an ecological dimension.

A vicious circle hence links the activity of financial institutions to climate change (Scialom, 2023). By providing cheap and plentiful financing - whose risks are poorly priced - to companies involved in fossil fuel research, exploration and production, financial institutions are enabling and even accelerating climate change. In turn, climate change is a major factor of financial instability.

In response, Baer et al. (2021) highlighted that financial policy could be based on a 'promotional motive' (and not only on a 'prudential motive') - which means that financial policy instruments could be mobilized to directly mitigate climate change, rather than only tackling its destabilizing effects. In this paper, we also take the view that financial policy should be an integral component of sustainable policies, rather than being only dedicated to the control of climate-induced financial risks. In so doing we attempt to respond to the UN Secretary General's recent call for "*innovative approaches and bold policy decisions*" (UN, 2023)[2] to tackle the UN SDGs.

[2] See https://www.un.org/en/desa/un-sets-out-bold-solutions-to-rescue-SDG-finance.

We contribute to this discussion by exploring the effects of recent calls for a new paradigm in prudential supervision, one which would be based on scientific knowledge about planetary boundaries, rather than financial data. In particular, we investigate the effects of adopting a loan-to-value (LTV) inspired approach to brown credit as suggested by NGO Finance Watch (2023)[3]. According to its proponents, this policy would indeed permit to curtail fossil fuel use below a science-guided threshold, which is currently estimated at 77% of fossil fuel resources (Carbon Tracker, 2013).

Using Philia 1.0, a new PK-SFC ecological model, we report a set of simulations suggesting that in the short run, such ecosystemic prudential regulations could effectively green banks' balance sheets, credit flows, and curtail brown investment, at the cost, however, of a significant recession. In the longer run, the induced green transition appears to set the economy on a more sustainable pathway, decreases ecosystem-induced inflationary pressures, and mitigates macroeconomic losses, with positive effects on new postgrowth welfare metrics. These results highlight the relevance of a new ecosystemic prudential regulation framework to tackle climate change. They call for further research, in particular regarding the identification of policies permitting to mitigate its short-run macroeconomic cost.

The remainder of this article is structured as follows. Section 2 discusses ecosystemic prudential regulation in reference to the broader literature on climate change and prudential regulation. Section 3 situates Philia 1.0 within the ecological PK-SFC modelling literature, describes its accounting structures, and discusses the key features of the baseline and brown scenario. Section 4 analyses the effect of an ecosystemic prudential policy scenario. Section 5 brings together our conclusions.

2. Climate change and prudential regulations

While financial regulation is still imbued with a conception of financial markets as being both able to self-regulate and to optimally allocate funds, there is a growing consensus among scholars that such a *dogma* proves particularly inadequate when it comes to dealing with climate change (Campiglio et al., 2018; Chenet et al., 2021). In particular, the now widely accepted concept of 'double materiality' (European Banking Authority., 2021) underlines that the current banking regulation paradigm both underestimates those risks banks face because of climate change (Smoleńska and Van 'T Klooster, 2022) and fail to incentivize banks to stop funding high-emitting economic sectors. Indeed: "*The share of high-emitting economic sectors in bank lending is around 75% higher than its equivalent share in economic activity, while more than 60% of banks' interest income derived from firms operating in the most carbon-intensive sectors*" (ECB, 2023, p. 4).

Exploring the exposures of the European banking system to climate risky assets, Battiston et al. (2017) found that, whereas European banks have few connections with firms directly engaged in fossil fuel extraction, they are nonetheless widely exposed to fossil-fuel dependent sectors, such as real estate and transport. In addition, a significant part of the European banking system exhibits important connections to institutional investors that are directly exposed to fossil fuel

[3] "*Given that only the exploitable portion of a fossil fuel reserve will continue to have value when action is finally taken to limit global temperature increases by curtailing fossil fuel use, fossil fuel financing should, in a macroprudential logic, be constrained by a loan-to-value mechanism, very much like real estate financing*" (Finance Watch, 2023, p. 37).

extraction. Banks are therefore highly exposed to "*capital stranding cascades*" (Cahen-Fourot et al., 2021).

Banking regulation has the potential to break the climate-finance vicious circle. To achieve this objective, however, regulators face a double challenge. First, regulations should allow banks to deal with those risks that will eventually materialize because of climate change. Second, regulations should prevent banks from financing those activities which contribute the most to climate change. Addressing these challenges would, however, require a new paradigm: regulators need to acknowledge that market-based rules are intrinsically limited because of the limitations of the market logic itself when it comes to both assessing risks and allocating funds (Campiglio, 2016). As a consequence, the sole manner to deal with the above-mentioned challenge is to break apart from market-based regulation and to engage into a "*guided transition*" (Smoleńska and Van 'T Klooster, 2022), in order to "*prevent a Minsky climate moment*" (Dikau and Miller, 2022).

Several prudential instruments have already been envisioned to engage such a "*guided transition*" (Le Quang and Scialom, 2022; Schoenmaker and Van Tilburg, 2016). A first series of proposals suggest to modify banks' capital requirements (D'Orazio and Popoyan, 2019; Holscher et al., 2022). The underlying objective would be to fine-tune banks' capital to their real exposures to climate risky assets – hence dealing with the first aspect of the double materiality prospect – and to incentivize them to invest more (less) in green (brown) assets. Two tools have been put forth to achieve this goal: a green-supporting factor (GSF) or a brown-penalizing factor (BPF). While the GSF seems to be the most straightforward way to incentivize banks to invest in green assets, it has however proven disappointing when applied to the funding of small and medium-sized enterprises (Dietsch et al., 2016; European Banking Authority, 2016). Furthermore, a GSF could possibly release the capital constraint, thus weakening the banking system as a whole (Dunz et al., 2021; Van Lerven and Ryan-Collins, 2018).

Taking into consideration these limitations, Lamperti et al. (2021) have put forth a "*green Basel II policy scheme*" that would combine three instruments: a GSF, green credit guarantees, and carbon-emission adjustment in credit ratings. Using a macro-financial agent-based model, they showed that while, when used separately, these instruments all have adverse unintended consequences; when combined, they could allow the economy to enter a virtuous circle. Thomä and Gibhardt (2019) also showed that a BPF would be more efficient than a GSF, as the former would apply to a larger universe of assets than the latter. Testing various combinations of these two instruments within a stock-flow consistent model, Dafermos and Nikolaidi (2021) showed that they may be more effective when applied simultaneously or in combination with a green fiscal policy.

However, many central bankers are still reluctant to employ capital requirements to deal with climate change. For instance, the Bank of England (2021) has argued that capital requirements could successfully deal with the consequences of climate change, but not with its causes. In the same vein, the European Banking Authority has warned that "*a dedicated prudential treatment which would explicitly aim at redirecting lending could have the following undesirable or unintended consequences, which could have an impact on financial stability*" (European Banking Authority, 2022, p. 16). This echoes Oehmke and Opp (2023), who showed that capital requirements are an efficient tool to deal with the risks arising from climate change but cannot efficiently help in reducing emissions.

Dealing accurately with the 'double materiality' prospect may thus require an entirely new approach to prudential supervision. Recently, several institutions (Breckenfelder et al., 2023;

Coelho and Restoy, 2023) and academics (Hiebert and Monnin, 2023) have put forth that macroprudential, rather than micro-prudential instruments, would be best appropriated given the systemic nature of financial climate risks. Indeed, macroprudential regulations are often recommended in order to tackle the transversal dimension of systemic risk (i.e. interconnections and concentration of risks at a given time), which turns out to be a specific feature of climate risk (Borio, 2003).

Nevertheless, most existing macroprudential tools are calibrated to the risk-weighted assets that banks calculate themselves, and are thus in line with micro-prudential policies. Such is the case, for instance, of countercyclical capital buffer or capital surcharges for systemic risks. The main problem with this approach is that in a world where climate magnifies radical uncertainty, financial climate risks cannot be correctly assessed using backward-looking risk model (which assume a probabilistic world).

Given the above, tackling the global sustainability crisis might entail a new orientation for prudential policies. Recently, Hiebert and Monnin (2023) suggested to tailor two new macroprudential instruments to address systemic climate-related financial risks: (i) 'systemic risk capital buffers' (to enhance the resilience of the financial system to climate-related shocks and help mitigate the build-up of exposure in the future); and (ii) 'exposure concentration limits' (which could target and therefore mitigate sources of risk where they are most significant).

European NGO Finance Watch (2023) attempted to translate this recommendation into a concrete policy recommendation by putting forth a new ecosystemic prudential ratio framework. According to existing estimates, 77% of proven fossil fuel reserves must indeed be left under the ground to keep global warming below 2°. With a probability of 83%, the exploitable value of fossil fuels would therefore be 23% (Carbon Tracker, 2013). Therefore, no more than 23% of the value of fossil fuel reserves should be extracted for the 2° scenario to be reached. Denoting L_B^D the demand for brown loans and L_B^S the supply of brown, ensuring that $\frac{L_B^S}{L_B^D} < 23\%$ would thus set the economy and the financial system on a sustainable pathway in line with the Paris Agreement.

Finance Watch (2023) underlined the similarities between this approach and a loan to value (LTV) ratio (which is well-known to prudential supervisors, for managing property risk in particular). The goals of ecosystemic prudential supervision, however, are slightly different. In contrast to the LTV approach, the ratio is not constructed based on the amount of credit issued in the previous period, but on the global carbon budget. In so doing it gives financial supervision a promotional, as well as a prudential objective: brown credit being restricted; banks' and firms' balance sheets should get greener, and climate systemic risk should decrease.

Proposals of this kind clearly suggest a paradigm shift for prudential regulation. The new paradigm would not be solely based on financial criteria, but on planetary boundaries. However, their myriad of economic, financial and ecosystemic implications have not yet been explored. This is the intended contribution of this paper.

Using Philia 1.0, an intermediate size ecological PK-SFC model (Didier and Lagoarde-Ségot, 2024; Lagoarde-Ségot and Revelli, 2023), we analyse and discuss the systemic effects of an ecosystemic prudential regulation in reference to a steady state baseline scenario and a brown scenario (where no sustainability policy is put into place).

3. Philia 1.0, an ecological PK SFC model

3.1.Key characteristics and contribution

Philia 1.0 belongs to a recent stream of PK-SFC models addressing ecological and climate issues, postgrowth and degrowth, in a strong sustainability framework[4] (Carnevali et al., 2021; Dafermos et al., 2018; Dafermos and Nikolaidi, 2021; Jackson and Victor, 2020; Monserand, 2022) (table 1).

It features a relatively detailed monetary and financial side, with banks, investment funds, a Central Bank, and rentier households making portfolios decisions over several monetary and financial instruments. Production is undertaken by a three-tiered productive sector (with financialized listed corporation, SMEs, and public sector firms) and households are divided into working and rentier households (which permits to monitor the distribution of income and wealth in the economy). The model accounts for inflation, and the latter plays a pivotal role in modelling the retroaction from the ecosystem. The deterioration of the ecosystem and the depletion of energy and material resources generates an inflationary trend which erodes the wage share, demand and GDP growth.

Philia 1.0 also branches out to the post-growth literature by including new biomimetic resilience indicators (Lagoarde-Ségot and Mathieu, 2024; Ulanowicz et al., 2009). It is a discrete-time model that can be used for analytical purposes, in reference to a steady state scenario, following the approach of Godley and Lavoie (2012).

The economic block of Philia 1.0 shares the unique features of PK-SFC models (Godley and Lavoie, 2012, chap. 13). First, behavioral equations are nested in a double-entry accounting matrix derived from the National Income and Product Account (NIPA). The coherent stock-flow integration of income and financial accounting restricts the range of possible results and allows for the full interpretation of causal relationships between flows, stocks, budget constraints and portfolio decisions. Second, banks act as creators of inside credit money and purchasing power, i.e., money is endogenous. The monetary system thus supplies financial liabilities in response to demand in interaction with various behavioral and prudential rules. Third, the Central Bank (which is modelled based on the ECB) has no direct control over the money supply. It implements its monetary policy rate by setting the deposit facility rate and main refinancing rate, and through market neutral quantitative easing whenever the banking sector fails to hit the required capital adequacy ratio. Fourth, the government also issues outside money through net deficit spending. Fifth, agents display a procedural rationality inspired by Simon (1986). They act in such a way as to eliminate observed deviations between past values and targeted values; with their mistaken expectations generating an undesired accumulation or depletion of stocks that signals a required change in behavior. The model hence achieves economic closure stock fluctuations rather than through price adjustment, with each sector's balance sheet featuring a buffer that serves to reconcile expected with realized outcomes.

[4] More generally, stock-flow consistent (SFC) models, as pioneered by the seminal work of Godley and Lavoie (2012) are increasing used in the post-Keynesian literature, either as analytical tools (Mazier, 2020; Tange, 2024; Yajima, 2023), as structural macro-econometric models (Canelli et al., 2024; Valdecantos, 2022), or as the developed form of a structural VAR model (Gaysset et al., 2019; Gimet et al., 2019).

Table 1 An overview of recent PK-SFC ecological macroeconomic models

Model	Ecosystem	Firms	Households	Money	Inflation	Balance of payments	Simulation	Purpose
DEFINE 1.0 Dafermos et. al (2018)	Thermodynamics Physical flow matrix Physical flow stock matrix Ecosystemic feedback on capital stock and population health	Homogeneous firms Private investment limited by factor utilization rate Financing of investments: cash, bond issue, bank loans	Homogeneous households Explicit modeling of the labor market	Endogenous money Credit rationing Dynamic portfolio choice of households Green and brown bond market Quantitative easing	No	No	Discrete time Calibration/ reference scenario for the world economy Sensitivity analysis and Monte-Carlo simulations	Impact of climate damage on consumption, investment, demand for financial assets, potential output indicators in a reference scenario Effects of a Green Quantitative Easing program on financial stability, bond market, household wealth and climate change
LOWGROW Jackson and Victor (2020)	Environmental burden index (EBI)	Private and public sector Categorization of investments: productive, non-productive, additional, non-additional, residential and productive	Homogeneous households Choice of homogeneous portfolio	Endogenous money Fixed allocation of household portfolios Financing of investments: cash, share issues and bank loans	Arising from goods market tensions	'Rest of the world' block	Discrete time Calibration (Canadian economy) Comparison with reference scenario	Evolution and decomposition of a sustainable prosperity index under a baseline scenario, a carbon reduction scenario and a sustainable scenario
'TWO AREA ECOLOGICAL SFC' Carnevali et.al (2021)	Thermodynamics Physical flow matrix Physical flow stock matrix Feedback on capital stock and household consumption	Homogeneous firms	Heterogeneous incomes: workers and capitalists Heterogeneous portfolio selection	Endogenous money Dynamic allocation of international household portfolios	No	Symmetric two-country model with heterogeneous green structure	Discrete time Calibration on World Bank data Comparison to a reference scenario	Impact of four shocks : an increase in the preference for safe financial assets, an increase in the preference for green financial assets, an increase in household preference for 'green' consumer products; fiscal policy experiments.

3.2. Accounting structure

Table 2 shows Philia 1.0's simplified accounting structure. It comprises seven institutional sectors: the household sector (divided into working and rentier households), the government sector (divided into the Treasury and the remainder of the public sector), a social businesses sector owned by working households, a sector of listed non-financial corporations, a banking sector, a Central Bank, and a sector of investment funds. The latter owns the banking sector's equity and uses the proceeds of the fund shares issued to rentier households to purchase corporate equities and Treasuries, and deposits.

The model depicts a three-tiered productive structure: public sector firms, whose balance sheet is consolidated with that of the Treasury, social businesses, which finance their investment through retained earnings and bank loans, and listed firms, which finance their investment through retained earnings, loans, as well as bond, commercial paper and equity issues. The model also features two categories of households. Working households get their income from the wage bill and the redistributed profits from social businesses; and keep their savings as sight and deposit accounts. Rentier households earn financial income in the form of interest and investment fund dividends; and keep their savings as deposits and investment fund shares. Financial sector instruments include reserves, sight deposits, savings deposits, loans, bonds, commercial paper, equities, investment fund shares and Treasuries. Their corresponding interest rates are supply-led and respect both the term and risk structure. Finally, the Central Bank operates a refinancing desk, a deposit facility, is the last resort buyer of Treasuries, and may repurchase risky asset portfolios from banks through a market-neutral quantitative easing in order to keep the banking sector's capital adequacy ratio above its regulatory target.

Table 2 Simplified transaction matrix

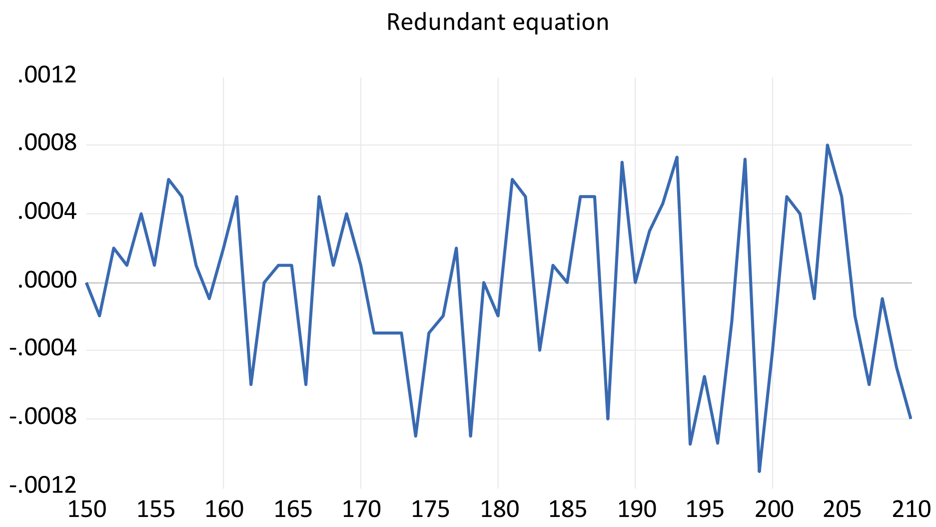
	Households		Government			SME/SSE		Listed firms		Banks		Central Bank		Investment funds	
	Working	Rentiers	Treasury	Public sector											
				Current	Capital	Current	Capital	Current	Capital	Current	Capital	Current	Capital	Current	Capital
Final consumption	$-C_w$	$-C_k$		$+C_p$		$+C_c$		$+C_k$							
Public expenditure			$-G$			$+G_c$		$+G_k$							
Taxes	$-T_w$	$-T_k$	$+T$			$-T_c$		$-T_k$							
Public deficit			$-DEF_g$		$+DEF_g$										
Investment				$+I_p$	$-I_p$	$+I_c$	$-I_c$	$+I_k$	$-I_k$						
Depreciation				$-DA_p$	$+DA_p$	$-DA_c$	$+DA_c$	$-DA_k$	$+DA_k$						
Wages	$+W$			$-W_p$		$-W_c$		$-W_k$							
Entrepreneurial profits	$+FD_c$			$-F_p$	$+F_p$	$-F_c$	$+FU_c$	$-F_k$	$+FU_k$					$+Div_k$	
Bank profits										$-F_b$				$+F_b$	
Central bank profits					$+F_{Cb}$							$-F_{Cb}$			
Investment fund profits		$+F_s$												$-F_s$	
Interest paid on :															
Central bank refinancing										$-r_a A$		$+r_a A$			
Private debt instruments						$-r_{d,c}D_c$		$-r_{d,k}D_k$		$+rD$					
Bank deposits	$+i_d M_w$	$+i_d M_m$								$-i_d M$				$+i_d M_s$	
Central bank portfolio						$-r_{d,c}R_c$		$-r_{d,k}R_k$				$+rR$			
Mandatory reserves										$+r_h H$		$-r_h H$			
Excess reserves										$+r_e H_e$		$-r_e H_e$			
Treasuries			$-r_g GB$							$+r_g GB_b$		$+r_g GB_{bc}$		$+r_g GB_s$	
Δ STOCKS															
Central bank loans											$+\Delta A$		$-\Delta A$		
Private debt instruments							$+\Delta D_c$		$+\Delta D_k$		$-\Delta D$				
Bank deposits	$-\Delta M_w$	$-\Delta M_k$									$+\Delta M$				$-\Delta M_s$
Reserve currency	$-\Delta H_w$	$-\Delta H_k$									$-\Delta H_b$		$+\Delta H$		
Equities									$+\Delta E_{k,s}$						$-\Delta E_{k,d}$
Investment fund shares		$-\Delta S$													$+\Delta S$
Central bank asset purchases											$+\Delta RA$		$-\Delta RA$		
Treasuries					$+\Delta GB$						$-\Delta GB_b$		$-\Delta GB_{cb}$		$-\Delta GB_s$
Bank equity											$+\Delta BE$				$-\Delta BE$
Central bank equity					$-\Delta K_{cb}$								$+\Delta K_{cb}$		

Note: this table shows the Philia's transaction matrix of the Philia model. The shaded area describes the flow of funds. (+) denotes a use of money and (-) a source of money. For the sake of clarity, this matrix consolidates bank loans, private bonds and commercial paper (and their respective interest rates) into the 'private debt instruments' category. This matrix also consolidates brown and green. Please refer to https://github.com/lagoarde/philia for a full description of the model and replication codes.

The equality between share purchases by investment funds ($\Delta E_{k,d}$) and share issues by listed companies ($\Delta E_{k,s}$) featured in table 2 is the model's hidden equation (equation (1), figure (1)). The diagrams showing the closure of the economic and ecosystemic sides of the models can be found in the online technical appendix.

$$\Delta E_{k,d} = \Delta E_{k,s} \tag{1}$$

Figure 1 Macroeconomic closure



Equation (1) highlights some of the model's post-Keynesian features. As shown in their capital account (table 2), investment funds allocate the proceeds of their own share issues (ΔS) to purchase newly issued corporate equities ($\Delta E_{k,s}$). In line with the pecking order theory, the latter are issued by listed firms to fill in the gap between their external financing needs ($f_{d,k}$) and the credit flow supplied by the banking sector ($f_{s,k} \leq f_{d,k}$) (equation (2)).

$$\Delta E_{k,s} = f_{d,k} - f_{s,k} \tag{2}$$

One implication of equation (1) is that the volume of finance raised through equity issues is constrained by the share of rentier household's savings that they allocate to investment funds – i.e. by the market for loanable funds. This situation is different from that of bank credit, which is issued by banks as they perform their monetary creation function [5].

Philia 1.0's features a material and energy balance sheet ensuring it is aligned with thermodynamics (Carnevali et al., 2021). Neither energy nor matter is created or destroyed, and any use of energy also implies a dissipation in the form of heat (law of entropy). Annual production affects the conversion of material resources into reserves, CO2 concentration and the volume of the socioeconomic stock. The corresponding tables and diagrams can be found in the online appendix. A full discussion of the model's behavioural equations can be found in the Github repository[6].

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[5] From an endogenous money perspective, banking credit logically dominates loanable funds regardless of the complexity of market intermediation schemes (Bouguelli, 2020).

[6] https://github.com/lagoarde/philia

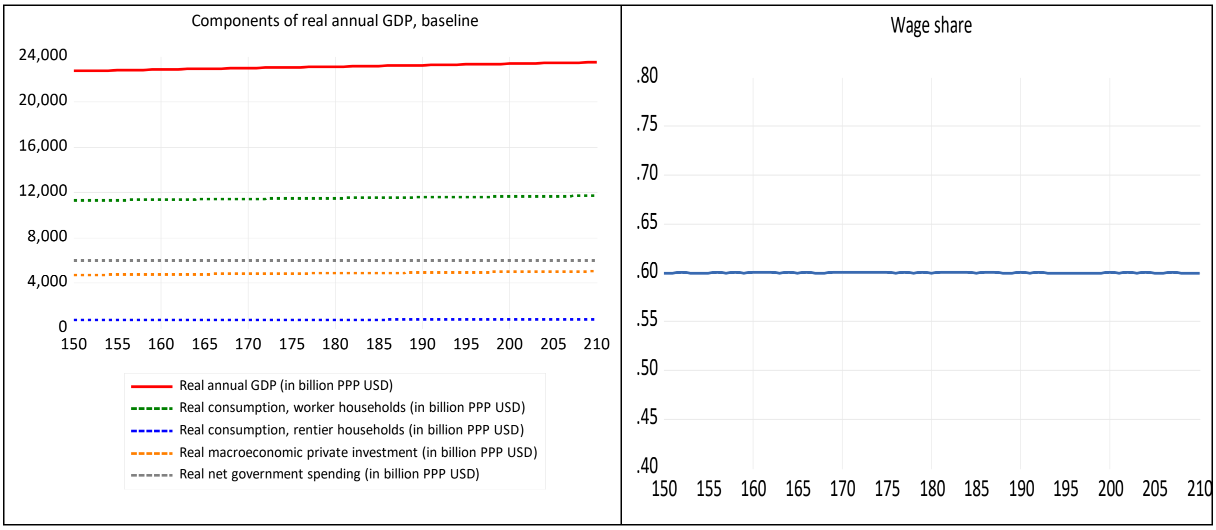
3.3. The baseline scenario

We calibrate the model using Eurozone data, and use credible parameters taken from the SFC modelling literature. Using the Broyden algorithm, the model stabilizes after 30 iterations and reaches its most stable stationary state after 140 periods. The real GDP growth rate then strictly equates 0.06% for 120 periods, and then gradually increases to 0.13% from period 288 until period 500 which is the end of our simulation horizon. We pick the most stable interval (from period 150 to 210) as our baseline scenario. Following Godley and Lavoie (2012) and subsequent literature, we then interpret all simulations in reference to that baseline scenario, which constitutes our steady state[7].

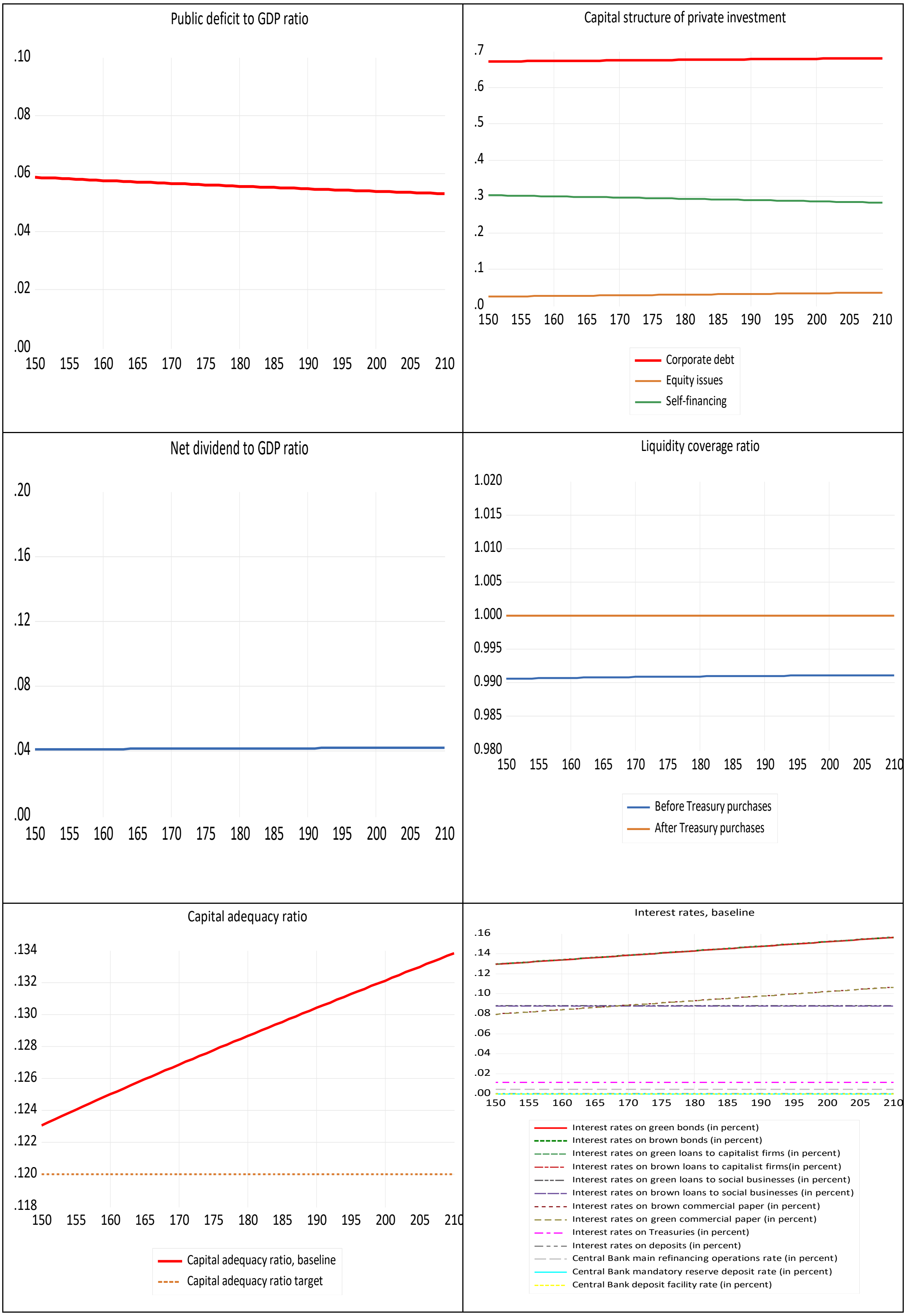
As shown in figure 2, real GDP stands at about $23,000 billion PPP at the beginning of the baseline scenario. Consumption accounts for 52% of real GDP, public spending for 26% and private investment for 21%. The wage share stands at around 60% of GDP and the public deficit stands at 5.9%, then declines slowly to 5% over the reference period. Corporate debt (loans, corporate bonds and commercial paper) represents 67% of corporate financing, self-financing 30%, and listed share issues 3%. Net dividend payments as a percentage of GDP are around 4%. Banks modulate their purchases of Treasuries to maintain the liquidity ratio at 100% and the capital adequacy ratio lies above the regulatory target. The risk and term structure of interest rates is respected.

The baseline scenario thus depicts an artificial economy with a size and structure like that of the eurozone – assuming away net exports which represents 1.75% of eurozone GDP (Eurostat, 2024).

Figure 2 The baseline scenario



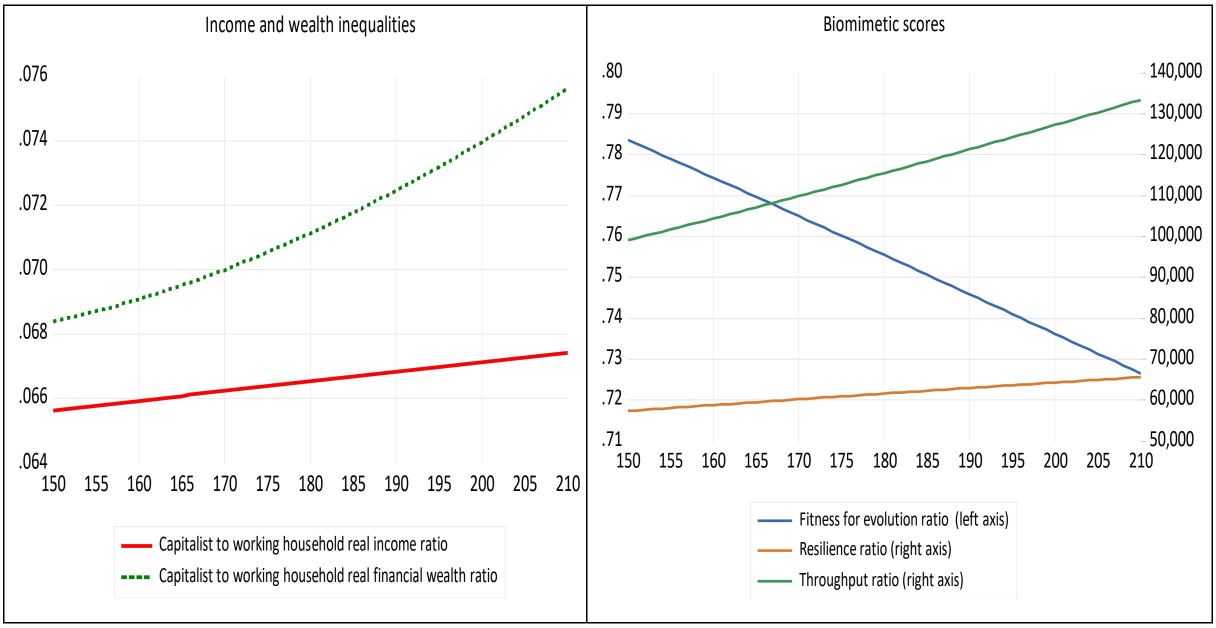
[7] The 'steady state' is a purely analytical device permitting to gain insight into the impact of the initial and terminal effects of a given shock (Godley and Lavoie, 2012).


Public deficit to GDP ratio
Capital structure of private investment
Corporate debt
Equity issues
Self-financing
Net dividend to GDP ratio
Liquidity coverage ratio
Before Treasury purchases
After Treasury purchases
Capital adequacy ratio
Capital adequacy ratio, baseline
Capital adequacy ratio target
Interest rates, baseline
Interest rates on green bonds (in percent)
Interest rates on brown bonds (in percent)
Interest rates on green loans to capitalist firms (in percent)
Interest rates on brown loans to capitalist firms(in percent)
Interest rates on green loans to social businesses (in percent)
Interest rates on brown loans to social businesses (in percent)
Interest rates on brown commercial paper (in percent)
Interest rates on green commercial paper (in percent)
Interest rates on Treasuries (in percent)
Interest rates on deposits (in percent)
Central Bank main refinancing operations rate (in percent)
Central Bank mandatory reserve deposit rate (in percent)
Central Bank deposit facility rate (in percent)

Under the baseline scenario, income and wealth inequalities increase, which is a typical stylized fact for finance-led economies (Szymborska, 2022). The ratio between the financial wealth of rentier and working households increases by one point (from 6.8% to 7.8%). The ratio between the income of rentiers and working households increases by 0.2 points (from 6.5% to 6.7%).

This structural imbalance is confirmed by inspecting the biomimicry-based resilience scores. The economy's fitness for evolution score decreases from 0.78 to 0.73, i.e. below the 'window of resilience' (0.85) identified in Ulanowicz et al. (2009). Indeed, 'throughput' develops faster than 'resilience', which implies that money does not circulate evenly in all sectors. As a result, monetary strangleholds located in the rentier and financial sector undermine the economy's ability to absorb unexpected shocks (figure 3).

Figure 3 Income and wealth distribution



3.4. The brown scenario

Starting from the steady state (period 150), we activate the ecosystemic equations to describe a 'brown scenario'. Our main results are shown in figure 4. We calibrate the ecosystem so that total CO_2 emissions reach 37 billion tons in period 162 (the amount observed in 2023 for the world economy (Global Carbon Budget data). In so doing, we thus assume that the green trajectory of the rest of the world mirrors that of our artificial economy.

At the end of the simulation, global temperatures have risen by 3 degrees. Rising temperatures, coupled with the scarcity of material and energy resources, increase the value of the ecological destruction function from 0.02 to 0.25 at the end of the simulation (figure 4).

Figure 4 The brown scenario

These ecosystemic events generate inflationary biases in the economy (with annual inflation reaching 0.15% at the end of the simulation). Inflation, in turn, is the main retroaction mechanism by which climate damages the economy.

As shown in equation (3.1) to (3.4), inflation (π) results from three factors: adaptive inflation expectations (π^a) and two idiosyncratic shocks.

The first idiosyncratic shock (π^e) arises from observed ecological damages (d_{t-1}), material (dep_{m-1}) and energy depletion (π^e). The second idiosyncratic shock (π^f) arises from firm's mark-up pricing over wage costs ($\frac{\Delta WB_{-1}}{Y_{-1}}$).

$$\pi = \pi^a + \pi^e + \pi^f \quad (3.1)$$

$$\pi^a = \pi_{-1} + o_1(\pi_{-1} - \pi^a_{-1}) \quad (3.2)$$

$$\pi^e = o_2(dep_{l-1} + dep_{m-1} + d_{t-1}) \quad (3.3)$$

$$\pi^f = o_3\left(\frac{\Delta WB_{-1}}{Y_{-1}}\right) \quad (3.4)$$

Inflation generates macroeconomic welfare losses through its anti-redistributive effects, which decrease aggregate demand (Lavoie, 2022). During labour negotiations, employee representatives target a wage bill (WB^a) equal to the product of the wage share negotiated during the last round of negotiations ($\iota_{wb,-1}$) and real GDP (equation (4.1).

$$WB^a = \iota_{wb,-1}\, \hat{Y} \quad (4.1)$$

With positive inflation, nominal GDP exceeds real GDP (i.e. $Y > \hat{Y}$). Therefore, the ex-ante wage share (ι^a_{wb}) - computed as a ratio of the agreed wage bill (WB^a) and nominal output (Y) - will come short of trade unions' wage share target (i.e. $\iota^a_{wb} < \iota_{wb,-1}$) (equation (4.2)).

$$\iota^a_{wb} = \frac{WB^a}{Y} \quad (4.2)$$

Trade unions adjust the target wage share ($\overline{\iota^T_{wb}}$) accordingly (equation 4.3), but the latter adjusts partially due to the bargaining power of corporate executives (Ω_{wb}) (equation (4.4)). Inflation thus decreases the wage share, and ultimately affects the nominal wage bill (WB) (equation (4.5)).

$$\iota^T_{wb} = \iota_{wb,-1} + \bar{\bar{\iota}}(\iota_{wb,-1} - \iota^a_{wb}) \quad (4.3)$$

$$\iota_{wb} = \iota^a_{wb} + (\iota^T_{wb} - \iota^a_{wb})\Omega_{wb} \quad (4.4)$$

$$WB = \iota_{wb} Y \quad (4.5)$$

As shown in figure 4, the real wage share shrinks from 60% in the baseline scenario to 47% at the end of the brown scenario. This generates a drop in working household income, aggregate demand, and GDP. Inflation also widens the gap between nominal and real GDP, with the GDP deflator reaching 106 at the end of the simulation (versus 100 in the steady-state scenario).
Climate change also affects household behavior. Households react to climate destructions (d_{t-1}) by building up precautionary savings, which decreases their propensity to draw out of their accumulated savings (α_2) (equation (5)). The latter parameter decreases from 0.2 to 0.195 during the simulation.

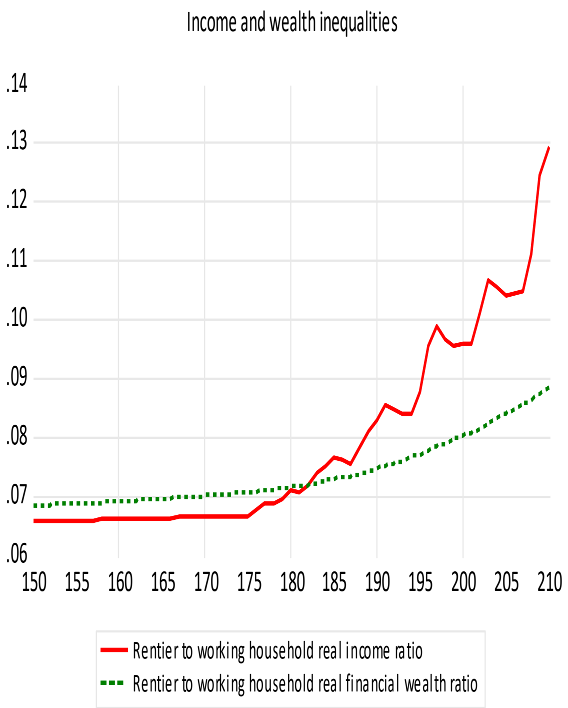
$$\alpha_2 = \frac{\alpha_{2,-1}}{(1 + \vartheta d_{t-1})} \quad (5)$$

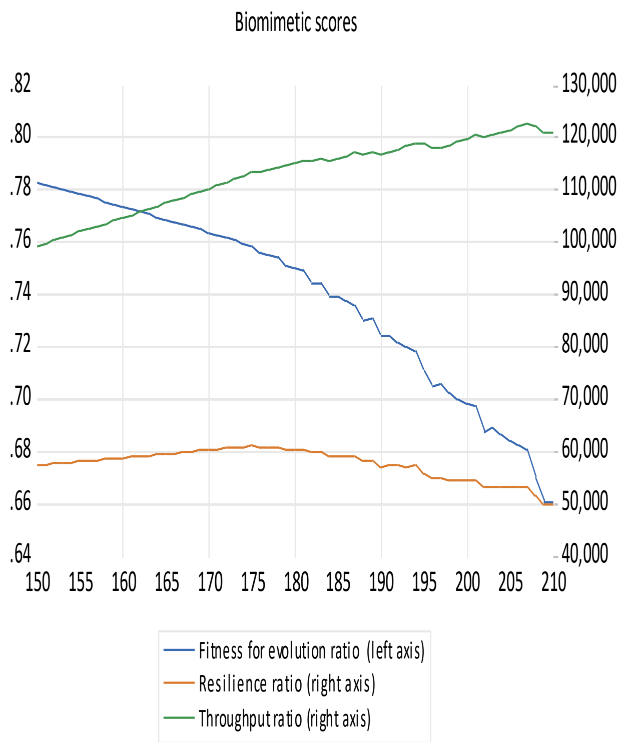
Overall, by the end of the simulation period, nominal GDP is 18.5% lower than in the baseline scenario. Real GDP is 22.5% lower than in the baseline scenario. This order of magnitude is aligned with recent estimates of the cost of global warming (Kotz et al., 2024; Waidelich et al., 2024). One should also note that the reported costs are net of the impact of automatic stabilizers. Indeed, under the brown scenario public deficit increases by 4 points (from 5% in the baseline scenario to 9%).

Under the brown scenario, income and wealth inequality also increase (figure 5). The ratio between rentiers' and workers' income gains 6 points (from 6.5% to around 13%), and the ratio between the financial wealth of rentiers and that of workers gains 2 points (from 7% to 9%). Inspection of the postgrowth metrics confirms this trend, as the fitness for evolution decreases by 10% due to a lower resilience and monetary strangleholds. The explanation is that the financial income and wealth of working households, which depend upon on wages, declines sharply under the brown scenario. Rentiers, who only receive financial income (dividends paid by listed companies, banks and interest payments from investment funds) are protected from the direct effect of the declining wage share.

These analytical results are thus aligned with recent estimates showing that the costs of climate disruption are borne by households with the lowest incomes and wealth (Waidelich et al., 2024).

Figure 5 Income and wealth distribution





4. The ecosystemic prudential regulation scenario

We now explore an alternative scenario in which ecosystemic retroaction takes place, but ecosystemic prudential regulation curtails banks' ability to issue brown credit to listed firms, as discussed in section 2.

Following Le Héron and Mouakil (2008), in our model banks determine the brown credit supply ($f_{s,k,b}$) considering the corresponding demand ($f_{d,k,b}$) as well as a lender and taxonomyspecific specific lending risk ($LR_{k,b,-1}$)[8]. As shown in equation (6), under the new scenario the brown credit supply is capped by an ecosystemic prudential ratio (EPR) (which we set at 23% following Finance Watch (2023)). This ratio, however, is not applied to the demand for brown loans originating from the SME sector.

$$f_{s,k,b} = f_{d,k,b}\left(1 - LR_{k,b,-1}\right)EPR \tag{6}$$

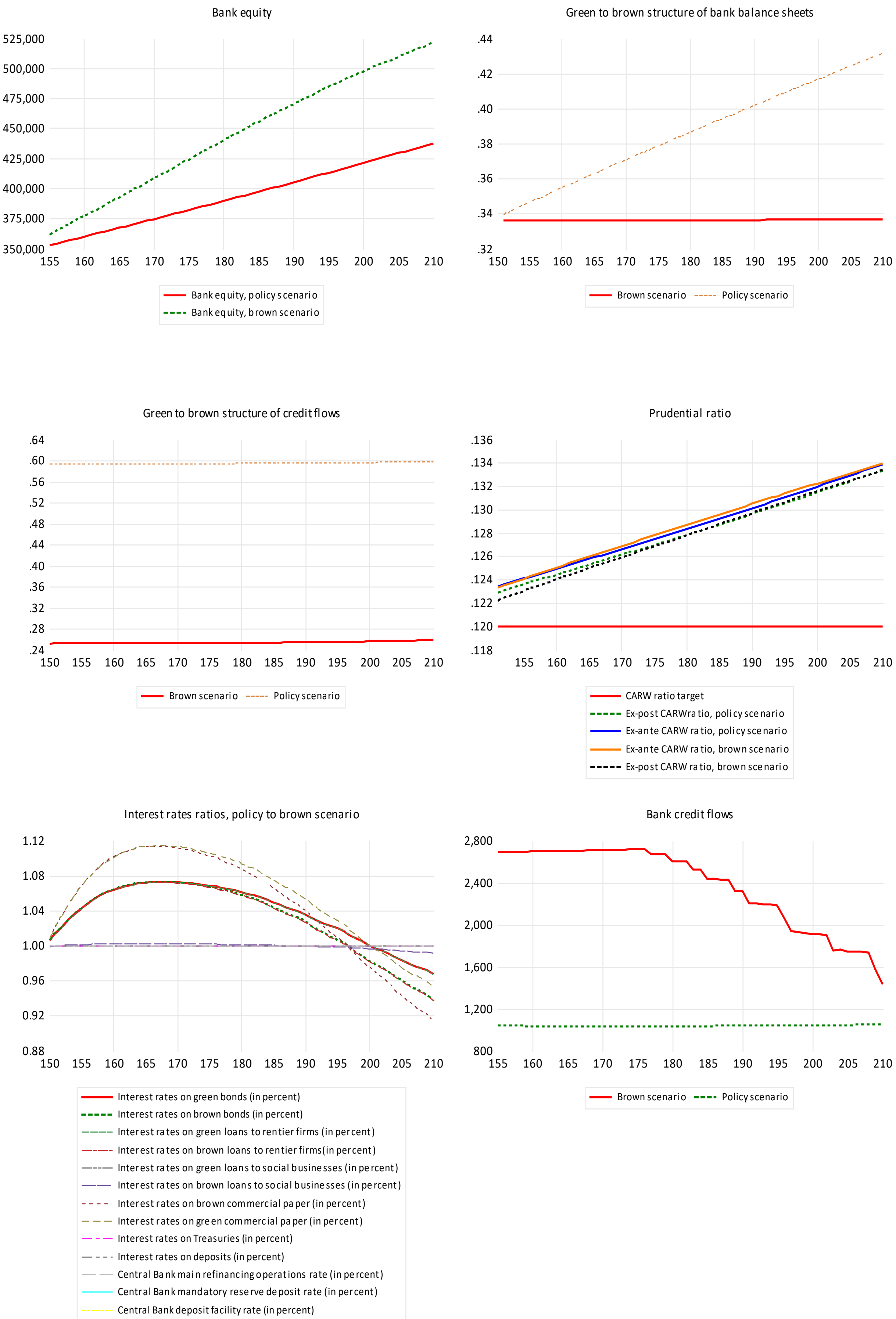
4.1.Impact on the banking sector

This single policy shock induces a rapid greening of the banking sector. Banks indeed significantly green their balance sheets: the proportion of green to brown assets goes up to 44% in the policy scenario, as compared to 33% in the brown scenario. In the meantime, the share of green credit in total credit reaches 60%, as compared to 25% in the brown scenario.

This green transition comes at the cost, however, of a restriction in the overall credit supply and a deterioration in lending conditions. Indeed, the amount of credit issued to listed firms is more than halved, while banks sharply increase interest rates in the face of deteriorating economic conditions. Bank equity, while still positive, grows slower than under the brown scenario. The impact on secondary market prices is ambiguous. On the one hand, the green transition shall reduce asset stranding. On the other hand, the drop in credit conditions shall increase systemic risk. This simulation thus assumes stationary secondary market prices. Under these conditions, the ecosystemic prudential regulation does not appear to impede bank's ability to hit their capital adequacy ratio (figure 6).

[8] The decomposition of credit into loans, bonds, and commercial paper, as well as the endogenous factors affecting the credit demand, and the lender risk are not discussed here for space-saving considerations but can be found in the technical appendix.

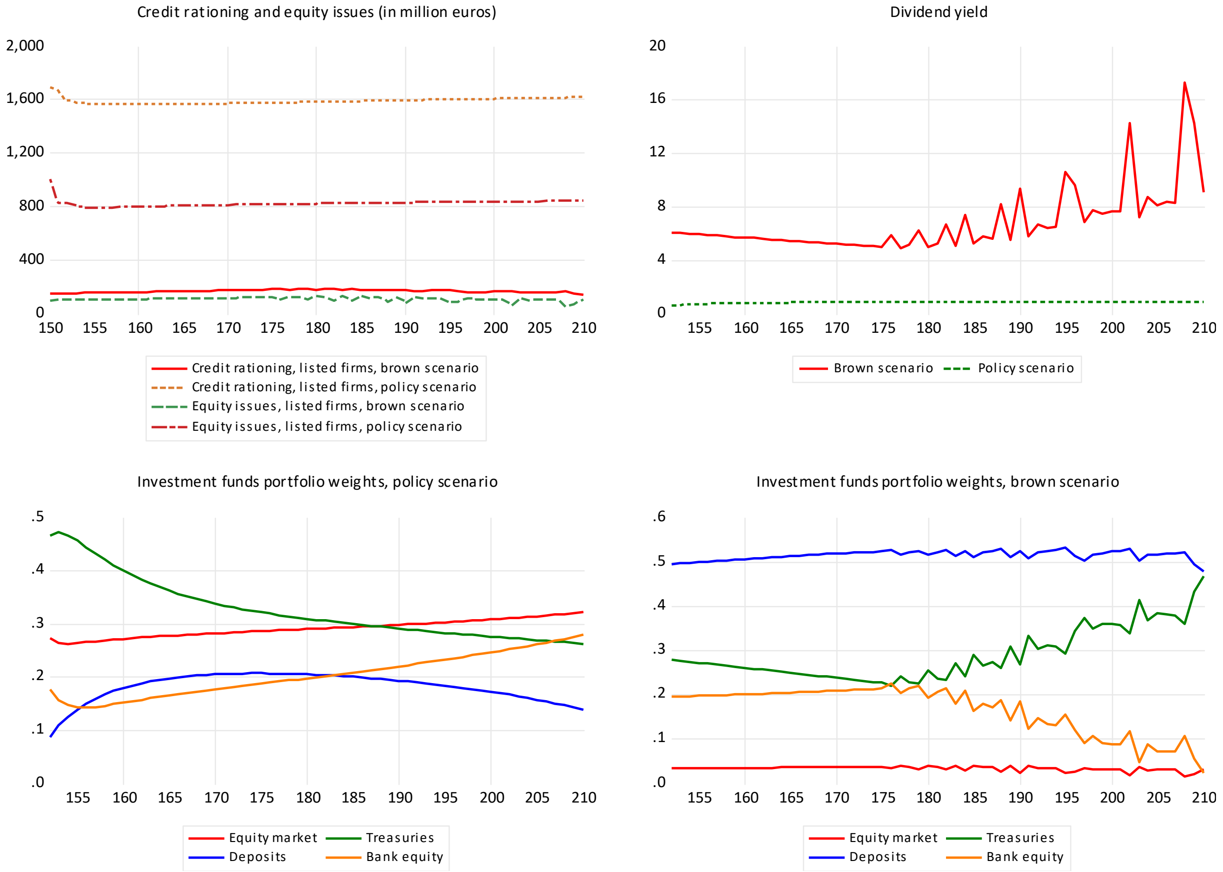
Figure 6 Impact on the banking sector



4.2.Impact on investment finance

As shown in figure 7, the curtailing of brown credit leads listed firms to issue more equity. Investment funds respond by rebalancing their asset portfolios toward the equity market, with equities amount to 30% of the total assets under management (as compared to about 3% in the brown scenario). However, equity financing fails to cover the credit gap, as equity funding is limited by the volume of loanable funds, i.e. the share of rentier household's savings allocated to the purchase of investment fund shares (as per equation (1)). In addition, the increased use of equity for brown financing does not appear to benefit rentier households and investment funds. As the massive issuance of new equity dilutes shareholder power, the dividend per share is nearly divided by ten at the end of the simulation. Brown equity issues thus backfires on investment funds and rentier households.

Figure 7 Investment finance



4.3. Impact on welfare and the green transition

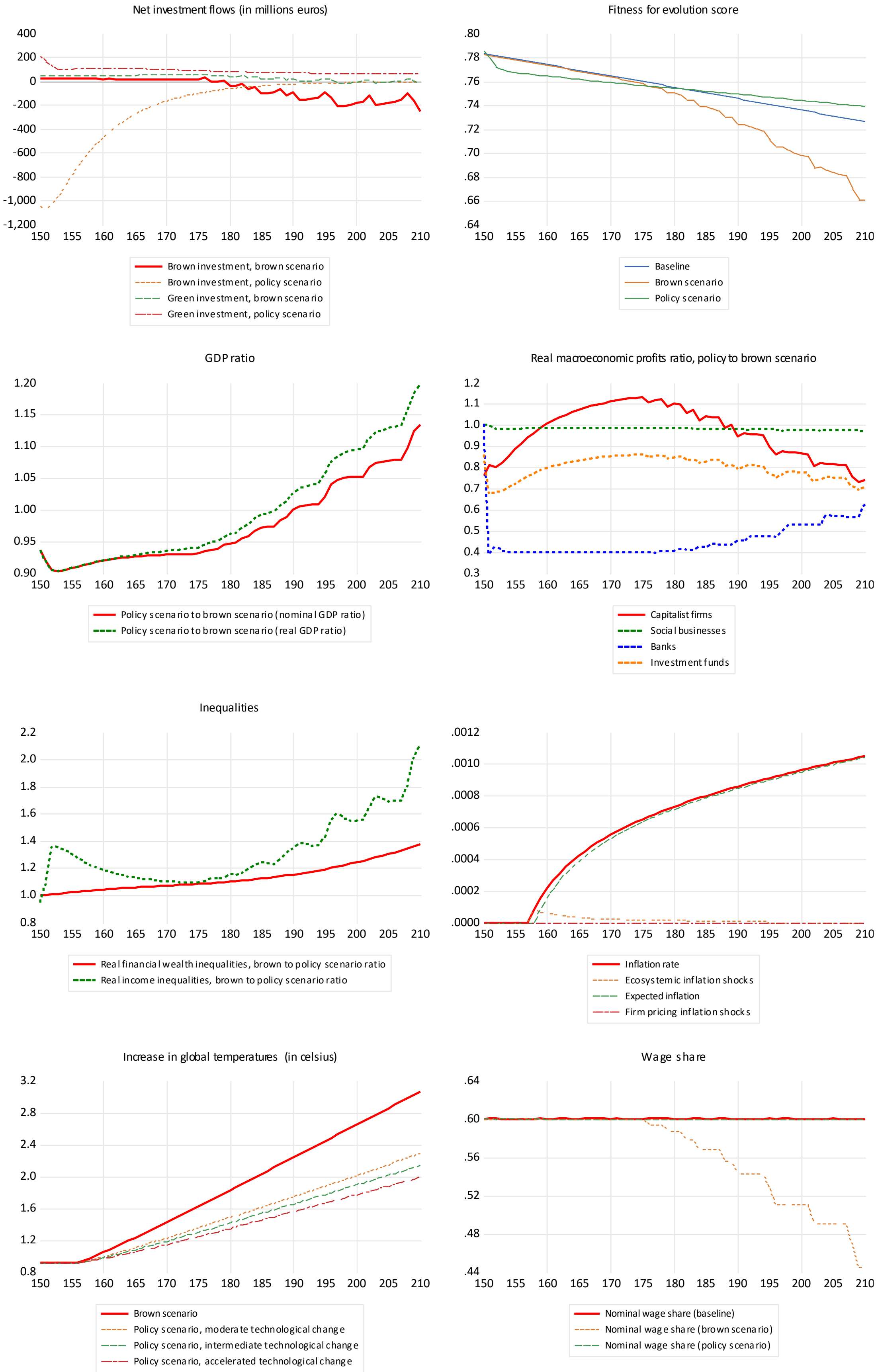
The ecosystemic prudential regulation scenario appears to set the economy on a sustainable climate pathway, at the cost, however, of significant short-run macroeconomic losses.

Indeed, listed firms massively disinvest in brown technologies: the net brown investment flow is negative in comparison to the brown scenario. The transformation of the productive structure also induces a shift toward greener energy sources, which, in turn, reduces energy consumption (the latter nearly divided by four between the brown and the policy scenario). Assuming a constant technology, the prudential framework sets the economy on a 2.3-degree pathway. In a more optimistic scenario with rapid technological change that decreases the economy's energy footprint, the economy hits the 2-degree target at the end of the simulation. Our findings are thus in line with projections by Finance Watch and the Carbon Tracker.

However, the policy also induces significant short-run losses. Both real and nominal GDP are 10% lower than under the brown scenario, and all sectors but the SME sector post lower profits. In the longer run, however, the green transition appears to pay off. Through the curtailing of inflationary pressures, the wage share remains comparable to that observed under the steady state. At the end of the simulation, GDP is 20% higher than under the brown scenario and goes back to the baseline level. In addition, both income and financial wealth inequalities tend to decrease in comparison to the brown scenario over the short and long run. This result is confirmed by the higher fitness for evolution score which is driven by increased resilience (figure 8).

Our simulations thus have clear analytical insight. While ecosystemic prudential regulations could efficiently tackle climate change, their political acceptability may be problematic as they generate short term losses. The reframing of the financial supervision framework shall require additional policies seeking to mitigate their short-term effects. However, the identification of an 'ecological policy-mix' is beyond the scope of this paper, and left to further research.

Figure 8 Welfare and the green transition



5. Conclusion

Several voices have recently called for turning prudential supervision into a full component of the sustainable transition. In particular, NGO Finance Watch (2023) suggested introducing new macroprudential ratios that would directly curtail brown credit below planetary boundaries. The underlying objective would be to protect the environment and society from the decisions of the financial sector, thereby transforming prudential regulation into an active instrument of the green transition.

In this paper, we explored the effects of such reforms in an analytical modelling framework. After discussing our model's steady state, and the key features of a 'brown' scenario, we reported a set of simulations suggesting that ecosystemic prudential regulations could effectively green banks' balance sheets, credit flows, and curtail brown investment - at the cost, however, of significant macroeconomic losses. In the longer run, we found that the induced green transition sets the economy on a more sustainable pathway, decreases inflationary pressures, and maintains real GDP at the baseline level, with distributional effects favourable to wage-earning households.

Much of course remains to be investigated. Other models could identify the factors affecting the timing and distribution of short run losses, and identify which macroeconomic policies could mitigate the latter in the most effective way. However, one important insight of the present paper is that policy makers should adopt a holistic approach – rather than a pure financial approach – to tackle climate change. The very acceptability of sustainability policies is at stake.

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Appendix – model output

Figure A1 Welfare block output

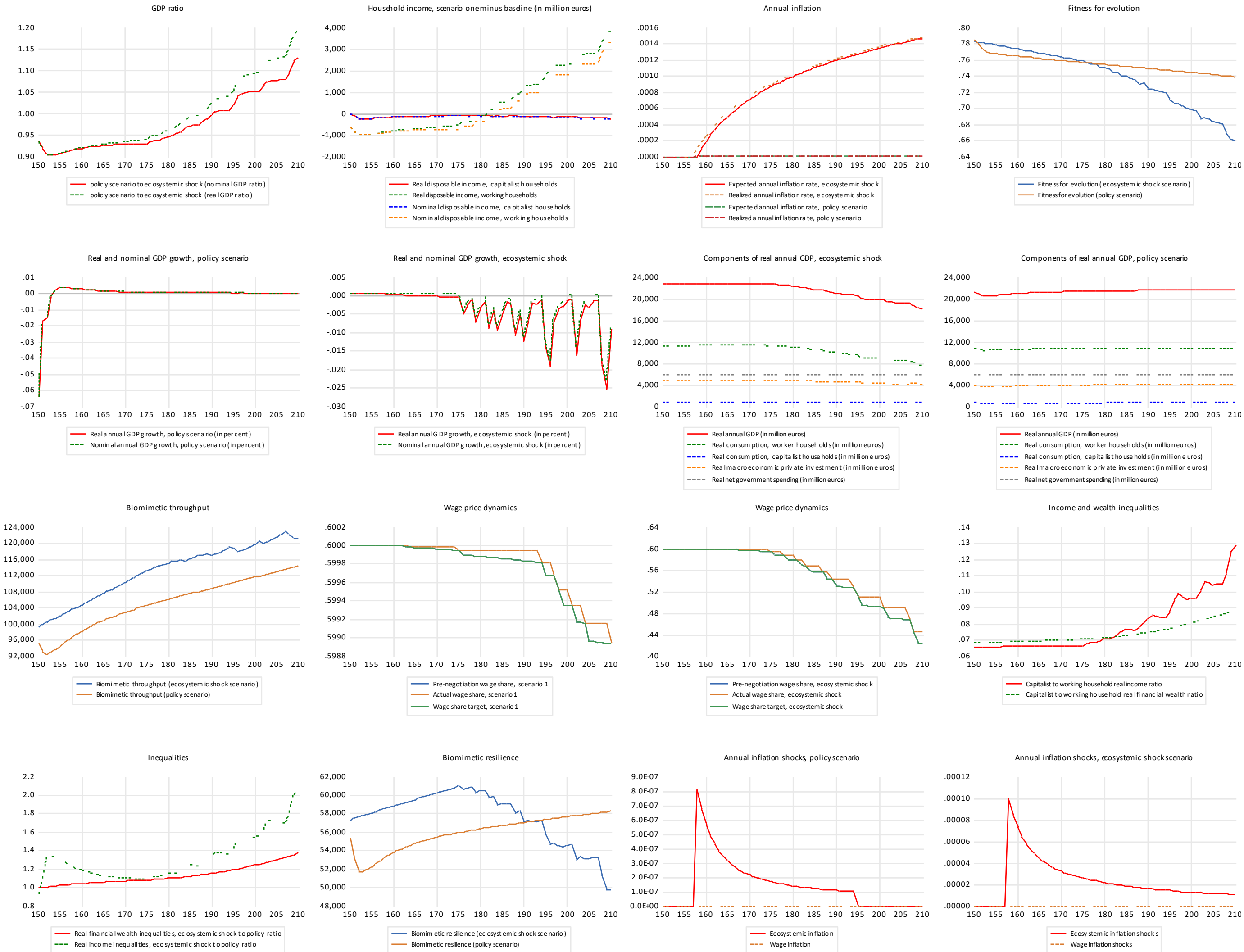

Figure A2 Investment

Table A3 Monetary side

Figure A4 Prudential side

Figure A5 Investment funds

Figure A6 Ecosystem