The Green Transition (GX) in Japan and its macroeconomic implications: an empirical SFC perspective

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Abstract:

This thesis investigates the macroeconomic implications of Japan's "Green Transformation" (GX) strategy to achieve carbon neutrality by 2050. Confronted by persistent economic stagnation, demographic decline, a high dependence on imported fossil fuels, and mounting fiscal pressures, Japan faces complex trade-offs in aligning climate policy with economic and financial stability. Employing an empirical Stock-Flow Consistent (SFC) model built from Japanese flow-of-funds and national accounts data, this study simulates the interactions between climate-related physical damages, mitigation and adaptation investments, and a range of policy tools, including carbon taxation, green subsidies, and monetary policy. Scenario analysis is conducted to evaluate the effects of policy choices on economic growth, inflation, sectoral balances, and the achievement of Japan's Nationally Determined Contributions. The results suggest that, under current assumptions and policy settings, Japan is unlikely to reach its carbon neutrality target by 2050 due to an insufficient carbon price. The analysis further highlights that while carbon taxes are the most effective policy instrument for driving decarbonization, they entail significant short-term economic costs, whereas green subsidies offer private sector benefits at the expense of public finances. The study concludes that a combination of increased carbon pricing and targeted recycling through green subsidies and public investment is required to support the transition, and that persistently low interest rates will remain critical for financing while creating pressure from interest spread for the BOJ through the exchange rate channel and Japan's position as a net creditor to the rest of the world. This paper tries to contribute to existing modeling approaches of the Japanese economy and discuss the macroeconomic dynamics of the green transition in Japan.

Contents

1 – Introduction

The challenge posed by climate change and the corresponding global drive toward sustainability represent not only the need to face incoming physical disruptions but also substantial macroeconomic transformations. The Intergovernmental Panel on Climate Change (IPCC) brought light to the severity of physical risks which could severely disrupt human societies with temperature increases above 2°C compared to pre-industrial levels. Recent discussions point out the transition risks stemming from shifts in climate policy, technology, and preferences. The notion of "Green Swans," catastrophic events driven by the intertwinement of transition and physical risk with potential systemic impacts on the financial system, further highlights the importance of integrating climate considerations into financial stability objectives and prudential regulations.

Japan is not isolated from the consequences of climate change, and it will play a substantial role in climate mitigation, being the 5th largest CO2 emitter in the world. The country is however facing unprecedented challenges, due to its reliance on imported fossil fuels and energy products, its ageing population, rising debt levels and decades long stagnation. The Japanese government released in 2022 its green transformation (GX) plan to address climate change and meet its Nationally Determined Contributions targets under the Paris Agreement of Carbon neutrality by 2050. It plans extensive public-private investment, financed partly through innovative financial instruments such as GX transition bonds and complemented by carbon pricing mechanisms. The GX strategy, while promising significant environmental benefits and new economic opportunities, also implies substantial macroeconomic repercussions, including potential trade-offs between economic growth, inflationary pressures, and financial stability concerns. Furthermore, it remains uncertain whether environmental targets will be achieved.

This study attempts to examine the macroeconomic dynamics of the green transition for the Japanese economy. It focuses on the green transition through three lenses: climate damage, climate change mitigation and climate change adaptation. Recent studies have been using Stock-Flow Consistent modeling, a methodology emphasizing a rigorous accounting structure integrating balance sheets and the financial system and which features enough flexibility to integrate environmental issues.

This paper employs an empirical SFC approach tailored to the Japanese context to assess the macroeconomic implications of Japan's green transition by integrating climate-related variables as well as financial variables. It aims to explicit impacts of the planned pathways as well as trade-offs implied by different macroeconomic policy tools. Policy implications in terms of fiscal tools and policy mix follow from simulations.

Findings highlight that under current assumptions, Japan is unlikely to meet its NDC and reach carbon neutrality by 2050 due to a low expected carbon price. Secondly, Japan risks facing deflationary pressure and labor shortages over the course of the period. Lower domestic prospects could reduce investment while favoring outward investment as in the past two decades. Furthermore, while carbon tax appears to be the best policy instrument to shift incentives and drive the green transition, it is also the costliest in terms of economic performance and could negatively affect investment, consumption and the private sector. While green subsidies shift incentives and benefit the private sector, the government bears its cost with the risk of snowballing public debt. Two main conclusions can be drawn in terms of fiscal policy: carbon pricing should be increased, and it should be compensated with carbon tax recycling into green subsidies and public investment to dampen its recessionary and initial inflationary effects. Last, the importance of low rates in financing the transition is confirmed, but constraints are likely to emerge on the BOJ which would have to face external pressures with spread interest. The inflationary impact of the green transition should not constitute an issue in the deflationary context imposed by economic fundamentals of the Japanese economy.

This paper is organized in 6 sections: it first reviews existing literature on integrated impact assessment and climate modeling, exposes the methodology, examines results, then discusses policy implications before concluding on limitations and further research.

2 – Literature Review

This section reviews the existing literature in 3 sub-sections: the Japanese economy, climate change and its consequences, and Stock-Flow Consistent modeling.

2.1 – The Japanese Economy

2.1.1 – Economic trajectory

Japan's post-1990 economic trajectory has been characterized by prolonged stagnation and deflation punctuated by episodic reforms and shocks (Randall 2024). After the late-1980s rapid growth and subsequent asset bubble burst, Japan entered the "Lost Decade" of the 1990s: real GDP growth averaged only about 1% per year in that decade, dramatically down from 4% in the 1980s. Equity and land prices collapsed: by mid-1992 the Nikkei stock index had fallen 60% from its 1989 peak, and land values fell persistently throughout the 1990s. This crash left banks with mounting nonperforming loans (NPL) and coupled with “Zombie” firms depressing growth in the 1990s, major banks and securities firms failed in 1997-1998 generating a recession from 1997 to 1999 and inflation to turn negative until 2008 (Randall 2024).

By the early 2000s, under Prime Minister Koizumi’s reforms, banks wrote off bad loans and recapitalized, helping end the financial sector drag by mid-decade. Koizumi’s administration (2001–2006) pursued “structural reform”, including the accelerated disposal of nonperforming loans, fiscal consolidation efforts, and deregulation. The Japanese economy saw a period of growth from 2000 to 2006 despite persisting deflation (Randall 2024)..

The Global Financial Crisis (GFC) of 2008 hit Japan via a collapse in exports and industrial output contracting Japan’s real GDP by over 6% in 2009. Japan’s banking system, having deleveraged, was however less directly impaired than in the West. Aggressive fiscal stimulus and monetary easing helped Japan rebound after 2009, yet deflationary pressures re-emerged with the aggressive use of monetary easing from the US and the EU (Randall 2024).

The 2011 great Tohoku earthquake, with more than 20 000 casualties and the Fukushima Daiichi incident, had dramatic social, political and economic consequences. In addition to the human consequences of the disaster, it also led to decontamination, reconstruction, and revitalization measures for the Fukushima prefecture, an increase in Greenhouse gas (GHG) emissions and an increase in reliance on fossil fuels with the closure of nuclear power plants (Randall 2024).

The accession to power of Prime Minister Abe was accompanied with ambitious policy packages under the “Abenomics”. A VAT tax hike and a drop in oil prices, however, led to declining inflation again, and real wages lagged behind labor productivity due to the rise in non-regular workers share, backward-looking inflation expectation and a focus from workers on job security rather than wage increases (Randall 2024) (Hoshi et Kashyap 2020).

Japan entered the COVID-19 pandemic in 2020 with these longstanding weaknesses. The pandemic induced a severe but brief recession: real GDP fell by 4.5% in 2020 as global trade collapsed (Randall 2024). The government responded with massive fiscal stimulus (worth over 40% of GDP through multiple supplementary budgets) and the BoJ expanded asset purchases. These measures cushioned the downturn, followed by a moderate recovery of 1.6% growth in 2021. The energy price shock and supply chain disruptions post-COVID and the war in Ukraine led to imported inflation and accentuated pressures on the BOJ following the yen's depreciation and hikes in interest prices on the other side of the pacific.

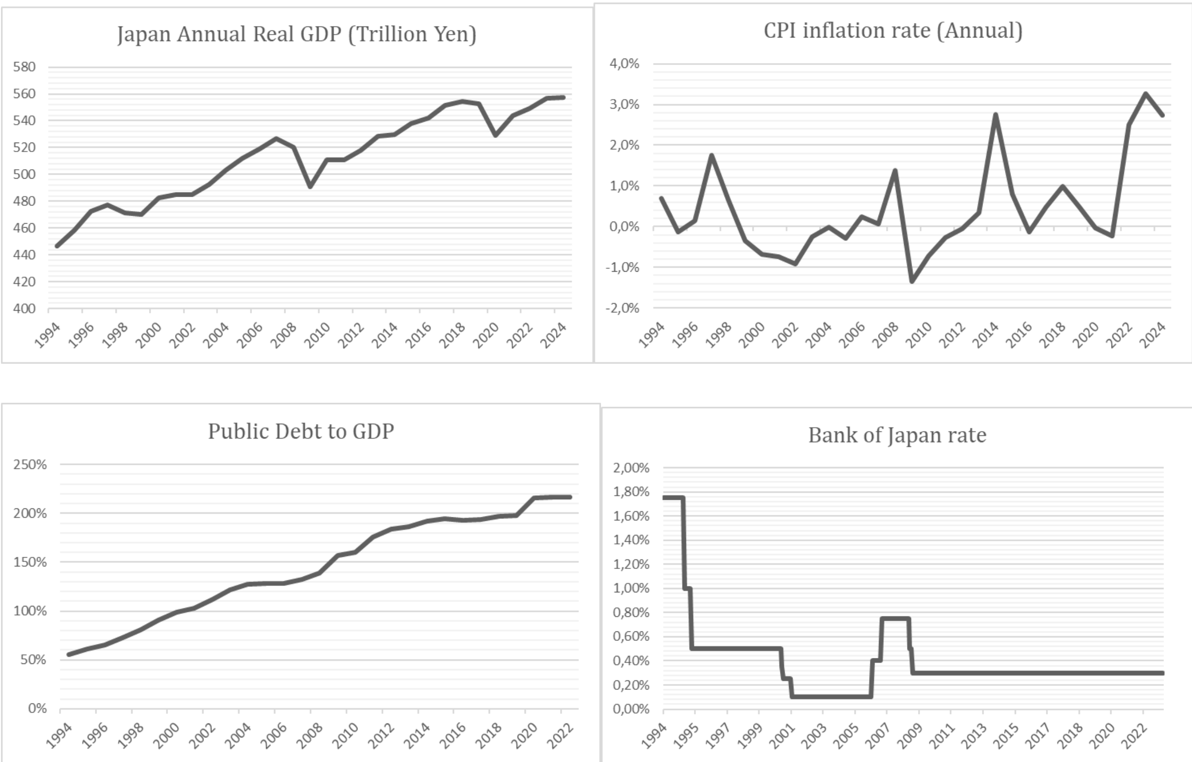

Figure 1 - Key Economic Indicators (source: FRED, author's elaboration)

Randall (Randall 2024) highlights Japan's remarkable performance on education, safety, infrastructure and diffusion of digital technology infrastructure. It identifies key structural challenges that contributed to Japan's low growth over 1990-2020. First, Japan's productivity growth slowed over the last two decades. Total factor productivity has lagged other advanced economies, and by the 2010s output per hour in Japan was significantly lower than the US' despite relatively high levels of research and development spending and quality broadband infrastructure. While low productivity levels are offset by large labor inputs, an ageing population will impose constraints in the long run. The IMF notes ultra-low interest rates allowed many low-productivity small and medium enterprises (SMEs) to survive longer than they otherwise would, delaying the exit of inefficient firms and necessary restructuring. Government support SMEs through for example credit guarantees kept afloat low-productivity and zombie firms which constraints effective resource allocation amidst heightened tensions on the labor market (Hong, Igan et Lee 2021).

Inward foreign direct investment (FDI) in Japan has been persistently low by international standards (Randall 2024). Japan's stock of inward FDI stayed at around 4% of GDP for decades and by 2023 it reached close to $250 billion, 8% of GDP, one of the lowest among OECD countries. This is in stark contrast to Japan's role as a major foreign investor abroad: its outward FDI stock is about $2.1 trillion (the second largest globally after the US). The low level of inward FDI has long been recognized and linked to structural factors such as Japan's "insider" corporate governance system and market barriers. Despite policy efforts under Abenomics to attract FDI, progress has been modest. The lack of foreign capital and competition in domestic markets has potentially reduced innovation and productivity growth. Meanwhile, Japanese firms have increasingly invested overseas, seeking higher returns and markets abroad, which has led to a net positive international investment position exceeding 60–80% of GDP. A shrining domestic market, low rates, and ageing population constitute the main drivers to increased FDI and the JETRO announces rates of return of overseas investment of 8% on average. Cross border M&A as well as greenfield investment have been drivers of Japan's outward FDI and financing has also been made through debt (AMRO 2019).

Japan's nonfinancial companies have accumulated massive cash reserves instead of investing. Corporate cash and deposits reached about 230 trillion yen by the mid-2010s (50% of GDP), which is far higher than in other countries. This rise in cash holdings began in the 1990s as firms deleveraged after the bubble and continued through periods of deflation when holding cash was a relatively attractive store of value. High cash buffers are especially prevalent among SMEs, which historically kept 15 to 20% of assets in cash. Large firms too increased cash reserves after the 2008 crisis. Existing literature explains Japan's corporate cash hodlings by precautionary motives, foreign asset and intangible assets accumulation (which are more difficult to collateralize) and lower corporate tax rates(Kim, Murphy et Xu 2023).

2.1.2 – Economic policy and macroeconomic regime

Japan's macroeconomic policy has been characterized by fiscal stops and go and ultra-accommodative monetary policy through the last 30 years (Randall 2024). The government implemented large stimulus packages repeatedly from 1993 and 1998–1999 periods, leading to a sharp rise in public debt. However, these efforts were partially offset by premature attempts at fiscal consolidation (such as a 1997 consumption tax hike) which coincided with the banking crisis and worsened the recession. Over the long term, Japan's gross public debt surged from 60% of GDP in 1990 to about 200% of GDP by 2010 and 240% by 2020. Prime Minister

Koizumi carried out important reforms through its financial revival program, privatizations and a new corporate act for governance to address structural deficiencies which led to the 1990s lost decade. Abe Shinzo's mandate was marked by the Abenomics which included three arrows: monetary policy, flexible fiscal policy and structural reforms. Structural reforms comprised measures to increase female labor force participation (the "Womenomics"), income tax cuts, corporate governance reforms and favoring Venture Capital (Randall 2024).

Monetary policy, constrained by zero interest rates, forced the BOJ to experiment with Unconventional Monetary Policy (UMP). The Bank of Japan cut the policy rate to 0.5% by 1995 and effectively to 0% by 1999 as deflation set in. In 2001 the BoJ pioneered quantitative easing (QE), expanding base money and purchasing government bonds to combat deflation. The BoJ exited zero rates and QE in 2006 with signs of recovery but was forced back to zero as deflation persisted post-GFC. In 2013, under new Governor Kuroda, the BoJ launched "quantitative and qualitative easing" (QQE) as part of Abenomics, a massive asset purchase program coupled with a commitment to overshoot a 2% inflation target. The BoJ's balance sheet expanded to 100% of GDP by late 2010s. From 2016 negative interest rates on a part of bank's excess reserves were introduced to encourage bank lending and yield control curve policy dragged down long-term government bond yield. These measures kept borrowing costs low but failed in achieving sustained 2% inflation. By 2020, with the policy rate at the Zero Lower Bound (ZLB) and huge BoJ bond holdings, Japan had "limited room" for further monetary or fiscal stimulus, shedding light at the constraints of its macro policy toolkit after decades of cumulative easing (Randall 2024).

In terms of theoretical framework, the French regulation school provides a different theoretical perspective on Japan's macroeconomic regime (Boyer, et al. 2023). The French regulation school studies economies through the concept of modes of regulation and of regimes of accumulation. "A regime of accumulation is the logic that ensures a general and relatively coherent fit between the evolution of production, the circulation of goods and the distribution of incomes, thus allowing for the extended reproduction of capital." (Boyer, et al. 2023) and a "A mode of regulation consists of the set of norms, institutions, laws, and social networks that stabilize and guide the regime of accumulation, ensuring its reproducibility over time despite inherent tensions and contradictions" (Boyer, et al. 2023). The authors when assessing forms of capitalism, place Japan in a group comprising Taiwan with a less regulated international commerce, high levels of instruction, high social spending and patents, lower bank profitability as well as an inclusive governance in terms of human rights and democracy. T. Yamada proposes the concept of "Company-ist regulation" for Japan, with a particular compromise on job security between employers and employees and a "main bank"-company relation. This model was however shattered through international openness and financial liberalization coupled with the aftermath of the Plaza agreements. It destabilized the Japanese economy and generated uncertainty at first, then pushed multinational firms to seek for commercial surplus abroad with FDIs and portfolio investment, which led to the decoupling of multinational firms and the domestic economy and increased inequalities (Boyer, et al. 2023).

While this paper does not attempt to define a macroeconomic regime *per se*, Japan's recent economic and institutional history allows to shed light at overarching features which will be key in modeling its economy: its relationship with the rest of the world, its banking-based finance, its heavy government intertwinement with its economy both through fiscal and monetary policy and its labor market marked by a high job security and relatively low structural unemployment.

2.2.3 – Specificities of the Japanese economy

Developing on the Japanese macroeconomic regime, several structural features appear from existing literature.

First with its Bank-centric financial system, Japanese corporate finance traditionally relies on banks rather than equity or bond markets (Weinstein et Yafeh 1998). Banks play a dominant role in credit allocation, and households also keep a large share of savings in bank deposits. This means monetary policy operates strongly via bank lending channels. It also explains why the 1990s banking crisis had such a strong repercussion on the real economy, and that recovery required bank recapitalization and reforms. The close government–bank–corporate relationships historically facilitated industrial policy but also led to delayed recognition of bad loans in the 1990s. The heavy reliance on domestic banks is mirrored by relatively underdeveloped capital markets; inward portfolio investment is low, and corporate bond markets are smaller than in the US. In recent years corporate leverage has however evolved towards more equity financing (Chong, Law et Yao 2016).

Japan's labor market is segmented into regular employees (typically male, full-time, lifetime employment with seniority wages) and non-regular workers (part-time, temporary, or contract workers with lower pay and little job security). Since the 1990s, the share of non-regular employment has risen dramatically, from about 16% of workers in 1995 to 32% by 2019. Firms increased non-regular hiring to cut labor costs and gain flexibility amid slow growth. Today, a majority of women and older workers are in non-regular roles. This duality has been extensively studied and has several implications (Aoyama, et al. 2022) (Hoshi et Kashyap 2020) (Motobashi 2023). It suppressed wage growth and consumer spending, as non-regular workers earn on average less than regular ones and tend to have precarious contracts. It also widened inequality and reduced labor productivity, since employers invest less in training non-regular staff. Hence, despite unemployment falling to very low levels , wage inflation stayed weak due to the lower of bargaining power of non-regular workers and a tendency to focus on job security over wages.

High corporate liquidity holdings have been a specific feature of the Japanese economy. While the topic being previously examined, the IMF suggests that the increase in intangible assets and foreign assets, which are harder to collateralize, heightened uncertainty and lower corporate tax rates have led to companies holding more cash (Kim, Murphy et Xu 2023).

Japan being a net creditor to the rest of the world is a distinctive feature which had impact on Japan's macroeconomic regime (Boyer, et al. 2023) (AMRO 2019). Japanese firms and investors have extensive holdings abroad, from US Treasuries to direct investments in Asia. This yields a substantial primary income flow: Japan earns far more on its foreign assets than it pays on liabilities, contributing 3–4% of GDP to the current account each year (Sekine 2022). One specific aspect is outward FDI: Japanese multinationals shifted production overseas aggressively from the 1990s onward (due to yen appreciation and slow domestic growth), resulting in outward FDI stocks larger than inward stocks. While this makes Japan financially robust externally (it's insulated from balance-of-payments crises and benefits from global growth via income receipts), it also means domestic industries like manufacturing have offshored capacity, potentially being at the origin of lower potential growth (AMRO 2019) (Boyer, et al. 2023).

Last, conjunctural features such as population ageing, stagnating growth and deflation extensive periods at the zero lower bound, record-high public debt owned domestically and monetary policy innovation are key traits to be considered to properly depict the Japanese economy's period 1990s.

2.2 – Climate change

2.2.1 – Emerging thing: physical risk, transition risk, green swans

The IPCC's Assessment Reports, namely WGII (Impact and adaptation) and WGIII (Mitigation), compile results from a range of models. They highlight that limiting warming to 1.5–2°C requires transformative change in energy, transport, land-use, and that delays significantly raise costs. They report estimated GDP losses from unabated climate change could be substantial by 2100 ranging from a few percent for moderate warming to20% or more globally if warming exceeds 3°C) (IPCC 2023). Yet, models also show that early action could limit long-run losses and even yield co-benefits such as reduced air pollution, new green industries. There is debate on appropriate levels of intervention, as economists like Nordhaus might argue a 3°C world is economically manageable (with a few percent output loss in DICE) (Nordhouse 1992), whereas others like Stern warn of much higher damage and catastrophic risk that justify very aggressive mitigation now via a precautionary principle (Stern 2022).

Climate change has rapidly moved to the forefront of economic and financial literature. While earlier work focused on damage on the one hand with DICE, and "green growth" (OCED 2011), recent discussions started to acknowledge further the risk incurred by the green transition itself.

The notion of **"**greenflation**"** describes inflationary pressures that arise from the green transition. As economies pivot to cleaner energy and low-carbon technologies, certain costs may increase (Chung et Kim 2024). For instance, massive investment in renewable energy and electric vehicles requires substantial amounts of metals like lithium, cobalt, and copper. Demand for these can outstrip supply, driving up commodity prices. Retrofitting industrial processes to cut emissions can raise production costs in the short run (until efficiencies are gained). In essence, climate mitigation consists in replacing existing capital with less emission-intensive capital to produce the same output which could generate inflationary pressures as highlighted by Pisani Ferry on the French economy (Pisani-Ferry et Mahfouz 2023). He notes that the transition is akin to a supply shock and a structural shift combined, so treating it as just an environmental issue is insufficient, and it must be central to macroeconomic strategy (Pisani-Ferry 2021). He and co-authors quantify potential impacts for France: if governments need to facilitate trillions in green investment, debt/GDP may rise before the payoff is realized. They also point out the distributional consequences of climate action implying the need for transitional support. Moreover, climate policies increase the price of carbon-intensive activities by design, and while long-run impact on inflation are not necessarily found to be significant, they could occur in the short run through carbon pricing (CEPR 2025). Heightened inflation could impose pressures on central banks to increase interest rates, while lower rates are deemed essential to finance transition investment

Existing literature coined the distinction between physical risks and transition risks of climate change. Physical risks arise from the direct impacts of climate change on economies: more frequent and severe extreme weather events (heatwaves, floods, droughts, tropical cyclones) and long-term shifts (rising sea levels, changing rainfall, ecosystem disruptions). They can destroy assets, disrupt supply chains, reduce productivity and necessitate costly adaptation. The IPCC has documented the escalating frequency of climate extremes and their "widespread adverse impacts" on human systems and ecosystems. For example, it is certain that human-induced warming has increased the likelihood of heat extremes and heavy precipitation events. Physical risks thus pose a threat to assets, corporate earnings (through damage and input shortages), and overall economic output (through lost productivity and infrastructure destruction). There is also a tail-risk of hitting climate "tipping points", irreversible changes activating feedback-loops leading to changes in ecosystemic equilibria with dramatic consequences (IPCC 2023) (Bank of International Settlements 2020).

Transition risks stem from social adjustment to climate change. As societies implement climate policies, technological changes, and consumer preference shifts to reduce GHG emissions, certain assets will lose value or be stranded as sunset industries are forced to exit markets. The risk of a disorderly transition on financial stability (for example through sudden changes in regulation or carbon pricing) has been stressed out by the BIS and the NGFS in their seminal 2020 report (Bank of International Settlements 2020). If mismanaged, a disorderly transition could trigger job losses, abrupt repricing of financial and credit defaults for firms unable to adapt.

The 2020 report coined the term of "Green Swans", referring to Nassim Taleb's "black swans" (unforeseen, high-impact events situated at probability distribution tails). Green Swan events refer to potentially extremely disruptive climate-linked occurrences that could trigger systemic financial crises and differ from Black-Swans from the quasi certainty they will occur. The BIS authors argue that climate risks "defy conventional approaches to risk management" due to radical (Knightian) uncertainty, non-linearity, and endogeneity (policy responses can change the trajectory). They warn such events could be behind the next systemic financial crisis if preventative action is not taken. Moreover, green swan risks challenge central banks' mandates, potentially forcing central banks into roles like "climate rescuer of last resort" to stabilize the system in the case of climate shocks. The literature thus calls for integrating climate considerations into prudential regulation and for central banks to coordinate with broader climate policy efforts (Bank of International Settlements 2020).

Climate change's direct impact and cost has been extensively studied in past literature, and the green growth narrative has somewhat lost some of its momentum as the notions of risk are brought into discussion and the concrete impact of the transition is examined.

2.2.2 – Climate change impact assessment and modeling approaches

Assessing the economic impact of climate change and the costs of mitigation and adaptation has given rise to a variety of modeling approaches. A prominent framework in the literature is Integrated Assessment Models (IAM), which seek to integrate climate science with economics. One of the pioneer models is W. Nordhaus's DICE model (Dynamic Integrated model of Climate and the Economy). DICE is a neoclassical growth model augmented with a carbon cycle, a climate module, and a damage function that links global temperature increase to output losses. Nordhaus uses DICE to compute an "optimal" emissions reduction path that balances abatement costs against the economic damages of climate change taking account a discount factor (Nordhouse 1992). Nordhaus's approach essentially treats climate change as a global externality that can be addressed by a globally efficient carbon price. Despite their traction and heuristic value, IAMs like DICE have been criticized on several fronts: the choice of damage functions (which are highly uncertain for large temperature changes) may underestimate risks, the use of high discount rates can undervalue future climate damages, and the omission of potential catastrophic or non-market damages (biodiversity loss, ecosystem services, critical natural capital). Subsequent IAMs have explored alternative assumptions (Stern 2022). Nonetheless, IAMs remain influential in informing policymakers about trade-offs.

Another class of models consist of macroeconomic models with climate modules built in to analyze the impact of different policy instruments. These include Dynamic Stochastic General Equilibrium (DSGE) models adapted for climate policy analysis. Traditional DSGE models are modified to include carbon emissions, climate policy shocks, or even damage functions. For example, some authors have introduced a "climate policy" shock into a DSGE to simulate how a sudden tightening of carbon regulations might affect output and inflation (Matsumara, Naka et Sudo 2023). DSGE models are based on micro-foundations, rational expectations and stochastic shocks with generally representative agents dynamically optimizing their levels of consumption and investment. Some critics argue that DSGEs, from their assumptions, may not handle Knightian uncertainty and potential non-linearities of climate change well. They often assume smooth adjustment, whereas climate change may entail abrupt regime shifts. Another limitation is that standard DSGEs assume the economy gravitates to full employment equilibrium and then struggle to represent persistent damage or underemployment that could result from climate shocks.

In contrast, post-Keynesian and ecological economics adopted different approaches with different types of models and assumptions. Among them, Stock-Flow Consistent (SFC) models have emerged as a possible alternative workhouse to DSGE modeling of climate change's impact. SFC models, somewhat analogous to Computable General Equilibrium models, use a different set of assumptions (for example with output being demand-determined instead of supply-determined), and incorporate an explicit accounting structure to ensure the closure of the model. While these models were initially purely macroeconomic, their framework fit well the framework of ecological economics (with the economic system being a subsystem embedded in the ecosystem and the notions of planetary boundaries) (Nikiforos et Zezza 2017). Their environmental and ecological extension can integrate the framework laid out by Georgescu-Roegen or Herman Daly, who long argued that conventional models ignore the entropic constraints of the planet as a system (Georgescu-Roegen 1971). Recent works in ecological macroeconomics incorporate feedback loops (climate damage reduces output, which affects investment, which then may reduce mitigation capacity) potentially leading to worse climate outcomes. These models stress the possibility of non-linear, destabilizing dynamics, such as a climate–debt feedback: if climate damages lower growth, governments and firms might incur more debt to compensate, which could heighten financial fragility, risking a collapse before climate impacts fully play out.

Bovari et al. (2018) in with the GEMMES **(**General monetary and multisectoral macrodynamic for the ecological shift) model developed for the Agence Française de Développement (French Development Agency) (Agence Française de Développement 2021) integrate the SFC approach with nonlinear monetary dynamics with a damage function and abatement cost. They highlight that the 2°C target by 2100 is already out of reach unless climate sensitivity is lower or low emission technology develops at much faster pace. The interplay between the economy, finance and climate instability could lead to degrowth. Nonetheless, with an appropriate carbon path (a minimum of 140USD per ton of CO_2 by 2030 and 300 in 2040 to reach the 2,5°C target) and wealth redistribution debt-to-output ratio could be reduced which would facilitate a growth path without recession (Bovari, Giraud et Mc Isaac 2018). Nguyen T. (2022) exemplified how climate change could impact developing economies by integrating adaptation cost and building a damage function based on empirical estimates from existing literature through SFC modeling (Nguyen 2022). Dafermos et al. (2018) with their Dynamic Ecosystem FINance-Economy (DEFINE) model, propose an integrated ecological SFC approach, calibrated on global data and merging the SFC approach with the flow-fund model of Georgescu-Roegen (Dafermos, Nikolaidi et Galanis 2018). It comprises energy, matter, recycling and waste as well as a climate component and was then adapted to fit empirical country-level data for the UK (Dafermos et George 2023), testing for different policy scenarios (green subsidies, public investment, carbon tax, green capital requirements). Yan et al. (2025) offered a perspective on the green transition using the SFC approach and comprising compound risks related to geopolitical risk, pandemics and shocks in energy prices (simulated with a Markov state transition matrix) with the SERENE model. (Yan, Wang et Wu 2024) Calibrated on the Chinese economy, it uses different scenarios (the absence of action, carbon tax, green bonds and green equity) and indicates the presence of "non-linear loss amplification effect due to compound risks, which can lead to a decline in economic resilience" as well as "different degrees of effectiveness in transitioning" depending on policies adopted (with carbon tax and equity policy causing more instability than green bonds policies).

2.2.3 – Climate change in Japan

Japan faces significant physical risk according to the IMF (IMF 2024). Climate models project heavier rainfall events in East Asia, and typhoons, flooding (Yanagihara, et al. 2024) and rising sea levels would directly impact the country and incur important losses (Bank of Japan 2022). Vulnerability nonetheless remains relatively low thanks to strong capabilities to cope with it. Japanese insurers are well-capitalized and experienced in catastrophe risk. The reliance on coal and coal power plants also implies significant transition risk due to stranded assets related to coal power generation.

It has in recent years launched major initiatives to green its economy under the banner of GX policy (Green Transition). Japan's contribution to global GHG emissions amounts to close to 3% and it is the world's 5th largest emitter in absolute terms. Its economy relies heavily on imported fossil fuels (especially after the post-2011 reduction in nuclear power). Japan's GHG profile include a high share of emissions from electricity generation and heat (48%), industry (17,5%), and transportation (19%). Per capita CO_2 emissions in Japan (close to 9 ton of CO_2

per capita) are lower than the US but higher than the EU (International Energy Agency 2022). Following the Paris Agreement, Japan pledged to cut emissions 26% below 2013 levels by 2030, but the target was revised under the Suga and Kishida administrations and made more ambitious with 46% reduction by 2030 and net-zero by 2050.

The GX strategy was formulated in 2021–2022 and adopted under the GX Promotion Act in May 2023. The GX plan lays out sector-specific roadmaps and mobilization of finance for decarbonization. The government estimates about 150 trillion yen in public-private investment is needed over the next decade (2023–2032) to put Japan on track for its 2030 and 2050 targets (Japanese Government 2021) (GR Japan 2023). It pledged 20 trillion yen of green public investment which will be financed via GX transition bonds (with the remaining 130 trillion yen expected to come from private financing). These transition bonds are a new class of government debt instruments whose proceeds fund green and transition projects. Their service is intended to be aided by revenue from carbon pricing mechanisms (Climate Bonds Initiative 2023).

Japan's approach emphasizes "transition finance". Rather than focusing solely on pure green projects, Japan is promoting pathways for high-emitting sectors (steel, chemicals, cement, etc.) to transition gradually. The government, through METI and MOE, issued Basic Guidelines on Climate Transition Finance in 2021 to guide banks and investors in funding emissions-reduction efforts by carbon-intensive firms (Ministry of the Environment 2020). They also developed Sectoral Transition Roadmaps for key industries (steel, chemicals, power, automobile) to help financial institutions evaluate if a company's decarbonization strategy is credible. Major banks in Japan have announced policies to restrict financing for new coal power and to increase green lending (GR Japan 2023). Japan's private banks and institutional investors have joined international coalitions like GFANZ (Glasgow Financial Alliance for Net Zero) and are increasingly incorporating TCFD disclosures of climate risks. The Financial Services Agency (FSA) and BoJ conducted a pilot climate scenario analysis in 2022 with large banks and insurers to assess their exposure to climate risks. Using NGFS scenarios, this pilot found that Japanese financial institutions are indeed exposed: on average, about 20% of major bank loan books are to carbon-intensive sectors, meaning transition policies could affect credit risk.

Despite having the lowest carbon tax in the world with 289 yen per ton of CO2, Japan's climate policy plans on developing carbon pricing (Mizuho Information and Research Institue 2017)

(Ishikawa 2024). In 2022–2023, under the GX initiative, Japan designed a national carbon pricing framework comprising two elements: an emissions trading system (ETS) and a carbon levy. The GX-ETS began in April 2023 on a voluntary, experimental basis with about 680 participating companies that account for 40% of national emissions. By 2026 or so, the plan is to formalize a mandatory ETS with government-defined caps and third-party monitoring. Meanwhile, a carbon levy on fossil fuel imports is set to start around FY2028, initially at a low rate and rising gradually. The carbon price is expected to ramp up over the 2030s, but some analysts suggest that Japan's implied carbon price might only be on the order of 10–20USD/ton in the early years, roughly one-tenth of the $130/ton the IEA estimates developed countries need by 2030 for a 2°C path. Some observers have criticized the Japanese plan as "too slow and low" to meet the 2030 target. Auctions for emission permits in the power sector for example will not start until 2033, and the initial carbon levy risks being too low (Okabayashi et Golubkova 2023). The government's GX policy explicitly ties climate action to economic strategy, aiming to capture global markets for green technologies. The concept of "green growth" is emphasized via the promotion of cutting-edge green industries such as offshore wind industry, next-generation batteries, and digitalization to optimize energy use.

2.3 – Stock-Flow Consistent Modelling

2.3.1 – History and types of modeling

Stock-Flow Consistent (SFC) modeling's intellectual origins of SFC models trace back over 70 years. The earliest influence was Morris Copeland work in the 1940s on the flow of funds. Copeland introduced quadruple-entry bookkeeping to systematically track money flows between sectors. He developed a framework to tie together production, income, and financial transactions, ensuring that every flow is recorded as an outflow from one sector and an inflow to another. This approach laid the foundation for the modern System of National Accounts and flow-of-funds accounts. The idea was that an economic system could be analyzed as a set of interlinked balance sheets and transactions, maintaining consistency: every buyer has a seller, every financial asset is someone else's liability (Nikiforos et Zezza 2017).

In the postwar decades, James Tobin and colleagues at Yale incorporated stock-flow consistency into formal macroeconomic models. Tobin's 1960s–70s work integrated a financial sector with multiple assets into Keynesian macro models. His famous papers insisted on explicit stock-flow linkage, for instance, how saving (a flow) accumulates into wealth (a stock), and portfolio choices allocate wealth among assets (Nikiforos et Zezza 2017). Parallel to Tobin, Wynne Godley developed what is known as the modern SFC approach. Godley, originally at the UK Treasury and later Cambridge University and the Levy Institute, constructed models (the "New Cambridge" approach) that tracked the financial balances of governments, households, and firms, arguing that these balances have to add up (one sector's deficit is another's surplus). By the 1990s, Godley began collaborating with Marc Lavoie to formalize a general SFC modeling framework which led to the workhouse of "Monetary Economics" in 2006 (Nikiforos et Zezza 2017) (Nguyen 2022).

Godley and Lavoie laid out how to build a complete macro model using matrices to enforce accounting consistency: a Transactions Flow Matrix (detailing all income, spending, and financial transactions between sectors) and a Balance Sheet Matrix (detailing each sector's stocks of assets and liabilities). Every flow in the model appears in the flow matrix and every stock in the balance sheet; and importantly, flows change stocks from one period to the next in a coherent way. The models are then given behavioral equations, for example consumption depending on income and wealth based on macro-level stock-flow targets (Godley et Lavoie 2006).

From the 2000s, SFC modeling grew into a defined field which can distinguish 2 main types of SFC models: theoretical (or stylized) models and empirical (policy-oriented or estimated) models. Theoretical SFC models are often small, simplified economies used to illustrate particular mechanisms (Nikiforos et Zezza 2017). For example, Godley & Lavoie present a series of pedagogical models that might include just households, firms, and a government, with one or two financial assets. These models are not calculated to actual data but are solved to analyze properties. Researchers have used such models to examine scenarios like debt-led growth against debt-burdened stagnation, interactions of fiscal and monetary policy, and so on. Notably, Godley and others used an SFC approach in the 2000s to warn of the unsustainable build-up of private debt and external deficits in the US and UK, which echoed the 2008 subprime crisis. Indeed, Godley's "Seven Unsustainable Processes" paper (2000) outlined imbalances in the US (falling household saving and rising external deficit) that could lead to a crash, which was missed in standard DSGE models at the time that did not include financial frictions (partially corrected after 2008) (Nikiforos et Zezza 2017).

Empirical SFC models are large-scale macro models parameterized to match a specific economy's data (national accounts, flow-of-funds). These are used for forecasting and policy analysis, similarly to how central banks use DSGE or structural macro models. These models are then used to simulate different policy scenarios and examine their potential impact.

The SFC approach has gained traction especially after the Global Financial Crisis and new hybrid types of models have emerged: agent-based models (ABM) that ensure stock-flow consistency (so-called AB-SFC models) (Caiani, et al. 2017) and convergence with Input-Output and ecological economics. Central banks have started building and using SFC models as an additional policy analysis instrument (for example with the Bank of England, the Bank of Italy, and the central bank of Albania).

2.3.2 – Method and specificities

Stock-Flow Consistent modeling follows a methodology based on accounting principles, specific theoretical structure and post-Keynesian assumptions. Their accounting structure follows flow consistency: every inflow must be matched with an outflow, hence every payment for a sector (for example interest paid by households) is a receipt for another sector (interest received by a bank). Stock consistency must similarly be ensured: an asset must match a liability for the entire economy. Last, Stock-flow consistency has to be observed, with flows changing stocks and inducing feedback effects between stocks and flows. The accounting structure hence follows quadruple book-keeping accounting: an outflow, an inflow, a change in asset and a symmetrical change in liability (Nguyen 2022) (Godley et Lavoie 2006).

The modeling structure is based on two matrices and two types of equations. The balance sheet matrix lays out the financial framework: it distinguishes between sectors, their assets and liabilities and their net wealth. The transaction-flows matrix captures all transactions and flows (income, expenditures) for the economy and resulting changes in net wealth. Accounting identities (equations) close the model and ensure stock-flow consistency while intertemporal dynamics for sectors' expenditure and financial decisions are modeled through behavioral equations. Behavioral equations are generally based on theory and calibrated or estimated based on data or previous studies (Nikiforos et Zezza 2017).

Theoretical assumptions vary depending on models (and can even integrate DSGE-style rational expectations as in Makrelov, et al. 2018). They are, however, generally based on post-Keynesian assumptions. Output is determined by demand (although supply constraints can be imposed as in (Nguyen 2022) and (Dafermos et Nikolaidi 2022)) and adjustments take place through quantity rather than price adjustments. This implies that models do not assume full utilization of resources and allows to model persistent unemployment or operation under full capacity. Expectations, when present, are generally adaptative (instead of rational), and money is endogenously determined through balance sheet interactions and credit creation (deposits are for example created through loans rather than exogenous levels fixed by the central bank). Large-scale models are generally iteratively solved in discrete time and there is not necessarily a fundamental distinction between short-term and long-term effects as the long-run is "a succession of short-terms" (Pierros 2024). Still, modeling choices can lead to short-run adjustments and shocks with long term equilibrium drive via cointegration techniques (Zezza et Zezza 2020). This also implies path-dependency for long-term trends and business cycles. This gives the ability to generate multiple equilibria or even unstable trajectories when unsustainable stock-flow processes occur.

2.3.3 – Empirical SFC models

Empirical applications of Stock-Flow modeling approaches have developed over the past two decades. Passarella and Zezza distinguish two approaches in empirical SFC models: theory-to-data and data-to-theory (M. V. Passarella 2018). The former one implies the construction and adaptation of a theoretical model then calibrated to data for a particular country, while the latter consists in building the Stock-Flow consistent model from available national account and flow of funds data. (M. V. Passarella 2018) and (Zezza 2019) provides advice, existing methods and best practice when building empirical SFC models.

Empirical SFC models have been developed for various countries to address a large range of macroeconomic issues. Zezza (Zezza et Zezza 2020) and Passarella et al. (Passarella et Canelli 2022) built empirical SFC models on the Italian economy. These models enabled to study sovereign debt sustainability for the Italian economy and do show that "the Italian government debt is unlikely to enter a sustainable trajectory in the next few years" without yield curve control. The Levy Institute developed models for the US economy with which they published policy analysis reports arguably pointing at risks which culminated with the 2008 crisis. Models were also built for a variety of countries such as Denmark (Byrialsen, Raza et Valdecantos 2022), France (Mazier et Reyes 2022), Viet Nam (with closures through FDIs) (Nguyen 2022) the UK (Burgess, et al. 2016) and Latin America (Nalin, et al. 2023). An SFC-ABM theory-to data approach was used on the Japanese economy to study the links between the dual labor market, output and wage dynamics (Fujiwara et Di Guilmi 2022). The show that the uncertainty on demand and loss of bargaining power of workers are the main drivers behind Japan's low inflation and Philips' curve dynamics while unconventional monetary policy can have “deflationary consequences, by allowing financially distressed firms which are more likely to resort to secondary workers, to survive”.

The impact of climate change and climate mitigation has started to be taken into account in empirical SFC modeling with the SFC-FR in France**,** integrating energy and emissions for the French economy and evaluating scenarios for France to reach net zero (Mazier et Reyes 2023). Preliminary results indicated that achieving net-zero might involve short-term output trade-offs but is feasible with sustained investment and supporting fiscal and monetary policy. The Vietnam model innovatively integrate the issue of damage through an estimated damage function based on local damage estimations on each sector, mortality and productivity through an array for studies as part of the AFD GEMMES project in Viet Nam. The UK adaptation of the DEFINE model builds an empirical version of the Define model to inquire green transition and NDC achievement for the UK by 2030. Jackson et al. also provides a simulation model for Canada from 2017 to 2067 using SFC modeling to provide projections under different sustainability and transition scenarios. They suggest that green growth “may be slower than ‘brown growth’” (Jackson et Victor 2020).

To conclude, climate change damage, mitigation and adaptation requires holistic frameworks because of its multifaceted nature. It will not only affect the real economy, ecosystems and human societies, but also the financial sector which itself has feedback effects on other sub-systems. Japan will be significantly exposed to climate change and has planned ambitious policies to tackle it. Being a large GHG contributor with specific economic institutions and structures, and facing decades-long difficulties, assessing its future challenges seems crucial to ensure the success of the GX policy. The empirical Stock-Flow Consistent methodology, by integrating finance and showcasing a high degree of flexibility in integrating country-specific structures as well as environmental concerns, appears to be a good candidate and will therefore be adopted in the following section.

3 – Methodology

This section exposes the methodology adopted in this paper. It first presents the research design, then develops on the model itself, exposes data collection and treatment and finally presents estimations used for simulations.

3.1 – Research design

This study draws on the empirical Stock-Flow Consistent Methodology to analyze macroeconomic dynamic of the green transition in Japan through three main channels: environmental performance, impact on the real economy and impact on financial conditions. It builds an empirical stock-flow consistent model of the Japanese economy and estimates it through traditional econometric techniques (Ordinary Least Square and Error Correction Models) following Zezza (2019). After checking for stock-flow consistency and goodness of fit, it calibrates a baseline scenario to 2050 which integrates climate and transition variables from 2024. It then runs simulations by modifying policy parameters and relating them to baseline simulations.

3.2 – An empirical stock-flow consistent model of the Japanese economy

3.2.1 – Construction of the model

The empirical Stock Flow Consistent model for the Japanese Economy (hereafter referred to as SFC-JPE) is built based on practice highlighted in (Zezza 2019) and on past approaches. Its accounting structure is derived from the balance sheet of the Japanese economy in Flow of Fund data by the Bank of Japan as well as national accounts data. The Balance Sheet is then simplified and data reclassified based on simplifications and assumptions, ensuring stock-flow consistency. The Transaction-Flow matrix is directly derived from national accounts with some modifications to make it fit the SFC approach. The green transition and impact of climate change is derived mainly from three approaches: the DEFINE model for climate mitigation by integrating and endogenizing green capital accumulation and ecosystemic feedbacks, the Viet Nam and World Bank (World Bank 2021) model for adaptation cost based on De Bruin 2009 (De Bruin, Dellink et Tol 2009).

3.2.2 – Assumptions

The SFC-JPE model follows usual post-Keynesian assumptions which distinguish it from CGE or DSGE modeling. It is demand-led with output determined by aggregate demand. Firms adjust production to meet demand and labor adjusts accordingly. It integrates supply-side constraints with a production function as in the Viet Nam model, which however only determines an output gap. It follows adaptative expectation rather than model-consistent rational expectation and hence does not showcase dynamic optimization mechanisms.

3.2.3 – The accounting structure: Balance sheet and Transaction Flow Matrix

Table 1 shows Japan's simplified balance sheet based on Japanese data. Simplifications were made to reduce model's complexity and based on Flow of Fund data for both balance sheets and transactions. The model aggregates balance sheets into six sectors: households and non-profit institutions serving households, the non-financial corporate sector (firms), the general government, the financial sector, the Bank of Japan and the rest of the world. The model integrates 12 financial assets: reserves, cash, deposits, advances, bank reserves, loans, government bonds, equity, foreign assets, insurance/pension products and a "other net asset" category serving as residual.

When observing total assets and liabilities, households showcase a large positive financial net wealth, firms a consequent negative financial net wealth (which turns positive when including fixed assets), the general government a negative financial net wealth, the financial sector and the central bank a slightly positive net wealth and the rest of the world a large negative net wealth.

As in other approaches cash is assumed to be held exclusively by households, international reserves (gold and special drawing rights) are held at the central bank, fixed capital is owned by households, the general government and the non-financial sector, and inventories are owned by firms and the government. Deposits are assets for households, the government, firms and are liabilities for the financial sector and the central bank (which both hold government deposits). Advances are liabilities for the financial sector and assets for the central bank and reserves follow the opposite direction. Loans are made from the financial sector for firms and households. Equity is issued by banks and firms and held by households and the rest of the world as it holds a significant (18%) amount of domestic equity.

Several reclassifications were made for simplicity. Equity liabilities are netted out for banks and firms, foreign currency deposits, foreign loans, derivatives and other less significant assets and liabilities were reclassified in other net assets.

Several specificities can be observed from the Japanese accounts and existing literature. First, as Japan ramped up direct investment amidst lower domestic economic prospects (AMRO

2019) it is a net creditor to the world and owns a significant level of foreign assets. A foreign asset category was created by aggregating foreign direct investment and foreign portfolio investment which represents 12% of the total balance sheet. Firms, financial institutions and the government were found to be the most significant holder of foreign assets. Secondly, after two decades at the zero lower bound and almost uninterrupted unconventional monetary policy, the central bank's balance sheet has grown significantly, to the point it owns close to 36% of total bond assets in 2023. If bonds are mainly held domestically (at 85%), the rest of the world remains significant by holding 15% of debt securities. Insurance and pension instruments represent 5% of assets and are held by households at 99% while mainly being liabilities to the financial sector. Attention was hence paid to quantitative easing and the central bank's holding of government bonds and impact of bank's reserves. Japanese firms have been accumulating liquidity to face uncertainty, and because intangible assets and foreign assets could not be collateralized for loans (Kim, Murphy et Xu 2023) while firms finance is still arguably mainly dominated by banks despite changes in debt-to-equity ratios. Firms hence also hold deposits which plays a role in the model's dynamics.

On a final note, while households do not hold directly large amounts of government bonds, they indirectly hold a significant part through non-banking financial institutions which could also allow for an approach à la Zezza (Zezza et Zezza 2020) aggregating the non-monetary financial sector into household's balance sheet, but which was not opted for because of the structure of national account data.

Table 2 shows the transaction flow matrix on which the accounting structure is derived, and which will be detailed in equations. The Zezza and the BoE approach was selected by integrating a differentiated production column as production does not occur only within firms. Residual payments were aggregated into other net payment based on national account data.

	Households & NPISH	Non-Financial Corporations	General Government	Financial Sector	Bank of Japan	Foreign Sector	Discrepancy	Total
Fixed Assets	K_HH	K_NFC	K_GG					K
Inventories		V_NFC	V_GG					V
Reserves					RES	-RES		0
Cash	+H				-H			0
Deposits	+M_HH	+M_NFC	+M_GG	-M	-M_GG			0
Advances				-AD	+AD			0
Bank reserves				+R	-R			0
Loans	-L_HH	-L_NFC		+L				0
Bonds			-B	+B_FI	+B_CB	+B_ROW		0
Shares	+E_HH	-E_NFC		-E_FI		+E_ROW		0
Foreign assets		+FA_NFC	+FA_GG	+FA_FI		-FA		0
Insurance	+INS			-INS				0
Other Net Assets	+OA_HH	OA_NFC	OA_GG	OA_FI	OA_CB	OA_ROW	Disc	0
Net financial wealth	NW_HH	NW_NFC	NW_GG	NW_FI	NW_CB	NW_ROW		0
Column total	0	0	0	0	0	0	0	+K+V

Table 1 - Japan Simplified Balance Sheet

	Production	Central Bank	Financial Institutions	General Government	Non-Financial Corporations	Househoulds	Rest of the World	Total
GDP	+GDP			-C_GG-I_GG-DV_GG	-I_NFC-delta_V_NFC	-C_HH-I_HH	-X+M	0
Wages and Salaries	-WB-SC			+SC		+WB+Wbrow	-WB_ROW	0
Wage to Abroad	-WB2row						+WB2ROW	0
Mixed Income	-MIXY					+MIXY		0
Indirect taxes	-IT			+IT				
Subsidies	+SUBS+GSUBS			-SUBS-GSUBS				
Operating Surplus	-OS		+OS_FI	+OS_GG	+OS_NFC	+OS_HH		
Interest Payments		+	+/-	+/-	+/-	+/-	+/-	0
Dividends		+	+/-	+	+/-	+	+/-	0
Other Net Payments			+/-		+/-	+	+/-	0
Primary income		Profit_CB	YP_MFI	YP_GG	YP_NFC	YP_HH	YP_ROW	0
Direct taxes			-DT_FI	+DT	-DT_NFC	-DT_GG		0
Social benefits				-SB		+SB		
Social contributions				+SC_HH		-SC_HH		
Seignorage		-Profit_CB		+Profit_CB				
Other (net) current transfers			+OT_FI	+OT_GG	+OT_NFC	+OT_HH	+OT_ROW	0
Disposable income			YD_FI	YD_GG	YD_NFC	YD_HH	YD_ROW	
Demand				-C_GG		-C_HH	-X+M	
Savings			+S_FI	+S_GG	+S_NFC	+S_HH	+S_ROW	
Final demand				-I_GG-delta_V_GG	-I_NFC - delta_v_NFC	-I_HH		
Net lending		NLB	NLB	NLB	NLB	NLB	NLB	0

Table 2 - Japan Transaction-Flow Matrix

3.2.4 – Model overview

The model's presentation is made organized in different blocks while it does not represent the way it is thereafter solved in BIMETS. It consists of accounting equations to keep the model closed and behavioral equations to determine its dynamics. Financial closures are based on previous approaches and on the accounting structure derived previously with certain assets being residuals for each sector, and some sectors being residuals for closing assets. It proceeds as follows. Households spend their remaining funds on other assets which are closed by the financial sector. The non-financial corporations sector closes its budget by emitting equity, and the rest of the world purchases the remaining equity. The government closes its budget by emitting bonds, and the financial sector closes the asset row. Following Ngyuen (Nguyen 2022) and with the central bank being a lender of last resort, the financial sector closes through advances which are accommodated by the central bank.

Every sector determines its final demand which is then produced and feeds into income from production (wages, operating surplus, taxes, subsidies). Primary income then is derived from returns on assets through interest, dividends payments and other net payments. Direct taxation and social benefits then redistribute revenues to reach disposable income. Savings are obtained by subtracting consumption and the net lending/borrowing (NLB) position for each sector is obtained for each sector by subtracting final demand. From Godley and Lavoie (Godley et Lavoie 2006) the NLB and the net acquisition of financial assets (NAFA) must be equal. However, financial data and national accounts generally do not match, and a discrepancy term is added to force consistency. Financial behavior varies depending on sectors, as some act as residuals on certain assets, and behavioral equations determine the purchase of certain assets or the emission of certain liabilities which will be discussed during the model description.

Climate change impact corresponds to a threefold process: damage, adaptation and mitigation. Damages are modeled following a modified DICE and DEFINE approach with a damage function featuring higher damage for large temperature increases following Nguyen. Adaptation follows Nguyen and De Bruin. A distinction between productive capital and adaptation capital is introduced. Firms, households and the government invest in adaptation capital which can't be used in production but allows for reducing damage due to climate change. It implies a trade-off between income generation and loss avoidance.

Mitigation follows a simplified DEFINE approach through an ecosystem block and endogenizing transition decisions. It uses a theoretical distinction between green and conventional productive capital. Only firms and governments invest in conventional or green capital (for simplicity, households invest in capital without direct impacts on the ecosystem part of the model). The ratio of green to conventional capital then determines the level of energy intensity and of renewable energy share. In other words, investment in green capital leads to energy efficiency gains and to more clean energy. Firms endogenously invest in green capital based on unit cost of renewable and nonrenewable energy (Dafermos et Nikolaidi 2022) and the government can adopt policies based on a set of three different instruments: carbon taxes, green subsidies and green public investment.

Environmental performance is hence here solely measured by CO2 emissions and cumulative emissions. Eventually, energy intensity and the share of fossil fuels determine CO2 emissions. Damage, adaptation and mitigation being prospective in their approach, the model's results are dependent on calibrated parameters. Calibrated parameters were taken from the DEFINE model.

3.2.5 – Equations

This sub-section will present the model's equations in 10 blocks: ecosystem, production, firms, households, general government, central bank, financial institutions, rest of the world, labor market and prices, asset pricing and rates. Time is indexed with a subscript and sector is indexed with a superscript.

Ecosystem

Emissions, efficiency and technology

The ecosystem section uses previously quoted models' equations (DEFINE and Nguyen). CO2 emissions (CE) depend on CO2 intensity of nonrenewable fuel energy and energy generation from fossil fuels, with a proportion of sequestration with CCS (Carbon Capture and Storage) technology (1) feeding into cumulated carbon emissions (2). Total energy used for production (ENE) depends on energy intensity and output (3). Green capital lowers energy intensity and increase the use of renewables, so efficiency increases when the ratio of green capital to conventional capital increases (6). Energy intensity (INT_t^{energy}) and the proportion of non-fossil fuel (ι_t^{NFF}) follow a logistic relationship from the GK/CK ratio (5)(6).

$$CE_t = INT_t^{CE} \times ENE_t^{FF}(1 - seq_t) \tag{1}$$

$$CCE_t = CCE_{t-1} + CE_t \tag{2}$$

$$ENE_t = INT_t^{ENE} y \tag{3}$$

$$INT_t^{\mathrm{ENE}} = \epsilon_{max} - \frac{\epsilon_{max} - \epsilon_{min}}{1 + \vartheta_1 \exp\left(-\vartheta_2 \frac{K_{t-1}^G}{K_{t-1}^C}\right)} \tag{4}$$

$$\iota_t^{NFF} = \frac{1}{1 + \vartheta_3 \exp\left(-\vartheta_4 \frac{K_{t-1}^G}{K_{t-1}^C}\right)} \tag{5}$$

$$ENE_t^{NFF} = \iota_t^{NFF} ENE_t \tag{6}$$

$$ENE_t^{FF} = ENE_t - ENE_t^{NFF} \tag{7}$$

Damage and Adaptation

The increase in temperature incurs damages to gross output following a DICE function similarly as in DEFINE. The damage function is based on temperature increase in comparison to pre-industrial levels following a quadratic form (8).

$$GDF_{Tt} = 1 - \frac{1}{1 + \eta_1 TEMP_t + \eta_2 TEMP_t^2 + \eta_3 TEMP_t^{6.754}} \tag{8}$$

Adaptation capital corresponds to an unproductive share of fixed assets which reduces damage through a protection function of gross damage and follows a law of motion of capital with a uniform depreciation rate (9)(10)(11)(12)(13). As in Nguyen (Nguyen 2022), NFC and households' adaptation investment balances protection (via the protection function) and an opportunity cost term based on past operating surplus and a preference parameter α_{PF} (14) (15). The general government decides on its adaptation investment based on the (expected) gross damage to the economy (16). Expected gross damage equals the damage function multiplied by output (17). The protection function (PF), similarly as in World Bank (World Bank 2021), depends on the level of adaptation capital and the theoretical maximum amount of adaptation capital ($k_{t-1}^{A,max}$) to cover all damage incurred by climate change (18). The latter, while it originally depends on growth as damage is expected to increase proportionally to growth, was here assumed to increase with respect to accumulation to stabilize the model in the case of negative shocks on output (for example with increase in rates) (19). The net damage function (NDF_t) is gross damage reduced by the protection provided. (20)

$$i_t^A = i_t^{A,NFC} + i_t^{A,HH} + i_t^{A,GG} \tag{9}$$

$$k_t^{A,NFC} = (1-\delta)k_{t-1}^{A,NFC} + i_t^{A,NFC} \tag{10}$$

$$k_t^{A,HH} = (1-\delta)k_{t-1}^{A,HH} + i_t^{A,HH} \tag{11}$$

$$k_t^{A,GG} = (1-\delta)k_{t-1}^{A,GG} + i_t^{A,GG} \tag{12}$$

$$k_t^A = k_t^{A,NFC} + k_t^{A,HH} + k_t^{A,GG} \tag{13}$$

$$i_t^{A,NFC} = \alpha_{PF}(1-PF_t)GD_{Tt}^e + (1-\alpha_{PF})\left(\frac{k_{t-1}^{A,NFC}}{k_{t-1}} * \frac{OS_{t-1}^{NFC}}{k_{t-2}}\right) \tag{14}$$

$$i_t^{A,HH} = \alpha_{PF}(1-PF_t)GD_{Tt}^e + (1-\alpha_{PF})\left(\frac{k_{t-1}^{A,HH}}{k_{t-1}} * \frac{OS_{t-1}^{HH}}{k_{t-2}}\right) \tag{15}$$

$$i_t^{A,GG} = (1-PF_t)GD_{Tt}^e \tag{16}$$

$$GD_{Tt}^e = GDF_{Tt} * y \tag{17}$$

$$PF_t = \gamma_1^{PF}\left(\frac{k_{t-1}^A}{k_{t-1}^{A,max}}\right)^{\gamma_2^{PF}} GD_{Tt}^e \tag{18}$$

$$k_t^{A,max} = \frac{1+\frac{i_t}{k_{t-1}}}{\frac{i_t}{k_{t-1}}+\delta} \tag{19}$$

$$NDF_t = (1-PF_t)GDF_{Tt} \tag{20}$$

Production

Output

Gross Domestic Product (Gy) is determined by demand components following usual post-Keynesian and SFC demand-led assumption (22). Gross Domestic Product net of climate damage (y) corresponds to GDP minus net damage (23). A supply constraint is introduced through an output gap, a Cobb-Douglas production function determining it (25) (26) and exogenous TFP increases (27). Nominal variables are obtained with GDP component's GDP deflators (24). Aggregate consumption is the sum of household and government consumption. (28). Total investment is the sum of investments by NFCs, households, and government (29). Total changes in inventories are the sum of investments by NFCs and the government. (30). Total indirect taxes depend on output and carbon emissions with their respective rates (31). The operating surplus is calculated by subtracting wages, employer's social contributions, indirect taxes, and mixed income from GDP, then adding subsidies (30). The wage bill depends on the wage rate and nominal GDP and employer's social contribution to an exogenous share of the wage bill (33)(34).

$$Gy_t = c_t + i_t + \Delta v_t + ex_t - im_t \tag{22}$$

$$y_t = Gy_t(1 - NDF_t) \tag{23}$$

$$p_t^y y_t = p_t^{c,HH} c_t^{HH} + p_t^{c,GG} c_t^{GG} + p_t^{i,HH} i_t^{HH} + p_t^{i,NFC} i_t^{NFC} + p_t^{i,GG} i_t^{GG} + p_t^y \Delta v_t + p_t^{ex} ex_t - p_t^{im} im_t \tag{24}$$

$$y^* = A_t k_{t-1}^{\alpha} \mathrm{LF}_{t-1}^{1-\alpha} \tag{25}$$

$$og = \frac{y - y^*}{y^*} \tag{26}$$

$$A_t = \left(1 + \theta_{\mathrm{t}}^{\mathrm{A}}\right) A_{t-1} \tag{27}$$

$$c = c_t^{HH} + c_t^{GG} \tag{28}$$

$$i_t = i_t^{NFC} + i_t^{HH} + i_t^{GG} \tag{29}$$

$$\Delta v_t = \Delta v_t^{NFC} + \Delta v_t^{GG} \tag{30}$$

$$IT_t = \tau_{IT} Y_t + \tau_{CT} CE_t \tag{31}$$

$$OS_t = Y_t - WB_t + \mathrm{WB}_{\mathrm{t}}^{\mathrm{ROW}} - WB2ROW_t - SC_t - IT_t + SUBS_t + GSUBS_t - MIXY_t \tag{32}$$

$$WB_t = w_t \times Y_t \tag{33}$$

$$SC_t = \varphi_t^{SC} \times WB_t \tag{34}$$

Firms

Firms receive an exogenous share of the operating surplus, receive interest from their deposits and foreign assets, pay dividends on equity and interest in loans. They decide on investment and inventories, allocating a share of the investment to green capital following DEFINE. They then decide on how much cash to retain and how much foreign asset to purchase. They finance their deficit or surplus through loans and the rest with equity.

Financial Balance sheet

Asset	*Liabilities*
Deposits (M)	Loans (L)
Foreign Assets (FA)	Equity (E)
Other Assets (OA)	

Income

Non-financial Corporations receive an exogenous share (β_{NFC}) of operating surplus. (31). NFC's primary income adds up operating surplus, returns on deposits, foreign assets and other net payments, minus interest payments on loans and dividends (32). NFC disposable income equals primary income plus other net transfers minus direct taxes, which also equals NFC savings (33). Direct taxes paid by NFCs are a fixed fraction of lagged operating surplus (34).

$$OS_t^{NFC} = \beta_{NFC} OS_t \quad (35)$$

$$YP_{\text{NFC}} = OS_{\text{NFC}} + r_t^M M_{t-1}^{NFC} + r_t^{FA} FA_{t-1}^{NFC} + RTL_t^{NFC} - r_t^E E_{t-1}^{NFC} - r_t^L L_{t-1}^{NFC} + ONP_t^{NFC} \quad (36)$$

$$YD_t^{NFC} = YP_t^{NFC} - DT_t^{NFC} = S_t^{NFC} \quad (37)$$

$$DT_t^{NFC} = \phi_{CT} OS_{t-1}^{NFC} \quad (38)$$

Final demand

Similarly to Nguyen, Investment is a function of real lending rate, capacity utilization rate (proxied by output over potential output), profit rate and change in equity price (financialization decreases investment (Nguyen 2022)) (39). Following DEFINE**,** the share of green investment adjusts based on the difference between the unit cost of renewable and non-renewable energy (41). Firms' adaptation investment share is the ratio of adaptation investment to total NFC investment (41). Conventional investment is the residual of total investment after green and adaptation investments are subtracted (43). Both green and conventional capital depreciate at the same rate and accumulate with investment (44) (45). Total firms' productive capital is the sum of conventional and green capital stocks (46). Change in NFC inventories depends on sales and capacity utilization rate (47). Sales correspond to the sum of consumption, investment, and exports (48). The effective total unit cost of renewable energy is the base unit cost adjusted for green subsidies (49) and the total unit cost of non-renewable energy includes the base cost plus a tax component on emissions (adjusted for sequestration) (50). The base unit cost of renewable energy decreases with time reflecting on technology improvement and changes in non-fossil fuel usage (51). The initial unit cost of non-renewable energy increases to reflect resource depletion (52).

$$i_t^{NFC} = f\left[i_{t-1}^{NFC}; r_t^L; \frac{y_t}{y_t^*}; \frac{OS_{t-1}^{NFC}}{K_{t-2}^{NFC}}; \dot{p}_t^E\right] \tag{39}$$

$$i_t^{G,NFC} = \beta_t^{G,NFC} i_t^{NFC} \tag{40}$$

$$\beta_t^{G,NFC} = \beta_0^{G,NFC} - \beta_1^{G,NFC}(tucr_{t-1} - tucn_{t-1}) \tag{41}$$

$$\beta_t^{A,NFC} = \frac{i_t^{A,NFC}}{i_t^{NFC}} \tag{42}$$

$$i_t^{C,NFC} = i_t^{NFC}\left(1 - \beta_t^{G,NFC} - \beta_t^{A,NFC}\right) \tag{43}$$

$$k_t^{G,NFC} = (1 - \delta_t^{NFC})k_t^{G,NFC} + i_t^{G,NFC} \tag{44}$$

$$k_t^{C,NFC} = (1 - \delta_t^{NFC})k_t^{C,NFC} + i_t^{C,NFC} \tag{45}$$

$$k_t^{NFC} = k_t^{C,NFC} + k_t^{G,NFC} \tag{46}$$

$$\Delta v_t^{NFC} = f\left[s_t; \frac{y_{t-1}}{y_{t-1}^*};\right] \tag{47}$$

$$s_t = c_t + i_t + ex_t \tag{48}$$

$$tucr_t = ucr_t(1 - GSUBS_t) \tag{49}$$

$$tucn_t = ucn_t + \tau_{CT} INT_t^{CE}(1 - seq_t) \tag{50}$$

$$ucr_t = (1 - g_{ucrtech})ucr_{t-1} \tag{51}$$

$$ucn_t = (1 + g_{ucnressources})ucr_{t-1} \tag{52}$$

$$NFC_t^{NFC} = S_t^{NFC} - I_t^{NFC} - \Delta V_t^{NFC} \tag{53}$$

Financial side

Assets

Firms decide on how much liquidity to keep in the form of deposits. Japanese firms tended to accumulate cash and deposit over the last two decades due to uncertainty and an increase holding in intangible assets and foreign assets which are more difficult to collateralize (54). While corporate tax rate is found in Kim, Murphy et Xu (2023) to have a negative relationship with cash holding, the implicit direct tax rate did not show the correct sign nor significance during estimation and was then dropped. Declining domestic prospects, resource-seeking and market opportunities determine their holding on foreign assets. Foreign assets are hence a function of oil price (resource-seeking, expecting increase in foreign assets when resource prices increase to rely less on imports), USD-JPY spot exchange rate (yen depreciation against the dollar leading to capital outflows), potential growth and foreign demand (proxied by global industrial production index in the absence of world quarterly GDP) (56). Foreign assets are first estimated and change in foreign assets are obtained by subtracting net capital gains on foreign assets from the difference between both periods (a similar procedure is applied for deposits). Other assets are projected exogenously (58).

$$\Delta M_t^{NFC} = f[s_t; FA_t^{NFC}; IA_t^{NFC}] \tag{54}$$

$$M_t^{NFC} = M_{t-1}^{NFC} + \Delta M_t^{NFC} \tag{55}$$

$$FA_t^{NFC} = f\left[p_t^{oil}; x_t^{NFC}; g_{t-1}^{y*}; FD_t\right] \tag{56}$$

$$FA_t^{NFC} = FA_{t-1}^{NFC} + \Delta FA_t^{NFC} + NKG_t^{FA,NFC} \tag{57}$$

$$OA_t^{NFC} = OA_{t-1}^{NFC} + \Delta OA_t^{NFC} + NKG_t^{OA,NFC} \tag{58}$$

Financing

Funding is first obtained through loans and equity based on financing needs with a discrepancy term coming from the original data (between net lending and net acquisition of financial assets) (59). Japanese firms have been adjusting their debt-to-equity ratio by relying more on equity in the past two decades (Chong, Law et Yao 2016). Debt-to-equity ratio depends on firms' fixed assets over total assets, asset profitability (EBIT, proxied by operating surplus over past capital stock), relative cost of loans compared with equity, output gap and the VIX to account for financial volatility (60). Equity funds the residual funding needs of firms (63). NFC net wealth is computed from capital, inventory changes, deposits, foreign assets, minus loans and equity, plus other assets (65).

$$FUND_t^{NFC} = -(NFC_t^{NFC} - \Delta M_t^{NFC} - \Delta FA_t^{NFC} - \Delta \mathrm{OA}_t^{NFC} - disc_t^{NFC}) \tag{59}$$

$$\frac{L}{E_t}^{NFC} = f\left[\frac{k}{TA_t}^{NFC}; EBIT_t^{NFC}; r_{t-1}^{E} - r_{t-1}^{L}; VIX_t; og_t\right] \tag{60}$$

$$\Delta \mathrm{L}_t^{NFC} = \frac{L}{E_t}^{NFC} \left(\mathrm{L}_{t-1}^{NFC} + E_{t-1}^{NFC} + FUND_t^{NFC}\right) - \mathrm{L}_{t-1}^{NFC} \tag{61}$$

$$\mathrm{L}_t^{NFC} = \mathrm{L}_{t-1}^{NFC} + \Delta \mathrm{L}_t^{NFC} + NKG_t^{L,NFC} \tag{62}$$

$$\Delta E_t^{NFC} = \Delta L_t^{NFC} - FUND_t^{NFC} \tag{63}$$

$$E_t^{NFC} = E_{t-1}^{NFC} + \Delta E_t^{NFC} + NKG_t^{E,NFC} \tag{64}$$

$$NW_t^{NFC} = k_t^{NFC} p_t^k + \Delta v_t^{NFC} p_t^v + M_t^{NFC} + FA_t^{NFC} - L_t^{NFC} - E_t^{NFC} + OA_t^{NFC} \tag{65}$$

Household

Households receive income from wages and mixed income, interest in deposits, dividends, returns on pensions and insurance and other net payments. They pay for social contributions and income tax and receive social benefits. They first decide how much to consume and to invest, then on how much liquidity to hold, then how many loans to take. They then invest the remaining amount between equity, insurance/pensions and other assets following a Tobin approach based on expected returns.

Financial Balance sheet

Asset	*Liabilities*
Cash (H)	Loans (L)
Deposits (M)	
Equity (E)	
Insurance/Pension (INS)	
Other Assets (OA)	

Income

Household operating surplus equals wages, wages received from the ROW, and mixed income (66). Household primary income aggregates operating surplus and returns on various assets, minus interest on loans (67). Household disposable income corresponds to primary income minus taxes and social contributions, plus social benefits and other net transfers (68). Household direct taxes are a fixed fraction of primary income (69). Household savings equal disposable income minus consumption (70).

$$OS_t^{HH} = WB_t + WB_t^{ROW} + MIXY_t \tag{66}$$

$$YP_t^{HH} = OS_t^{HH} + r_t^M M_{t-1}^{HH} + r_t^{INS} INS_{t-1}^{HH} + r_t^{OA} OA_{t-1}^{HH} + r_t^E E_{t-1}^{HH} - r_t^{HL} L_{t-1}^{HH} + ONP_t^{HH} \tag{67}$$

$$YD_t^{HH} = YP_t^{HH} - DT_t^{HH} - SC_t^{HH} + SB_t^{HH} + ONT_t^{HH} \quad (68)$$

$$DT_t^{HH} = \phi_{IT} YP_t^{HH} \quad (69)$$

$$S_t^{HH} = YD_t^{HH} - C_t^{HH} \quad (70)$$

Final demand

Following Godley & Lavoie, consumption depends on disposable income and wealth (70). Investment under the form of an accumulation function (to stabilize projections) depends on change in mortgage rate, household loan-to-value ratio, uncertainty (proxied by the VIX) and the relative price of house to the price of investment (72).

$$c_t^{HH} = f\left(\frac{YD_t^{HH}}{p_t^c}; \frac{NW_{t-1}^{HH}}{p_t^c}\right) \quad (71)$$

$$\frac{i_t^{HH}}{k_{t-1}^{HH}} = f\left(\frac{YD_t^{HH}}{p_t^{i,HH}}; \frac{p_t^{house}}{p_t^{i,HH}}; r_{t-1}^{HL}; LTV_{t-1}^{HH}; VIX_{t-1}\right) \quad (72)$$

$$LTV_t^{HH} = \frac{L_t^{HH}}{K_t^{HH} + E_t^{HH} + INS_t^{HH} + OA_t^{HH}} \quad (73)$$

$$k_t^{HH} = (1 - \delta_t^{HH})k_{t-1}^{HH} + \left(1 - \beta_t^{A,HH}\right)i_t^{HH} \quad (74)$$

$$\beta_t^{A,HH} = \frac{i_t^{A,HH}}{i_t^{HH}} \quad (75)$$

$$NFC_t^{HH} = S_t^{HH} - C_t^{HH} - I_t^{HH} \quad (76)$$

Financial side

Households decide on how much liquidity they wish to hold as a buffer. Household deposits depending on consumption and net wealth effect from equity revaluation (75) and cash depending on deposits.

$$\Delta \mathrm{M}_t^{HH} = f(C_t^{HH} - C_{t-1}^{HH}; C_t^{HH}) \quad (77)$$

$$M_t^{HH} = M_{t-1}^{HH} + \Delta M_t^{HH} \quad (76)$$

$$\Delta \mathrm{H}_t^{HH} = f(\Delta \mathrm{M}_t^{HH}) \quad (77)$$

$$H_t^{HH} = H_{t-1}^{HH} + \Delta H_t^{HH} \quad (78)$$

They then decide on how many new loans to take following depending on changes in mortgage rate changes, real disposable income, capital indebtedness (loan to value ratio) and relative price of houses to investment (79) and invest in illiquid assets with the remaining amount (equity, insurance, other assets) (81) following a Tobin procedure (the share of illiquid assets before capital gains GIA_t^{HH} in the form of weights determined by expected returns determine the purchase of different assets) (81) (83) (86). Expected returns ρ depend on lagged returns as in Zezza (Zezza et Zezza 2020) with adaptative expectation based on 0.4, 0.3, 0.2 and 0,1 weights for lags from 1 to 4 (84) (87). Returns correspond to rate spread with government bonds rates and asset price changes $\dot{p}$ (85) (88). Other assets are then obtained as a residual (92).

$$\Delta L_t^{HH} = f\left(\Delta r_{t-1}^{HL}; \frac{YD_t^{HH}}{p_t^{c,HH}}; LTV_{t-1}^{HH}; \frac{p_{t-1}^{house}}{p_{t-1}^{i,HH}}\right) \tag{79}$$

$$L_t^{HH} = L_{t-1}^{HH} + \Delta L_t^{HH} + NKG_t^{L,HH} \tag{80}$$

$$\Delta IA_t^{HH} = NFC_t^{HH} - \Delta LA_t^{HH} + \Delta L_t^{HH} - \mathrm{disc}_t^{HH} \tag{81}$$

$$GIA_t^{HH} = E_{t-1}^{HH} + INS_{t-1}^{HH} + OA_{t-1}^{HH} + \Delta IA_t^{HH} \tag{82}$$

$$\lambda_t^{E,HH} = f\left([E|\rho]_t^{E,HH}\right) \tag{83}$$

$$[E|\rho]_t^E = 0.4 \times \rho_{t-1}^{E,HH} + 0.3 \times \rho_{t-2}^{E,HH} 0.2 \times \rho_{t-3}^{E,HH} 0.1 \times \rho_{t-4}^{E,HH} \tag{84}$$

$$\rho_t^{E,HH} = \dot{p}_t^{E,HH} + \left(r_t^{E,HH} - r_t^{M,HH}\right) \tag{85}$$

$$\lambda_t^{INS,HH} = f([E|\rho]_t^{INS}, HH) \tag{86}$$

$$[E|\rho]_t^{INS} = 0.4 \times \rho_{t-1}^{INS,HH} + 0.3 \times \rho_{t-2}^{INS,HH} 0.2 \times \rho_{t-3}^{INS,HH} 0.1 \times \rho_{t-4}^{INS,HH} \tag{87}$$

$$\rho_t^{INS,HH} = \dot{p}_{t-1}^{INS,HH} + \left(r_{t-1}^{INS,HH} - r_{t-1}^{M,HH}\right) \tag{88}$$

$$E_t^{HH} = \lambda_t^{E,HH} GIA_t^{HH} + NKG_t^{E,HH} \tag{89}$$

$$\Delta E_t^{HH} = E_t^{HH} - \mathrm{E}_{t-1}^{HH} - \mathrm{NKG}_t^{E,HH} \tag{90}$$

$$INS_t^{HH} = INS_t^{HH} - INS_{t-1}^{HH} - \mathrm{NKG}_{t-1}^{INS,HH} \tag{91}$$

$$\Delta OA_t^{HH} = \Delta IA_t^{HH} - \Delta E_t^{HH} - \Delta INS_t^{HH} \tag{92}$$

$$INS_t^{HH} = \lambda_t^{INS,HH} GIA_t^{HH} + NKG_t^{INS,HH} \tag{93}$$

$$OA_t^{HH} = OA_{t-1}^{HH} + \Delta OA_t^{HH} + NKG_t^{OA,HH} \tag{94}$$

$$NW_t^{HH} = k_t^{HH} p_t^k + H_t^{HH} + M_t^{HH} + E_t^{HH} + INS_t^{HH} - L_t^{HH} + OA_t^{HH} \tag{95}$$

Government

The Government collects taxes and receives interest on deposits and other assets, the central bank's profits, pays subsidies, green subsidies, interests and social benefits. Consumption, Changes in Inventories and investments are exogenous. It finances its deficit through bonds.

Financial Balance sheet

Asset	*Liabilities*
Deposits (M) Other Assets (OA)	Bonds (B)

Income

Government operating surplus equals indirect taxes net of subsidies (96). Government primary income aggregates operating surplus returns on deposits, central bank profits and net other payments, minus bond interest (97). Government disposable income is primary income plus taxes and other net transfers minus social benefits (98). Government social benefits are modeled as a function of unemployment and the elderly population (99).

$$OS_t^{GG} = IT_t^{GG} - SUBS_t^{GG} - GSUBS_t^{GG} \tag{96}$$

$$YP_t^{GG} = OS_t^{GG} + r_t^M M_{t-1}^{GG} + \mathrm{ONP}_{t-1}^{GG} - r_t^B B_{t-1}^{GG} + \Pi\mathrm{CB}_t^{GG} \tag{97}$$

$$YD_t^{GG} = YP_t^{GG} + DT_t^{GG} + SC_t^{HH} - SB_t^{HH} + \mathrm{ONT}_{t-1}^{GG} \tag{98}$$

$$SB_t^{GG} = f\left(u_t; \frac{POP_t^{>65}}{POP_t}\right) \tag{99}$$

$$DT_t^{GG} = DT_t^{NFC} + DT_t^{FI} \tag{100}$$

$$S_t^{GG} = YD_t^{GG} - C_t^{GG} - I_t^{GG} - \Delta V_t^{GG} \tag{101}$$

Final demand

Government consumption, investment and inventories are projected exogenously (101) (102). The share of government investment allocated to green projects (104) (106). Government green subsidies level is given by a green subsidy share of renewable energy times non-fossil fuel energy use (108).

$$C_t^{GG} = (1 + \alpha_{CG})C_{t-1}^{GG} \tag{102}$$

$$i_t^{GG} = k_t^{GG} - k_{t-1}^{GG}(1 - \delta_t^{GG}) \tag{103}$$

$$\beta_t^{G,GG} = \frac{i_t^{G,GG}}{i_t^{GG}} \tag{104}$$

$$\beta_t^{A,GG} = \frac{i_t^{A,GG}}{i_t^{GG}} \tag{105}$$

$$I_t^{G,GG} = I_t^{G,GG} \tag{106}$$

$$I_t^{C,GG} = I_t^{GG}\left(1 - \beta_t^{A,GG} - \beta_t^{G,GG}\right) \tag{107}$$

$$\Delta V_t^{GG} = \beta_{VG} V_{t-1}^{GG} \quad (108)$$

$$GSUBS_t^{GG} = \beta_{GSUBS_t}{}^{GG} ENE_t^{NFF} ucr_t \quad (109)$$

Financial side

Government deposits and other assets are projected exogenously (109), and the general government finances its deficit through bonds (114).

$$\Delta M_t^{GG} = M_t^{GG} - M_{t-1}^{GG} \quad (110)$$

$$M_t^{GG} = M_{t-1}^{GG} + \Delta M_t^{GG} \quad (111)$$

$$\Delta OA_t^{GG} = OA_t^{GG} - OA_{t-1}^{GG} \quad (112)$$

$$OA_t^{GG} = OA_{t-1}^{GG} + \Delta OA_t^{GG} + NKG_t^{OA,GG} \quad (113)$$

$$\Delta B_t^{GG} = -(NFC_t^{GG} - C_t^{GG} - I_t^{GG} - \Delta V_t^{GG} - \Delta M_t^{GG} - \Delta OA_t^{GG} - \mathrm{disc}_t^{GG}) \quad (114)$$

$$B_t^{GG} = B_{t-1}^{GG} + \Delta B_t^{GG} + NKG_t^{B,GG} \quad (115)$$

$$NW_t^{GG} = k_t^{GG} p_t^k + M_t^{GG} - B_t^{GG} + OA_t^{GG} \quad (116)$$

Central Bank

The central bank's behavior appears difficult to model as it has been using unconventional monetary policy which increased bank's reserves while staying at the lower bound over a long period, making Taylor rule estimation difficult. It receives profits based on its balance sheet that it gives back to the general government. The BOJ intervenes by setting interest rates and purchasing government bonds, effectively setting bank's reserves in times of UMP.

Financial Balance sheet

Asset	*Liabilities*
Reserves (RES)	Bank reserves (R)
Advances (AD)	Cash (H)
Bonds (B)	
Other Assets (OA)	

Monetary Policy and Central Bank Intervention

The central bank in normal times provides advances to financial institutions and deposits to the government and cash to households on demand (118)(119)(121). It holds international reserves

(117) and it receives interests on advances, government bonds, and pays interests to the banks (123). It fixes its refinancing rate following an augmented Taylor rule with response to spread with the FED's rate (124). Its reserve rate is based on the refinancing rate and quantitative easing (QE) activation. QE activation follows a logistic regression based on inflation, output gap, central bank refinancing rate and change in refinancing rate (126). It is activated when probability is superior to 0.5. When QE is active, banks reserves are supply determined by the central bank (Zezza et Zezza 2020) which targets a certain share of government bonds depending. Bond purchase depends on QE activation, change in government bond yield (to take into account yield curve control policies), output gap and inflation rate differential with the 2% target (133). Excess reserves are the difference between reserve requirements and total reserves (128).

$$\Delta RES_t^{CB} = RES_t^{CB} - RES_{t-1}^{CB} \tag{117}$$

$$\mathrm{H}_t^{CB} = \mathrm{H}_t^{HH} \tag{118}$$

$$M_t^{GG,CB} = \mathrm{M}_t^{GG,CB} \tag{119}$$

$$RES_t^{CB} = RES_{t-1}^{CB} + \Delta RES_t^{CB} + NKG_t^{RES,CB} \tag{120}$$

$$\Delta AD_t^{CB} = \Delta AD_t^{FI} \tag{121}$$

$$AD_t^{CB} = AD_{t-1}^{CB} + \Delta AD_t^{CB} \tag{122}$$

$$\Pi \mathrm{CB}_t = r_t^A AD_{t-1} + r_t^B B_{t-1}^{CB} - r_t^R ER_{t-1} \tag{123}$$

$$r_t^{AD} = f(\pi_t - \pi^*; og_t; \$SPREAD_{t-1}; r_{t-1}^{AD}) \tag{124}$$

$$r_t^{ER} = f(r_t^{AD}; QE_t) \tag{125}$$

$$P(QE(t) = 1) = \frac{1}{1 + \exp\left(-(\beta_0 + \beta_1 og_t + \beta_2 r_t^R + \beta_3 \pi_t)\right)} \tag{126}$$

$$\Delta R_t = \begin{cases} R_t^d, & QE_t = 0 \\ R_t^d + R_t^s, & QE_t = 1 \end{cases} \tag{127}$$

$$ER_t = R_t - RR_t^{FI} \tag{128}$$

$$RR_t^{FI} = \propto_{RR} M_t \tag{129}$$

$$R_t^s = B_t^{d,CB} \tag{130}$$

$$R_t^{CB} = R_{t-1}^{CB} + \Delta R_t \tag{131}$$

$$\Delta B_t^{CB} = \begin{cases} 0, & QE_t = 0 \\ B_t^{d,CB}, & QE_t = 1 \end{cases} \tag{132}$$

$$B_t^{d,CB} = f\left(\Delta B_{t-1}^{CB}; \pi_t - \pi^*; og_t; \$SPREAD_{t-1}; \$SPREAD_{t-2}; QE_t\right) \quad (133)$$

$$B_t^{CB} = B_{t-1}^{CB} + \Delta B_t^{CB} + NKG_t^{B,CB} \quad (134)$$

$$OA_t^{CB} = OA_{t-1}^{CB} + \Delta OA_t^{CB} + NKG_t^{OA,CB} \quad (135)$$

$$NW_t^{CB} = B_t^{CB} + AD_t^{CB} - H_t^{HH} - M_t^{GG} - R_t^{CB} + OA_t^{CB} \quad (136)$$

Financial Institutions

Financial institutions receive a share of the operating surplus, receive interests on reserves, household loans, conventional loans, green loans, government bonds, foreign assets and other assets, and pay interests on advances and deposits, insurance/pensions and dividends on net equity. They adjust their reserves, accommodate demand for loans and allocate their remaining income between government bonds, equity, foreign assets and other assets. They finance the rest through equity and advances works as a residual similarly to Nguyen as the central bank acts as a lender of last resort.

Financial Balance sheet

Asset	***Liabilities***
Bank reserves (R)	Advances (AD)
Loans (L)	Equity (E)
Bonds (B)	Deposits (M)
Foreign Assets (FA)	Insurance/pension (INS)
Other Assets (OA)	

Income

Financial institutions receive a fixed share of aggregate operating surplus (137). Their primary income aggregates return on various assets other net payments, minus payments on advances, deposits, and insurance/pensions (138). Corporate taxes are a fixed fraction of their operating surplus.

$$OS_t^{FI} = \beta_{FI} OS_t \quad (137)$$

$$\begin{aligned} YP_t^{FI} = {} & OS_t^{FI} + r_t^{ER} ER_{t-1} + r_t^{HL} L_{t-1}^{HH} + r_t^{L} L_{t-1}^{NFC} + r_t^{B} B_{t-1}^{FI} + r_t^{FA} FA_{t-1}^{FI} \\ & - r_t^{E} E_{t-1}^{FI} - r_t^{AD} AD_{t-1} - r_t^{M} M_{t-1}^{HH} - r_t^{INS} INS_{t-1}^{HH} \end{aligned} \quad (138)$$

$$YD_t^{FI} = YP_t^{FI} - DT_t^{FI} \tag{139}$$

$$DT_t^{FI} = \phi_{CT} OS_{t-1}^{FI} \tag{140}$$

$$S_t^{FI} = YD_t^{FI} \tag{141}$$

Financial side

Financial institutions accommodate the demand for household and firms' loans (144), insurance/pension products (146), and deposits (143) and adjust their reserves accordingly (150). The financial sector closes the bond market as the BOJ can purchase bonds with QE (148). They then purchase foreign assets based on changes in reserves and domestic prospects (proxied by GDP over potential GDP), the spot exchange rate, price changes in foreign assets to seek profit as their foreign assets mainly consist of portfolio investment (152). Banks financed themselves through deposits, insurance and through equity following a constant exogenous share of equity to assets (154). Change in other assets is the residual sum of changes in other assets across NFCs, households, government, and ROW following (156) (Nguyen 2022). The central bank, being a lender of last resort provides advances to close financing needs (158).

$$\Delta M_t^{FI} = \Delta M_t^{HH} + \Delta \mathrm{M}_t^{NFC} \tag{142}$$

$$M_t^{FI} = M_{t-1}^{FI} + \Delta \mathrm{M}_t^{FI} \tag{143}$$

$$\Delta L_t^{FI} = \Delta L_t^{HH} + \Delta L_t^{NFC} \tag{144}$$

$$L_t^{FI} = L_{t-1}^{FI} + \Delta L_t^{FI} + NKG_t^{L,FI} \tag{145}$$

$$\Delta INS_t^{FI} = \Delta INS_t^{HH} \tag{146}$$

$$INS_t^{FI} = INS_{t-1}^{FI} + \Delta INS_t^{FI} + NKG_t^{INS,FI} \tag{147}$$

$$\Delta B_t^{FI} = \Delta B_t^{GG} - \Delta B_t^{CB} - \Delta B_t^{ROW} \tag{148}$$

$$B_t^{FI} = B_{t-1}^{FI} + \Delta B_t^{FI} + NKG_t^{B,FI} \tag{149}$$

$$R_t^d = \max(\alpha_{RR} M_\mathrm{t} - R_{t\text{-}1}^{FI}; 0) \tag{150}$$

$$R_t^{FI} = R_{t-1}^{FI} + \Delta R_t^{FI} \tag{151}$$

$$\Delta FA_t^{FI} = f\left[\Delta R_t^{FI}; \frac{y_{t-1}}{y_{t-1}^*}; x_t; \dot{p}_{t-1}^{FA}; \dot{p}_{t-2}^{FA}\right] \tag{152}$$

$$FA_t^{FI} = FA_{t-1}^{FI} + \Delta FA_t^{FI} + NKG_t^{FA,FI} \tag{153}$$

$$\Delta E_t^{FI} = \gamma_t^{E,FI}(M_t^{FI} + \mathrm{AD}_t^{FI} + OA_t^{FI} - NKG_t^{E,FI}) - \Delta \mathrm{E}_{t-1}^{FI} \quad (154)$$

$$E_t^{FI} = E_{t-1}^{FI} + \Delta E_t^{FI} + NKG_t^{E,FI} \quad (155)$$

$$\Delta OA_t^{FI} = -(\Delta OA_t^{NFC} + \Delta OA_t^{HH} + \Delta OA_t^{GG} + \Delta OA_t^{ROW}) \quad (156)$$

$$OA_t^{FI} = OA_{t-1}^{FI} + \Delta OA_t^{FI} + NKG_t^{OA,FI} \quad (157)$$

$$\Delta AD_t^{FI} = -(YD_t^{FI} - \Delta \mathrm{FA}_t^{FI} - \Delta \mathrm{L}_t^{FI} - \Delta \mathrm{B}_t^{FI} - \Delta \mathrm{R}_t^{FI} + \Delta \mathrm{E}_t^{FI} + \Delta \mathrm{M}_t^{FI} - \mathrm{disc}_t^{FI}) \quad (158)$$

$$AD_t^{FI} = AD_{t-1}^{FI} + \Delta AD_t^{FI} \quad (159)$$

$$NW_t^{FI} = R_t^{FI} + B_t^{FI} + FA_t^{FI} + L_t^{FI} - E_t^{FI} - AD_t^{FI} - M_t^{FI} - INS_t^{FI} + OA_t^{FI} \quad (160)$$

Rest of the world

Exports are determined by foreign demand. The ROW exogenously demands bonds, purchases residual equity and other assets are exogenously projected. It accommodates official reserves and for foreign asset demand.

Financial Balance sheet

Asset	*Liabilities*
Bonds (B)	Reserves (RES)
Equity (E)	Foreign Assets (FA)
Other Assets (OA)	

Income

The rest of the world's operating surplus equals the difference between wages paid and received by the ROW (161). The ROW's primary income aggregates operating surplus with returns on bonds, equity, foreign assets (subtracted), and other assets (162). ROW savings are defined as disposable income adjusted by the trade balance (exports minus imports) (164).

$$OS_t^{ROW} = WB2ROW_t^{ROW} - WB_t^{ROW} \quad (161)$$

$$YP_t^{ROW} = OS_t^{ROW} + r_t^B B_{t-1}^{ROW} + r_t^E E_{t-1}^{ROW} - r_t^{FA} FA_{t-1}^{ROW} + r_t^{OA} OA_{t-1}^{ROW} \quad (162)$$

$$YD_t^{ROW} = YP_t^{ROW} \quad (163)$$

$$S_t^{ROW} = YD_t^{ROW} - IM_t + EX_t \quad (164)$$

Final demand

Following Nguyen and Zezza**,** imports are estimated based on domestic demand and import prices relative to domestic prices and export prices (to account for intermediate consumption) (169). Export demand depends on lagged foreign demand (proxied by world Industrial Production Index), the relative export price, and foreign asset holdings (170). Import prices are determined by oil prices, relative prices and the spot exchange rate (171) and export prices on unit labor cost, share of non-regular workers (which impact bargaining power), import prices (to account for intermediate goods), exchange rate. Foreign and oil prices are exogenous. Exchange rate depends on the bond spread (Yen-dollar), relative prices, trade balance, foreign reserves and the spread with the FED rate (173).

$$im_t = f\left(DMD_t; DMD_{t-1}; \frac{p_t^{im}}{p_t^y}; \frac{p_t^{im}}{p_t^{ex}}\right) \quad (165)$$

$$ex_t = f(FD_{t-1}; x_{t-1}; FD_t) \quad (166)$$

$$p_t^{im} = f\left(p_{t-1}^{oil}; \frac{p_t^y}{p_t^{ROW}}; x_{t-1}\right) \quad (167)$$

$$p_t^{ex} = f\left(p_{t-1}^{im}; ULC_{t-1}; NRW_{t-1}; x_{t-1}\right) \quad (168)$$

$$x_t = f\left(r_t^B - r_t^{\$}; \frac{p_t^y}{P_t^{ROW}}; tb_t; r_t^{AD} - r_t^{US}; RES_t; p_{t-1}^{oil}\right) \quad (169)$$

$$tb_t = ex_t - im_t \quad (170)$$

Financial side

Bond demanded by the external sector are exogenously determined (173). The ROW closes the equity market by purchasing the residual (175). It also accommodates demand in foreign assets (177). Other assets are exogenous (178).

$$\Delta RES_t^{ROW} = \Delta RES_t^{CB} \quad (171)$$

$$RES_t^{ROW} = RES_{t-1}^{ROW} + \Delta RES_t^{ROW} \quad (172)$$

$$\Delta B_t^{ROW} = B_t^{ROW} - B_{t-1}^{ROW} \quad (173)$$

$$\Delta E_t^{ROW} = \Delta E_t^{NFC} + \Delta E_t^{FI} - \Delta E_t^{HH} \quad (174)$$

$$E_t^{ROW} = E_{t-1}^{ROW} + \Delta E_t^{ROW} \quad (175)$$

$$\Delta FA_t^{ROW} = \Delta FA_t^{NFC} + \Delta FA_t^{FI} \quad (176)$$

$$FA_t^{ROW} = FA_{t-1}^{ROW} + \Delta FA_t^{ROW} \quad (177)$$

$$\Delta OA_t^{ROW} = OA_t^{ROW} - OA_{t-1}^{ROW} \quad (178)$$

$$\mathrm{NW}_t^{ROW} = S_t^{ROW} + B_t^{ROW} + E_t^{ROW} - RES_t^{ROW} - FA_t^{ROW} - OA_t^{ROW} \quad (179)$$

Labor market

Population and the population above 65 are projected exogenously (180) (181). Active population depends on lagged labor force, population above 65, population and female labor force participation to take into account the effect of Womenomics (182). Based on Nguyen**,** the number of employed workers depends on lagged GDP (demand side) and active population (supply side) (184). Wage rate growth is determined by unemployment, labor productivity (GDP/Workers) and the share of non-regular workers (Aoyama, et al. 2022) (Fujiwara et Di Guilmi 2022)(187).

$$POP_t = \left(1 + \gamma_{pop}\right)POP_{t-1} \quad (180)$$

$$\mathrm{POP}_t^{>65} = \gamma_{>65} POP_t \quad (181)$$

$$LF_t = f\left(POP_t; LF_{t-1}; \mathrm{POP}_t^{>65}, WLF_t\right) \quad (182)$$

$$NbW = f(LF_t; y_t) \quad (184)$$

$$w_t = f\left(U_{t-1}; \frac{y_{t-1}}{NbW_{t-2}}; \frac{NRW_t}{NbW_t}\right) \quad (185)$$

$$U_t = 1 - \frac{NbW_t}{LF_t} \quad (186)$$

$$ULC_t = \frac{WB_t + SC_t}{Y_t} \quad (187)$$

Prices, interest rates & asset pricing

Price level

GDP deflator is a function of output gap, unit labor cost, import price, potential output to take into account underlying long term deflationary trends and non-regular workers to proxy for losses of bargaining power and deflationary wage pressures (192). Prices of domestic GDP components are based on GDP deflator for household consumption and firms' investment (189). Household investment being mainly residential, its price deflator does not follow the same dynamics, and it is based on construction cost proxied by unit labor cost, price of import and mortgage interest rate, on GDP deflator and on housing prices (191). Government investment following similar dynamics as household investment deflator, it follows GDP deflator, household investment deflator and spot exchange rate (190). As in Nguyen with consumption price, the government consumption deflator is a residual (195).

$$p_t^y = f\left(y_{t-1}^*; \frac{y_{t-1}}{y_{t-1}^*}; ULC_{t-1}; x_t; og_t; NRW_t; \frac{IT_{t-1}}{Y_{t-1}}\right) \quad (188)$$

$$p_t^{I,NFC} = f(p_{t-1}^y) \quad (189)$$

$$p_t^{I,GG} = f(p_{t-1}^y; p_{t-1}^{i,HH}; x_t) \quad (190)$$

$$p_t^{I,HH} = f(p_{t-1}^y; p_{t-1}^{im}; ULC_t; r_{t-1}^{HL}; p_{t-1}^{house}) \quad (191)$$

$$p_t^{C,GG} = f(p_{t-1}^y) \quad (192)$$

$$p_t^{V,GG} = f(p_{t-1}^y) \quad (193)$$

$$p_t^{V,NFC} = f(p_{t-1}^y) \quad (194)$$

$$p_t^{C,GG} = \frac{Y_t - I_t - C_t^{HH} - EX_t + IM_t}{y_t - i_t - c_t^{HH} - ex_t + im_t} \quad (195)$$

$$\pi_t = \frac{p_t^y - p_{t-1}^y}{p_{t-1}^y} \quad (196)$$

Asset pricing

Following Zezza & Zezza's methodology (Zezza et Zezza 2020) and Nguyen (Nguyen 2022). Asset price changes and net capital gains (revaluation due to changes in asset price or write offs) are modeled for equities, bonds, foreign assets and loans (assuming firms and households follow the same patterns) based on (197) and (198). Change in loan values (due for example to write-offs) depend on income effects from revaluation in equity (change in equity price) and household indebtedness (loan to value ratio). Change in bond valuations follow changes in refinancing rates, spread between US treasury bond and JGB bonds, central bank's interventions (changes in CB holding of bonds over total bonds) and changes in equity prices (200). Growth in equity prices is related to the Nikkei225 index, to changes in implicit bond rates, to financial volatility (VIX) and to changes in exchange rate which would impact exports and imports (200). Changes in foreign asset prices depend on their past value, change in equity prices and the VIX (201). Net capital gains for each assets indexed are then derived (202-207).

Estimate for equity prices following Zezza:

$$E_t = E_{t-1} + \Delta E_t + \dot{p}_t^E E_t \quad (197)$$

Hence:

$$\dot{p}_t^E = \frac{E_t - E_{t-1} - \Delta E_t}{E_t} = \frac{REVAL_t^E}{E_t} \quad (198)$$

Price changes are then estimated endogenously as specified, assuming an identical basket of assets within each asset category.

$$\dot{p}_t^L = f(\dot{p}_{t-1}^L; \Delta r_{t-1}^L; \Delta OS_t; VIX) \quad (199)$$

$$\dot{p}_t^B = f\left(\dot{p}_{t-1}^B; \Delta r_{t-1}^{AD}; r_t^B - r_t^{\$}; \frac{\Delta B_{t-1}^{CB}}{B_{t-1}}; \dot{p}_t^E\right) \quad (200)$$

$$\dot{p}_t^E = f(\Delta Nikkei225_{t-1}; VIX_t; VIX_{t-1}; \Delta x_{t-1}) \quad (201)$$

$$\dot{p}_t^{FA} = f\left(\dot{p}_{t-1}^{FA}; \dot{p}_{t-2}^{FA}; \dot{p}_t^E; VIX_t\right) \quad (202)$$

$$NKG_{a,t}^{NFC} = \dot{p}_t^a a_{t-1}^{NFC} \quad (203)$$

$$NKG_{a,t}^{HH} = \dot{p}_t^a a_{t-1}^{HH} \quad (204)$$

$$NKG_{a,t}^{GG} = \dot{p}_t^a a_{t-1}^{GG} \quad (205)$$

$$NKG_{a,t}^{CB} = \dot{p}_t^a a_{t-1}^{ROW} \quad (206)$$

$$NKG_{a,t}^{FI} = \dot{p}_t^a a_{t-1}^{FI} \quad (207)$$

$$NKG_{a,t}^{ROW} = \dot{p}_t^a a_{t-1}^{ROW} \quad (208)$$

Rates

At the ZLB estimations for rates are trickier due to the effect of quantitative easing. Rates on government bonds were also used to take into account the effect of quantitative easing on other lending rates. Lending rates to firms depends on government bond's rate, collaterals (fixed assets) and equity yield (to account for firm's performance) (208). Deposit rates depend on refinancing rates for banks and the lagged spread between deposit rates and refinancing rates (209). Mortgage rates depend on bond rates (210). Bond rates depend on the refinancing rate and central bank's acquisition of government bonds (211). Insurance returns depend on underlying portfolios which would contain bonds and equity, insurance and pension yields hence depend on equity and bond yield (212). Dividends are a share of firms and financial institutions' operating surpluses, and equity yields are hence dividends per equity (212)(213). Foreign assets yield depends on their past value, GDP growth (to account for relative changes in yield when domestic conditions increase or decrease) and US treasury bond rates (215).

$$r_t^L = f\left(r_{t-1}^b; k_{t-1}^{NFC}; r_{t-1}^E\right) \quad (209)$$

$$r_t^M = f(r_t^{AD}; r_{t-1}^M - r_{t-1}^{AD}) \quad (210)$$

$$r_t^{HL} = f\left(r_t^b\right) \tag{211}$$

$$r_t^B = f\left(r_{t-1}^{AD}; \Delta B_{t-1}^{CB}\right) \tag{212}$$

$$r_t^{INS} = f(r_t^B; r_t^E) \tag{213}$$

$$r_t^E = \frac{DIV_t}{E_{t-1}^{NFC} + E_{t-1}^{FI}} \tag{214}$$

$$DIV_t = \gamma_t^{DIV}(OS_t^{NFC} + OS_t^{FI}) \tag{215}$$

$$r_t^{FA} = f\left(r_{t-1}^{FA}; \mathrm{g}_t^y; x_t; \mathrm{r}_t^{US}\right) \tag{216}$$

3.3 – Data

3.3.1 – Data collection

Non-seasonally adjusted data between 1997 and 2023 was obtained from various sources, mainly from Japanese national accounts and BOJ statistics for Japanese data which are based on the 2008 System of National Accounts. Non-seasonally adjusted data was chosen as seasonally adjusted data can create discrepancies and financial data do not have seasonal adjustment. Quarterly flow of fund data exists both in national accounts and Bank of Japan statistics, but the latter was opted for as it disaggregated the central bank from financial institutions and discrepancies between the NLB and NAFA occur in both datasets. Financial data consists in three main tables: stocks of assets and liabilities, transaction of asset and liabilities and reconciliation tables. Stocks and liabilities follow market values and reconciliation tables consist in differences between stocks at the previous table, final stocks and transaction amount. They represent changes in valuation and write-offs and are understood as net capital gains (NKG) in this study.

Quarterly real economy variables such as GDP and its components, GDP price deflators, capital stock, primary and disposable income (and its components) are taken from the national accounts (integrated accounts, income and outlay accounts, main time series). Labor market data (labor force, number of workers, participation) were extracted from labor force surveys. Annual population data and previsions were taken from Japan's statistical yearbook. Refinancing and deposit facility rates are taken from the BOJ statistics.

Other data was extracted from various international databases. Primary energy consumption and WTI oil price predictions were taken from the International Energy Agency. The unit cost of renewables and fossil fuels were also taken from the Levelized Cost of Electricity (LCOE) at the IEA. Exchange rates are expressed in JPY-USD. Exchange rates, WTI oil prices, FED rates, US treasury bond rate, house prices, the NIKKEI225 index were taken from the FRED Louis database. Global price data was taken from the global inflation database. Intangible assets were taken from the OECD database. Carbon emissions, fossil fuel energy consumption, renewable energy consumption were taken from the World Bank World Development Indicator database. Temperature increases for SSP1, SSP2, SSP3 and SSP5 were taken from the World Bank Climate Knowledge Portal database.

3.3.2 – Data Treatment

As often with stock-flow consistent modeling, some data are unavailable, and discrepancies arise which necessitate a heavy data treatment before processing with the model.

First, balance sheet simplifications require the aggregation and reclassification of asset categories. The method which was opted for was to determine the amount of each asset based on the sole sector supposed to hold it as an asset or a liability. The symmetric liability in the opposite sector was then retrenched to this amount to equal holdings of each asset and liability and the rest reclassified as (netted out) other assets. This procedure was applied to all stocks, transactions and revaluations. Because of market revaluations, there is a (large) discrepancy between total assets and total liabilities in the initial datasets. There are several ways of coping with this sort of issue, for example by moving this discrepancy into one of the sector's other assets or ignoring capital gains and reconstructing stocks and flows from initial stocks and transactions only. However, the method opted for was to keep the difference through a discrepancy term. The reclassification of assets and liabilities eventually forces the discrepancy into net other assets as by construction all assets and liabilities are equal for modeled non-residual financial instruments.

Secondly, similarly to past approaches, implicit rates were estimated for different financial assets based on revenue over lagged amount of assets, and other rates were deducted, adding for a payment discrepancy term to ensure data match. As the government's main liability is bonds, the implicit rate was obtained from interest payment and the amount of outstanding bonds. Rates on foreign assets were obtained from the rest of the world property income payments over the amount of foreign assets. The share of dividends from operating surplus was obtained first by estimating it from household dividend revenue and generalizing to all dividends. Firms loan rate was obtained from firms' interest payments over their amount of loans. The same process was applied to mortgage rates. Deposit rate was deducted after estimating based on household interest revenue and deposits. Insurance and pension products were estimated based on insurance revenues over total insurance. Other net payments consist in the difference between national accounts data and model estimated payment data. A similar procedure was applied to transfers where only direct taxes, social contributions and benefits were kept and the rest classified as other net transfers.

Another key issue stemming from data differences comes from the difference in the original data between the NLB and the NAFA. Theoretically, net changes in stocks of assets and liabilities should correspond to net lending/borrowing in the transaction-flow matrix. In essence, after receiving income, spending it on consumption, investment or inventories, the resulting surplus or deficit implies either a capacity or a need for funding. No matter what purchases are made in the financial sphere (for example purchasing foreign assets for companies or pension products for households), the net acquisition of financial assets must be equal to this surplus/deficit. For example, in the case of expenditures higher than income, the household sector must take out loans to finance its deficits. In practice, the NLB does not equal the NAFA (which comes from the way data is collected or estimated, which varies between agencies and datasets). A discrepancy term between the NLB and the NAFA is therefore systematically implemented. In projections out of sample to 2050 these discrepancies were progressively brought to 0 at a quarterly 5% rate.

When data was available at different frequencies than quarterly several methods were applied. There were very few missing observations in time series (for example three quarters on women labor force participation) and they were hence dealt with linear interpolation. Regarding national income data, while sectoral disaggregation is available for most sectors, it is not the case for NFC, FI and NPISH (which must be aggregated with households). Hence, the remaining quarterly income outlay amounts were proportionally allocated based on annual calendar year data with the financial acting as a residual (as with rounding since NPISH amounts are very small, having it as a sector can lead to negative amounts for payments or receipts). Regarding the LCOE, since the mitigation calibration follows DEFINE which is expressed in trillion USD per EJ, an exchange rate of 150 yen per dollar was used to convert the data into yens. Exogenous data when not available for 2050 (for example other assets, reserves, oil prices) were projected based on the average of the last four values of a variable or the trend growth concerned variables.

3.4 – Estimation

The entire model was then coded in R and estimations and simulations were made with the BIMETS package and making use of existing code provided by Passarella (Passarella et Canelli 2022). Econometric estimations used basic Ordinary Least Square (OLS) and Error Correction Model (ECM) with separate estimations for short and long run coefficients as in Zezza. The final model uses more than 440 variables for 103 observations (as degrees of freedom are burnt with the use of up to 4 lags) and estimation is performed over 1999/Q1 to 2023/Q3. As data is non-seasonally adjusted, seasonality was treated with seasonal dummies. Specific disrupting events such as a very large variation in financial data in Q3 and Q4 2007, the Global Financial Crisis (GFC) and the COVID-19 pandemic were treated with dummies. The latter, however, did not always show significance and could be dropped to improve model fit and parsimony.

Estimations sometimes showcased surprising results regarding the sign of certain coefficients. Several factors could cause these results: data construction, estimation techniques (multicollinearity, omitted variable), equation specification, difference in underlying parameters in the Japanese economy due to its structure, difficulties in estimation due to the sample as the Japanese economy experienced deflation, long periods at the zero lower bound and unconventional monetary policy for the last 2 decades. Results were kept as model fit was generally good both in individual equations and forecasting, but further research could improve estimations through more robust econometric techniques, a different data treatment, a larger sample size by reclassifying pre-1997 (2008 SNA) data to increase sample size.

The following tables summarize econometric estimations with coefficients, significance levels (at the 0,5, 0,1 and 0,01 levels) standard errors and key statistics. Variable names were rewritten to facilitate interpretation and readability.

Firm investments (log)

eq. 1	Coefficients	Significance level	Statistics	
Intercept	2.592564	***	**Std. Er.**	0.02400778
Firm investments (log, lag 1)	+0.8089043	***	**Sample**	99
Loan rate	-4.735267	*	**Adj-R2**	0.9520431
Capacity Utilization Rate (log)	+0.7561478	***	**F statistic**	195.55
Profit rate (log, lag 1)	+0.04951946			
Change in equity price	-0.03822524			
GFC	-0.02201874			
COVID	+0.004862081			
Q1	-0.1229846	***		
Q2	+0.04148193	***		
Q3	-0.2624649	***		

Changes in firm inventories

eq. 2	Coefficients	Significance level	Statistics	
Sales	0.0235418	**	**Std. Er.**	7352.331
Capacity Utilization rate (lag)	-37512.48	**	**Sample**	99
Q1	+16680.89	***	**Adj-R2**	0.8646437
Q2	-26217.93	***	**F statistic**	91.34331
Q3	+21026.4	***		
COVID	-4176.663			
GFC	+5605.072			

Firms' investment follows expected signs with however not every variable showing significance. Increases in interests and financialization (proxied by increase in equity prices) decrease firm's investments. A higher capacity utilization (proxied by GDP over potential GDP) and a higher profit rate (NFC operating surplus over lagged capital) increase investment.

Firms' inventories seem to follow seasonal patterns. They accumulate more inventories when capacity utilization rate is lower, and their level also depends on total sales.

Firm deposits

eq. 3	Coefficients	Significance level	Statistics	
	(long-run)			
Sales (log)	-1.929206			
Foreign Assets (log)	+0.3944092	***	**Std. Er.**	0.06351891
Intangible Assets (log)	+0.7629386	***	**Sample**	99
Covid	+0.07938238		**Adj-R2**	0.9999809
GFC	-0.02155745		**F statistic**	1035103
eq. 4	*(short-run)*			
Change in Foreign Assets (lag 1)	0.276528	*	**Std. Er.**	32120.42
GFC	-11863.71		**Sample**	99
Q1	-17776.1	*	**Adj-R2**	0.7961279
Q2	+85064.41	***	**F statistic**	56.22837
Q3	-9370.084			
COVID	+189860.8	***		
Error Correction Term	-819612.5	***		

Firms' deposits were estimated with cointegration techniques through an error correction model. Long-run and short-run coefficients were estimated separately. While foreign assets and intangible assets follow IMF's results (Kim, Murphy et Xu 2023) with corporate deposits increasing with foreign assets and intangible assets with high level of significance, implicit corporate tax rate (direct taxes over GDP) did not show the correct signs nor significance and were therefore dropped, which could be due to differences in data construction (implicit instead of explicit rate for corporate tax, and logged foreign assets and intangible assets instead of shares of total assets). Shares of total assets and other control variables were not used respectively to improve the model fit and significance, and to keep the model parsimonious and limit the number of exogenous variables. In the short run changes in deposits were mainly driven by seasonal patterns and by changes in foreign assets.

Firm Foreign Assets (log)

eq. 5	Coefficients	Significance level	Statistics	
Intercept	-4.898243	***	**Std. Er.**	
Oil price (log)	-0.4248779	***	**Sample**	0.1746006
Exchange rate (log)	+0.4634195	**	**Adj-R2**	99
Potential growth (lag 1)	+71.09145		**F statistic**	0.8360049
World Industrial Production Index (log)	+3.949317	***		63.44734
Q1	-0.1609277	*		
Q2	-0.03046354			
Q3	-0.04861804			
COVID	+0.1499763			

Resource-seeking theory predicts that Japanese firms would increase foreign asset acquisitions when global oil prices rise, seeking to secure inputs and diversify supply chains. However, the regression results indicate that firms actually reduce their foreign asset purchases when oil prices increase, possibly due to heightened cost pressures, tighter liquidity, or increased uncertainty deterring investment. This finding contrasts with the standard hypothesis and suggests that balance sheet or risk effects may outweigh resource-seeking motives in aggregate. Yen depreciation increases firms' holding of foreign assets which could point at firms seeking better opportunities when domestic economic fundamentals deteriorate or seeking higher returns abroad due to rate differentials (as foreign assets contain both FDI and portfolio investment). In accordance with market-seeking theories, higher foreign prospects abroad (proxied by world industrial production index) lead to firms purchasing more foreign assets. The potential growth rate did not show significance but showed a sign opposite to expectations.

Firms Debt-to-Equity ratio

eq. 6	Coefficients	Significance level	Statistics	
Intercept	0.002693539		**Std. Er.**	0.04786456
Fixed Asset Ratio (lag 1)	+0.7298542	***	**Sample**	99
Fixed EBIT (lag 1)	-1.65713		**Adj-R2**	0.6540029
Equity-Loan rate spread (lag 1)	-1.348099		**F statistic**	38.04788
VIX	+0.003865146	***		
Output Gap	-0.4434298	*		

A higher fixed asset ratio, higher uncertainty, lower output gap and lower profitability leads to a higher debt-to-equity ratio which is in line with the literature (despite no significance for profitability). The yield spread between equity and loan, however, showed an unexpected sign with no significance, with increased holding of equity when the cost of equity, which could however be explained by an increased emission of equity when profits and hence expectations are higher (in the model's specification an increase in profit for the same amount of equity mechanically drives up the equity yield).

Household Consumption (log)

eq. 7	Coefficients	Significance level	Statistics	
	(long-run)			
Intercept	11.1977	***	**Std. Er.**	0.01834599
Household Real Disposable Income (log, lag 1)	-0.1277244		**Sample**	99
Household Real Net Wealth (log, lag 1)	+0.2441911	***	**Adj-R2**	0.8159074
GFC	-0.01283931		**F statistic**	63.04867
COVID	-0.05428447	***		
Q1	+0.004900076			
Q2	+0.005030741			
Q3	-0.03743804	***		

eq. 8	Coefficients	Significance level	Statistics	
	(short-run)			
Change in Household Real Disposable Income	-4.154598	***	**Std. Er.**	0.01378873
Change in Household Real Net Wealth	+0.7100613		**Sample**	99
GFC	-0.01324358		**Adj-R2**	0.665725
COVID	-0.03367495	**	**F statistic**	25.64542
Q1	+0.05780166	***		
Q2	-0.04671848	***		
Q3	-0.008853395			
Error Correction Term	-0.5501429	***		

Household consumption was estimated to be an error correction model as in Zezza and Nguyen. In the long run only, net wealth shows a significant and positive effect on consumption, which could be due to demographic structures. In the short run only changes in real household disposable income drive changes in consumption, but surprisingly both in the long and the short run consumption decreases with increase in disposable income. This could also be due to low expectations, which would incentivize households to save more when economic prospects improve.

Household capital accumulation rate

eq. 9	Coefficients	Significance level	Statistics	
Intercept	+0.1090492	**	**Std. Er.**	0.0008248951
Household Disposable Income/Investment price (log, lag 1)	+0.008968137	**	**Sample**	99
Household Loan-to-value ratio (lag 1)	-0.004153563		**Adj-R2**	0.7870117
Change in mortgage rate (lag 1)	-0.0469823		**F statistic**	46.26491
House price/Investment price (log)	+0.01169924	**		
VIX (lag)	-6.945545e-05	***		
Q1	-0.0009323887	*		
Q2	+4.803113e-06			
Q3	-0.001275578	***		

Household investment shows expected and significance behavior for real disposable income and housing prices but the opposite sign for change in mortgage rate. Investment increases with real disposable income and with housing prices as investment becomes more attractive. Loan-to-value ratio seem to highlight pro-cyclical behavior of credit and household investment. Increase in mortgage rate leads to an increase in investment which is counterintuitive but could be explained by higher rate being associated with higher expectations during the lower bound and low inflation period.

Household Deposits

eq. 10	Coefficients	Significance level	Statistics	
	(long-run)			
Intercept	13.60966	***	**Std. Er.**	0.0388863
Deposit rate	-40.06995	***	**Sample**	99
Household Nominal Consumpion	+2.722639e-06	***	**Adj-R2**	0.8787331
Household Savings	+1.884345e-06	***	**F statistic**	89.76683
Q1	-0.2486432	***		
Q2	+0.09930868	***		
Q3	-0.06322344	***		
GFC	+0.0006397139			
COVID	-0.03212621			

eq. 11	Coefficients	Significance level	Statistics	
	(short-run)			
Change in Nominal Consumption	-0.6914893	*	**Std. Er.**	31236.94
Equity price change	+70999.88	*	**Sample**	99
Q1	+129444.3	***	**Adj-R2**	0.8811926
Q2	-48663.06	**	**F statistic**	105.8973
Q3	+87386.32	***		
COVID	+116537.3	***		
Error Correction	-1039007			

Change in Cash

eq. 12	Coefficients	Significance level	Statistics	
Intercept	1787.78		**Std. Er.**	5722.407
Change in Household Deposits	+0.09847304	***	**Sample**	99
Q1	+29208.04	***	**Adj-R2**	0.9465202
Q2	-20062.94	***	**F statistic**	347.8934
Q3	-6390.809			
COVID	+3464.78			

Household deposits were estimated with an ECM which however showed significance only at the 10% level (8%). In the long run all signs are significant for deposit rate, consumption and savings. The deposit rate however presents the opposite to the expected sign. Equity price changes have a positive effect on deposits possibly indicating a wealth effect or portfolio rebalancing towards safer assets when equity markets rise. Change in deposits follow seasonal patterns. Changes in cash follow changes in household deposits as expected with a high significance level.

Change in Household loans

eq. 13	Coefficients	Significance level	Statistics	
Intercept	-1055107		**Std. Er.**	11649.68
Household diposable income/investment price (log)	+75957.67		**Sample**	99
Change in Mortgage rate	-1.088304e+07		**Adj-R2**	0.5626893
Household loan to value ratio (log, lag 1)	-956847.4	***	**F statistic**	16.76212
House prices/Household investment price (lag 1)	-31597.76	***		
COVID	+26101.85	*		
Q1	-1589.119			
Q2	+6460.419			
Q3	-7868.083			

Households take out more loans when real disposable increase, which could result from credit being pro-cyclical (the coefficient is, however, not significant). Households take out less loans when interests are higher, but coefficients are not significant. When households are more indebted, they tend to take out less loans. The negative sign on relative house prices to investment prices could be explained as homes become relatively more expensive, fewer households are able or willing to borrow, resulting in a decline in new loans.

Household desired share of equity

eq. 14	**Coefficients**	**Significance level**	**Statistics**	
Intercept	0.4798716	***	**Std. Er.**	0.03383107
Expected returns on equity	+0.2335682	***	**Sample**	99
Expected returns on insurance	-0.8276657	*	**Adj-R2**	0.4682629
Income/Net wealth	-3.561508	***	**F statistic**	22.5754
COVID	-0.003622438			

Household desired share of insurance/pension products

eq. 15	**Coefficients**	**Significance level**	**Statistics**	
Intercept	0.5399141	***	**Std. Er.**	0.03147826
Expected returns on equity	-0.2107715	***	**Sample**	99
Expected returns on insurance	+0.8167135	*	**Adj-R2**	0.2399721
Income/Net wealth	+1.445675	**	**F statistic**	8.735657
COVID	+0.008786834			

Households seek to invest more in equity when returns on insurance products are lower and returns on equity higher which is consistent with the Tobin approach. When income relative to wealth increases, households tend to hold a lower share of equity which might be due to higher liquidity of pension/insurance products.

Households seek to invest more in insurance when returns on equity are lower and returns on insurance higher which is consistent with the Tobin approach. Regarding income/net wealth, the coefficient follows the opposite direction. The model fit is however lower than for equity investment.

Social Benefits

eq. 16	**Coefficients**	**Significance level**	**Statistics**	
Intercept	11.64145	***	**Std. Er.**	0.01540872
Share of population >65	+3.565913	***	**Sample**	99
Unemployment rate	+2.265409	***	**Adj-R2**	0.9870064
GFC	-0.01184642		**F statistic**	1064.456
COVID	-0.02450192	*		
Q1	+0.08386079	***		
Q2	+0.005585226			
Q3	+0.06923257	***		

Social benefits positively depend on the share of the population over 65 years old and unemployment rate which is consistent with theory. Unexpectedly the GFC and COVID signs are negative.

Central Bank Refinancing rate

eq. 17	**Coefficients**	**Significance level**	**Statistics**	
Intercept	7.180554e-05		**Std. Er.**	0.0001806899
Output gap	+0.0005253015		**Sample**	99
Distance to target inflation	+0.0002071196		**Adj-R2**	0.860112
Spread with the FED rate (lag 1)	-0.007083487		**F statistic**	121.5121
Refinancing rate (lag 1)	+0.9070754	***		

Rate on excess reserves				
eq. 18	**Coefficients**	**Significance level**	**Statistics**	
Intercept	0.0002512978	**	**Std. Er.**	0.0001861454
Refinancing rate	-0.1284574	*	**Sample**	99
QE	-0.0002068492	***	**Adj-R2**	0.09386665
			F statistic	6.075926

Estimations are difficult to perform for the Taylor rule at the ZLB. There is significant persistence of policy rates from previous periods. Inflation and output gap are not significant but show a sign consistent with theory when the FED rate is taken into account (which is however not significant). The BOJ rates diminish when the spread with fed rate (BOJ rate – US rate) increase. Several specifications were attempted, and the US rate showed significance when lag 1 and lag 2 were included, with inflation targeting and output gap showing the opposite signs. The theory-consistent results were opted for as those results likely come from the prolonged period of zero lower bound and unconventional monetary.

The rate on excess reserve showed significant signs for all variables but moves in the opposite direction from the refinancing rate, which could be due to a large increase. The fit is however low, and it is likely due to omitted variable bias.

Central bank purchase of bonds				
eq. 19	**Coefficients**	**Significance level**	**Statistics**	
Intercept	6177.052		**Std. Er.**	55882.29
Central bank purchase of bonds (lag 1)	+0.5786047	***	**Sample**	99
Distance to target inflation	+971907.6	*	**Adj-R2**	0.5484289
Output gap	-275975.1		**F statistic**	20.83668
COVID	+83886.87			
QE	+31157.13	*		

Central bank purchase of bonds depends on quantitative easing activation, with policy persistence (similarly to a Taylor rule), output gap and distance to target inflation. The output gap, however, shows the wrong sign with no significance, which could be explained by quantitative easing mainly aiming at avoiding deflation.

Financial Institutions purchase of foreign assets				
eq. 20	**Coefficients**	**Significance level**	**Statistics**	
Intercept	496505.8	***	**Std. Er.**	35657.73
Change in bank reserves (lag 1)	+0.07641324	**	**Sample**	99
Capacity utilization rate (lag 1)	-503037.6	***	**Adj-R2**	0.271941
Exchange rate	+590.869	*	**F statistic**	6.229211
VIX	-1366.39	*		
Change in foreign asset price (lag 1)	-191131	*		
Change in foreign asset price (lag 2)	-253547.4	**		
COVID	-15697.63			

Changes in bank reserves, lowers domestic prospects, lower global volatility and yen depreciation drives up foreign assets purchase by financial institutions significantly. Surprisingly, an increase in foreign asset prices led to lower acquisition of foreign assets, attractivity of foreign assets by increasing valuation would hence matter less than decrease in real income relative to foreign asset prices. The equation however only allows to explain around 27% of variance.

Imports (log)

eq. 21	Coefficients	Significance level	Statistics	
Intercept	-28.51672	***	Std. Er.	0.04235454
Domestic Demand (log, lag 1)	+2.901777	***	Sample	99
Import price/export price (log, lag 1)	+0.700875	***	Adj-R2	0.9494425
Import price/domestic price (log, lag 1)	-0.1846719	*		
COVID	+0.02495718		F statistic	263.9126
Q1	-0.02365136			
Q2	-0.1586839	***		
Q3	-0.09184294	***		

Exports

eq. 22	Coefficients	Significance level	Statistics	
Foreign demand	+2821.801	***	Std. Er.	9178.261
Foreign demand (lag 1)	+1103.445	***	Sample	99
Exchange rate (lag 1)	+32.6039		Adj-R2	0.9642937
COVID	-13924.85	*	F statistic	662.6544

Imports increase in a significant manner with domestic demand. The import price elasticity is negative as expected when related to the GDP deflator (similar results were obtained with consumption deflator) while it is positive when related to the export price deflator with high significance. Initially, every specification attempted (import price alone, import price/world prices, inclusion of spot and real exchange rate) led to a positive elasticity of import to import deflator. If results are accurate, this could be potentially resulted from a large share of inelastic goods (such as energy) in exports and price-making behavior for exporting firms. Further research, different specifications or estimations would be needed to confirm or refine these unexpected estimates.

As expected, exports increased with foreign demand but showed little sensitivity or opposite signs to the export price deflator. Exchange rate was opted for despite low significance as signs were theory-consistent: a yen depreciation leads to higher exports.

Import price

eq. 23	Coefficients	Significance level	Statistics	
Intercept	20.72952	***	Std. Er.	3.341475
Domestic price/Foreign price	-15.30918	***	Sample	99
Exchange rate (lag 1)	+0.5937364	***	Adj-R2	0.9422821
Oil prices	+0.3917172	***	F statistic	200.9891
Q1	+1.168875			
Q2	-0.03344078			
Q3	+0.1241754			
GFC	+4.365726	*		
COVID	+0.5961756			

Export price

eq. 24	Coefficients	Significance level	Statistics	
Intercept	6.813886		Std. Er.	2.228808
Unit labor cost (lag 1)	-42.6239	*	Sample	99
Percentage of Non Regular Workers (log, lag 1)	-49.43661	***	Adj-R2	0.9231319
Exchange rate (lag 1)	+0.3237473	***	F statistic	131.7678
Improt price (lag 1)	+0.2862653	***		
Q1	-1.608937			
Q2	+1.813171	*		
Q3	-2.659078			
GFC	+0.8036561			
COVID	-2.225551			

Import price deflator increases when the yen depreciates, oil prices increase and the real exchange rate decreases (when domestic prices are relatively lower in comparison to world prices), with high significance and which is consistent with expected behavior.

Export prices are found to decrease when unit labor costs increase, which could be due to the sample. The development of non-regular contracts leads to a decrease in export price deflators, which seem consistent with a decrease in workers' bargaining power. The increase in import prices also increased export prices, which could be explained by the increased cost of imported intermediary goods. Surprisingly, the yen depreciation increases export prices. It could be interpreted as partial exchange rate pass-through with some price -making power for Japanese exporters.

Exchange rate

eq. 25	Coefficients	Significance level	Statistics	
Intercept	1.775435		Std. Er.	0.08756211
Trade Balance (lag 1)	-3.106608e-06	***	Sample	99
Reserves (log, lag 1)	+0.2101833	***	Adj-R2	0.5968862
Domestic price/Foreign prices	-0.1768931		F statistic	21.72965
Japanese-US bond rate spread (lag 1)	-0.06097347	***		
Change in refinancing rate (lag 1)	-13.66284	***		
Oil prices	-0.002195432	***		
QE	+0.06861684	*		

The yen depreciates when trade terms improve and when the central bank accumulates reserves. The relative domestic prices show the expected sign but are not significant. An increase in Japanese bond-US rate spread appreciates the yen which is also consistent with interest rate parity. Decreasing oil prices and quantitative easing depreciate the yen as expected.

Labor Force

eq. 26	Coefficients	Significance level	Statistics	
Population	+1.574654e-05	***		
Labor force (lag 1)	+0.3411218	***	Std. Er.	22.98606
Population>65	-8.039138e-06	***	Sample	99
Women Labor Force Participation	+53.4872	***	Adj-R2	0.9999883
Q1	-57.82223	***	F statistic	1209659
Q2	+0.1736592			
Q3	+31.97107	**		

Number of employed Workers (log)

eq. 27	Coefficients	Significance level	Statistics	
Intercept	-4.041739	***	**Std. Er.**	0.003629189
Labor Force (log)	+1.214197	***	**Sample**	99
Real GDP (log)	+0.1502041	***	**Adj-R2**	0.9800914
			F statistic	2413.25

As in Ngyuen (Nguyen 2022) labor force depends on past labor force. The changes incurred by the Womenomics are taken into account with female labor force participation which has a positive impact on labor force. Population ageing as expected decreases labor force. As in Nguyen**,** both labor force and real GDP (supply and demand factors) increase the number of employed workers.

Wage rate

eq. 28	Coefficients	Significance level	Statistics	
Intercept	0.8490024	***	**Std. Er.**	0.008836619
Non Regular Workers	-0.2953675	***	**Sample**	99
Unemployment rate (lag)	-1.233418	***	**Adj-R2**	0.9572029
Productivity per worker (lag)	-0.001363968	***	**F statistic**	366.3121
Q1	+0.05369286	***		
Q2	-0.04205777	***		
Q3	+0.03071212	***		

As expected, wage rates decrease with the number of non-regular workers and when unemployment increases. However, productivity per worker is negatively associated with wages, which is not in line with expectations.

GDP Deflator

eq. 29	Coefficients	Significance level	Statistics	
Intercept	3.576144	***	**Std. Er.**	0.01174308
Unit Labor cost	+0.2760937	***	**Sample**	99
Exchange rate (log, lag 1)	+0.09821344	***	**Adj-R2**	0.9288286
Non regular worker share (log)	-0.3299234	***	**F statistic**	256.7915
Indirect tax rate (lag 1)	+1.27118	***		
Output gap (lag 1)	+0.2313691	***		

Prices increase with unit labor cost, yen depreciation, the (implicit) indirect tax rate and output gap and decrease with a higher share of non-regular workers which is in line with previous studies and literature.

Firm investment deflator

eq. 30	Coefficients	Significance level	Statistics	
Intercept	24.93865	***	**Std. Er.**	2.382944
GDP deflator (lag 1)	+0.7562612	***	**Sample**	99
			Adj-R2	0.6929644
			F statistic	222.1812

Household consumption deflator

eq. 33	Coefficients	Significance level	Statistics	
Intercept	49.45795	***	**Std. Er.**	1.934415
GDP deflator (lag 1)	+0.5115305	***	**Sample**	99
			Adj-R2	0.6099556
			F statistic	154.2535

Firm investment deflator and household consumption deflator follow GDP deflator with high level of significance although fit could potentially be improved. The current specification, similar to Nguyen was, however, kept for parsimony and acceptable results.

Government Investment Deflator

eq. 31	Coefficients	Significance level	Statistics	
GDP deflator (lag 1)	0.1112362	***	**Std. Er.**	1.262459
Household Investment Deflator (lag 1)	+0.9128078	***	**Sample**	99
Exchange rate (lag 1)	-0.02907733	**	**Adj-R2**	0.9998351
COVID	-0.2065996		**F statistic**	150102.7

Household investment deflator

eq. 32	Coefficients	Significance level	Statistics	
Intercept	4.308013	***	**Std. Er.**	0.03114361
Import deflator (log, lag 1)	+0.2941389	***	**Sample**	99
Unit labor cost (lag 1)	+0.3003832	***	**Adj-R2**	0.805369
Price deflator (log, lag 1)	-0.7352211	***	**F statistic**	68.58614
Mortgage rate	-23.72461	***		
House price (lag 1)	+0.474121	***		
COVID	+0.04862116	*		

The government investment deflator closely follows household investment deflator and was hence based on the latter. Household investment deflator is mainly based on costs related to residential construction (labor cost, materials, overall price levels, lending costs, property costs). Results are in line with expectations: import prices, unit labor cost, increase in mortgage price and housing prices lead to an increase in investment cost. Unexpectedly an increase in GDP deflator is associated with a decrease in household investment prices.

Change in Loan price

eq. 34	Coefficients	Significance level	Statistics	
Intercept	0.001949597		**Std. Er.**	0.002931682
VIX	-0.000155355	***	**Sample**	99
Change in loan interest (lag 1)	-0.005768166	*	**Adj-R2**	0.2618394
Change in operating surplus (lag 1)	+5.113848e-09	.	**F statistic**	7.952488
Change in loan price (lag 1)	-0.2884379	**		
GFC	+0.00863579	***		

Change in bond price

eq. 35	Coefficients	Significance level	Statistics	
Change in bond price (lag 1)	-0.2833723	***	**Std. Er.**	0.008468834
Central bank purchase of bonds/Total bond (lag 1)	+0.2197491	*	**Sample**	99
Change in US-JP goverment bond spread (lag)	+0.01432214	***	**Adj-R2**	0.3009477
Change in refinancing rate (lag 1)	+9.67753	*	**F statistic**	9.437961
Change in Equity price	-0.01681556			

Change in Equity price

eq. 36	Coefficients	Significance level	Statistics	
Intercept	+0.01696115		**Std. Er.**	0.06169056
VIX	-0.005104863	***	**Sample**	99
VIX (lag 1)	+0.004723936	***	**Adj-R2**	0.536122
Change in exchange rate (lag 1)	-0.001516758		**F statistic**	23.65249
Change in Nikkei price index (lag 1)	+3.984105e-05	***		
Q4 2007	-0.09303653			

Change in foreign asset price

eq. 37	Coefficients	Significance level	Statistics	
Intercept	0.0195577		**Std. Er.**	0.03738137
Change in foreign asset price (lag 1)	-0.1894152	*	**Sample**	99
Change in foreign asset price (lag 2)	-0.1941565	*	**Adj-R2**	0.2291409
VIX	-0.0009103872		**F statistic**	5.161555
Change in equity price	+0.1808046	***		
COVID	+0.009095702			
GFC	-0.01347242			
Q3 2007	-0.01670375			

As expected, changes in uncertainty (proxied by the VIX), in loan interest, and in operating surplus seem to be driving write-offs. When interest rates rise, operating surplus (at the 10% level with a p-value of 0,052) decreases or volatility increases the number of non-performing loans increase. The GFC dummy shows a surprising sign which could be due to policy intervention. For bond prices, increased demand with central bank intervention, increase in spread with American treasury bonds (larger Japanese government bond yield in comparison to US bonds) and decreases in equity price (insignificantly) increases bond prices. Increases in refinancing rates however increase bond price, which is unexpected but could be due to endogeneity (increases in refinancing rates increase demanded rates on Japanese bonds).

Regarding equity, the Nikkei225 price index seems to accurately depict reconciliation and volatility decrease equity price. Changes in foreign asset prices mainly follow an AR process and increase with equity prices with however a relatively mediocre fit.

Loan interest rate (log)

eq. 38	Coefficients	Significance level	Statistics	
Intercept	123.3372	***	**Std. Er.**	0.2144879
Bond yield (lag 1)	+114.8512	***	**Sample**	99
Firms real capital (log, lag 1)	-8.217768	***	**Adj-R2**	0.8319091
Equity yield (lag 1)	-15.50802	**	**F statistic**	162.6727

Mortgage interest rate (log)

eq. 39	Coefficients	Significance level	Statistics	
Bond yield (log, lag 1)	+0.5270018	***	**Std. Er.**	0.2375413
QE	-0.3187216	***	**Sample**	99
Q1	-0.0748843		**Adj-R2**	0.712171
Q2	+0.03192522		**F statistic**	41.41332
Q3	-0.1508639	*		
COVID	+0.06125064			

Interest on firm loans increases with overall rates (proxied by bond yield to proxy refinancing rates) and decreases with firms' holding of capital (which can act as a collateral). Increases in equity yield leads to a decrease in interest which could be interpreted as the lower rate asked for when economic performance increases.

Bond rate

eq. 40	Coefficients (long-run)	Significance level	Statistics	
Intercept	0.02464549	***	Std. Er.	0.001600608
Refinancing rate (lag 1)	+1.841693	***	Sample	99
Central Bank holding of bonds (log, lag 1)	-0.001581023	***	Adj-R2	0.5676803
			F statistic	65.34206
eq. 41	**Coefficients (short-run)**	**Significance level**	**Statistics**	
Change in refinancing rate (lag 1)	0.5497784	***	Std. Er.	0.0002853976
Q1	-0.0004037772	***	Sample	99
Q2	+0.000252756	***	Adj-R2	0.886701
Q3	-0.0005670371	***	F statistic	155.9588
Error Correction Term	-0.5846522	***		

Bond rate was estimated through an ECM. An increase of the BOJ rate raise the implicit rate and central bank intervention does the opposite, in line with Yield Control Curve policies and expected behavior.

Insurance Yield (log)

eq. 42	Coefficients	Significance level	Statistics	
Bond yield (log)	+0.4017572	***	Std. Er.	0.07550842
Equity yield (log)	-0.05326021	***	Sample	99
			Adj-R2	0.9014098
			F statistic	449.0066

Deposit rate (log)

eq. 43	Coefficients	Significance level	Statistics	
Refinancing rate (log)	+0.4502883	***	Std. Er.	0.2767847
Refinancing rate-deposit rate spread (lag 1)	+0.4962339	***	Sample	99
QE	-0.4197598	***	Adj-R2	0.6959541
Q1	-0.2259158	**	F statistic	38.38663
Q2	+0.2188311	**		
Q3	-0.2436132	**		

Foreign Asset yield (log)

eq. 44	Coefficients	Significance level	Statistics	
Foreign Asset yield (lag 1)	+26.46019	**	Std. Er.	0.06203633
Real GDP growth	-1.087159	**	Sample	99
Exchange rate	+0.001657706	**	Adj-R2	0.8015954
FED rate	+10.80624	***	F statistic	50.49252
Q1	-0.1320866	***		
Q2	-0.004217484			
Q3	-0.04792863			
COVID	-0.1401753	**		

The insurance rate follows bond rate as expected. It, however, goes in the opposite direction as the equity implicit rate. While it was expected to follow both, the reason for this sign could substitution between insurance/pension products and equity.

Probability of QE activation

eq. 45	Coefficients	Significance level	Statistics	
Intercept	+8.781	**	**Null deviance**	123.583
Distance to target inflation	+7.638		**Residual defiance**	54.675
Output gap	+22.510	.	**Sample**	101
Refinancing rate (lag 1)	-9191.075	**	**McFadden Pseudo-R^2**	0.558
Change in refinancing rate	-9208.083	*	Method	GLM (binomial)

The probability of QE activation follows closely the central bank rate with a good fit. Signs are, however, reversed for the output gap and inflation (higher inflation and output gap should decrease the probability of activation). The small coefficients and the overall model fit with data make the endogenization of QE, however acceptable.

3.5 – Scenario Analysis

After building and estimating the model, out-of-sample simulations are performed to 2050 after checking for model stability (which can run to at least 2100). A baseline scenario is first constructed based on Japan's announces on the GX transition. The baseline scenario consists in 10 years of green public investment equally spread (20 trillion, hence 2 trillion yens per year) and an increase in carbon tax (from 289 yens per ton of CO2 in 2023) to reach 1950 yens per ton of CO2 (Renewable Energy Institute 2023) after the introduction of the emission trading scheme in 2026/7 and assuming a growth rate of carbon pricing similar to the IEA recommendation (however with these different starting values which yields a lower carbon tax of 7740 yen per ton in 2050). Calibrations from DEFINE were used for green investment, energy intensity and renewable energy share parameters.

Alternative scenarios were then created by modifying parameters over the course of the simulation on 3 main scopes of analysis: fiscal policy, monetary policy and timing of the transition. 26 summary variables and their evolutions were then analyzed: environmental performance (energy intensity, carbon emissions, renewable energy share, green to conventional capital ratio) real variables (real GDP, real GDP growth, inflation rate, unemployment as well as exchange rate, capital, green capital and firms' green investment), financial variables (sectoral net wealth, government and private sector debt to GDP and net international investment position, trade balance was added) and policy variables (refinancing rate, probability of quantitative easing activation, carbon tax, government green investment).

In the case of fiscal policy, 4 scenarios were created to study the effect of different policy tools: a pure carbon tax scenario (hereafter CT), a pure green subsidy scenario (GSUBS), a pure green public investment scenario (GPI) and a mixed scenario. These policy scenarios consist of modifying the parameters related to the carbon tax, the green subsidies and the green public investment. First, a "policy budget" was estimated based on the cost of the amount of carbon tax and green public investment combined in the baseline scenario. Then, amounts were allocated following the same pace as in the baseline scenarios in policy tools associated with each scenario (one third for each in the case of the mixed scenario). Deviations are then analyzed on the 26 key variables to assess dynamics and trade-offs of each instrument and policy. The pure carbon tax scenario hence reaches 105 000 yen per ton by 2050 (the CT reaches this level as emissions are low in the baseline scenario towards latest stage despite not reaching carbon neutrality). Green subsidies initially 13,1% of renewable energy cost in 2024 and 20,5% in 2050 (Similarly as for the CT scenario, lower energy intensity leads to a relatively low consumption of renewable energy and costs decreases over the period based on assumptions). Green public investment oscillates between 5 and 5,9 trillion yen (peaking in 2034) in the GPI scenario.

In the case of monetary policy, 3 scenarios were created: a high-rate scenario with refinancing rate at 3% annually over the period (hence deactivating QE), a low-rate scenario with a refinancing rate at 0.003% over the period and a "QE" scenario in which QE is forced to be active.

In the case of timing, the importance of timing was studied to take into account recent developments on green swans, and an additional alternative scenario was added to study the effect of a carbon tax at the level recommended by the IEA. A fast transition, last minute transition and an IEA scenario were hence created. Both the fast and last-minute transition are based on the same "policy budget" as the baseline, with a fast ramp up then decrease of policy variables in the fast one and low levels with a fast last-minute increase for the last minute one.

4 – Simulation and Results

This section presents the model's performance before examining baseline scenario, and the effect of different policy mixes. The model performs relatively well in dynamic and static simulations and is stable enough to run long run projections. The baseline scenario is first examined before policy effects are analyzed.

4.1 – Goodness of fit

The model fits relatively well the data for both static and dynamic simulations. Static simulations consist in using the historical lag to predict one period ahead, while dynamic simulations consist in projections from the initial data point (here 1999 Q1), iteratively solving each period. Since dynamic simulations (when the model solves iteratively every period of the simulation) tend to perform less well and offer the least good predictions, these conservative results are displayed for selected variables. Simulation against observation tables are presented for selected data in the annex. Overall predicted real variables and financial variables follow the trends of the Japanese economy despite some over and underestimation (loans are for example overestimated for firms which leads to a lower net wealth, and it results in more advances for financial institutions). Stock-Flow consistency was checked for assets and liabilities by taking into account the discrepancy in original data.

4.2 – Baseline Scenario

4.2.1 – Damage and adaptation

Figure 2 presents simulation results on damage and mitigation resulting from climate change on the Japanese economy to 2050. Climate change will generate substantial damage to the Japanese economy. In the SSP3 scenario with an increase of 2,18°C compared to pre-industrial levels in 2050 (4,69 by the end of the century), gross damage accounts for 2% of GDP in 2050 which amounts to 16,81 trillion yen. Cumulated it represents 231,41 trillion yen over 25 years, which represents the equivalent of more than 40% of GDP in 2023 and 31% of GDP in 2050.

Adaptation measures help diminish damage over the course of the simulation to 0,6% of GDP in 2050, which however comes at the cost of adaptation (which diverts investment from productive use and diminishes potential output when impacting capital accumulation). Cumulated gross investment represents 102.94 trillion yen to reach 64,62 trillion yen of adaptation capital in 2050 (because of depreciation). Adaptation leads to gains with cumulated damage of 51.47 trillion yen over the period whose difference with cumulated gross damage is higher than incurred cost. Results are in line with existing literature, but valuations remain to be improved as adaptation is assumption-dependent and calibrated. Future work could refine parameter calibration and model specification based on empirical estimations and evidence for both the damage function and the protection function.

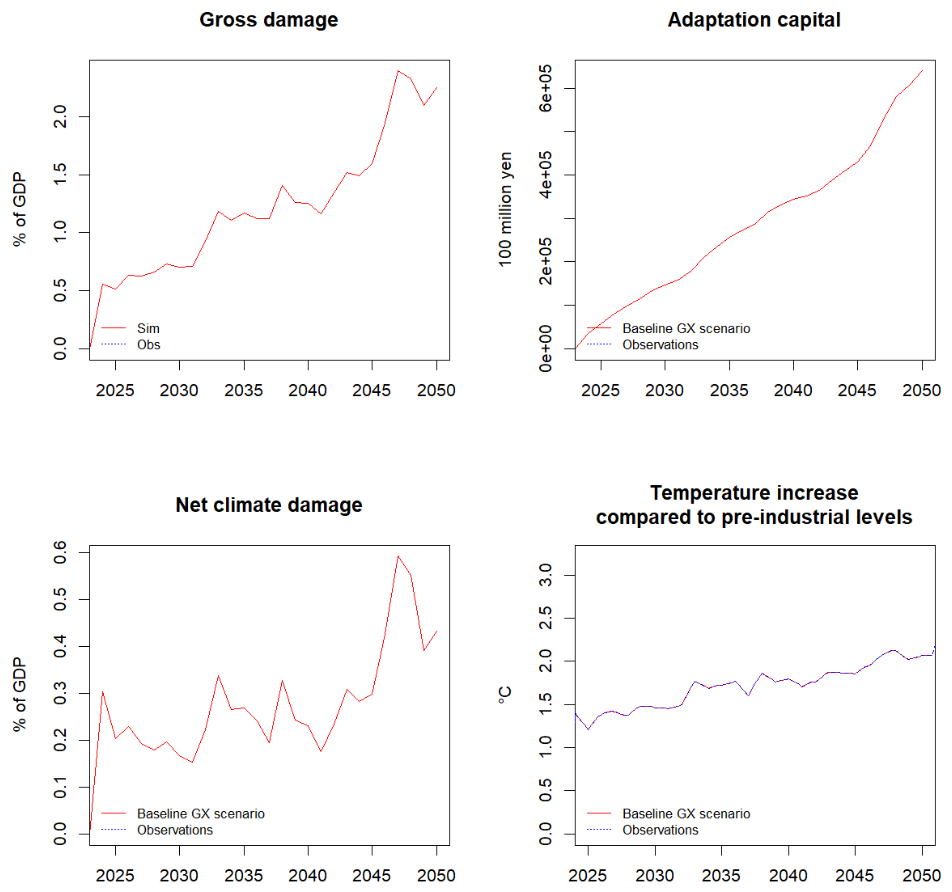

Figure 2 - Climate and Adapatation, baseline

4.2.2 – Environmental performance

Figure 3 presents climate mitigation performance with respect to Japan's NDC and GX transition objectives through energy intensity, CO2 emissions, share of renewable energy and the ratio of green to brown capital (values before 2023 are exogenously computed based on model equations, and the post-2011 shutdown of nuclear power plants which led to increased share of CO2 emitting energy sources explain the pre-2023 dynamics).

Overall, a "green transition" in the form of mitigation measures endogenously occur as expected with Green to Convectional capital attaining 14% by 2050 and Japan's CO2 emissions significantly decrease to reach 261.22 Mt of CO2 in 2050. Energy Intensity falls to reach 2.75 kWh per yen compared to 9 kWh per yen in 2023 which is a substantial decrease (68,9%) beyond transition plans.

Japan however fails to reach carbon neutrality by 2050 and does not reach its NDC with 1021 MtCO2 (against an objective of 760 Mt) 783 MtCO2 in 2035 (against an NDC of 570 Mt) and

533 MtCO2 in 2040 (against an NDC of 380 Mt). While model calibrations influence the output, policy analysis in next sections shed light at potential causes for Japan not reaching carbon neutrality.

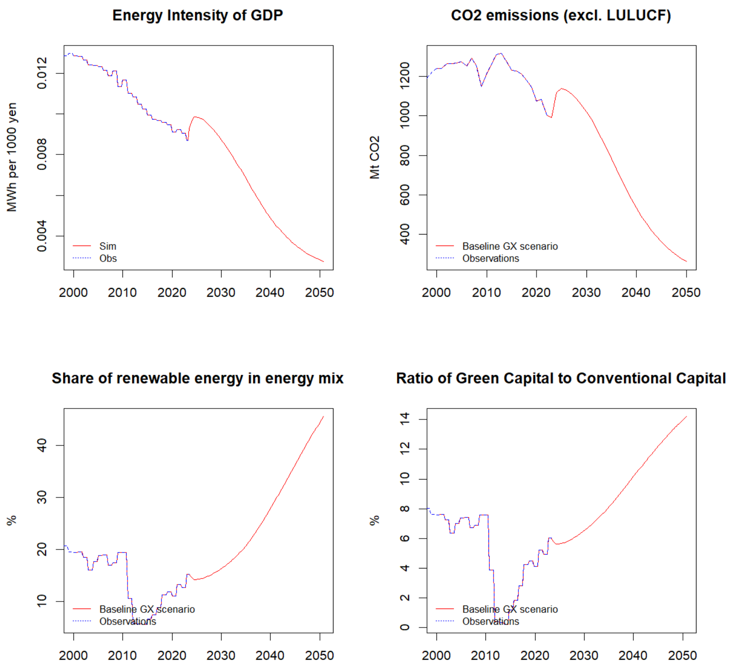

Figure 3 - GX performance, baseline

4.2.3 – Real variables

Figures 4 and 5 present the macroeconomic trajectory of the baseline scenario on key macroeconomic indicators: output, growth, inflation rate, unemployment, exchange rate and capital accumulation dynamics. Real GDP attains 742.49 trillion yen in 2050, which represents a 32,23% increase in 27 years with an annual mean growth rate of 0.88%. A first increase in growth is observed after the increase in green public investment. In the long run, Japan fails to move out of deflation with mean inflation of -0.13% on average over the period (partly due to the share of non-regular workers and unemployment capped at 0% minimum). Unemployment falls virtually to 0 after 2034. The model does not account for the effect of such labor shortage (apart from decreasing potential output through demographic dynamics) but it highlights the pressures the Japanese economy will experience from a shrinking labor market.

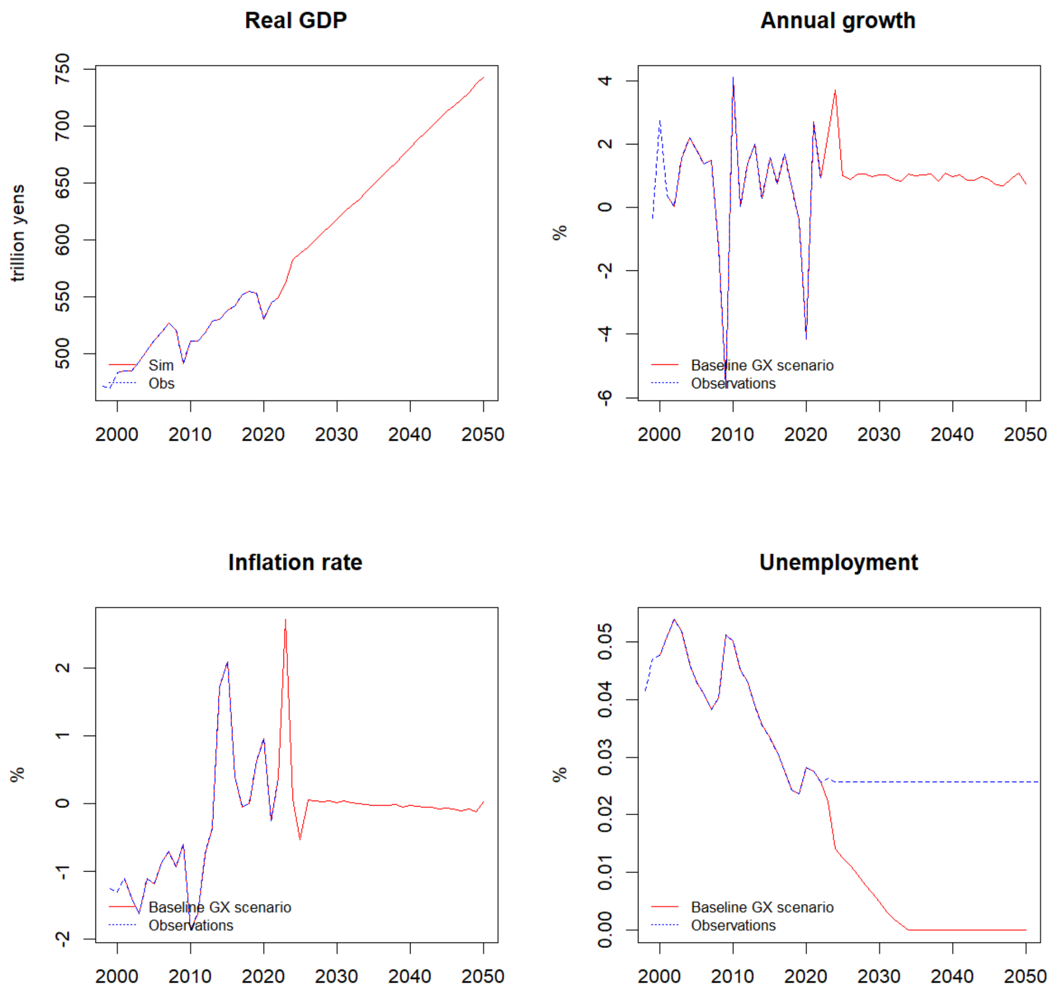

Figure 4 - Real variables, baseline

The yen first depreciates with the surge of public investment and inflation before appreciating. The yen stays relatively stable over the period but slightly depreciates which is expected with deflation. As expected with the green transition green capital accumulates at a faster rate than conventional capital and reaches 266.3 trillion yen (10,4% of capital stock) for a total of 562.66 trillion-yen gross investment (before depreciation) over the period. While the government expects private sector investment of 150 trillion yen over 10 years with the GX, only 107.32 trillion yen is invested over the 10 initial years in the simulations.

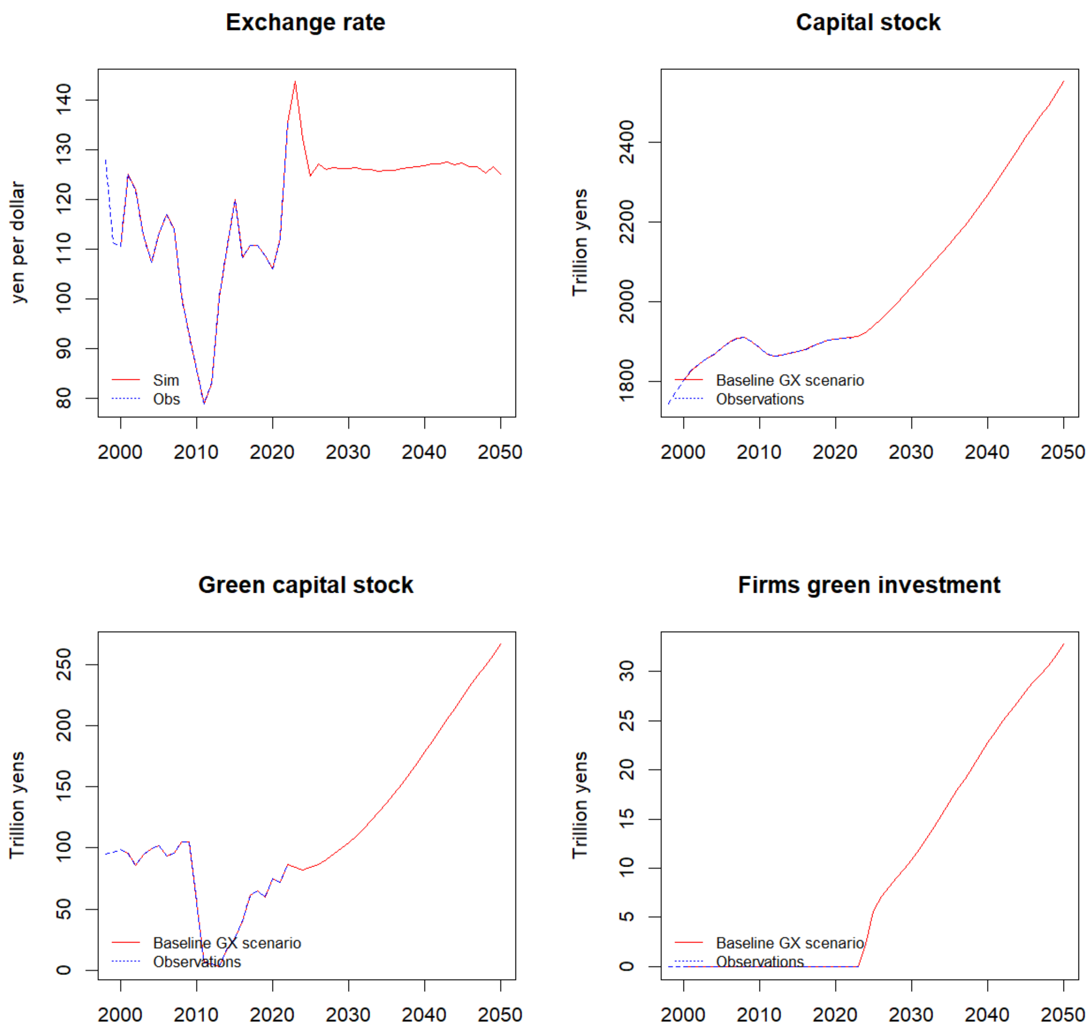

Figure 5 - Real variables, baseline

4.2.4 – Financial variables

Figure 6 and 7 present baseline dynamics for financial variables. First, the non-financial private sector sees an increase in net wealth, both for firms and households, with a negative initial shock in 2023 for firms.

Net wealth increases for the entire private sector (financial institutions, firms and households) while it decreases for the central bank, the government and the rest of the world. The surprising central bank's negative net wealth can be explained by the model's specification and dynamics. Since interest rates are higher and the FED rate over the simulation drive up Japanese rates, it quickly goes outside of quantitative easing, and the central bank reduces its balance sheet.

Furthermore, as the central bank is the residual sector for bank closure through advances, pre-existing excess reserves and the increase in funding from deposits (which is higher than the increase in financial institutions' assets) reduce the need for funding hence decreasing advances (or could increase reserves in a different specifications), turning the central bank's net wealth negative in the long run.

The government's net wealth also deteriorates with the use of debt securities to finance its deficits. The rest of the world's net wealth also deteriorates which is due to the increased purchase of foreign assets while Japanese growth remains modest compared to world growth, and rates lower.

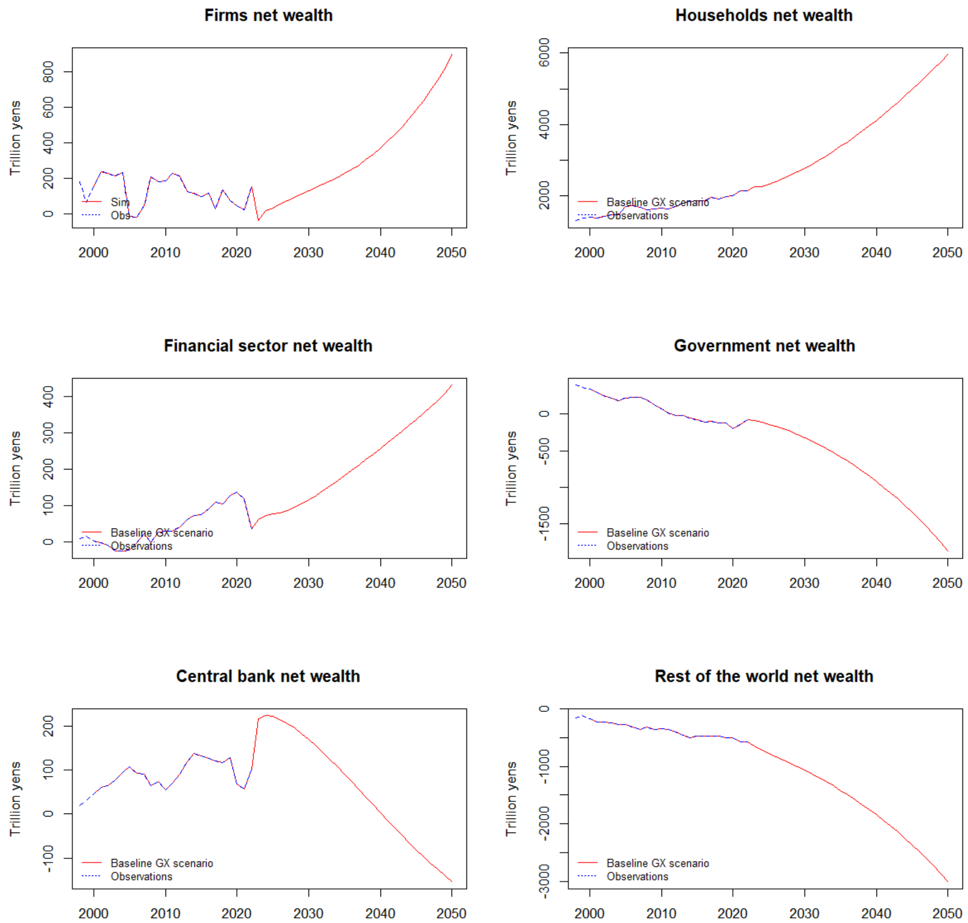

Figure 6 - Financial variables, baseline

When examining indebtedness, serious sovereign risk seems to appear with public debt-to-GDP levels reaching more than 450%. Several factors explain this snowballing effect. Population ageing incurs more social spending. Moreover, the rise in interest rates, being higher than growth and deflation leads to higher debt service and higher deficits. Private sector leverage (here including all liabilities) increases over the course of the simulation increases at but at a slower pace than public debt.

Public debt-to-GDP reaches more than 400% of GDP for the government and reaches 450%. Japan remains a main creditor to the world and its net international investment position improves further to 400% of GDP by 2050. Several factors explain these results. Changes in asset prices (some drift occur because of projected variables and foreign asset price valuation increase). The persistence of a trade surplus and Japan's relatively low economic performance (deflation, relatively low growth, labor shortages) in comparison the foreign sector drive the accumulation of foreign assets, strengthening Japan's position as a net creditor to the rest of the world. Overall, the baseline scenario seems to shed light at heightened sovereign risk, which can be nuanced as most public debt is held domestically, and the continuation of the previous process in which Japan sought profit abroad amidst lower domestic prospects.

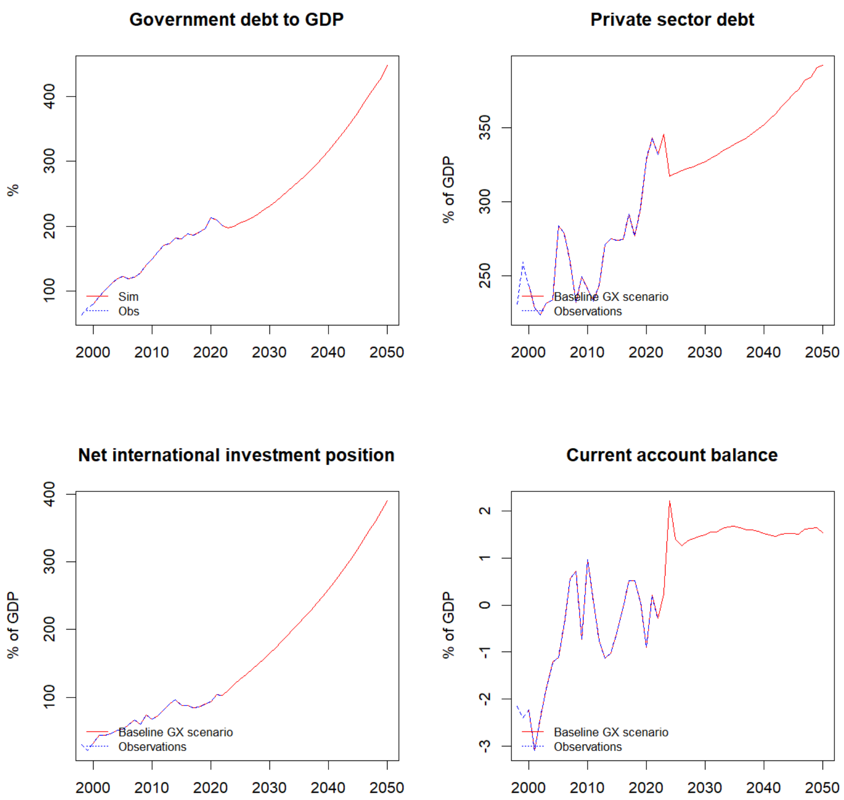

Figure 7 - Financial variables, baseline

4.2.5 – Policy variables

Figure 8 highlights the evolution of policy variables. At the zero lower bound a large share of refinancing rate fluctuation could be explained by the pressure from the spread with the FED rate. Since the fed rate is kept fixed at a higher level, the Bank of Japan financing rate increases to 0,6% annually and quantitative easing stops being used, which has an important impact on the simulation.

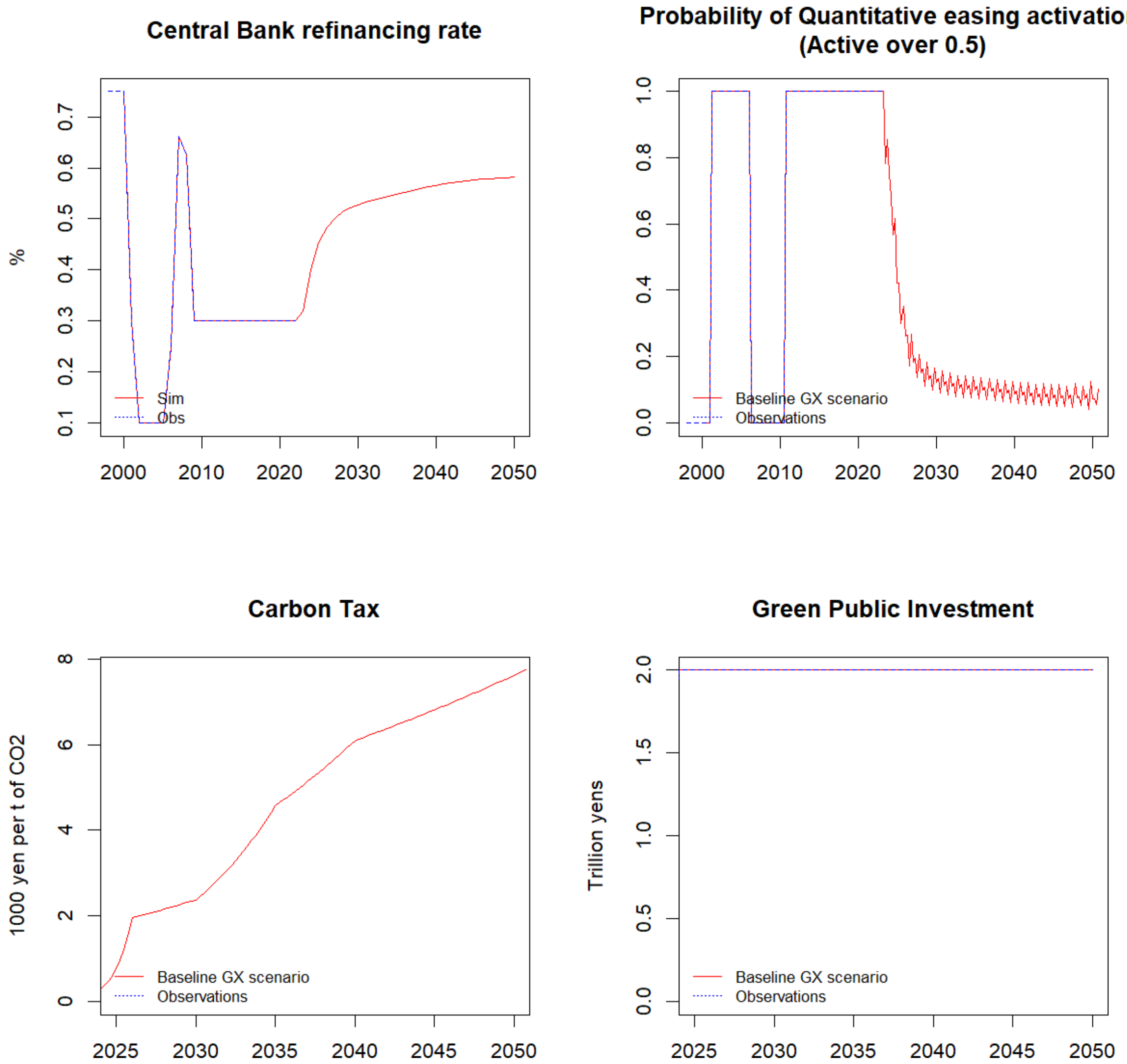

Figure 8 - Policy variables, baseline

4.3 – Policy Analysis

Fiscal policy, monetary policy and policy timings are presented in this sub-section under the form of deviation in comparison to the baseline scenario.

4.3.1 – Fiscal Policy

4.3.1.1 – Environmental performance

Figure 9 presents environmental performance for each fiscal policy scenario. First, the green public scenario performs less in terms of climate change mitigation: carbon emissions are more than 50% higher in 2050 than the baseline scenario which stems from higher energy intensity and a less important deployment of renewable energy share. Green public investment alone, while directly impacting green capital formation, does not shift incentives to the same magnitude as other fiscal policy tools. In terms of environmental performance, the carbon tax scenario performs the best, in which Japan reaches carbon neutrality by 2050. Carbon emissions attain respectively 192 MtCO2, 441 MtCO2 and 66MtCO2 in 2050 for the green subsidy, GPI and mixed scenarios.

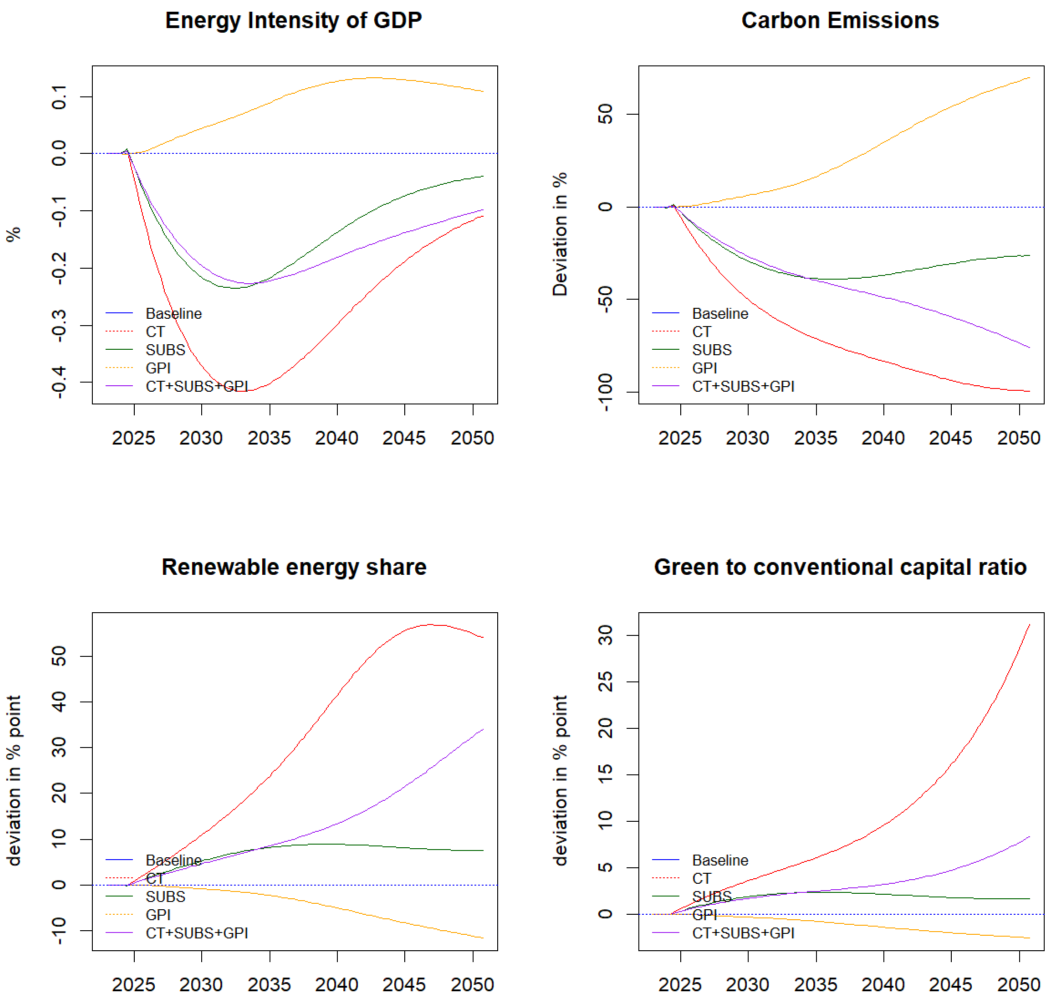

Figure 9 - GX performance, fiscal policies

4.3.1.2 – Real variables

Figures 10 and 11 present the effect of different fiscal policy mixes on real variables. Purely economic performance differs from environmental performance, and trade-offs start to appear. In the short term, all scenarios except the GPI scenario incur lower real GDP and lower growth due to lower level of public (and hence aggregate) investment. After this initial "relative shock", real GDP is the highest under the green subsidy scenario, and the carbon tax has the costliest effect on growth and output.

These results translate similarly for the unemployment rate, with however labor shortages occurring in all scenarios in the long run. The green public scenario performs slightly better in terms of GDP during the whole period, and the mixed scenario performs better than baseline in the medium and long run. Regarding inflation, while an increase in indirect tax leads to higher inflation in the short run, the recessive effect dominates in the long run and inflation remains lower. The opposite effect is observed for green subsidies with lower magnitudes as the passthrough to prices is lower than for the carbon tax. Overall, green subsidies perform best in terms of growth and GDP.

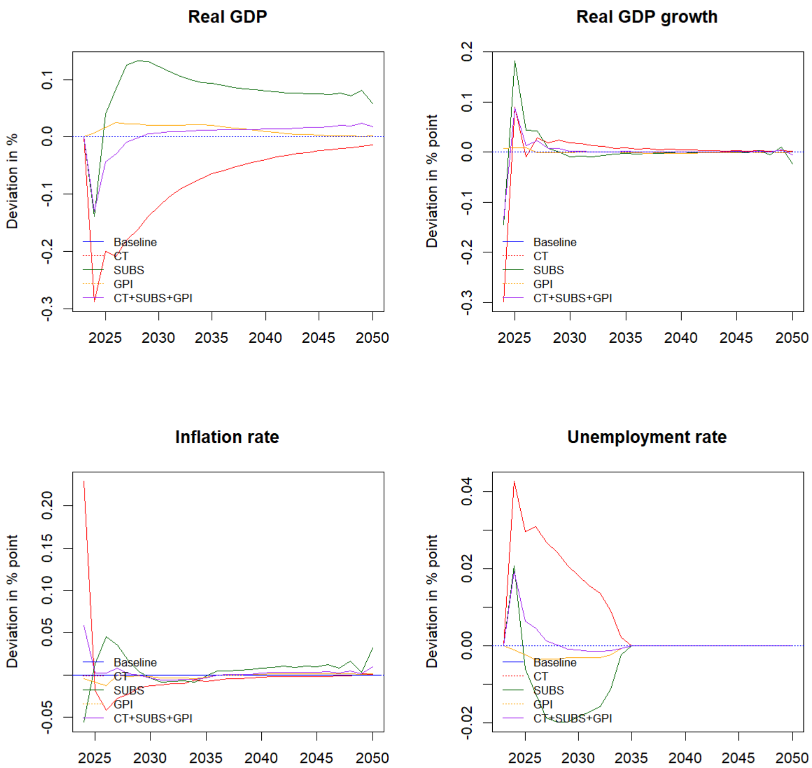

Figure 10 - Real variables, fiscal policies

The yen appreciates under a carbon tax scenario while it depreciates under the green subsidy one, which can be explained through three main channels: the recessive/expansionary effect, the impact on policy rates and the impact on relative prices and hence the trade balance. Green public investment also leads to a weaker yen over the entire period and the mixed scenario first makes the yen appreciate then depreciate in the long run.

Regarding capital accumulation dynamics, capital increases the most under the green public investment scenario without the recessive impact of a carbon tax. Without green public investment, capital stocks are higher for subsidies only until 2037, then lower as the total amount of green subsidies diminishes with lower energy intensity. The carbon tax seems to deter investment and capital accumulation and its strong performance in terms of transition could be imputed to both its recessive effect and the shift in incentives towards green capital.

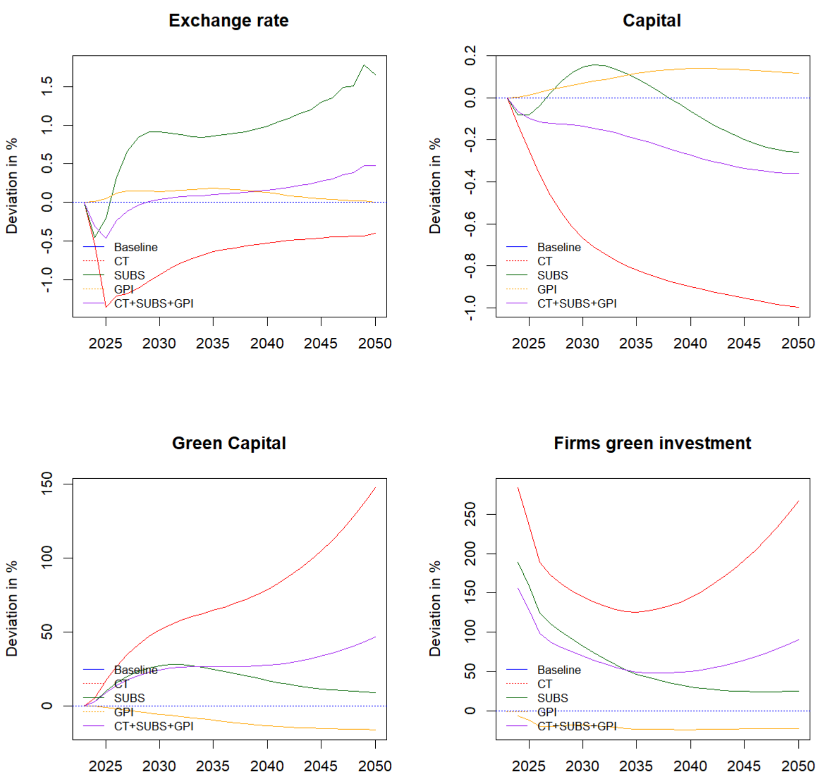

Figure 11- Real variables, fiscal policies

4.3.1.3 – Financial variables

Figure 12 and 13 present results for financial variables. As expected, green subsidies improve the net wealth of both firms and households. The financial sector also benefits from subsidies through operating surplus and interest rates increase. Green subsidies, however, incur a very large cost to the government which deteriorates its balance sheet position. The carbon tax scenario has surprisingly less impact on financial variables, but it improves the government's position with additional revenue and deteriorates the private sector's position. Green public investment displays surprising results as it deteriorates the private sector's net wealth, slightly improves the household net wealth and improves the government's net wealth. The increase in government net wealth can be attributed to a higher level of fixed capital while debt level increases by a smaller amount.

Effect differs in the medium and longer run for Japan's international position, as subsidies first relatively deteriorates the foreign position then an improvs it, with the opposite mechanism for the carbon tax. This dynamic can be explained by lower domestic prospects under a carbon tax scenario (with a symmetric effect under a green subsidy scenario) which leads to capital outflows (yen depreciation lower domestic prospects driving up foreign asset acquisition). Subsidies showcase slightly different results as slightly more inflation and depreciation occur in the long run, leading to a subsequent relatively higher purchase of foreign assets.

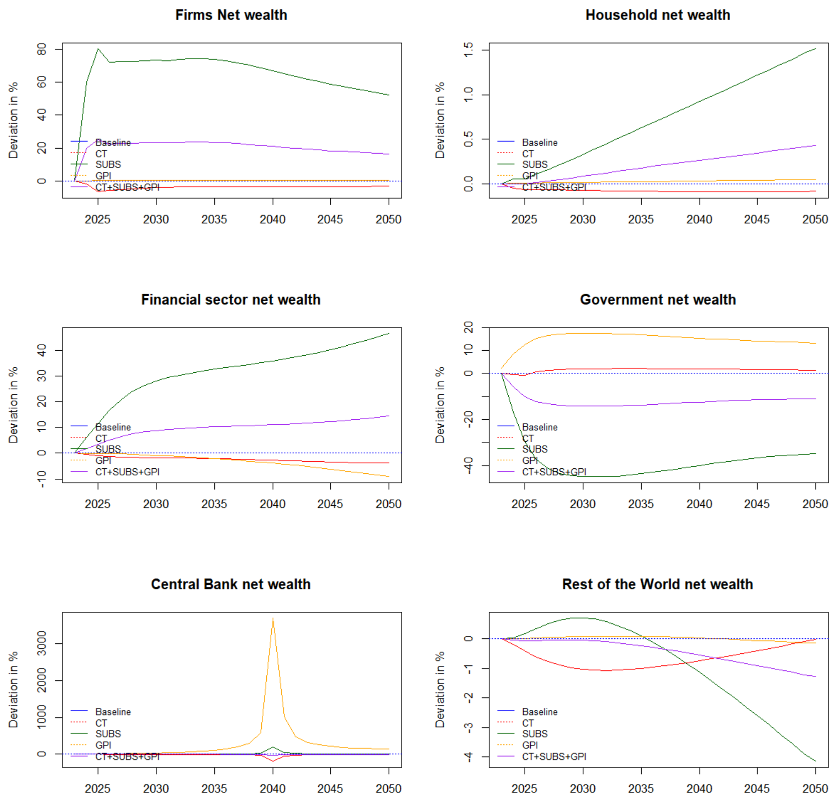

Figure 12 - Financial variables, fiscal policies

Surprisingly, government debt is lower under the full green public investment in comparison to the baseline scenario. Several channels cause this result: a higher level of green public investment leads directly to higher GDP and hence indirect tax revenue as is determined by demand in comparison to the baseline scenario. Subsidies represent the costliest policy instrument in terms of sovereign debts and a rise in carbon tax slightly improves the government's debt. The aggregate liabilities of the private sector to GDP relatively decreases in comparison to the baseline, with a starker effect from subsidies and private investment, while changes remain moderate for the carbon tax and the mixed scenario.

The net international position increase (after an initial decrease) with green subsidies: green subsidies indeed have a larger effect on real GDP when unit cost of renewables and energy intensity are high. The positive effect on real GDP leads to an increase in imports (which are mainly sensitive to domestic demand) in the long run (after a drop following the initial relative negative shock in output in comparison to the baseline). The reverse situation occurs with the carbon tax as it improves terms of trade of 0,3% of GDP through reduced exports, whose effect fades out over time. Green public investment, through increased demand for imports, leads to a slight deterioration of terms of trade over the period while the mixed scenario shows an initial improvement followed by a deterioration after 2030.

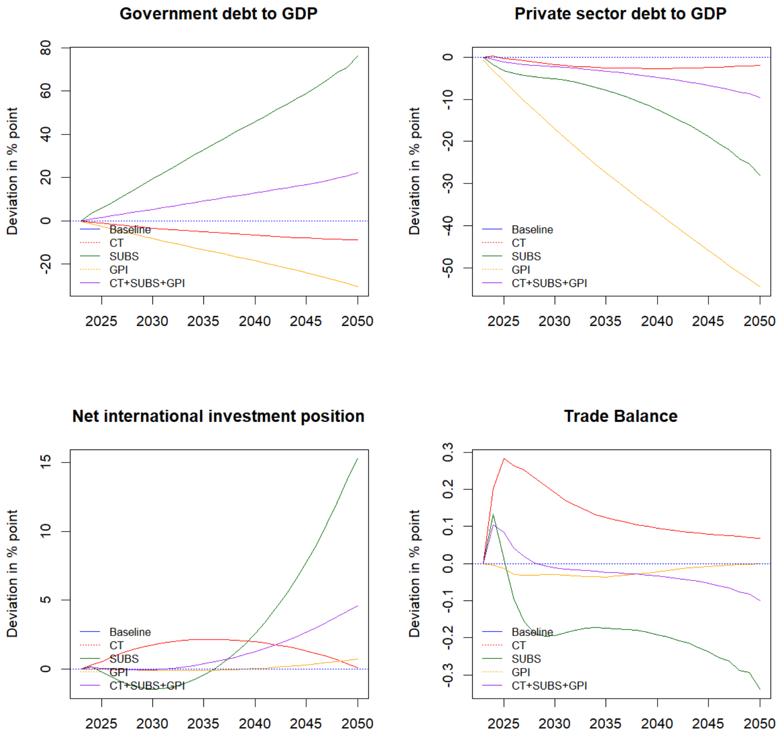

Figure 13 - Financial variables, fiscal policies

4.3.1.4 – Policy variables

Figure 14 highlights effects on endogenous policy variables. As the long run policy rate is mainly driven by lagged rate (policy persistence) and the FED's rate in this specification, quantitative ease remains inactive over the entire period. These simulations still allow to shed light at different pressures fiscal policy could induce on monetary policy. The initial recessive impact of a carbon tax first induces a drop-in refinancing rate followed by increases due to growth and indirect tax increase induced inflation. Subsidies (as well as the mixed scenario) through their expansionary effects lead to relatively higher rates over the period while rates first increase then relatively decrease in comparison to the baseline with a green public investment only scenario.

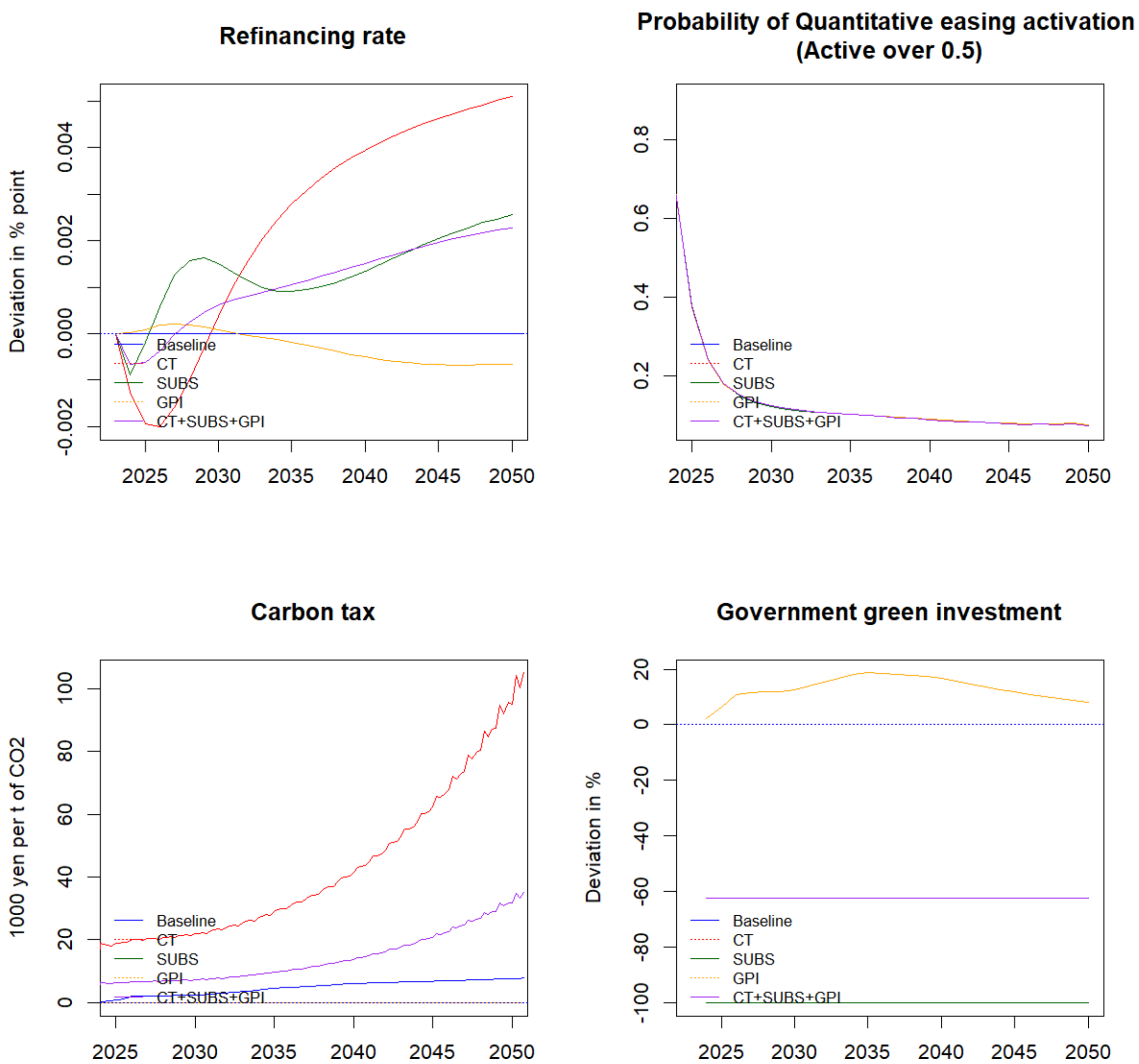

Figure 14 - Policy variables, fiscal policies

4.2.3 – Monetary Policy

This subsection presents results on monetary policy and its impact on environmental and economic performance. Three scenarios are tested: higher interest rates, lower interest rates and the activation of quantitative easing.

4.3.2.1 – Environmental performance

The first clear impact of higher interest rates is its negative impact on GX. If carbon emissions decrease by 0,5% until 2030 in comparison to the baseline scenario through its recessive impact, it discourages investment in the long run and in turn green investments and green capital accumulation. Lower rates induce a slightly better performance in the medium to long run, but effects are limited and quantitative displays a clearer impact on environmental performance.

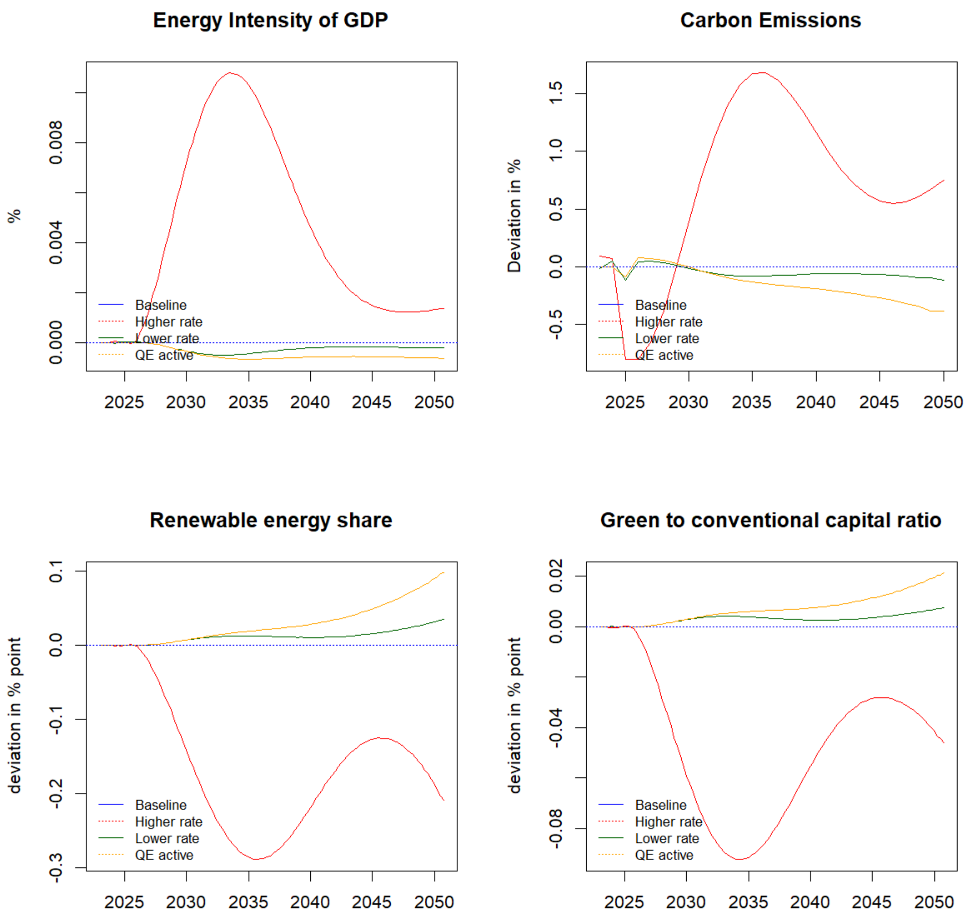

Figure 15 - GX performance, monetary policy

4.3.2.2 – Real variables

Real variables show expected outcomes with a recessionary effect (and lower inflation in the short run) of restrictive monetary policy and an expansionary impact of lower refinancing rates. Quantitative easing's has a stronger positive impact on GDP in ther medium run while it has a (relative) negative impact in the longer run on GDP. Under QE inflation also increases, however only in the short run.

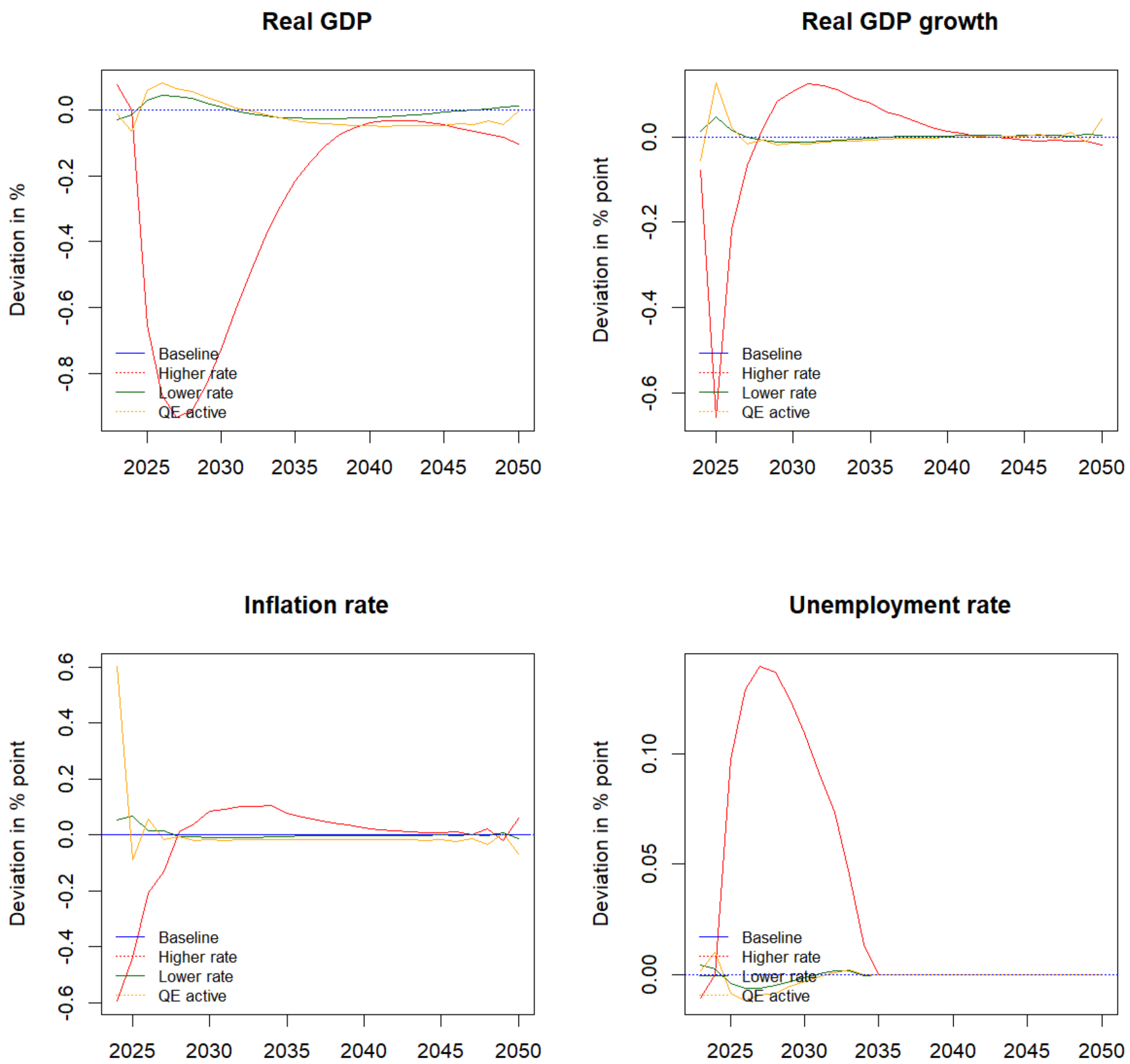

Figure 16 - Real variables, monetary policy

As expected, the yen appreciates higher rates and depreciates over lower rates. Quantitative easing has a stronger impact on yen depreciation than lower rates alone. While lower rates have a positive impact on capital accumulation and green investment, quantitative easing leads to a decrease in investment. Interestingly, green investment however increases more under quantitative easing than without for firms.

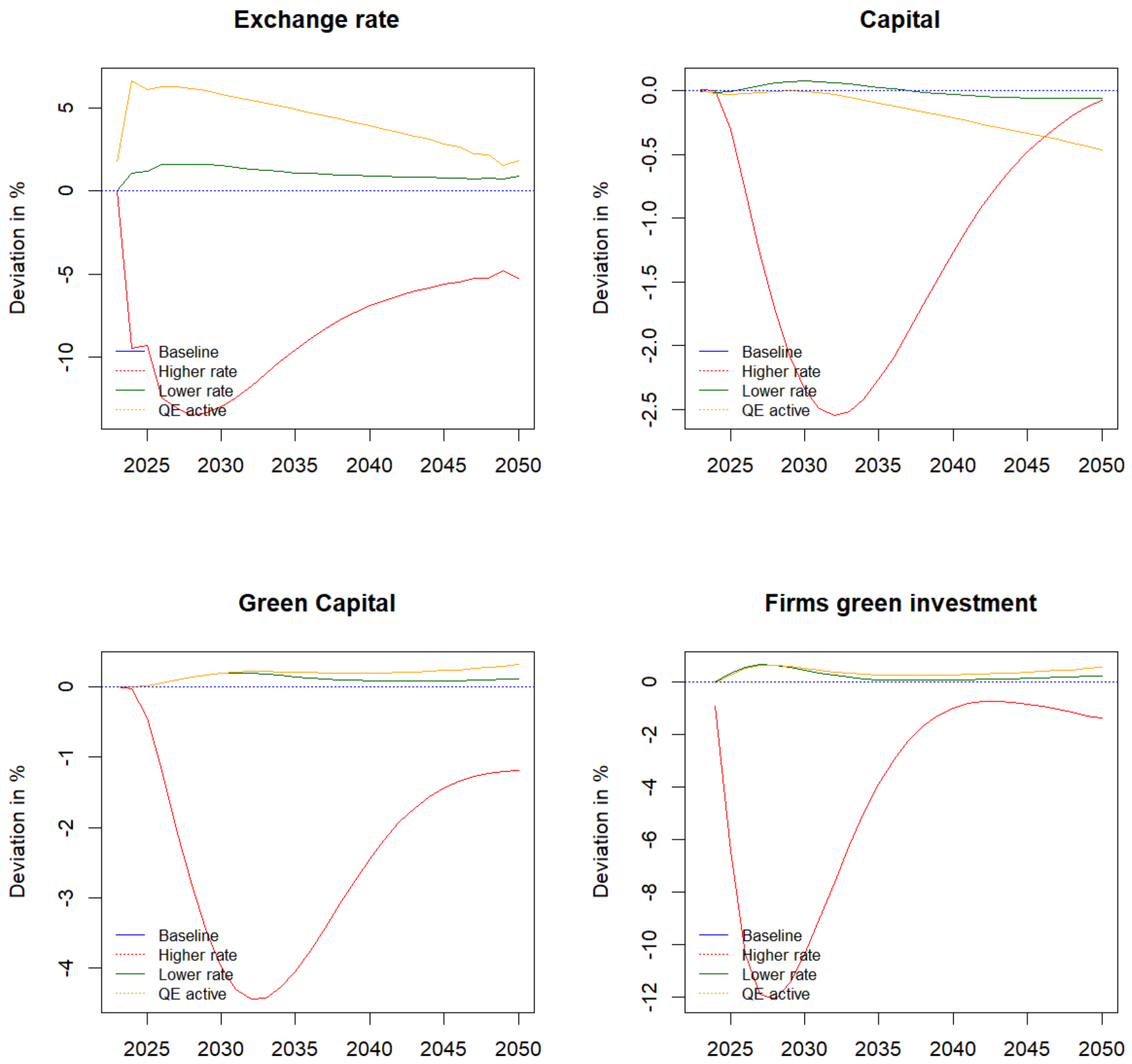

Figure 17 - Real variables, monetary policy

4.3.2.3 – Financial variables

Figure 18 and 19 present simulation results on financial variables. Firms and the financial sector's net wealth is relatively higher when QE is active while households' net wealth and the position vis-à-vis the rest of the world deteriorates. Higher rates lead to increased wealth for the financial sector, households and the central bank through higher interest rates (and hence higher returns on pension products and interest-bearing assets). Firms and the government are worse off in terms of wealth with higher leverage and interest payments. Higher rates lower the purchase of foreign assets and hence deteriorates the net international position (with less foreign asset purchase). The symmetric relationship can be observed with lower rates, and quantitative easing. QE improves firms' wealth in the short term, the financial sector's wealth but deteriorates the household sectors' net wealth.

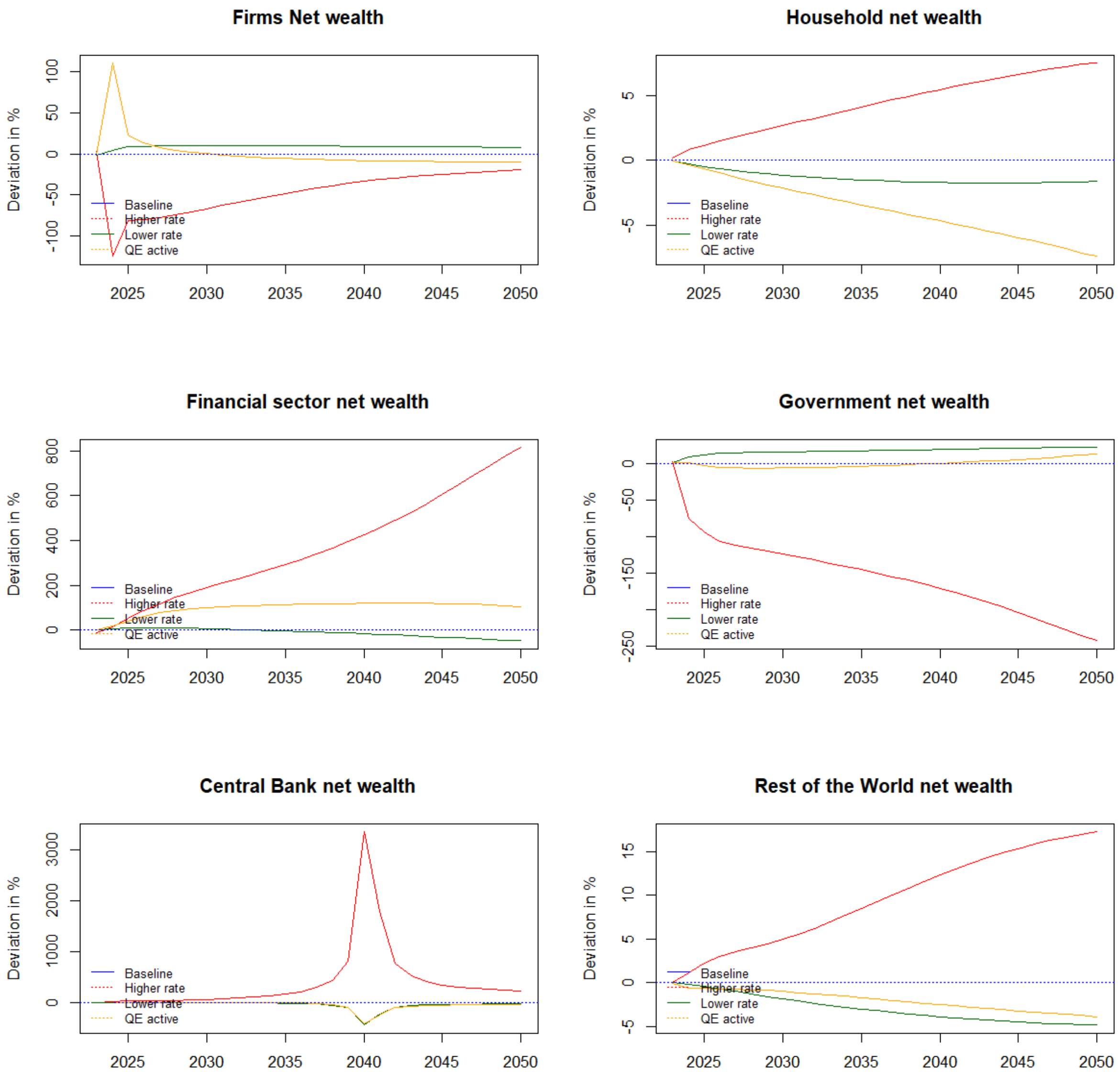

Figure 18 - Financial variables, monetary policy

Higher rates lead to a snowballing effect of government debt to GDP and private sector leverage, and a reduced net international investment position (through interests and foreign asset channels). Lower rates and quantitative easing produce the opposed effects with lower magnitudes for leverage. Trade balance follows a surprisingly different pattern, which can be due to a J-curve like pattern, with an improvement of terms of trade with yen appreciation (leading to higher purchasing power) and lower import (due to lower levels of domestic demand) with in the longer-run a decrease in exports due to the yen appreciation, the return of growth (and hence imports), effectively deteriorating terms of trade.

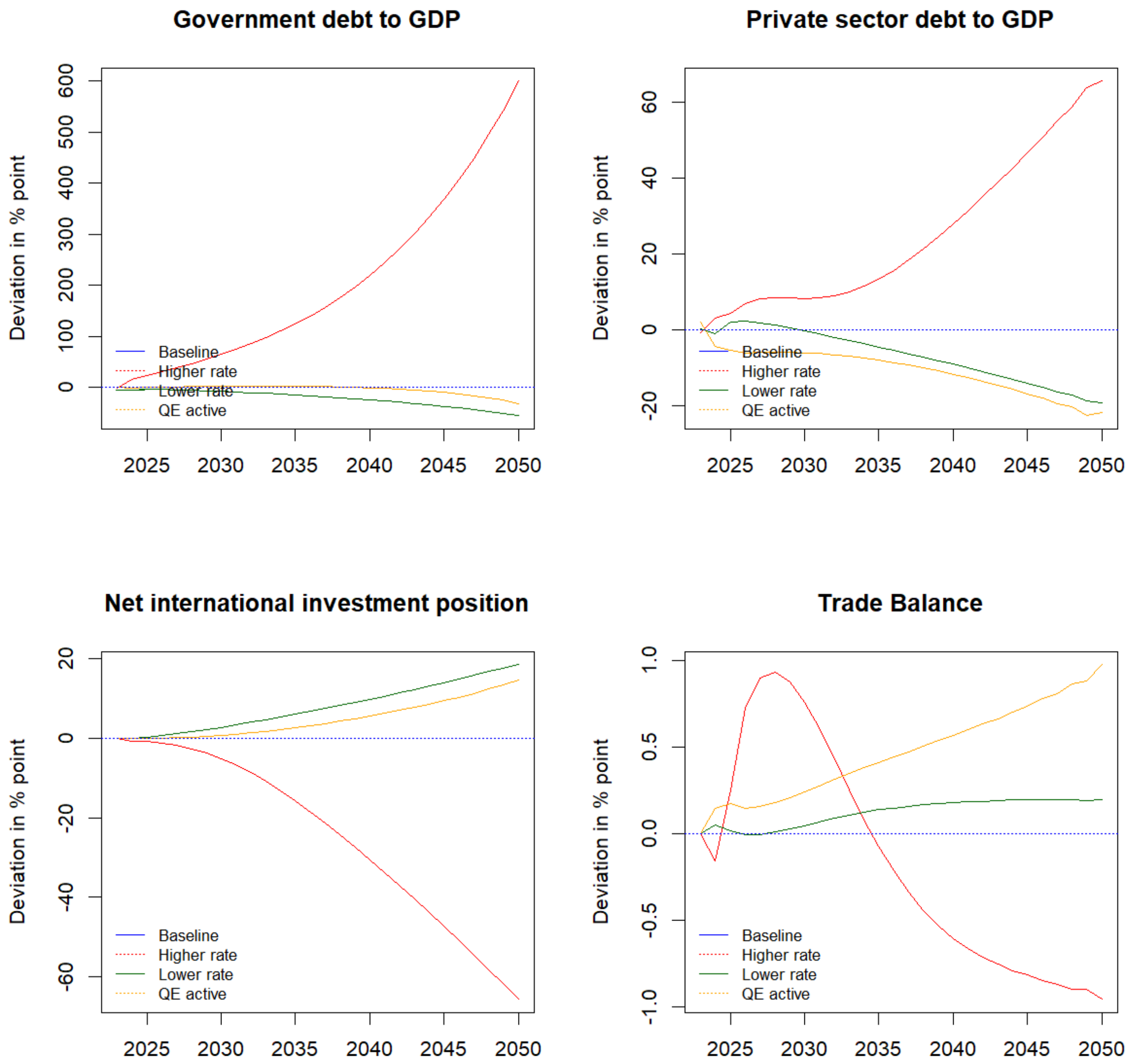

Figure 19 - Financial variables, monetary policy

4.3.2.4 – Policy variables

Figure 20 displays policy variable divergences with the baseline scenario. The probability of QE goes to zero as the refinancing rate goes to equilibrium in the QE scenario, but the QE activation was exogenously fixed. QE is supposed to be active with lower rates but was kept exogenously inactive to only account for the effect of interest rate differentials.

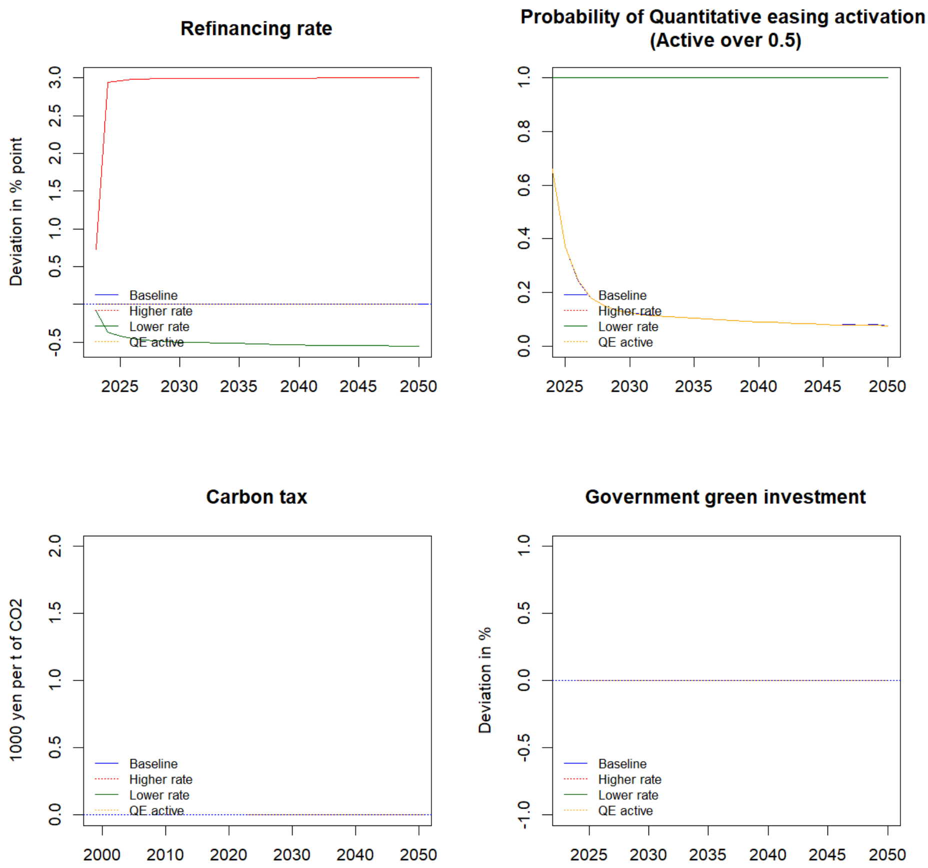

Figure 20 - Policy variables, monetary policy

4.3.3 – Timing

This section examines (for the same "policy budget") the impact of fast and last minute transitions and adds an alternative scenario based on the IEA recommendations on carbon tax levels. The fast transition is concentrated over the first 10 years while the late transition over the last 10 years.

4.3.3.1 – Environmental performance

Under the fast ramp up scenario, while performance in the first years improve compared to the baseline, the decrease in momentum (to stay within the same budget) leads to higher carbon emissions in the long run of 459 MtCO2 by 2050. Japan nonetheless attains its 2035 NDC in 2030 and the absence of further decarbonization comes from the progressive phasing-out of policy tools. As expected Japan fails to reach all of its intermediate NDCs in the last minute transition scenario. It however still reaches carbon neutrality in 2050 at the cost of higher cumulated emissions (by 2000 MtCO2 compared to the fast transition scenario). This result can be explanied by several factors: green investment endogenously increase before policy implementaiton with decrease in renewable energy costs and increase in fossil fuel costs. Secondly, as GDP (and investment levels) are higher at later stages, green capital accumulation can accelerate during the fast transition.

Last, the last minute transitition leads to a very sharp increase of the carbon tax from 2030 to reach close to IEA levels by 2040 and green investment doubling the levels of the baseline scenario, which shifts incentives at a much faster rate and represents a lower cost for the government (benefiting from higher revenue in comparison to a fixed level of investment). The IEA scenario performs overall better environmentally than the baseline and the other two scenarios, with cumulated emissions lower by 7000MtCO2 over the period, as carbon tax levels are higher and this alternative scenario was not constrained by the cost of the baseline scenario contrarily to other simulations.

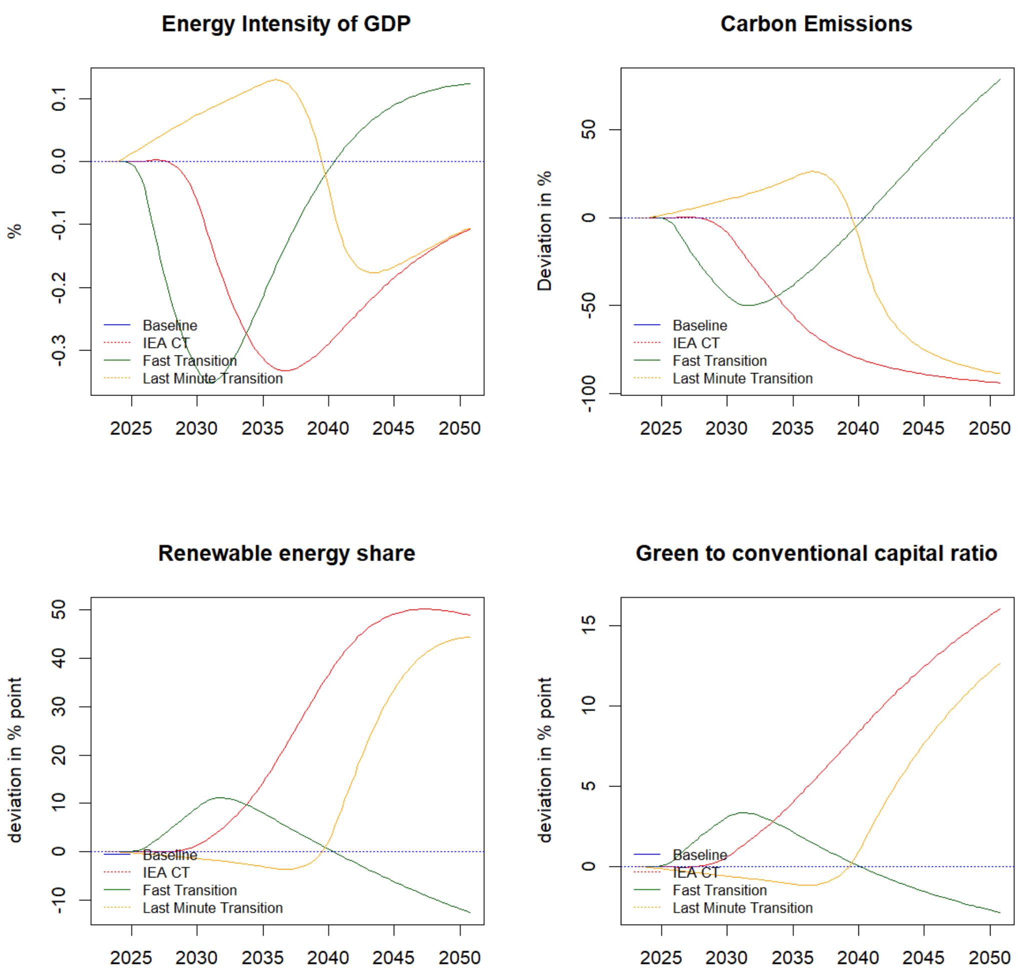

Figure 21 - GX performance, timing

4.3.3.2 – Real variables

Regarding real variables, the fast transition has an initial positive impact on GDP relative to the baseline scenario, with a level however lower by 2050. The last minute transition implies a lower GDP in the medium run and slightly higher in the long run. Effects on inflation are ambiguous as carbon tax initially pushes up prices then puts deflationary pressure by its recessive character while public investment pushes up inflation and growth. Overall, the IEA scenario leads to a slightly lower scenario in the long run but is not as costly as a pure carbon tax scenario was as public investment partly compensates the impact of the increased carbon tax. Similar results are obtained on capital accumulation dynamics, but the IEA carbon tax clearly shifts investment towards green capital which explains its environmental performance.

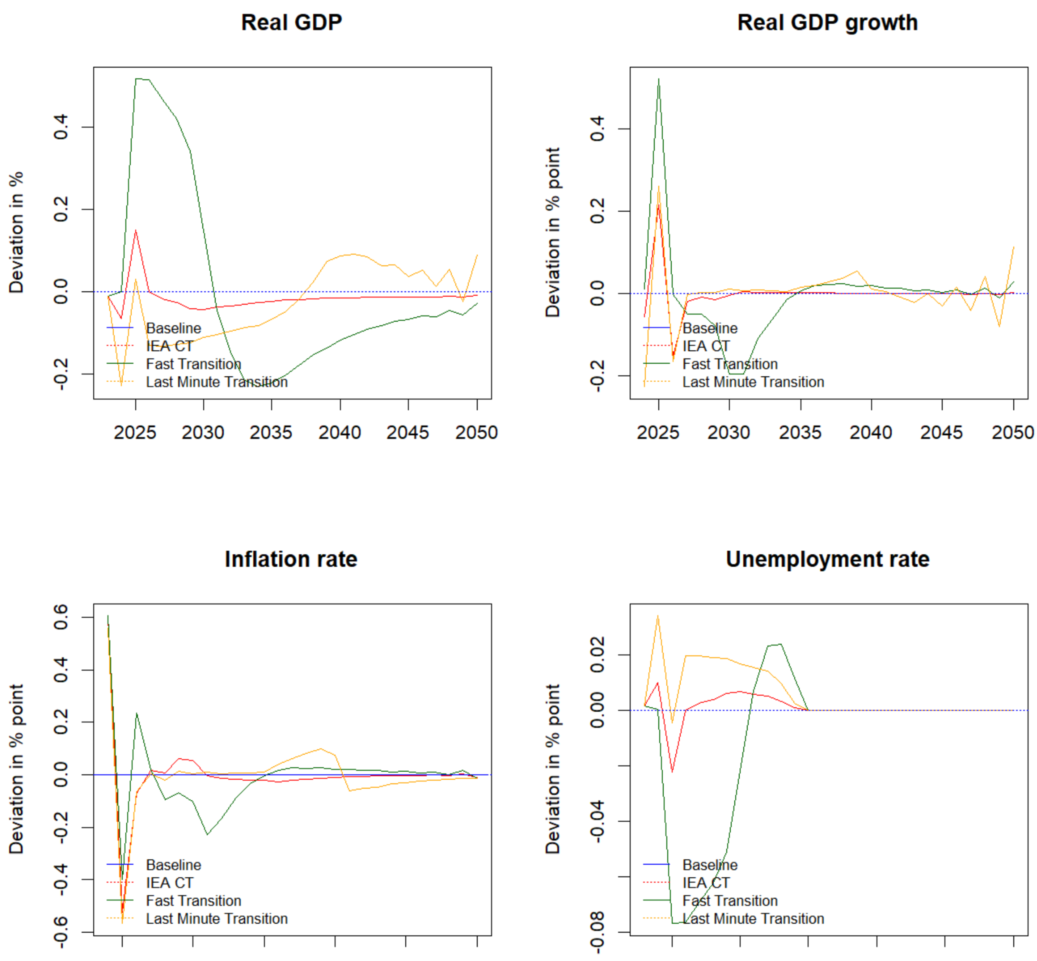

Figure 22 - Real variables, timing

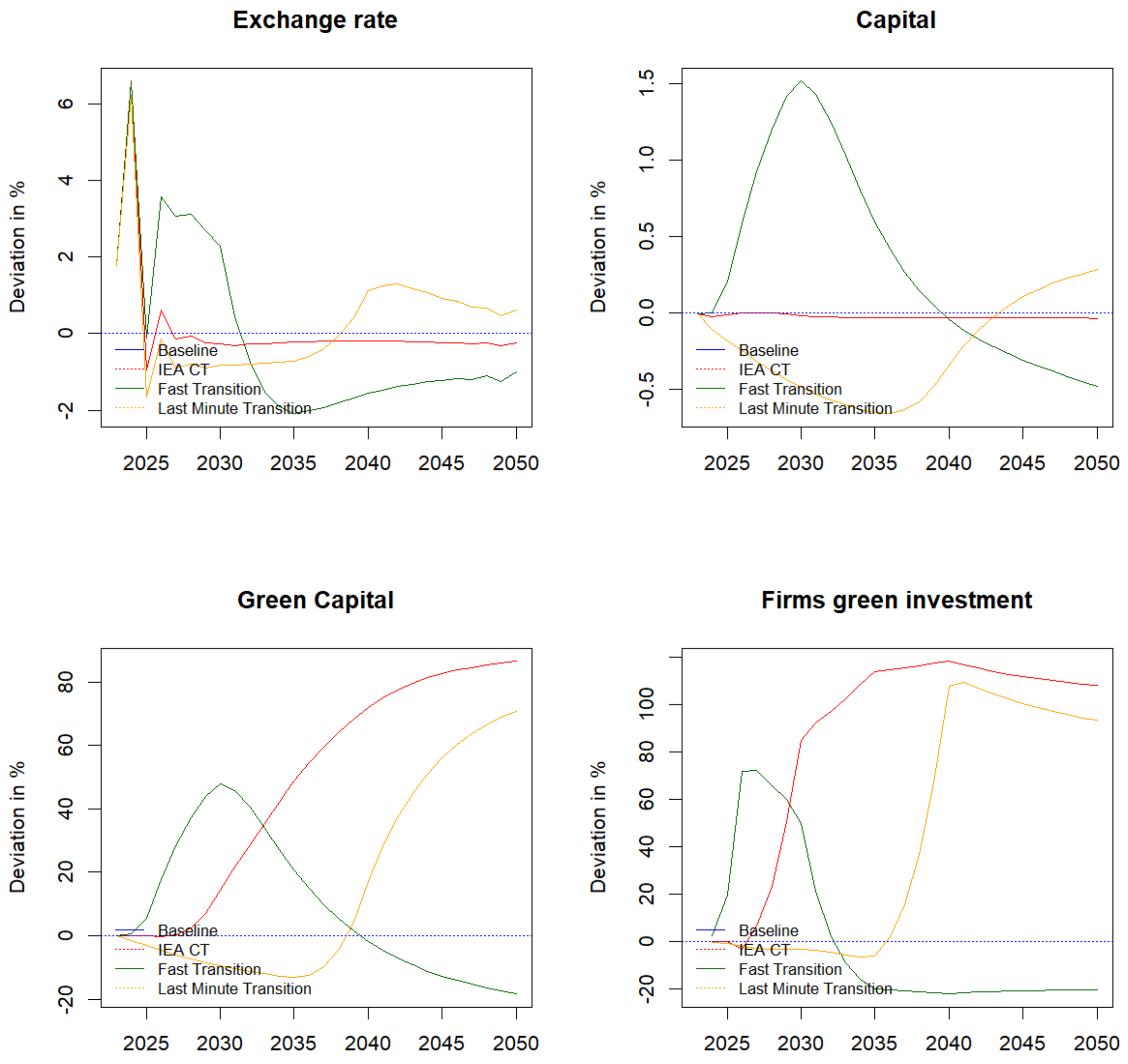

Figure 23 - Real variables, timing

4.3.3.3 – Financial variables

Figure 24 and 25 present results for financial variables. Net wealth is systematically lower for households in all scenarios, and higher for the financial sector while effects are more ambiguous for firms and the government. This is also due to the construction of the policy variables despite being at the same baseline cost. Effects overall attenuate over the course of simulations for firms and financial institutions, while household's net wealth remains lower and the international position deteriorates during the transition. The central banks' net wealth worsens with the last-minute transition while it improves in 2040 for the fast transition.

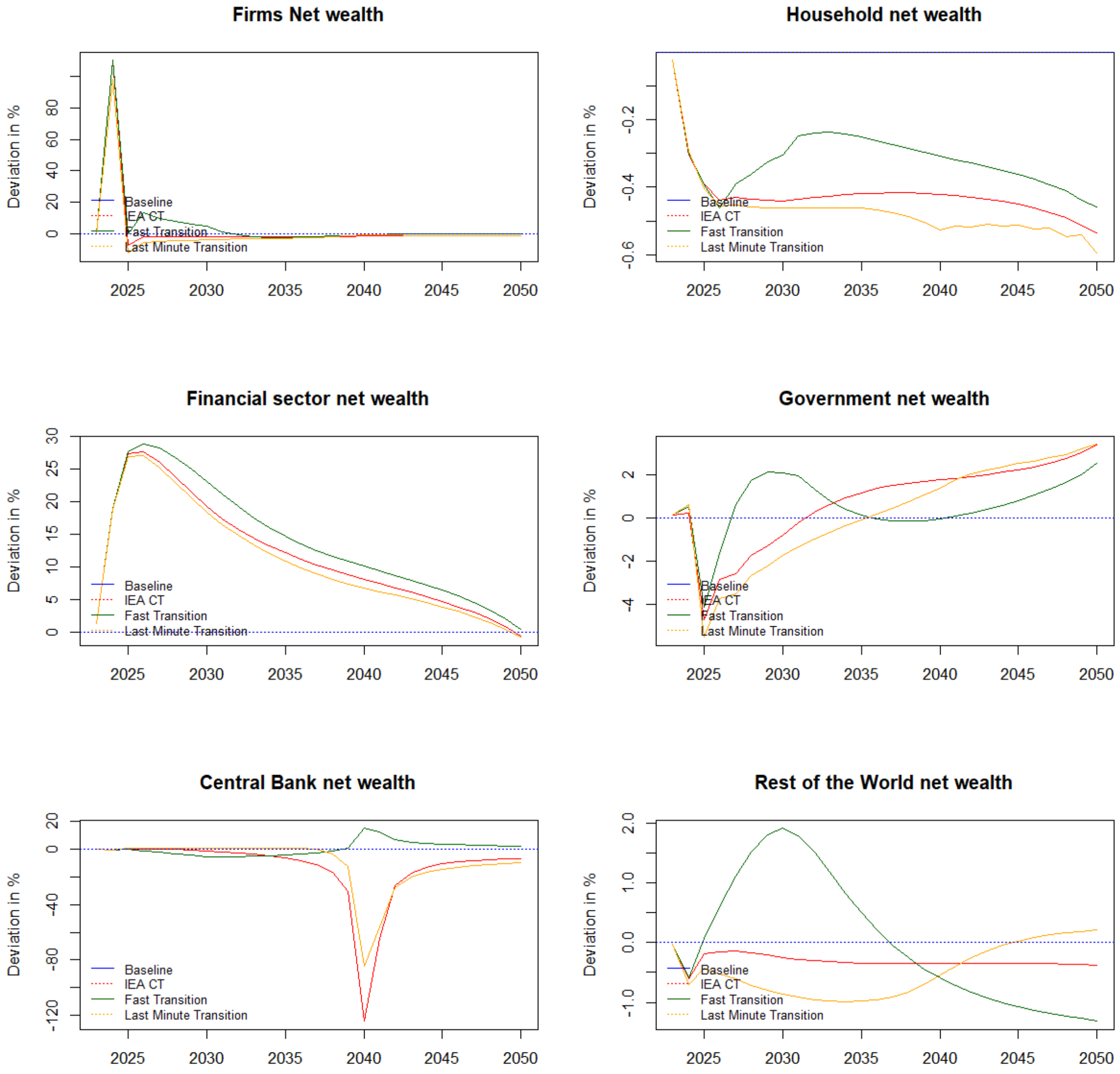

Figure 24 - Financial variables, timing

When observing debt to GDP ratios, although deviations are comprised between 4 and 8 percentage points, all scenarios showcase a long run lower public debt with a substantial increase during the fast transition. Several factors explain these results: differences in direct taxes (related to carbon tax and to GDP), investment and tax carbon levels and impacts on rates.

The fast transition leads to an initial increase in leverage for the private sector which increases leverage during the initial boom of investment and then decreases when the transition effort decreases. The symmetrical relationship is observed for the last-minute transition. The IEA carbon tax displays results analogous to the CT scenario with lower wealth but also lower private sector leverage. The net international investment position deteriorates with the transition and the increases in carbon tax improves in a long run improvement of the net international position.

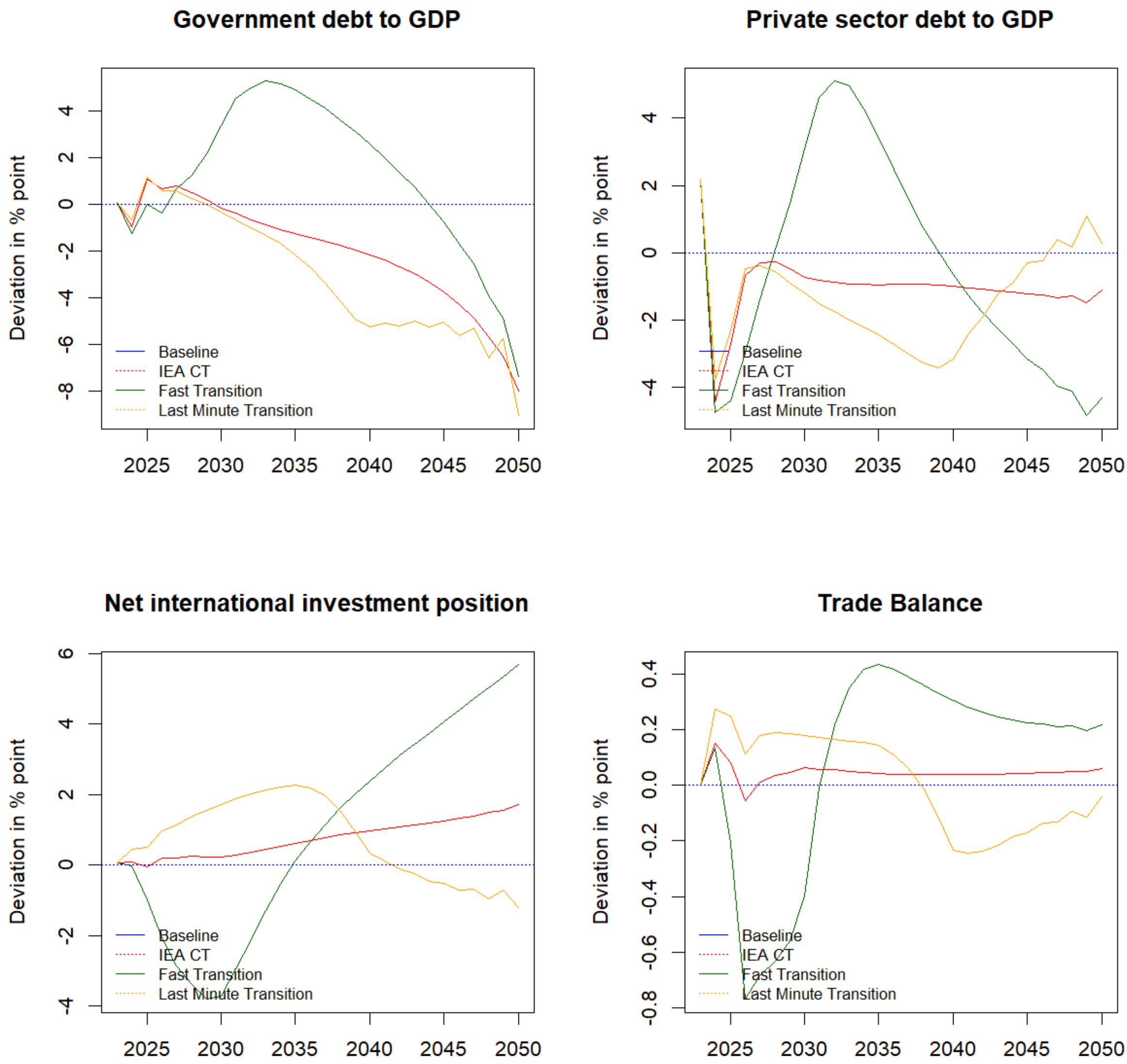

Figure 25 - Financial variables, timing

4.3.3.4 – Policy variables

Figure 26 presents result on the policy variables and illustrates pressures on the central bank. GX timing is associated with a hike in interest rates in comparison to the baseline scenario, which underscores the inflationary aspect of it: higher inflation and output gap leading to an endogenous increase in refinancing rates.

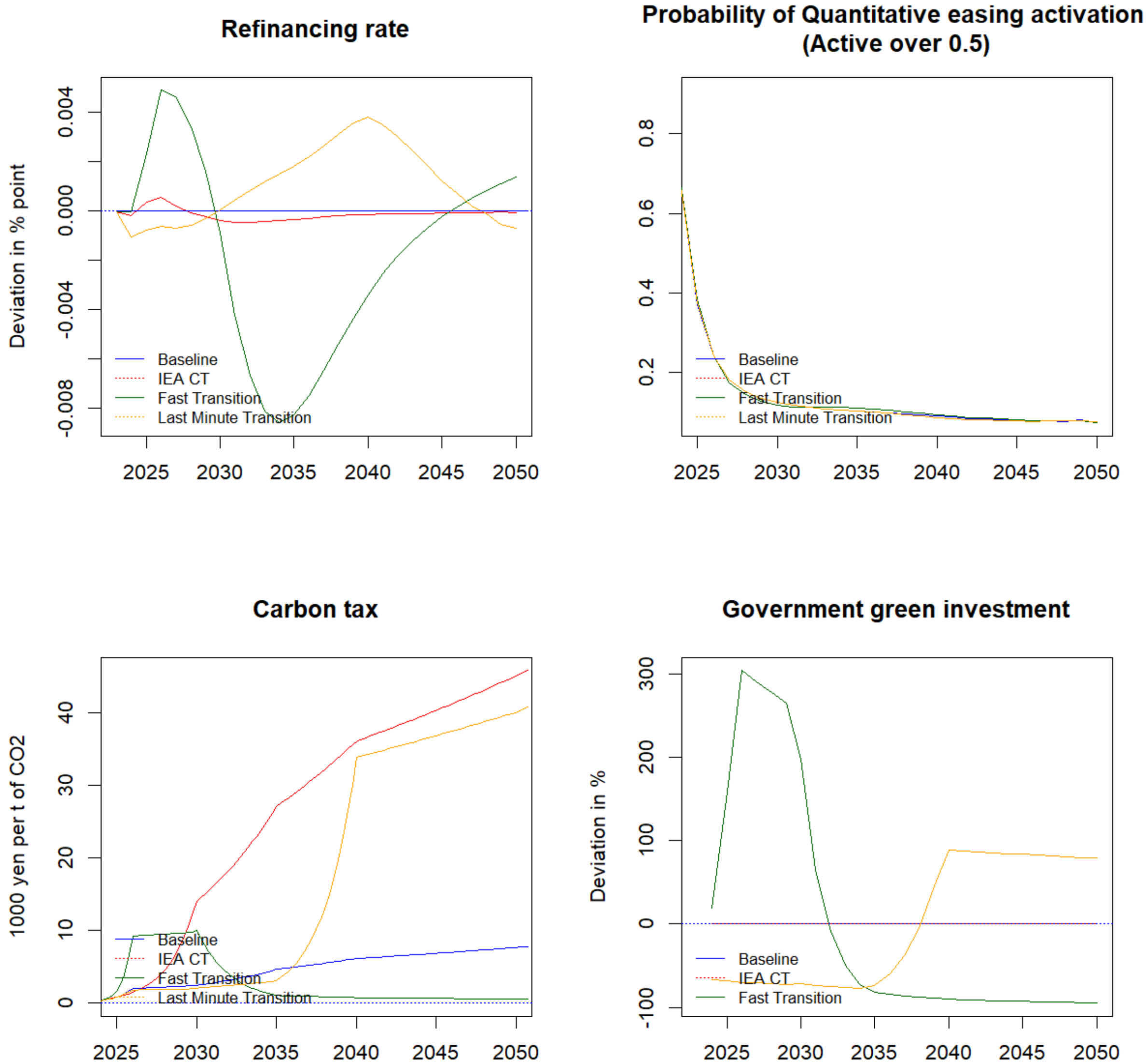

Figure 26 - Policy variables, timing

5 – Discussion and Policy Implications

5.1 – Climate Change and the Green Transition in Japan

The Japanese economy will directly suffer from the impact of climate change, adding to existing challenges of ageing population and heightened sovereign debt. By 2050, climate-related damage could represent up to 2% of GDP annually. Damage will be significant even to 2050, and adaptation will induce a non-negligeable cost to adapt the Japanese economy to higher average temperatures both through the diversion of funds away from production and mitigation, and from its direct cost. Damage and adaptation could hinder the GX objectives itself and was hence integrated in this study.

Despite a clear transition occurring under the current baseline scenario, under current assumptions it seems that Japan will not be able to meet its carbon neutrality goals by 2050. The carbon tax (and associated Emission Trading Schemes) seems to be the root cause for poor environmental performance. An ambitious Carbon tax and subsidies, by distorting incentives in favor of green capital which in turns favors energy efficiency and renewable energy use, produce the most desirable outcome in terms of carbon emissions. Simulations, however, shed light at existing trade-offs between GX performance, economic performance and financial stability which will be explored in the following subsection.

Last, simulations show mixed results in terms of transition timing. First, since the model does not integrate differentiated green finance, credit rationing, explicit default or non-performing loans, and stranded assets dynamics, conclusions cannot be drawn on the risk of green swans. They however highlight the expansionary and inflationary aspect of the current GX policy through increases in indirect taxation (repercussed on price) and public investment. Another key impact cons. Moreover, last minute transition shows better results in terms of carbon neutrality than a fast transition, through higher production capacities in later periods, but which comes at the cost of higher cumulated emissions and hence a higher contribution of Japan to global warming.

5.2 – Trade-offs between fiscal policy tools

Fiscal policy instruments produce different outcomes in terms of carbon emissions, economic performance and wealth distribution. First, carbon taxes are, as often highlighted in economic literature, the most efficient tool in terms of climate mitigation by directly shifting incentives towards greener investment. They, however, incur higher aggregate economic costs in terms of output and unemployment and negatively impact private sector wealth while slightly increasing government's leverage (although not in large magnitudes).

Green subsidies provide relatively similar environment performance in initial periods but are not sufficient in the long run to fully shift incentives after an initial take-off of green capital and renewable energy. By directly subsidizing production, GDP and inflation increase the most at the expense of deteriorating terms of trade and very high cost for the government which suffers from higher expenditures and lower capital stock.

Pure green public investment has a moderate impact on most variable, which is also due to its magnitude (as higher levels of public investments lead to higher outcome), since the increase in public investment in the pure public investment scenario is relatively modest in comparison to the baseline. Green public investment directly increases the stock of green capital and the overall stock of capital (which slightly improves potential output) while having a moderate impact on inflation and public finance (through increased revenues in indirect taxation). Furthermore, conventional investment was kept at the same increasing level for all simulations, but should conventional investment increase at a higher rate than green public investment, the impact on mitigation would be negative as more private investment would be required to offset conventional public investment.

Overall, the mixed scenario seemed to provide the best aggregate performance, as shortcomings of carbon tax and green subsidies were offset, at a moderate cost increase for the government but with higher inflation (in a deflationary context), higher wealth levels for the private sector and a situation in line with carbon neutrality by 2050. The concomitant use of carbon taxes and green subsidies appear as a form of carbon tax recycling, advocated for in previous research.

Long-run impact of Fiscal Policy	**Carbon Tax**	**Green Subsidies**	**Green Public Investment**	**Mixed**
GX objectives	*Best*	*Moderate*	*Low*	*High*
Output and Employment	*Lowest*	*Highest*	*Higher*	*Higher*
Inflation	*Lowest*	*Highest*	*Similar*	*Slightly higher*
Exchange rate	*Appreciation*	*Depreciation*	*Slight depreciation*	*Slight depreciation*
Trade Balance	*Best*	*Lowest*	*Slightly worse*	*Slightly worse*
Government debt	*Lower*	*Highest*	*Slightly lower*	*Higher*
Private wealth	*Lowest*	*Highest*	*Slightly higher*	*Higher*
International Position	*Higher*	*Worst then higher*	*Slightly higher*	*Higher*

Table 3 - Summary of fiscal policy trade-offs

5.3 – The role and consequences of monetary policy

Monetary policy simulations underscore the critical importance of interest rate levels in financing the transition. An increase in interest rates would hinder the GX by discouraging investment and cause significant risk by raising debt servicing cost for the Japanese government which is already heavily indebted. These simulations hence highlight the importance of keeping interest rates low enough to finance the transition. This consequence however comes at a cost and points at pressures the BOJ and then the yen will have to face. With lower growth and inflation with respect to the rest of the world, it is likely that it faces headwinds from rate differentials with the FED (and the rest of the world), and low interest rates could also divert domestic investment to foreign investment which feature higher returns.

With regards to unconventional monetary policy, exiting quantitative easing seems compromised as fundamentals generate deflation, and its negative impact might force the BOJ to keep using UMP to support the GX (and the Japanese economy overall). QE has mixed effects as on the one hand by keeping rates low it decreases investment costs, but it also led to a yen depreciation and capital outflows (hence diverting domestic investment for foreign investment). Its role on inflation also appears rather ambiguous, with inflation increasing only in the short run after activation. QE benefits the financial sector by providing liquidity and the government's debt financing which could play a role when increasing public subsidies and green public investment. Discussions on green QE have emerged in recent years but testing its potential impacts could be examined in future research, for example with an approach similar to current QE practice, or an approach "à la Werner" who advocated for direct purchase of GDP financing instruments (for example firms' green loans) (Werner 2013).

6 – Contributions, limitations and future research

6.1 – Contribution to existing literature

This study contributed to existing literature by applying a framework which was not applied before to the Japanese economy and the question of climate change. It laid the foundation of an empirical SFC model of the Japanese economy. Stock-flow consistent modeling, by integrating finance and a rigid accounting structure, offers the possibility to study unsustainable processes (which for example done by Godley for the subprime crisis) by looking at flows and feedback loops between stocks and flows, and the financial and real sector. They also enable modelers to take into account country specific factors as they are built on national accounts and must reflect a country's features. Japan's economy presents particular structures in its labor market, financial system, corporate governance, but and conjunctural specificities (deflation, foreign investment, corporate liquidity holding) which could be addressed with further studies using this framework.

Furthermore, integrated impact modeling and climate change, mitigation and adaptation as well as ex ante policy evaluation of the GX under a whole-economy framework are still relatively unexplored topics for the Japanese economy. This paper attempted to provide a qualitative assessment with quantitative methods of the GX commitments and their potential impact on the Japanese economy. It also tried to offer insights on potential trade-offs between policy tools and what mixture of fiscal instruments and monetary policy would best integrate these trade-offs.

6.2 – Limitations and Future research

This study presents numerous limitations which limit its heuristic impact and calls for prudence in result interpretation and future research.

6.2.1 – On the Lucas critique

Often raised in macroeconomic modeling, the Lucas Critique does apply to this model. It states that welfare analysis should be made in policy-invariant models, as policy changes would lead to shifts in behaviors (and hence the parameters of behavioral equations). This study fails to pass the critique in its pure sense, as this model, like most macro econometric models are not based on deep structural parameters (such as preferences). It still attempts to provide a way out (often advocated for in SFC modeling**)** which consists in running different scenarios to provide qualitative perspective on impacts than absolute quantification (Goutsmedt, et al. 2017). Still, this paper and this model could benefit from stability and sensitivity analysis to confirm (or infirm) findings and their relevance.

Another potential perspective on this critique consists in its relevance to this type of analysis. First, some others, such as Blanchard examined the stability of macroeconomic parameters and while some parameters are subject to shifts with policy, the shift is rather modest, and they do not necessarily occur (Goutsmedt, et al. 2017) (Blanchard 1984). Furthermore, the relative transitory aspect of the green transition (rather than a shock therapy) potentially decreases the risk of shifting parameters. Secondly, the critique arguably applies to models trying to address it (such as the DSGE program) and to any type of macroeconomic model (Sergi 2018). This does not imply that the Lucas critique is invalid for the SFC model, but that its tautological nature makes it potentially impossible to escape it, and this type of analytical exercise must be made keeping in mind caution when interpreting results.

6.2.2 – Modeling limitations and future research

Macroeconomic models rely heavily on initial assumptions, which is also the case here. One must first acknowledge the assumptions used and their limitations: aggregation of sectors, the use of (few) adaptative expectations (while other models may use representative agents, rational expectations and dynamic, stochastic intertemporal optimization) and the assumptions made for projections themselves (on US rate, global growth, oil prices). They create different outcomes on both estimated economic behavior of the modeled economy, and on the quantification of projections in the long run.

With respect to the model itself, some modeling choices could be improved to more accurately represent the dynamics of the Japanese economy. First, the financial sector and the rest of the world play a rather passive role (especially as the latter acts more as a residual with regards to its balance sheet). Foreign loan and foreign debt dynamics were not a point of focus, but it could represent a significant part of the equation as foreign debt has been rising in the past years. Credit rationing behaviors were not implemented and model dynamics, especially in the long run, may differ when integrating more constraints on financing. Japan and the BOJ have also been pioneers in experimenting unconventional monetary policy, and a more refined approach to Quantitative Easing (Yield control curve, Quantitative and Qualitative easing) as well as to negative interest rates could benefit the model's dynamics and the understanding of these tools.

Regarding the environmental section of the model and the modeling of damage, mitigation and adaptation, this approach is rather prospective. Adaptation is estimated based on assumptions on the protection function curvature and theory driven adaptation capital; climate damage is estimated through an aggregate theory-based DICE function and green capital is theoretically constructed based on previous calibrations. These three parts could be improved through empirical estimations of damage. This could be done for example with a more granular approach as in Nguyen (Nguyen 2022) using input-output tables (which are available for Japan at a 5-year interval frequency) and estimated damage on each sector. A similar analysis could be done on green capital by directly linking it to Japan's actual data as the Japanese government produces environmentally extended Input-Output tables. Not only would this improve the quantification and allows to properly evaluate the GX ex ante, but it would also enable a more refined analysis of the transition and its sectorial impact.

Green finance dynamics were also not integrated in this study and the topic would fit well with the SFC framework. The importance of green finance would here be three-fold, with the financing itself of the transition, the shift in incentive in the financial sector, and financial stability via the concept of stranded assets and green swans (and hence of timing).

Last, the estimation and specification of the model itself could be improved. Basic econometric techniques (OLS) and cointegration methods were used. The fit with actual data could however be increased, especially with respect to financial variables, which comes both from the accounting structure (and the closures of the model) and the behavioral equations themselves.

7 – Conclusion

The intersection of Japan's macroeconomic trajectory and the global imperative for climate action presents an crucial challenge. Japan's experience since the 1990s illustrates how structural and demographic headwinds and the legacy of financial crises can constrain economic dynamism despite innovative monetary and fiscal policy.

The accelerating imperative of climate change and mitigation brings new forms of uncertainty and risk to macro-financial management. The emergence of physical and transition risks, and the recognition of potential systemic "green swan" events, has made it clear that climate policy cannot be considered in isolation from macroeconomic and financial frameworks. For Japan, the climate transition is particularly complex: the country must balance decarbonization goals with economic performance, energy security, and the demographic realities of an aging population in a constrained fiscal space. The Green Transformation (GX) strategy, Japan's ambitious effort to mobilize public and private investment towards a low-carbon future, represents a significant policy shift, but it might not be sufficient to reach its long-term climate goals.

This paper highlights trade-offs and difficulties Japan may face during its transition, with labor shortages, domestic investment diverted abroad as well as deflationary and external pressures. Overall, this study concludes in the necessity of a mixed policy with a more aggressive carbon pricing, recycled in targeted green subsidies to balance out its recessionary effect and avoid a rebound effect from a lack of conditionality. While monetary low rates appear as necessary to finance the transition, the BOJ alone will not be able to compensate Japan's structural difficulties leading to stagnation, and it will be likely to face conflicting objectives. This model presents limitations which could be addressed in further research. It also does not touch upon redistributive effects of climate policies between heterogenous agents not fairness. Further research could build upon this study by improving model specification, estimations, especially on the environmental module and test for different sets of policies (for example by including climate finance, green QE or targeted monetary policy to finance the transition).

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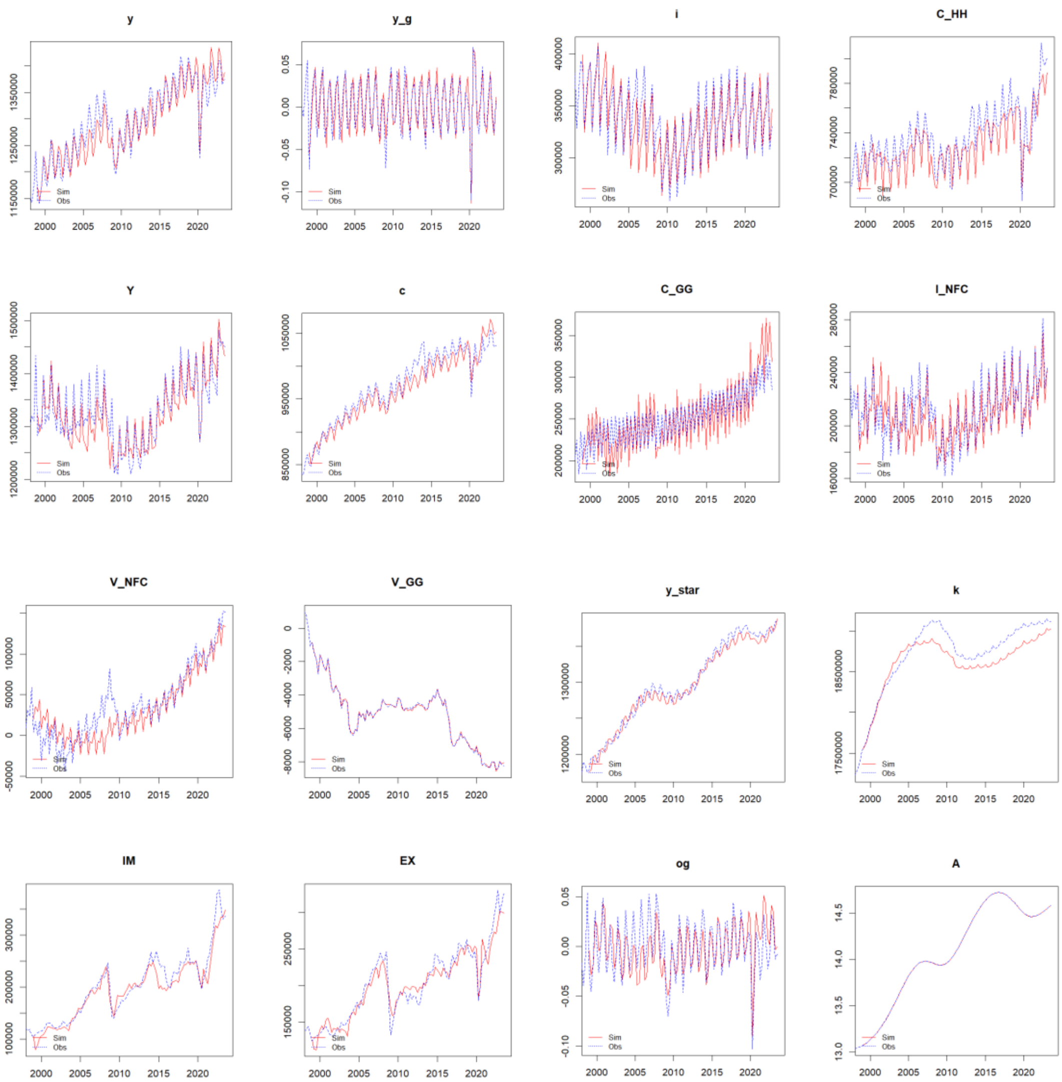
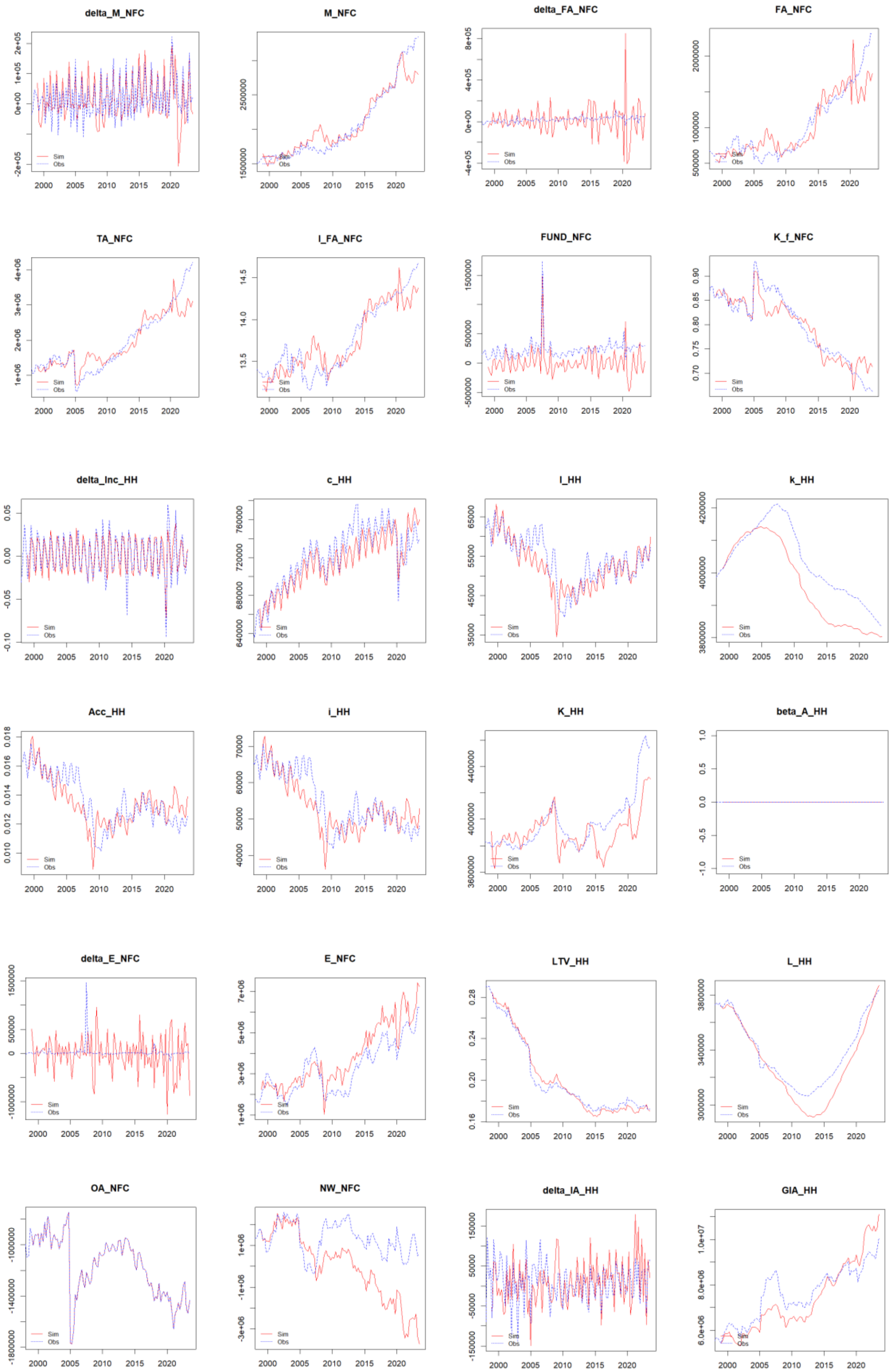
9 – Annexes

9.1 – Model fit

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c_HH
I_HH
k_HH
Acc_HH
i_HH
K_HH
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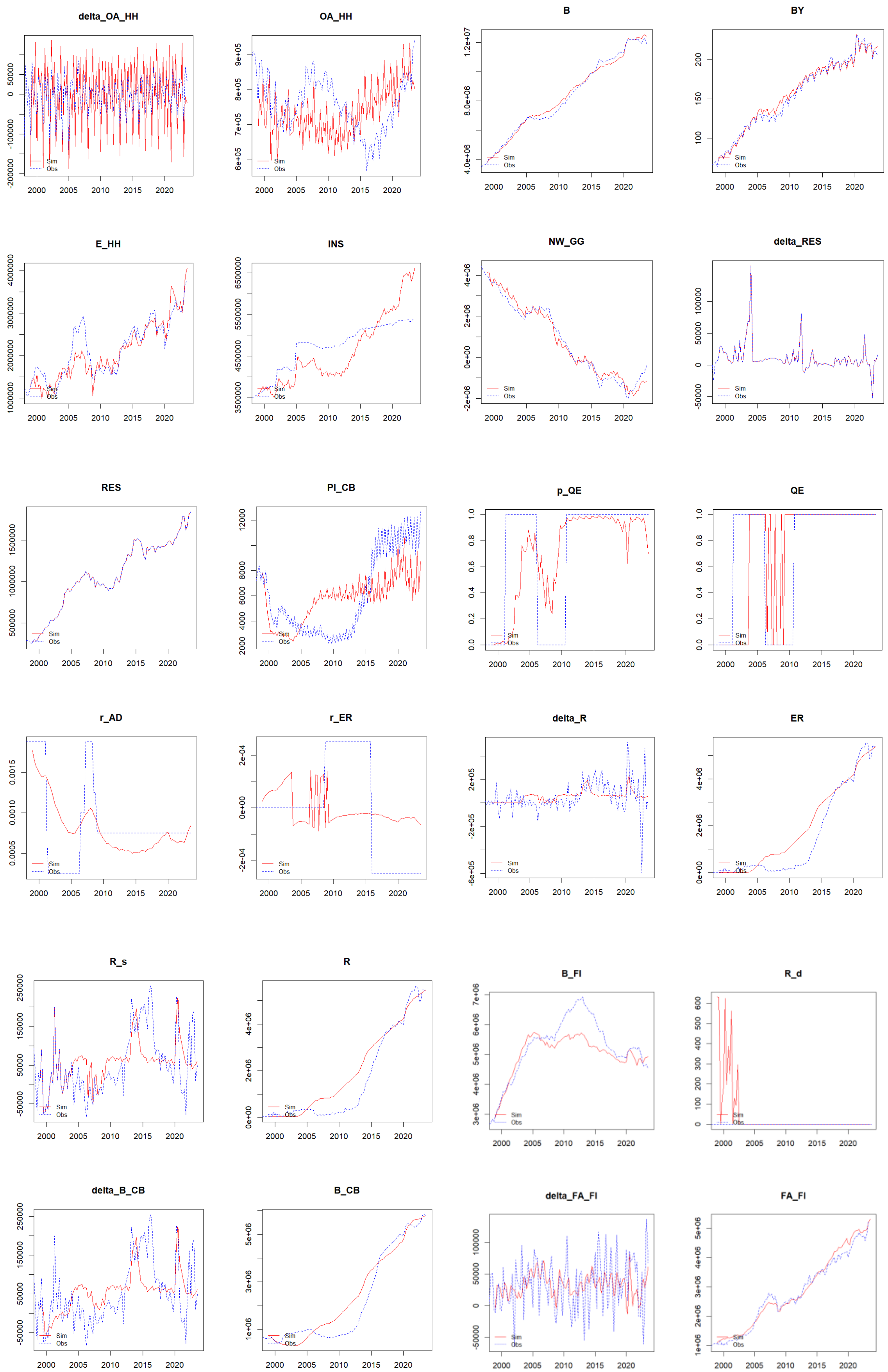
GIA_HH
Sim
Obs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B
BY
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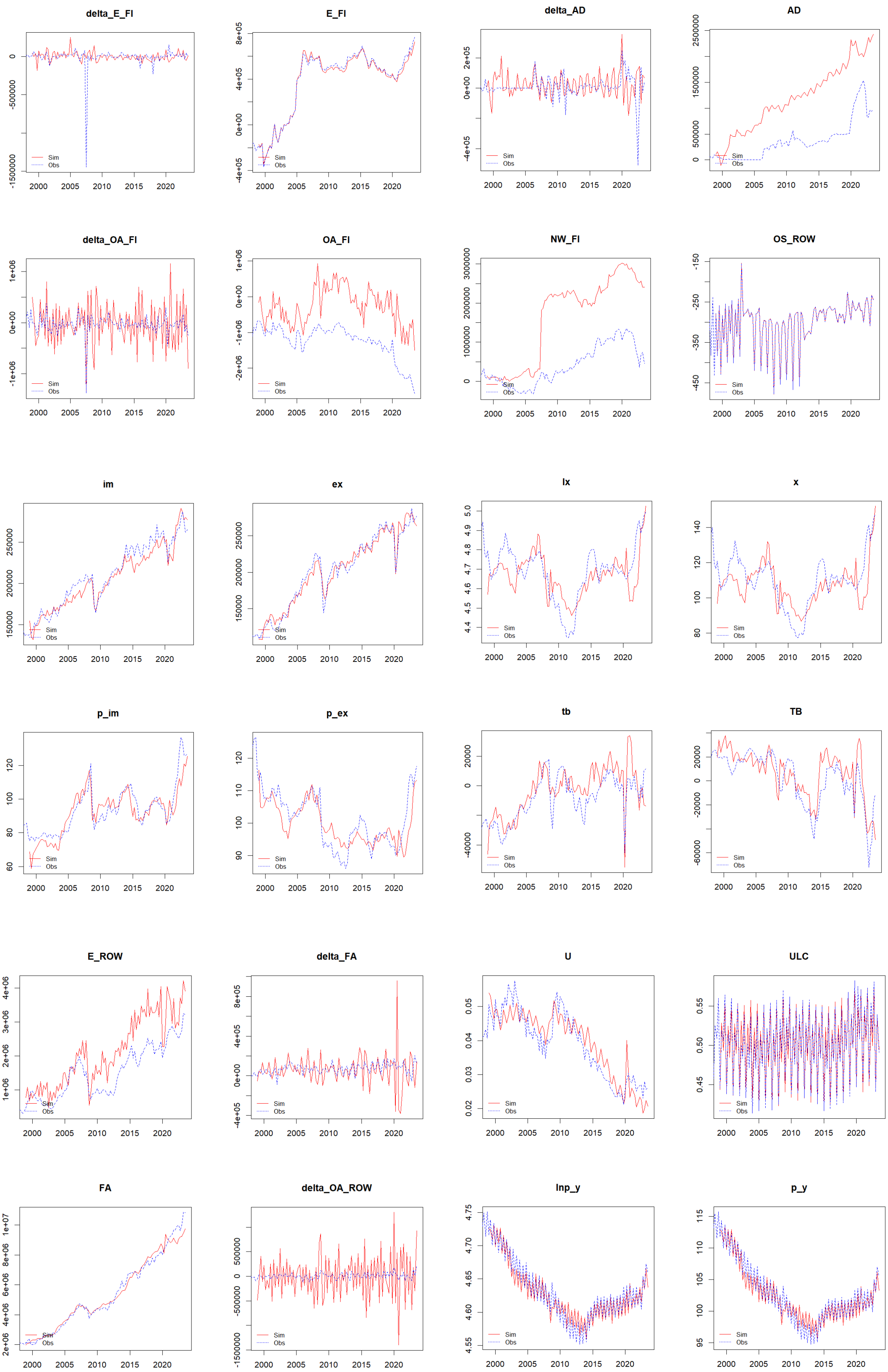
Obs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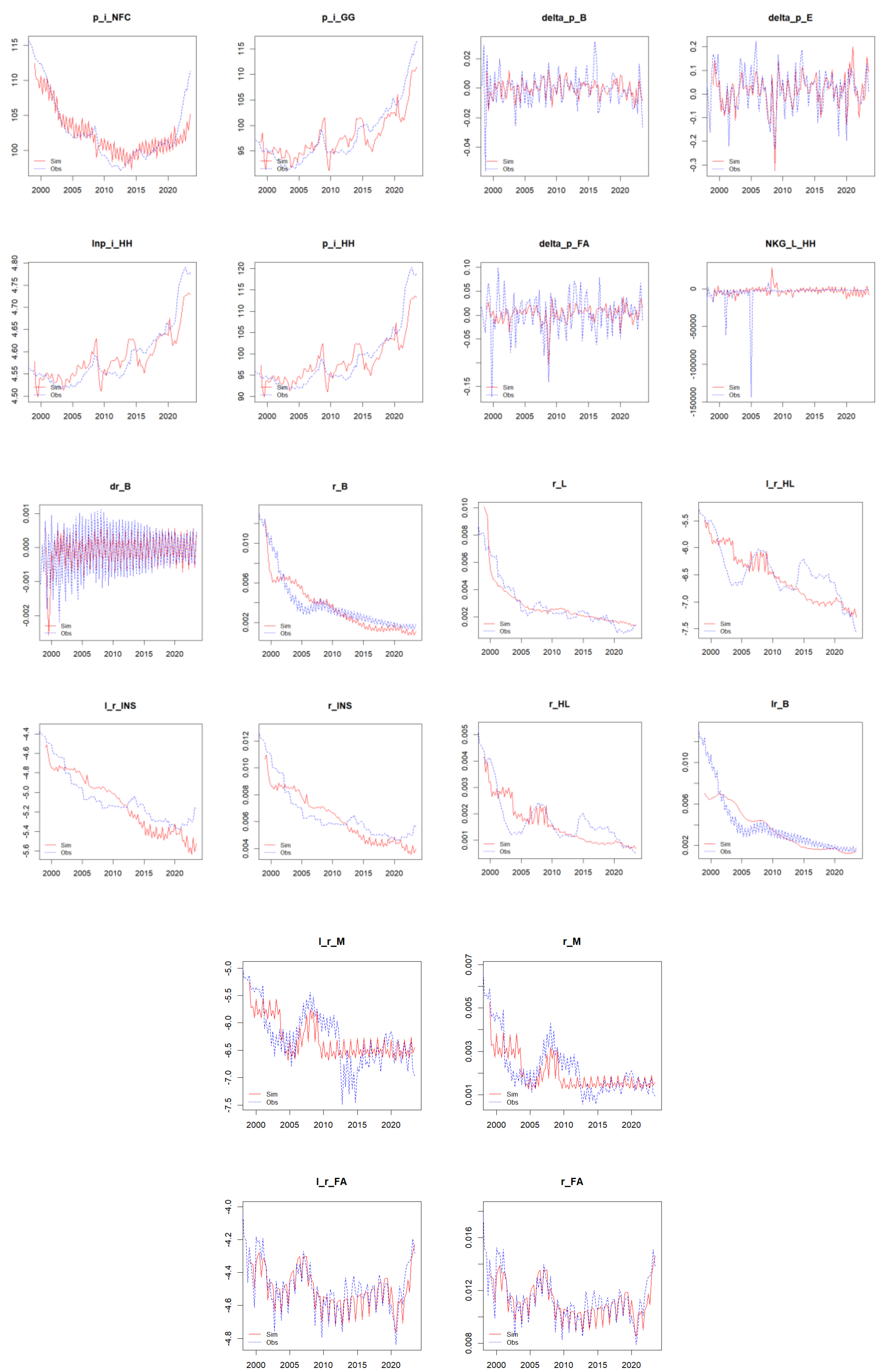
lnp_y
p_y
Sim
Obs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p_i_GG
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delta_p_E
lnp_i_HH
p_i_HH
delta_p_FA
NKG_L_HH
dr_B
r_B
r_L
l_r_HL
l_r_INS
r_INS
r_HL
lr_B
l_r_M
r_M
l_r_FA
r_FA
Sim
Obs

9.2 – Variable list

Variable	Description
A	Total Factor Productivity
AD	Advances
B	Bonds
c	Real consumption
C	Nominal consumption
CB	Central Bank
CCE	Cumulative carbon emissions
CE	CO2 emissions
v	Real inventories
V	Nominal inventories
$disc$	Discrepancy
DIV	Dividends
DMD	Domestic demand
DT	Direct taxes
E	Equity
$EBIT$	Firms' asset profitability
ENE	Energy
ENE^{FF}	Fossil fuel energy
ENE^{NFF}	Non fossil fuel energy
ER	Excess reserves
ex	Real exports
EX	Nominal exports
FA	Foreign assets
FD	Foreign demand
FI	Financial Institutions
$FUND$	Firms funding needs after the purchase of financial assets
$g_{ucnressources}$	Growth rate of non-renewables cost
$g_{ucrtech}$	Growth rate of renewables cost
GDF	Gross damage function
GDF_T^e	Gross expected damage at given temperature
GG	General Government

GIA	Household illiquid assets before capital gains
$GSUBS$	Green subsidies
Gy	Gross GDP before damage
H	Cash
HH	Households
I	Nominal investment
i^A	Adaptation investment
i^C	Conventional investment
IA	Intangible assets
im	Real imports
IM	Nominal imports
INS	Insurance/pension instruments
INT^{CE}	Carbon Intensity of fossil fuel energy
INT^{ENE}	Energy intensity of GDP
IT	Indirect taxes
k	Capital
k^A	Adaptation capital
$k^{A,max}$	Maximum adaptation capital to cover all damages
K^C	Conventional capital
K^G	Green capital
L	Loans
$\frac{L}{E}$	Firms debt-to-equity ratio
LF	Labor force
LTV	Loan to value ratio (loans/total assets)
M	Deposits
$MIXY$	Mixed income
NbW	Number of workers employed
NDF	Net damage function
NFC	Non-Financial Corporations
NFC^{sector}	Net Financing Capacity
NKG	Net capital gains
NRW	Share of non-regular workers
NW	Net Wealth

OA	Other (net) assets
og	Output gap
ONP	Other net payments
ONT	Other net transfers
OS	Operating surplus
$\dot{p}$	Price change
p^c	Consumption deflator
p^{ex}	Export deflator
p^{house}	House prices
p^i	Investment deflator
p^{im}	Import deflator
p^{oil}	Oil price (WTI)
p^y	GDP deflator
PF	Protection function
ΠCB	Central bank profit
POP	Population
$POP^{>65}$	Population above 65
QE	Quantitative easing activation
R	Bank reserves
r^{AD}	Refinancing rate
r^B	Government bond rate
r^E	Equity implicit rate (return on equity)
r^{ER}	Rate on excess reserves
r^{ER}	Foreign Asset implicit rate
r^{HL}	Household loan rate
r^{INS}	Insurance/pension implicit rate
r^L	Firms loan rate
r^M	Deposit implicit rate
r^{US}	Rate on US treasury bills
RES	International reserves (Gold and SDR)
$REVAL$	Asset revaluation (reconciliation table from the flow of funds data)
ROW	Rest Of the World
RR	Required reserves

S	Savings
s	Sales
SB	Social benefits
SC	Employers' social contributions
SC^{HH}	Household social contributions
$SUBS$	Subsidies
TA	Total assets
tb	Real trade balance
TB	Nominal trade balance
$tucn$	Total unit cost of non-renewables
$tucr$	Total unit cost of renewables
U	Unemployment rate
ucn	Unit cost of non-renewables (before taxes)
ucr	Unit cost of renewables (before subsidies)
ULC	Unit labor cost
v	Real inventories
V	Nominal inventories
w	Wage rate
WB	Wage bill
WB^{ROW}	Wages paid by the rest of the world
$WB2ROW$	Wages paid to the rest of the world
x	Exchange rate (dollar to yen)
y	Real investment
y	Real GDP (net of damage)
Y	Nominal GDP
y^*	potential GDP
YD	Disposable income
YP	Primary Income

9.3 – Parameters list

Variables	Description	Source
$\$SPREAD$	BOJ-FED rate spread	Data
α	Factor elasticity	Literature
α_{CG}	Government consumption growth parameter	Data
α_{PF}	Preference parameter on adaptation	Reasonable value
α_{RR}	Reserve requirements	Literature
β^{A}	Share of adaptation investment	Computed from the data
β^{G}	Share of green investment	Computed from the data and literature calibrations
β^{FI}	FI share of operating surplus	Computed from the data
β^{NFC}	NFC share of operating surplus	Computed from the data
β^{GSUBS}	Share of subsidized renewable energy	Exogenous
δ	Depreciation rate	Computed from the data
ϵ^{max}	Maximum energy intensity of GDP	Literature calibrations
ϵ^{min}	Minimum energy intensity of GDP	Literature calibrations
η^{1}	Damage function parameter	Literature calibrations
η^{2}	Damage function parameter	Literature calibrations
η^{3}	Damage function parameter	Literature calibrations
$\gamma_{>65}$	Share of the population above 65	Computed from the data
γ_1^{PF}	Protection function parameter	Literature calibrations
γ_2^{PF}	Protection function parameter	Literature calibrations
ι^{NFF}	Share of renewable energy	Computed from the data
λ	Household desired share of asset to illiquid asset	Computed from the data
ϕ_{IT}	Income tax rate (implicit)	Computed from the data
ϕ_{CT}	Corporate tax rate (implicit)	Computed from the data
φ_{SC}	Social contribution rate	Computed from the data
π	Inflation rate	Computed from the data
π^{*}	Target inflation	Literature

ρ	Return on assets (taking into account valuation)	Computed from the data
τ_{CT}	Carbon tax rate	Literature and exogenous
τ_{IT}	Indirect tax implicit rate	Computed from the data
θ^{A}	TFP growth parameter	Computed from the data
θ_1	Parameter linking energy intensity to the green to conventional capital ratio	Literature calibrations
θ_2	Parameter linking energy intensity to the green to conventional capital ratio	Literature calibrations
θ_3	Parameter linking share of renewable energy to the green to conventional capital ratio	Literature calibrations
θ_4	Parameter linking share of renewable energy to the green to conventional capital ratio	Literature calibrations