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Recycling carbon taxes for re-industrialisation

Addressing structural rigidity and financialisation in natural resource exporting countries

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Recycling carbon taxes for reindustrialisation

Addressing structural rigidity and financialisation in natural resource exporting countries

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Abstract

Inclusion of developing and emerging countries in the low carbon transition agenda is imperative to meet climate goals, and policies should be tailored to their unique characteristics. Despite their significance, the structural specifics of these countries are frequently overlooked in low-carbon transition models. In an effort to establish an appropriate framework for such analyses, this article formulates a Structural Stock-Flow Consistent (Structural SFC) model designed for open developing economies. This model categorizes production into three sectors: resource based exports, non-tradable goods and services, and other tradable sectors. While SFC models play a crucial role in emphasizing financial constraints, they frequently lack a multi-sectoral viewpoint and disregard structural specificities. Our model makes a dual contribution: (1) it offers a flexible framework capable of accommodating diverse country characteristics while balancing short-term demand with long term structural strategies, and (2) it underscores the inadequacy of relying solely on carbon pricing for economies deeply rooted in carbon-intensive sectors. By incorporating structurally distinct sectors within a genuinely monetary framework, the model enables us to comprehend the decisive role played by financial constraints arising from structural rigidities in shaping the dynamics of the low-carbon transition. Our findings show that the efficacy of carbon pricing is contingent on a country's commercial, financial, and production structure. Furthermore, the results emphasize the significance of carbon tax recycling in preventing recessions and promoting sustainable decarbonization. This is accomplished by bolstering innovation and competitiveness in low-emission industries.

Keywords

Low-carbon transition, Stock-Flow Consistent Model, Developing and emerging countries, Structural changes, Industrialization

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Résumé

L'inclusion des pays en développement et émergents dans l'agenda de transition bas carbone est nécessaire pour atteindre les objectifs climatiques, et les politiques doivent être conçues en fonction de leurs idiosyncrasies. Malgré l'importance de ces pays dans la décarbonation de l'économie mondiale, leurs spécificités structurelles sont souvent négligées dans les modèles de transition bas carbone. Dans le but de construire un cadre approprié pour ces pays, cet article développe un modèle structurel stock-flux cohérent (SFC structurel) pour les économies en développement ouvertes, catégorisant la production en trois secteurs: les exportations basées sur les ressources naturelles, les biens et services non échangeables et les autres secteurs échangeables. Bien que les modèles SFC soient importants pour mettre en évidence les contraintes financières, ils ne tiennent pas compte des spécificités structurelles. Les contributions de cet article sont doubles: (1) il fournit un cadre polyvalent qui capture les différentes caractéristiques des pays et contraste les dynamiques de demande de court terme avec des stratégies structurelles de long terme, et (2) il démontre que le seul recours à la tarification du carbone est insuffisant pour les économies ancrées dans des secteurs à forte intensité carbone. En prenant en compte des secteurs structurellement différents dans un cadre véritablement monétaire, le modèle permet de comprendre comment les contraintes financières dérivées des rigidités structurelles jouent un rôle décisif dans la détermination de la dynamique de la transition bas carbone.
Le modèle démontre que l'efficacité de la tarification du carbone dépend de la structure commerciale, financière et productive des pays. Il montre également que le recyclage de la taxe carbone est essentiel pour éviter les récessions et promouvoir une décarbonation durable en renforçant l'innovation et la compétitivité dans les industries à faibles émissions.

Mots-clés

Transition bas carbone, Stock-Flow Consistent Model, Pays en développement et émergents, Changements structurels, Industrialisation

1. Introduction

The Paris Agreement established a global objective to limit climate change to well below 2°C (and strive for 1.5°C), calling for targeted policies to achieve net-zero carbon emissions (UNFCCC, 2015). Despite developing and emerging countries contributing to 63% of global emissions, it is imperative to incorporate them into a low-carbon transition strategy tailored to their distinctive characteristics. However, many economic models overlook the unique features of these economies, disregarding the intricate interplay between finance and inherent structural constraints. As low-carbon transition policies affect industries in diverse ways (Savona and Ciarli, 2019), distinct dynamics emerge based on the productive, commercial, and financial frameworks of countries (IMF, 2020; Peszko et al., 2020; Magacho et al., 2023). This oversight can impede a comprehensive understanding of the challenges these nations face in adopting green technologies and transitioning to low-emission sectors.

This study introduces a Structural Stock-Flow Consistent (Structural SFC) model to investigate the dynamics of a low-carbon shift in small open developing economies. The model dissects the production process into distinct industries, acknowledging the heterogeneity of the productive structure inherent in developing and emerging countries. In this initial version of the model, we incorporate three structurally different sectors: resource-based commodities export industries, non-tradable goods and services, and other tradable goods and services, which compete internationally based on both price and quality.

SFC models stand out in elucidating financial constraints due to their inherently monetary nature (Godley and Lavoie, 2007) by distinguishing resource constraints (i.e. current account) from financial constraints (i.e. financial account) (Borio and Disyatat, 2015). However, multi-industry representation in these models is uncommon, with a few notable exceptions (Berg et al., 2015; Jackson and Jackson, 2021; Dunza et al., 2021; Yilmaz et al., 2023). By including sectors with structural differences within a genuinely monetary model, we can gain insights into how financial constraints arising from structural rigidities critically influence the trajectory of the low-carbon transition.

The contribution of the paper is twofold. Firstly, the model provides a versatile framework that can be tailored to match specific country characteristics, supporting policy analysis across diverse settings. Because it is a truly monetary model, with dynamic equilibrium, some hysteresis may emerge, and the moving path will depend on the structural characteristics of the economy. In a literature dominated by static equilibrium models, this approach provides insightful comprehension of the importance of complementary of short-term (demand) and long-term (structural) policies. Secondly, calibrating the model for economies that rely excessively on carbon-intensive industries, it shows that carbon prices may not be an effective measure. This is a recessive measure as it drains resources from the economy that will not necessarily reinvested in green industries. Recycling carbon tax, for example, proved necessary to avoid recession and led to recovery. Using this resources to stimulate innovation and the competitiveness of low-emitting industries can promote a sustainable long-term decarbonisation path.

The paper is divided into four sections following this introduction. The next section discusses the the significance of incorporating finance in a structural macroeconomic model to understand the impacts of low-carbon transition policies in developing and emerging countries. Section 3 describes the productive and financial structure of the model. Section 4 presents the simulation results designed to demonstrate the applicability of the model. Finally, the concluding remarks discuss the advances and contributions of this approach.

2. Literature review

The green transition has emerged as a central topic in global discussions, marked by numerous developing nations committing to reduce their greenhouse gas (GHG) emissions in alignment with the Paris Agreement (UNFCCC, 2015). This renewed commitment presents an additional challenge for economies already grappling with various aspects of economic and social sustainability. To meet their development objectives, emerging economies must not only pursue economic growth but also foster an inclusive system that addresses poverty and inequality simultaneously (Porcile et al., 2023).

Macroeconomic models have been extensively employed to offer guidance to policymakers at both national and international levels regarding the consequences of climate policies. These models aim to ascertain how such policies affect economic growth, public debt, employment, and other pertinent macroeconomic variables (Stern, 2007). In conventional multisectoral macroeconomic models, like the Computable General Equilibrium (CGE), the significance of finance and its interaction with real-world factors is often downplayed. Only a few CGE models addressing climate concerns incorporate finance (Liu et al., 2017; Paroussos et al., 2020). finance's impact on long-term dynamics is limited, primarily treated as a technological or sectoral friction in accessing funding sources (Liu et al., 2017; Paroussos et al., 2020). Due to assumptions such as market-clearing interest rates, where all savings are inevitably invested, any financial constraints in one sector can lead to excessive investments in others, resulting in a prevalent *crowding-in* effect. However, this scenario does not always mirror real-world situations, particularly in the context of climate change. For example, during periods of heightened systemic risks where default risks escalate, banks typically scale back lending across sectors. Conversely, during periods of economic upswing when anticipated profits increase and default risks diminish, banks are more lenient with their lending (Mercure et al., 2019).

Equilibrium models are grounded in rational choice theory, where individual agents are guided by incentives in making rational decisions to maximize their objectives and participate in market dynamics. Within this framework, the interactions of individual agents form a system characterized by checks and balances, ultimately leading to a stable equilibrium that acts as a self-regulating mechanism governing economic behavior. The interplay between various interdependent markets results in a general equilibrium.

The New Keynesian school (Mankiw, 1995; Stiglitz, 1989) introduces frictions that can disrupt this equilibrium. In the presence of market failures, such as externalities, system stability may not be achieved. Government intervention becomes justified to address these failures and reach a second-best situation. Externalities, like greenhouse gas (GHG) emissions, necessitate creating incentives that penalize industries responsible for their generation, particularly carbon-intensive activities. By penalizing high-emission activities, the system can rebalance itself, generating new incentives to invest in carbon-saving activities. In this system, financial institutions neither create nor destroy money, as there is no active credit creation. Savings are consistently available to be transformed into new investments in the most profitable activities (Mercure et al., 2019). The system relies on an automatic mechanism that readjusts the economy and introduces incentives, such as carbon pricing, to facilitate the green transition.

This approach may not be appropriate for analysing transition dynamics where demand deficiencies may constrain investment and lead to trajectories that diverge from a determined *ex-ante* equilibrium. This is the case, especially in the context of developing economies, where structural rigidities reduce their ability to migrate from declining to emerging industries. This is even more relevant for highly financialised economies, where financial imbalances can constrain the reallocation of funds from less profitable investments to more profitable ones. To understand the transition dynamics of financialised developing countries, we need to address these three fundamental elements that interact with each other and can make this process especially challenging for emerging economies: structural rigidity, demand deficiency and financialisation.

The Structuralist theory (Chenery, 1975; Haraguchi et al., 2017; Chang, 1994) provides valuable insights into the issue of structural rigidity. Developing economies require enhanced capabilities and absorptive capacity to adapt and diffuse cutting-edge technologies within their productive structures (Lee and Lim, 2001; Silverberg and Verspagen, 1995). The establishment of an innovative economy capable of traversing sectors and swiftly readapting and upgrading demands a substantial economic and social effort in creating the necessary supply conditions. This is achieved through the development of a robust and dynamic national innovation system (Lundvall, 2007). In this context, catching up is far from automatic and necessitates significant investments in physical and human capital, as well as research and development (R&D) (Grossman and Helpman, 1991). To effectively assimilate and spread new technologies, developing nations must prioritise investments in education and skill-building, thereby bolstering their human capital. R&D investment is also essential for developing indigenous technologies well-suited to the local context and adapting foreign technologies to local conditions. Yet, limited access to funding and high borrowing costs pose significant obstacles in mobilizing resources for these endeavors, especially for small and medium-sized enterprises (SMEs) (Lee et al., 2015).

Overcoming these obstacles necessitates developing nations to enact policies that support structural change. Examples include industrial strategies that promote technological education and advancement, as well as trade policies facilitating the integration of small and medium-sized enterprises (SMEs) into global value chains (GVCs) (Sikharulidze, 2011). Such policies can help address the lack of absorptive capacity and the limited access to finance that hinder developing countries from effectively catching up with developed economies. Furthermore, international cooperation and partnerships can play a vital role in providing financial and technical assistance to developing countries in their pursuit of sustainable and inclusive economic growth (Pietrobelli and Rabellotti, 2011).

The second significant obstacle to sustainable and inclusive economic growth in developing nations is demand deficiency, particularly concerning balance of payments challenges. In a monetary economy, investment decisions are influenced by expectations. During periods of high uncertainty, agents tend to shift their assets towards liquid assets, reducing spending and resulting in a lack of demand. Supply responds by reducing production capacity, impeding growth, and causing unemployment (Pasinetti, 2001).

For open developing economies, constrained by limited foreign currency access, the need to secure foreign exchange for essential imports for consumption and investment becomes critical. This challenge is heightened for countries that lag in technological innovation, relying on importing advanced technology and historically facing external restrictions and crises (Thirlwall, 1979; Cimoli and Porcile, 2014). Balance-of-payments constraints exert significant pressure on the economy to adjust to the availability of foreign currency when imports are crucial for the structural change process. Currency devaluations cannot persist indefinitely to compensate for this lack of foreign exchange. The economic adjustment occurs via *quantity* rather than prices. This adjustment implies that growth is constrained by demand through the balance-of-payments channel, forcing exports and imports to be balanced in the long run to avoid an explosion of foreign debt.

To address balance of payments constraints, developing countries must enhance their export potential by diversifying production, advancing technologically, and improving the quality of products and services. Additionally, policy initiatives that support local industries, including investments in infrastructure, educational programs, and research and development (R&D), can reduce import demand while strengthening domestic production (Botta et al., 2023; Porcile et al., 2022).

The third barrier is financialization, which impedes sustainable and inclusive growth. The current global economic framework heavily relies on open financial accounts, pressuring national economies to align their domestic macroeconomic policies with the rules and demands of international capital markets. Consequently, monetary policies often focus on inflation control and attracting foreign portfolios, with significant implications for real economies (Frankel, 2010; Borio and Disyatat, 2015). This emphasis compels developing nations to prioritize short-term financial equilibrium over long-term growth (Ghosh et al., 2016). Such an orientation poses risks of volatile capital movements, potential financial unrest, and economically damaging crises (Stiglitz, 2002). Moreover, depending on foreign capital inflows may result in an over-reliance on short-term finance rather than long-term investment in productive capacities, undermining growth prospects (Reinhart and Rogoff, 2009).

Therefore, developing countries must carefully manage their capital accounts and formulate financial policies that prioritize long-term sustainable growth over short-term financial stability. This may involve implementing capital controls, establishing regulatory oversight, and fostering domestic financial ecosystems that encourage enduring productive investments (Ghosh et al., 2016). Additionally, it is crucial for developing countries to exert greater influence in shaping the rules of the international financial system, ensuring alignment with the needs and priorities of the real economy rather than solely catering to the demands of international capital markets.

The three barriers outlined above cannot be adequately captured within a Computable General Equilibrium (CGE) framework. In the CGE approach, market-clearing mechanisms tend to downplay the significance of financial constraints and structural rigidities in the economy. As an alternative framework, employing Stock-Flow Consistent (SFC) modeling enables a better understanding of the interconnectedness between economic structure, demand, and financial dynamics. This approach facilitates the connection of short-run macroeconomic dynamics with long-run economic trajectories, shedding light on the key macroeconomic challenges faced by countries striving for a green transition. The SFC approach allows for money creation and recognizes feedback loops between finance and the real side of the economy. Short-term disequilibrium and imbalances among different economic sectors can have a substantial impact on long-term economic growth and sustainability in this approach.

In a CGE framework, mechanisms that discourage investments in one industry automatically encourage investment in others. Especially in CGE models lacking finance (and an investment function dependent on profitability) where national savings automatically determine investment through the saving-investment identity, a negative shock, such as carbon pricing, to high emission industries reallocates investment towards renewable energy. Conversely, in an SFC framework, a negative shock in the energy sector, such as a carbon tax, may have unintended consequences, such as reducing overall demand, leading to a contraction in other sectors and ultimately causing a recession. Unlike CGE models, which rely on a saving-investment identity, investment in low-emission sectors in SFC models is fundamentally driven by profitability in these sectors, dependent on demand and financing costs. Additionally, these investments are constrained by the availability of finance, implying that the dynamics of investment in green industries are driven by a complex interplay of real and financial conditions.

Similarly, crowding-out effects, particularly of public investment on private investment, predominate in a CGE framework where a given amount of national savings, derived from consumer and government decisions, determine total investment. In contrast, SFC models allow for both crowding-in and crowding-out effects, depending on the impact of public investment on private demand, lending rates, and financial dynamics. Furthermore, in an SFC framework, the explicit modeling of the financial sector implies that financial channels may exacerbate the contractionary effects of negative shocks, such as the loss of exports, leading to a deeper recession and, in some cases, a currency crisis (Godin et al., 2023). This perspective sharply contrasts with the dynamics of CGE models, in which movements in the exchange rate ensure long-term stabilization of the current account either by a reduction in imports, an increase in exports, or a combination of both.

The limitations of the CGE framework underscore the necessity for more comprehensive and integrated models capable of capturing the intricate feedback mechanisms between the real and financial sectors and the interplay between environmental and economic outcomes. Such models could furnish policymakers with a more accurate understanding of the impact of policy measures on economic and environmental sustainability. The role of policy in this newly proposed framework is notably distinct. Instead of serving solely as a mechanism to address market failures, policy plays an active developmental role in fostering structural change while maintaining macroeconomic stability, especially in the sensitive context of financialisation, open financial accounts, and financial dominance (Botta et al., 2023).

The proposed framework emphasizes the pivotal role of policy in addressing the triad of barriers that hinder sustainable and inclusive economic growth. Policy intervention becomes imperative to stimulate structural change and maintain macroeconomic stability within the realms of financialisation and open financial accounts. Instead of merely rectifying market failures, policies must proactively contribute to promoting sustainable growth and development. This shift in policy focus can span various domains, encompassing the encouragement of innovation, strengthening education, improving infrastructure, and strategically directing industrial development to nurture new sectors and fortify existing ones. Furthermore, macroeconomic policies should align with long-term development goals while safeguarding short-term macroeconomic stability, especially when considering external factors such as capital flows, exchange rate volatility, and global financial crises. However, the effectiveness of these policies hinges on the specific characteristics of each country, including institutional frameworks, political will, and the availability of financial resources. Hence, tailoring policies to suit individual country contexts becomes paramount to ensure they effectively support sustainable and inclusive growth.

3. The structural SFC model

The dynamics of the structural transformation process in resource-exporting countries should consider at least three distinct sectors (Skott, 2021). First and foremost, it is essential to categorize the economy into tradable and non-tradable sectors, as global dynamics affect them through different channels. While both sectors benefit from economic upturns, characterized by lower costs of accessing credit, inputs, and capital goods, as well as increased domestic demand, the impact on traded goods is nuanced. These industries, competing with imports for the domestic market and with other economies for exports, may not fully capitalize on upturns due to exchange rate dynamics.

Additionally, within tradable goods, a specific sector deserves attention: the one producing goods based on natural resources. This sector, heavily reliant on commodity exports, experiences unique impacts during economic cycles, especially in the context of rising commodity prices. Unlike other tradable sectors, it can be disproportionately positively affected during economic upswings. Furthermore, given its direct dependence on environmental services and its connection to environmental impacts, understanding how the green transition affects countries reliant on natural resource exports is crucial.

Based on Yilmaz and Godin (2020), we develop a continuous-time multi-sectoral SFC model for an open developing economy. The model by Yilmaz and Godin (2020) provides important insights into how an emerging open economy operates, highlighting financial and trade relationships with the rest of the world. Furthermore, because it is built on a continuous-time basis, the dynamics of disequilibrium and different adjustments are modelled explicitly.[1].

[1] For a detailed discussion of the advantages of using a continuous-time model over a discrete-time model, see Gandolfo (2012) and Yilmaz and Godin (2020)

Following Skott (2021), we divide the productive sectors into three: resource-based goods (r), non-tradable goods and services (n) and tradable manufactured goods (m). The main structural characteristics of the productive sectors are the following:

- Resource-based goods (r): produces a homogenous good for export market only; it is price-taker (produces commodity); investment is driven mainly by expected prices in international market; and it operates at full capacity
- Non-tradable goods and services (n): produces heterogeneous goods only for the domestic market; it is a price-maker (due to imperfect competition); investment is mainly driven by expected demand, despite depending on prices and idle capacity utilisation; it operates bellow full-capacity
- Tradable Manufactured goods (m): produces heterogeneous goods and services for export and domestic market markets; it is a price-maker (imperfect competition); investment is driven by domestic and foreign demand and the capacity to absorb this demand; it operates bellow full-capacity

Besides the productive sectors, we also consider institutional sectors. These sectors do not hire labour or produce. Instead, they are responsible for generating final demand and organising the financial transactions:

- Households (H): consumes goods and services; income comes from wages, profits, interest on deposits and social transfers; pays income taxes, social contributions, interest on lending; invests in firms and banks and receives dividends
- Government (G): taxes production and income, consumes only non-tradable goods and services, pays unemployed benefits and interest on bonds; receives Central Bank profits; invests in firms and banks and receives dividends
- Banks (B): finance firms and households by loans and government debt via purchases of public bonds; borrow from Central Bank according to their financial needs
- Central Bank (C): accommodates banks' money demand and determines the policy rate according to a Taylor Rule
- Rest of the World (W): besides imports and exports, also finances firms and banks by loans and FDI and government debt through purchases of public bonds

Figure 1 highlights the most important transitions between the productive and institutional sectors. Not all transitions are presented, but we can see from some key inter-sectoral relations.

3.1. Specific features of the model

As we mentioned above, the model presented here is a multi-sectoral version of the prototype growth model in (Yilmaz and Godin, 2020). Appendix A presents all model equations. Here we detail the fundamental modifications from the prototype model and lay out the most important characteristics of our model, particularly focusing on the structural differences between the sectors.

Table 1: Transactions Flows Matrix (TFM)

	NR exporters curr	NR exporters cap	Non-traded G&S curr	Non-traded G&S cap	Other G&S curr	Other G&S cap	HH	Gov	Commercial Banks curr	Commercial Banks cap	Central Bank	Rest of the World	$\sum$
NR export. (r)	$+X_r$											$-X_r$	0
Non-traded (n)	$-IC_r^n$		$+Y_n^P - IC_n^n$	$-\dot{V}_n$	$-IC_m^n$		$-C_n$	$-G$					0
Other G&S (m)	$-IC_r^m$	$-I_r^D$	$-IC_n^m$	$-I_n^D$	$+Y_m^P - IC_m^m$	$-I_g^D - \dot{V}_g$	$-C_g^D$					$-X_m$	0
Imports	$-IC_r^{m,IM}$	$-I_r^{IM}$	$-IC_n^{m,IM}$	$-I_r^{IM}$	$-IC_g^{m,IM}$	$-I_r^{IM}$	$-C_m^{IM}$	$+T_m^{IM}$				$+IM_m$	0
	$[GVA_r]$		$[GVA_n]$		$[GVA_m]$								$[GVA]$
		$[I_r]$		$[I_n + \dot{V}_n]$		$[I_m + \dot{V}_n]$							$[GKF]$
Wages	$-W_r$		$-W_n$		$-W_m$		$+W$						0
Taxes (output)	$-t_r^Y X_r$		$-t_n^Y Y_n^D$		$-t_m^Y Y_m^D$			$+T_Y$					0
Contributions							$-SC$	$+SC$					0
Social transf.							$+ST$	$-ST$					0
Inv. Accumul.			$-\dot{V}_n$	$+\dot{V}_n$	$-\dot{V}_m$	$+\dot{V}_m$							0
Interests, L	$-i^L L_r$		$-i^L L_n$		$-i^L L_m$				$+i^L L$				0
Interests, D							$+i^D D_H$		$-i^D D_H$				0
Interests, B^B								$-i^B B^B$	$+i^B B^B$				0
Interests, B^F								$-i^B B^F$				$+i^B B^F$	0
Interests, L^{FX}	$-i^{FX} L_r^{FX}$				$-i^{FX} L_m^{FX}$							$+i^{FX} L^{FX}$	0
Interests, B^{FX}								$-i^{FX} B^{FX}$				$+i^{FX} B^{FX}$	0
Interests, R_B									$+i^P R_B$		$-i^P R_B$		0
Interests, A									$-i^P A$		$+i^P A$		0
Interests, R^{FX}									$+i^{FX} R_B^{FX}$		$+i^{FX} R_{CB}^{FX}$	$-i^{FX} R^{FX}$	0
	$[NF_r]$		$[NF_n]$		$[NF_g]$				$[NF_B]$		$[NF_{CB}]$		$[NF]$
Dividends (H)	$-Div_r^H$		$-Div_n^H$		$-Div_m^H$		$+Div^H$		$-Div_B^H$				0
Dividends (G)	$-Div_r^G$		$-Div_n^G$		$-Div_m^G$			$+Div^G$	$-Div_B^G$				0
Dividends (F)	$-Div_r^F$		$-Div_n^F$		$-Div_m^F$				$-Div_B^F$			$+Div^F$	0
Dividends (CB)								$+NF_{CB}$			$-NF_{CB}$		0
Taxes (income)							$-T_H$	$+T_H$					0
Ret. Earnings	$-RE_r$	$+RE_r$	$-RE_n$	$+RE_n$	$-RE_m$	$+RE_m$			$-RE_B$	$+RE_B$			0
[Financial Needs]		$[TFN_r]$		$[TFN_n]$		$[TFN_m]$	$[NLP_H]$					$[CA = KA]$	
Domestic Inv.		$+DDI_r$		$+DDI_n$		$+DDI_m$	$-DDI$			$+DDI_B$			0
Public Inv.		$+PDI_r$		$+PDI_n$		$+PDI_m$		$-PDI$		$+PDI_B$			0
Foreign Inv.		$+FDI_r$		$+FDI_n$		$+FDI_m$				$+FDI_B$		$-FDI$	0
								$[GFN]$		$[OF_B]$			
Deposits							$-\dot{D}_H$			$+\dot{D}_H$			0
Lending, no FX		$+\dot{L}_r$		$+\dot{L}_n$		$+\dot{L}_m$				$-\dot{L}_i$			0
Lending, FX		$+\dot{L}_r^{FX}$				$+\dot{L}_m^{FX}$						$-\dot{L}^{FX}$	0
Bonds, B^B								$+\dot{B}^B$		$-\dot{B}^B$			0
Bonds, B^F								$+\dot{B}^F$				$-\dot{B}^F$	0
Bonds, B^{FX}								$+\dot{B}^{FX}$				$-\dot{B}^{FX}$	0
Operating Acc.								$-\dot{OA}$			$+\dot{OA}$		0
Bank Reserves										$-\dot{R}_B$	$+\dot{R}_B$		0
Int'l Res										$-\dot{R}_B^{FX}$	$-\dot{R}_{CB}^{FX}$	$+\dot{R}^{FX}$	0
Advances										$+\dot{A}$	$-\dot{A}$		0
$\sum$	0	0	0	0	0	0	0	0	0	0	0	0	0

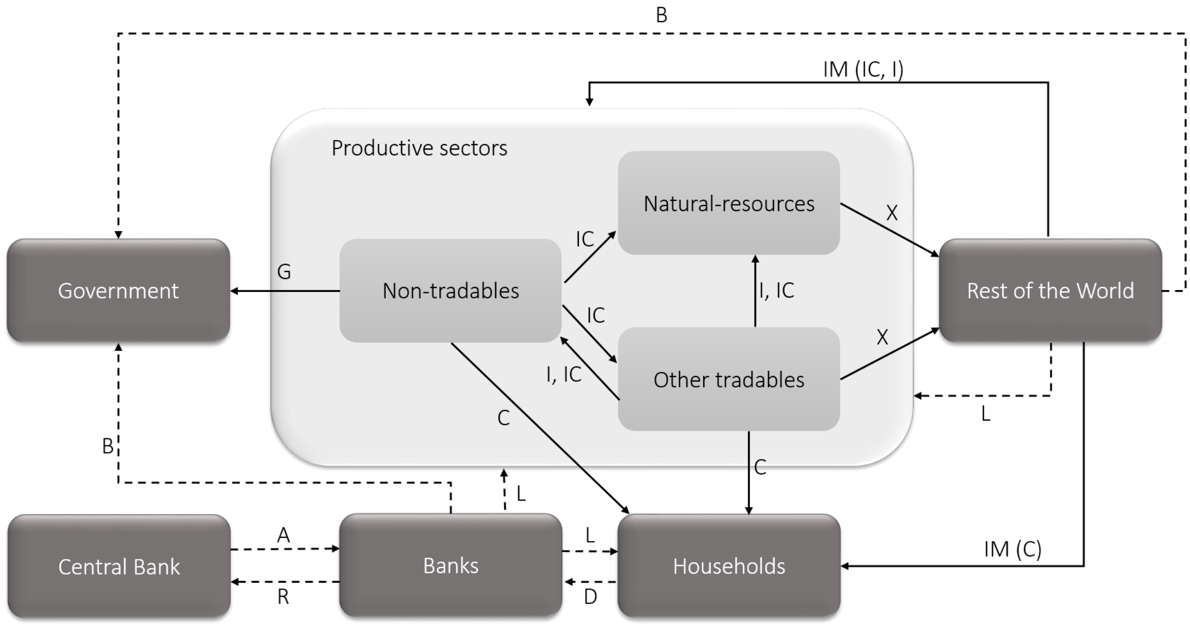
Notes:

$T_H = t_H[(1-s)wN + Div^H + i^D D_H]$, taxes (income)

$T_Y = t_r^Y X_r + t_n^Y Y_n^D + + t_n^Y Y_m^D$, taxes (output)

Operations involving purchasing of goods and services and production are expressed in real terms, but it is necessary to consider their respective prices. They are: IC, Y, C, G and I. V, X and M are already expressed in nominal terms.

Figure 1: Transactions among productive and institutional sectors



Not all transitions are presented. Solid lines represent flows of goods and services (compensated for monetary payments), and dashed lines represent flow of funds (compensated for interest payments and dividends). A: Advances; B: Bonds; L: loans; D: Deposits; R: Reserves; G: Government consumption; C: Household consumption; X: Exports; IM: Imports; IC: Intermediate consumption; and I: Capital investment.

3.1.1. Productive sectors

In most developing economies, even when the unemployment rate is low, labour shortages are not important constraints to growth because these economies are dual with large amounts of hidden unemployment (Skott, 2021). Therefore, production is not constrained by labour shortages, although wages may increase due to reduced unemployment, leading to higher costs and lower profitability.

In the case of resource-based goods, we assume that all production is exported, and hence there are no inventories in this sector. Production is therefore determined by the productive capacity, which is given by the stock of capital and the maximum capacity utilization that avoids over-depreciation of capital. In the other two sectors, capacity utilization varies, and hence production is not necessarily determined by actual capital stock. Firms will produce (constrained by the stock of capital) according to expected sales and investment in inventories to meet a desired inventory target, which serves as a buffer to meet demand in excess of expected sales. (Charpe et al., 2011).

In all sectors, investment is determined by the difference between expected gross profitability and the average cost of third-party capital, which is given by the average interest rate on new contracts and the leverage ratio. The higher the expected profitability in relation to the cost of third-party capital, the greater the investment in new capital. Expected gross profits depend, on the revenue side, on expected sales, expected prices and taxes. On the cost side, they depend on expected unit costs (labor costs and production factors as a proportion of production).

Producers of resource-based goods know that all production not consumed domestically will be exported at the ongoing global prices, and therefore the uncertain variables are expected prices and the expected nominal exchange rate. Producers of non-tradable and other goods and services, on the other hand, are price makers; therefore, they will receive the price they charge. However, unlike resource exporters, they may not sell all of their production; therefore, expected profitability depends on expected sales.

Other tradable goods and services are produced for the domestic market and exports. As the producers are price makers in this market as we stressed above, price competitiveness and demand matter in determining the volume of exports and imports. Even though developing countries tend to produce less sophisticated goods than developed economies, non-price competitiveness is an important determinant of their capacity to export(Fagerberg, 1988; Basile, 2001; Benkovskis and Wörz, 2016). The share of world exports therefore depends on price competitiveness, determined by relative prices and the exchange rate, and non-price competitiveness, which is a function of the productivity gap in relation to a reference economy, as in (Yilmaz et al., 2023; Godin et al., 2023)

Firms borrow to produce and invest. For simplicity, however, we will abstract from lending for working capital and focus only on long-term lending. Firms will first try to finance their financial needs by the equity market (domestic, foreign and public direct investment). They will then attempt to do so through foreign loans, and the remaining financial needs will be met through domestic loans. Financial restrictions on investment therefore arise from difficulties in accessing foreign credit and the increase in interest rates on national loans.

3.1.2. Households and Government

Households consume non-tradable and other tradable goods based on their disposable income and wealth. Households' disposable income is mainly driven by wages and dividends, although it also comprises interest on their deposits and social transfers from the government, less of income tax and social contributions paid to the government.

Salaries are not determined internally by each sector, but by the economy as a whole. The lower the employment rate, the lower the salary bargaining power; therefore, real wages can grow at a different rate than productivity growth. Furthermore, nominal wages grow in line with expected inflation.

We assume that the government has a strict fiscal rule for its consumption, which changes according to expected inflation and real output growth. The government consumes only non-tradable goods and services, which includes all government activities (public health, public education and public administration). The government also pays a basic income to the unemployed (social transfers), and the amount of these transfers grows with consumer inflation and growth in per capita production.

The public primary deficit evolves according to total taxation, social contributions, public consumption and social transfers. In addition to the primary deficit, the government must also finance interest expenditure on its obligations. To finance its deficit, the government issues bonds. Firstly, it decides the amount of bonds issued in foreign currency, and then the government issues bonds in domestic currency according to its financial needs. However, only a portion of these bonds supplied is absorbed by bank demand, creating a gap between the target and the actual Operating Account.[2]. If the operating account is low, the government increases the interest rate on bonds to reach the interest rate desired by banks.

3.1.3. Commercial banks and the Central bank

Commercial banks finance firms' and households' financial needs. Interest rates are given by the policy rate (defined by the Central bank) and a mark-up, which is assumed to be constant. Banks are required to maintain compulsory deposits with the Central bank in accordance with the mandatory reserve requirements. If their deposits and own funds are insufficient to cover their loans and reserves, they need advances from the Central bank. On the other hand, if there is excess liquidity, they lend to the Central bank, which pays the base rate as the interest rate.

The Central bank is responsible for monetary policy, as well as ensuring liquidity through advances to commercial banks. The central bank's profits are given by the difference between the revenue from these advances and the interest on compulsory deposits. The base rate follows a simplified Taylor rule, where the distance between expected inflation and the inflation target is used as a reference. The Central bank also conducts open market operations with foreign reserves to reduce nominal exchange rate volatility. If the Central Bank wants to keep the nominal exchange rate fixed, it absorbs any excess supply of foreign currency (within a fully sterilized intervention) over demand, increasing its reserves.

3.1.4. Rest of the world

International capital tends to be drawn towards financing enterprises in productive sectors, either through portfolio investments or foreign direct investment (FDI), and towards acquiring public debt. When capital flows are directed to financing public debt, it diminishes the government's reliance on banks, as mentioned earlier. Conversely, when capital flows are directed through portfolio investments and FDI, they alleviate the need for domestic loans by companies.

Global financial flows are determined by international liquidity. The influx of new foreign capital investments, whether direct or indirect, is contingent on the anticipated profitability of these investments in foreign currency. Apart from equity investments, foreign capital streams also contribute to government financing through the acquisition of bonds denominated in both domestic and foreign currencies. As previously mentioned, the issuance of foreign currency bonds is a governmental decision, representing a low-risk investment for foreign investors but posing a risky debt for the government. In the case of bonds denominated in the national currency, the determining factor for the flow is the disparity between the interest rate offered by the government and the global interest rate, along with the external risk premium, which takes into account the exchange rate risk for international investors.

[2] The Operating Account is necessary to ensure that the government will be able to pay its expenses, and will vary according to the difference between the supply and demand for bonds

The nominal exchange rate is determined by a mechanism for adjusting the supply and demand for foreign currency (which comprise current account and capital flows). Expected exchange rate depreciation and expected commodity prices follow a typical backward-looking expectation structure.

4. Simulation: carbon pricing

One of the most used instruments to promote decarbonisation is carbon pricing. This mechanism falls into three main categories: emissions trading systems (ETS), carbon taxation or mechanisms that combine elements of ETS and taxation (Narassimhan et al., 2018). The assumption underlying these mechanisms is that relative price change will lead households and companies to redirect their consumption or investment towards industries or technologies that emit less carbon. High-emitting industries (or industries producing with high-emitting technologies) will either charge a higher price for their output or reduce their margins, leading to less demand and less investment. On the other hand, low-emission industries will see their demand increase and investment will flow into these industries, leading to decarbonisation.

However, the effectiveness of this type of measure depends on some structural characteristics. First, for relative price change to play a role in consumption decisions, it must be price elastic. If the price elasticity of demand substitution is low, the change in relative prices will have a limited impact. Second, from a production point of view, there is a need for the economy to be able to produce either with low-emission technologies or in low-emission industries. If carbon pricing mechanisms are implemented, and there are no viable technological alternatives, investment will not flow to these industries. Third - and here finance plays a decisive role - demand and investment must flow from a high-emitting to a low-emitting industry or technology rather than just reducing in the former.

To test the effectiveness of carbon pricing in resource-exporting countries, we analysed the impact of the government implementing a carbon tax.[3] In the simulations, we assume that resource-based industry (r) emits more GHG than other tradable goods (m), and non-tradables (n) do not emit directly (but indirectly only due to the use of other industries inputs).

While the carbon tax may disproportionately affect resource-based industries in terms of production, it concurrently generates increased tax revenues, which may serve as a significant mechanism to instigate structural changes across various sectors. We examined three distinct applications of these features. Firstly, we evaluated the impact of the government retaining these revenues, leading to an augmentation of the public surplus and consequently exerting a positive influence on public debt and interest rates. Secondly, we simulated scenarios where the government redistributed the carbon fund to households through Social Transfers, resulting in no direct impact on the fiscal balance. It's important to note that in this case, the government is not depleting funds from the economy; rather, it is

[3] As we developed a country model, not a world model, modelling an ETS is not possible, as it is necessary to model not only the domestic carbon market but also the demand and supply functions of importing and exporting carbon.

redirecting resources from high-emitting industries towards consumption by other sectors. Lastly, we explored the potential outcomes if the government chose to invest directly in social infrastructure instead of transferring funds to households. This approach aims to create capacities for low-emission industries, fostering their competitiveness in both domestic and international markets. The underlying concept of this policy is not only to boost demand for low-emission industries in the short term but also to incentivize the industry by establishing the necessary conditions for structural change.

For analytical purposes, the baseline scenario (absent a carbon tax) is established on a trajectory of balanced growth, as detailed in Appendix A. Consequently, the carbon tax can be interpreted as a shock that initiates a new dynamic, potentially deviating from a state of equilibrium. Depending on the magnitude and direction of this shock, it has the potential to induce structural transformations in the economy, resulting in either a catching-up effect or an economic setback with corresponding repercussions. Table 2 outlines certain key macroeconomic variables that remain stable in the baseline scenario but may undergo impacts due to the carbon tax shock.

Table 2: Value of key variables in the baseline scenario

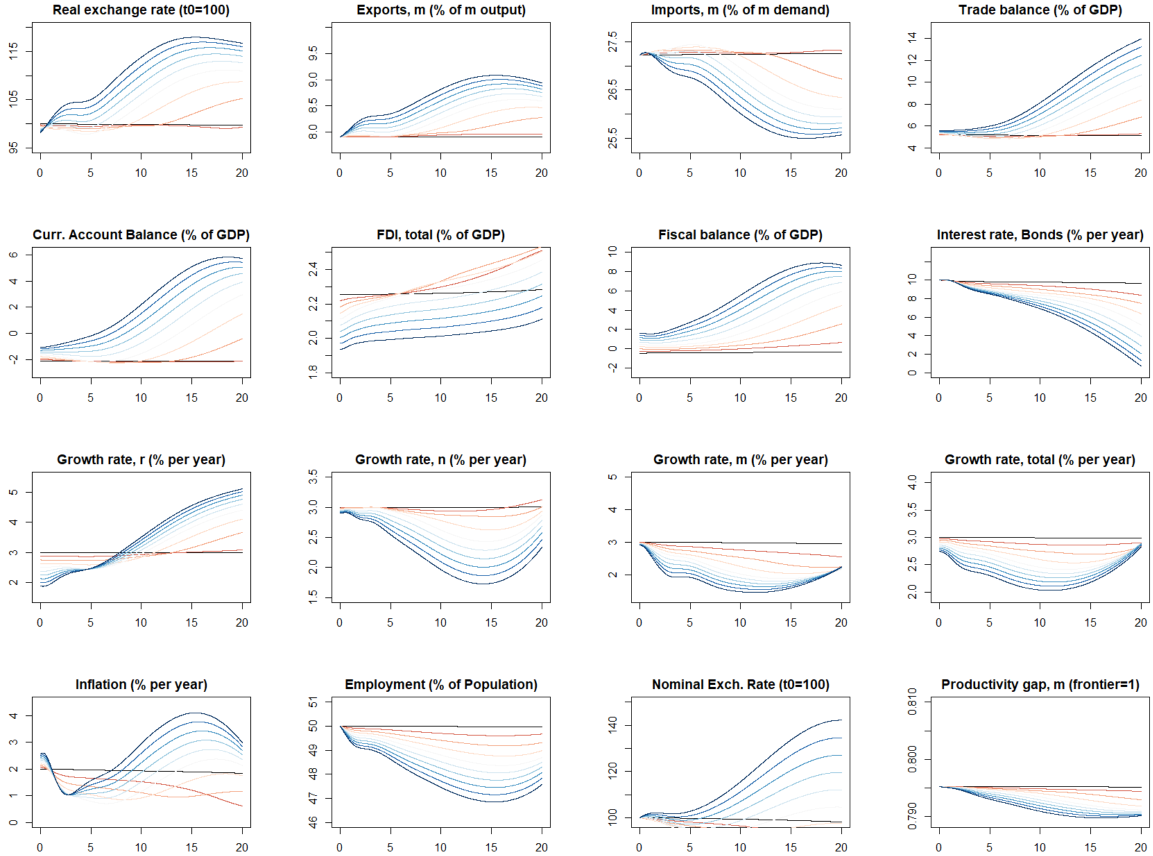
Variable	Measure	Value	Variable	Measure	Value
Household Consumption	% of GDP	50.0%	Leverage ratio, r	% of K_r	20.0%
Government Expenditure	% of GDP	20.0%	Leverage ratio, n	% of K_n	20.0%
Fixed investment, r	% of GDP	4.8%	Leverage ratio, m	% of K_m	25.0%
Fixed investment, n	% of GDP	11.5%	Productivity growth	% per year	2.0%
Fixed investment, m	% of GDP	10.1%	Population growth	% per year	1.0%
Exports, r	% of GDP	20.0%	Interest rate, FX	% per year	4.0%
Exports, m	% of GDP	5.0%	Interest rate, policy	% per year	6.0%
Import propensity, m	% of Y_m^D	27.2%	Interest rate, bonds	% per year	10.0%
Foreign Equity, r	% of EQ_r	20.0%	Interest rate, firms	% per year	14.0%
Foreign Equity, n	% of EQ_n	10.0%	Bonds, excl. FX	% of GDP	54.0%
Foreign Equity, m	% of EQ_m	10.0%	Bonds in FX	% of GDP	1.0%
Foreign Equity, B	% of EQ_B	20.0%	Reserves with CB	% of GDP	20.0%

4.1. Carbon taxation

Figure 2 displays the dynamics of several macroeconomic variables following the implementation of a carbon tax without recycling. The immediate consequences of the carbon tax include a jump in inflation and a decline in the profitability of resource-based industries, resulting in reduced investments within this sector. Given that the industry operates at full capacity, the decline in investment leads to a decrease in the overall growth rate, causing economic growth to drop from 3.0% to less than 2.0% per year.

The economic ramifications of carbon taxation extend beyond the effects on a specific industry. Given the interconnectedness of industries through input and capital demand, where income generated in one sector becomes the demand for others, the carbon tax is inherently a contractionary measure. The rise in fiscal surplus (accompanied by a decline in interest rates) proves insufficient to counterbalance these adverse effects. The decline

Figure 2: Simulation of Carbon tax



Carbon tax from zero (in red) to 10% (in blue) of base year's sales value.

in investments within natural resource industries translates to reduced demand for sectors involved in the production of capital goods. (in the case of the model, m). Consequently, the overall growth rate of the economy experiences a continuous deceleration, accompanied by a decline in the employment rate.

While the initial effect on the real exchange rate is negative, marked by an appreciation of the currency due to a domestic price increase, the overall low demand for goods results in real depreciation in the short term. The reduced demand leads to increased inventories, causing a decline in the mark-up. Consequently, enhanced price competitiveness stimulates the export of manufactured goods. Imports are likewise affected by these gains in price competitiveness, falling as a proportion of overall demand. The decline in imports is expedited by reduced demand for capital goods and other inputs. These trade-related impacts collectively result in a surplus in the current account.

The accumulation of current account surpluses serves to forestall a sustained real exchange rate depreciation. Several periods following the implementation of the carbon tax, the economy exhibits positive outcomes from both the financial and fiscal perspectives, despite experiencing a downturn in terms of production. In the medium term, employment continues to decline, along with an overall growth rate reaching 2.0%, primarily attributed to a decrease in tradables other than natural resources. Despite fiscal and current account surpluses and falling interest rates, this cycle persists, and it is only after nearly 15 years that employment begins to recover. The resurgence is propelled by the recovery in natural resources, which, in turn, stimulates non-tradables through demand and income effects.

However, the long-term repercussions could be severe. The decrease in investment in resource-based industries (r) fails to spur an increase in investment/production in other tradable goods and services (m), thereby thwarting the anticipated structural shift towards low-emission industries. Insufficient demand, financialization, and structural rigidity play pivotal roles in impeding this transformation. The decline in demand results in reduced imports, improving the current account position despite a decrease in exports from resource-based industries. Coupled with a fiscal surplus, this situation fosters a positive financial environment, attracting foreign direct investment (FDI) that sustains this cycle. The adverse conditions on the productive side, despite a decrease in interest rates, prove insufficient to reverse the favorable financial cycle, leading the economy into an extended period of financial bonanza characterized by a decline in manufacturing and tradable services. This process mirrors a Financial Dutch Disease, where, despite the loss of competitiveness in manufacturing, self-reinforcing financial mechanisms prevent current account deficits from triggering a reversal of exchange rate appreciation. (Botta, 2015).

In this context, it is evident that the carbon tax without recycling mechanisms has contractionary effects both in the short and medium/long-term. Despite the favorable outcomes on the fiscal and financial fronts, this policy exerts substantial adverse impacts on production and employment. Essentially, as the government withdraws resources from the economy, demand diminishes, and the decline in interest rates fails to counterbalance these negative shocks. The diminishing incentives for investment create a feedback loop, further suppressing demand and causing the nation to lag behind in terms of income and the transition to low-carbon industries.

4.2. Carbon taxation recycled as social transfers

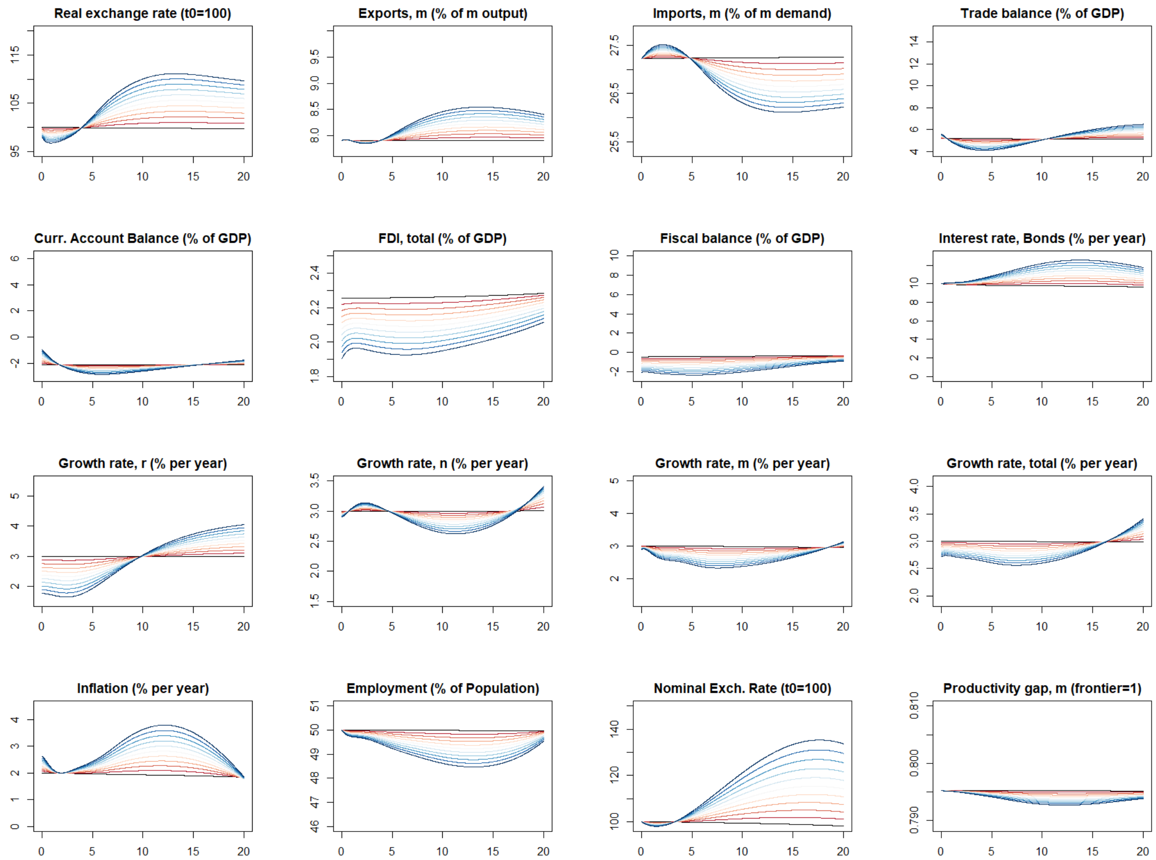
In the previous scenario, the tax revenues generated from the carbon tax were directed towards augmenting the fiscal surplus. This increase in the fiscal surplus occurred in the short term, facilitating a decline in the interest rate on government bonds. Despite the lower interest rates and the upswing in public savings, a widespread decrease in investment ensued due to insufficient demand.

Alternatively, we now explore two cases where these tax revenues are employed to invigorate the economy. In the first case, we examine the implications of recycling tax revenues as social transfers, and in the second case, allocating them to infrastructure investments.

Figure 3 illustrates the scenario in which fiscal revenues from the carbon tax are channeled to households, augmenting their disposable income through social transfers. The immediate consequences mirror those observed previously: higher inflation, a decline in profitability and investment within natural resources sector, resulting in an overall reduction in the economic growth rate. The distinction lies in the fact that, in this case, instead of a fiscal surplus, the fiscal deficit is exacerbated.

In the short run, we observe that due to the government's shift away from draining resources, there is a sustained high demand for non-tradables, preventing a continuous decline in the overall growth rate, which stabilizes at 2.7%. Although the employment rate continues to decrease due to productivity growing at 2.0% per year and population at 1.0%, the current account deteriorates, along with the fiscal deficit. Consequently, despite disinflation, interest rates increase.

Figure 3: Simulation of Carbon tax (recycled as social transfers)



Carbon tax from zero (in red) to 10% (in blue) of base year's sales value.

However, this dynamic is swiftly reversed. Fiscal and current account deficits continue to escalate, transforming the scenario into an inflationary environment in the medium run. The increase in interest rates aims to prevent inertial inflation by reducing demand and attracting foreign capital to finance the current account deficit, but it proves to be recessive. Non-tradables and tradables other than natural resources witness a decline in their growth rates in the medium-run.

The recovery of employment is driven mainly by natural resources, which becomes more profitable due to exchange rate depreciation. However, this is a very slow process - materializing only after period 10 in the simulation when the growth rate of this sector surpasses 3%. The negative impact of the policy on employment is not as pronounced as in the previous case where there is no recycling, but the recovery starts at the same period and is driven by the same factor: exports of natural resource based products.

Hence, recycling the carbon tax by transferring these resources directly to households, thereby augmenting their disposable income and consumption, can serve as an intriguing instrument to mitigate the issues associated with insufficient demand and the conflicts between financial and productive cycles observed in the earlier simulation. Furthermore, despite being a contractionary measure in the short term, the social costs of the carbon tax in terms of employment are offset by a rise in social spending. However, owing to structural rigidities, the sectors that reap the benefits of the transition are not the tradable ones (m), but the non-tradables (n). As real depreciation occurs at a gradual pace due to rising inflation and price competitiveness alone fails to instigate a substantial surge in exports for tradable sectors, the growth in these sectors does not adequately offset the decline in natural resources, which are high-emission industries. Rather, in the long run, as shown in figures, the natural resources sector (r) experiences a recovery propelled by macroeconomic conditions unfavorable to other sectors. This leads the economy to revert to a pattern of specialization in natural resources, consequently relying on high-emission industries.

4.3. Carbon taxation recycled as infrastructure investment

Finally, Figure 4 depicts the third set of simulations in which, rather than recycling carbon taxation through social transfers, the government opts to invest in infrastructure, with the objective to foster the development of essential technological and productive capacities and thereby effectively enhancing the international competitiveness of low-emission industries (Dosi et al., 2015). In this case, we have both demand impacts, as we had in the previous simulation (since these investments demand capital goods), and supply-side impacts. In the simulation, we include a term in productivity growth function of tradable sectors (m) that depends on public investment in infrastructure.[4] Because productivity increases non-price competitiveness, investment in infrastructure increases low-emission industries' competitiveness indirectly. Consoli et al. (2023) showed, however, that these impacts may be direct, as better environmental performance leads to higher export capacity.

The economic dynamics under this scenario exhibit significant divergence from the previous ones. In the short term, a surge in inflation, driven by heightened demand for capital goods, results in an appreciation of the real exchange rate. This, in turn, leads to a reduction in exports and an increase in imports, consequently causing an expansion of the current account deficit. The upswing in imports is further fueled by the higher domestic demand for imported manufactured goods. As we move into the medium term, the current account deficit leads to a depreciation of the real exchange rate. This, coupled with the impacts on price non-price competitiveness, fosters growth in exports and a decline in imports.

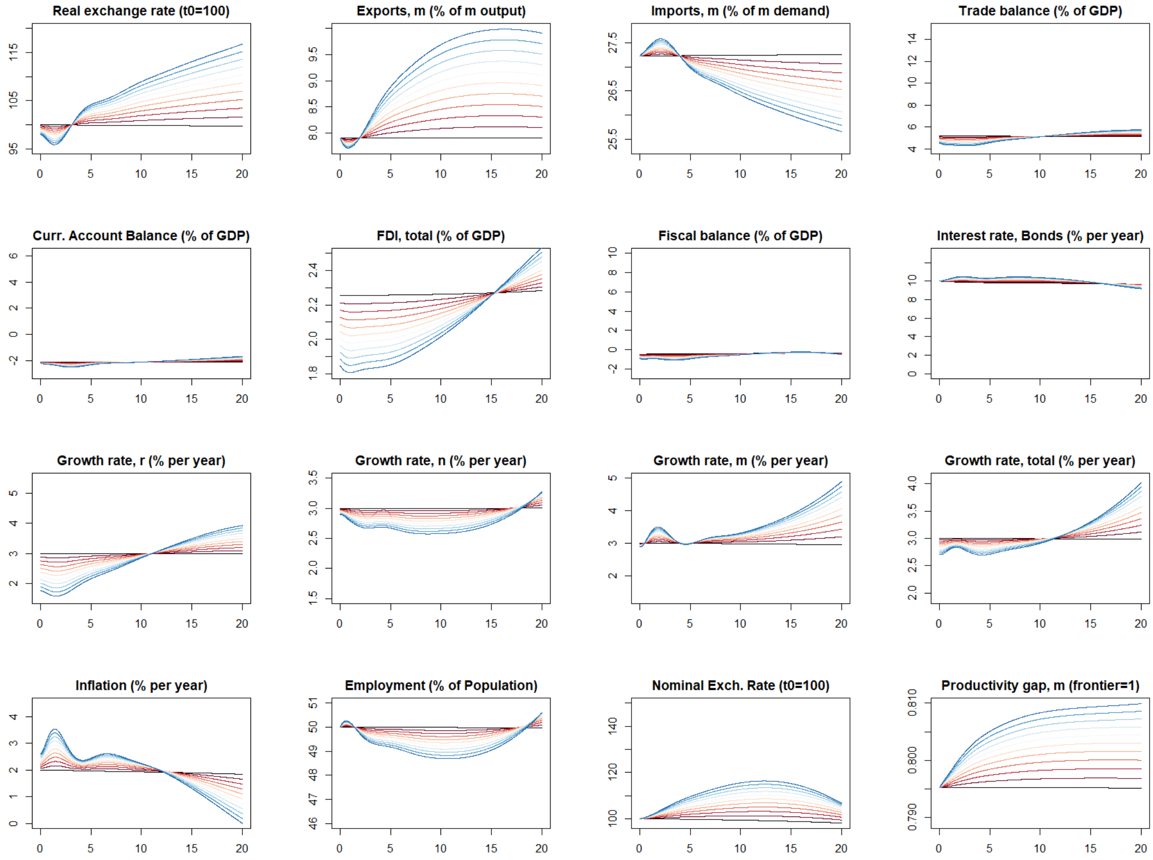
The most significant contrast between recycling carbon tax revenues through infrastructure investments and social transfers lies in their medium to long-term impacts. As low-emission

[4] The new productivity growth equation becomes:

$$\frac{\dot{a_m}}{a_m} = \frac{\left[(1-\delta) + a_m^p * \frac{I_m}{K_m}\right] K_m}{K_m + \dot{K_m}} - 1 + \gamma^{IG} \frac{IG}{p^K}$$

where γ_{IG} is the impact of this investment on m's productivity, and it is set to 0.001.

Figure 4: Simulation of Carbon tax (recycled as infrastructure investment)



Carbon tax from zero (in red) to 10% (in blue) of base year's sales value.

industries gain competitiveness in both domestic and international markets due to productivity growth, exports experience a quicker recovery, and imports commence a decline at an earlier stage. This results in a more rapid recuperation of these industries, evident after the simulation period 4 where the growth rate of *m* starts to increase. Consequently, there is a swifter transition from high to low-emission industries. Unlike the other scenarios, the recovery of employment and growth rate is not reliant on natural resources. Instead, it is the low-emission industries that drive the economic upturn, preventing the economy from encountering both insufficient demand, as in the case of non-recycling, and the deterioration of fiscal and current accounts, as observed in the case of recycling through social transfers.

In addition to mitigating conflicting patterns between financial and production dynamics and addressing issues of insufficient demand, investments in infrastructure overcome one of the primary bottlenecks for the effectiveness of a carbon tax in promoting the transition. Developing countries often grapple with structural rigidities that can impede or slow down the shift toward low-emission industries. However, as demonstrated in this latest simulation, a combination of demand and supply policies is crucial for fostering this transition in such economies. If the government can utilize resources to cultivate technological and productive capabilities in key industries essential for the transition, these industries will not only expand at the expense of carbon-intensive ones but also instigate a positive cumulative process of structural transformation and economic catching up.

The positive results of investing in infrastructure hinges on its ability to stimulate productivity growth within low-emission industries.[5] According to the baseline scenario, a 1.0 percentage point increase in GDP devoted to public investment is projected to correspond to a 0.1% rise in annual productivity growth. This acceleration would contribute to narrowing the productivity gap. However, if this impact falls short, the recovery cannot rely on increased exports from other tradable sectors. Consequently, all sectors except natural resources may experience a diminished growth rate. This underscores a crucial consideration when reallocating carbon taxes to drive reindustrialization: prioritizing investment in sectors with the greatest potential for productivity gains and international market access.

5. Concluding remarks

The inclusion of developing countries in the decarbonization agenda is crucial for achieving net-zero emissions in the forthcoming decades, since presently, these nations contribute to 63% of global emissions and their significance is on the rise (Abubakar and Dano, 2020). However, it is imperative to tailor policies to their unique characteristics. Traditional macroeconomic models, often rooted in dynamics of developed economies, fall short in addressing key challenges confronting developing and emerging countries during the pursuit of a sustainable and equitable transition. Structural rigidities stand out as a primary challenge for these nations as they endeavor to shift from high-emission to low-emission industries. Hence, there is a compelling need to develop tools that account for these specificities, addressing the primary constraints that may arise in this transformative process.

This paper introduces a Structural Stock-Flow Consistent (Structural-SFC) model specifically tailored for natural resource-exporting countries. Given the heterogeneous nature of their productive structures, where sectors significantly differ in aspects like market structure, productivity, and investment dynamics, relying on a one-sector model or a multi-sector model with structurally similar sectors may lead to misleading analyses of macroeconomic factors. Moreover, the role of finance is crucial in this transition, as there is no inherent guarantee that declining investment in high-emission industries will automatically translate into increased investment in low-emission industries. The adoption of SFC models proves essential in this context, offering a tool that accommodates money creation and destruction through credit, thus placing banks and financial institutions at the center of the dynamics driving the transition.

In order to understand the impacts of a low-carbon transition in these economies, especially those in which the export basket is excessively dependent on high-emission industries, we tested the imposition of a carbon tax, which increases the sale price of this sector, and leads to lower profitability.

[5] Appendix C provides a sensitivity analysis concerning the key speed of adjustments within the model and the effect of public infrastructure investment on the productivity of tradable goods. Altering the speeds of adjustment has minimal effects on the overall dynamics. The same cannot be said for the parameter that gauges the influence of investment on productivity.

The findings indicate that without recycling carbon tax revenues, the effectiveness of this measure is limited. Essentially, as industries are connected through input-output, capital absorption, and income-consumption relationships, falling investment in high-emitting industries leads to falling demand and investment in all other industries. Anticipated adjustment mechanisms, such as rising exports and falling imports in other industries compensating for the decline in high-emission exports, do not materialize. The absence of persistent current account deficits and real exchange rate depreciation further hinders the automatic shift of investment from high- to low-emission industries. Financial dynamics also exacerbate the situation, with positive financial conditions attracting foreign capital despite challenges in the productive sectors. This prolonged financial bonanza contributes to a lack of transition, intensifying problems in low-emission tradable sectors and impeding the desired economic shift.

The recycling of carbon tax revenues presents a more favorable scenario for the low-carbon transition. When these revenues are directed toward social transfers, the issue of insufficient demand is addressed, and the profitability of other industries remains intact despite the decline in high-emission industries' profitability. However, the transition is slow due to existing structural rigidities. Conversely, if these revenues are used to build capacity in low-emission industries, with environmental policies that goes beyond carbon tax (Costantini and Mazzanti, 2012), the transition process will occur more quickly as low-emission industries become more internationally competitive. This, in turn, sets off a cumulative causality process, where export growth boosts profitability in low-emission industries, driving increased investment, generating more demand, and further amplifying competitiveness gains.

As the model is built on a theoretical calibration, not representing any specific country, the simulations are explanatory. However, the sensitivity analysis we conducted (presented in Appendix C) indicates that the findings can be generalized to countries sharing similar production structures. Additionally, being a prototype version, the model's relative simplicity doesn't preclude its applicability to specific countries. Given its multi-sectoral framework, it can accommodate the consideration of environmental issues unique to various sectors in different countries. This includes examining the impacts of climate change on key industries, the consequences of biodiversity loss due to land use practices, and the effects of water-intensive activities in regions facing water stress.

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A. Model

A.1. Productive Sectors

A.1.1. Production and investment

Production process in all sectors is determined by a Leontief function where capital is partially employed, $Y_j^P = \min(a_j N_j, u_j K_j / b_j)$.[6]. Production is determined by actual capital (K), the capital-output ratio (b) and the capacity utilization rate (u), and hence labour employed (N) is determined by production and labour productivity (a):

$$N_j = \frac{Y_j^P}{a_j} \tag{1}$$

where j stands for all productive sectors: $j = \{r, n, m\}$.

Besides labour and capital, intermediate inputs are also used for production. The matrices of domestic and imported intermediate consumption (IC and IC^{IM}) are given by

$$\begin{bmatrix} IC_r^r & IC_n^r & IC_m^r \\ IC_r^n & IC_n^n & IC_m^n \\ IC_r^m & IC_n^m & IC_m^m \end{bmatrix} = \begin{bmatrix} c_r^r & c_n^r & c_m^r \\ c_r^n & c_n^n & c_m^n \\ c_r^m & c_n^m & c_m^m \end{bmatrix} \begin{bmatrix} Y_r^P & 0 & 0 \\ 0 & Y_n^P & 0 \\ 0 & 0 & Y_m^P \end{bmatrix} \tag{2}$$

and

$$\begin{bmatrix} IC_r^{r,IM} & IC_n^{r,IM} & IC_m^{r,IM} \\ IC_r^{n,IM} & IC_n^{n,IM} & IC_m^{n,IM} \\ IC_r^{m,IM} & IC_n^{m,IM} & IC_m^{m,IM} \end{bmatrix} = \begin{bmatrix} c_r^{r,IM} & c_n^{r,IM} & c_m^{r,IM} \\ c_r^{n,IM} & c_n^{n,IM} & c_m^{n,IM} \\ c_r^{m,IM} & c_n^{m,IM} & c_m^{m,IM} \end{bmatrix} \begin{bmatrix} Y_r^P & 0 & 0 \\ 0 & Y_n^P & 0 \\ 0 & 0 & Y_m^P \end{bmatrix} \tag{3}$$

where c_j^i and $c_j^{i,IM}$ are the domestic and imported inputs of i necessary to produce one unit of j.[7] For simplicity, however, we assume that natural-resources and non-traded goods are not imported.

Capital (K) accumulates according to investments (I) and the depreciation rate (δ). Investment increases capital whilst it depreciates as a proportion of the current stock, as follows:

$$\dot{K}_j = I_j - \delta_j K_j \tag{4}$$

For natural resources, all production not consumed domestically is exported, and hence there are inventories in this sector. In the case of the other two sectors, actual inventories evolve according to actual demand (Y^D) and production:

$$\dot{V}_{j'} = Y_{j'}^P - Y_{j'}^D \tag{5}$$

[6] Knoblach et al. (2020) discuss the empirical estimates of capital and labour substitution and shows they are very low in the aggregate level. One can expect that in the sectoral level it is even lower.

[7] Alternatively, in matricial terms: $\mathbf{IC} = \mathbf{c}\hat{\mathbf{Y}}^{\mathbf{P}}$ and $\mathbf{IC^{IM}} = \mathbf{c^{IM}}\hat{\mathbf{Y}}^{\mathbf{P}}$, where **IC** is the matrix of intermediate consumption, **c** is the technical coefficient matrix, $\mathbf{Y^P}$ is the vector of output, the superscript M indicated imports, and the hat indicates a diagonal vector.

where j' stands for all productive sectors but natural-resources: $j' = \{n, m\}$.

Sectoral investment is determined by the expected gross profitability (r^e) and the average cost of third-party capital, which is given by the average of the interest rate of new contracts ($i^{L,a}$) and the leverage ratio (l). The higher the expected profitability concerning the cost of third-party capital, the higher will be the investment in new capital:

$$I_j = \max[0, K_j(\kappa_0 + \kappa_1(r_j^e - l_r i_j^{L,e}) + \delta)] \tag{6}$$

where κ_0 is the autonomous investment, κ_1 is the sensitivity of the investment rate to net expected profitability (expected profitability discounted by interest payments).

The leverage ratio and the average interest rate of new contracts are given by

$$l_j = \frac{L_j + L_j^{FX} e}{K_j p^K} \tag{7}$$

and

$$i_j^{L,e} = \sigma_j^{FX}(i^{FX} + \mu_j^{FX})e^e + (1 - \sigma_j^{FX}) i_j^L \tag{8}$$

where L is the total lending in domestic currency, L^{FX} is the total lending in foreign currency, i^L and i^{FX} are the domestic lending interest rate and the world interest rate (in foreign currency), μ^{FX} is the mark-up over foreign lending and $i^{L,e}$ is the expected interest rate.

Expected gross profits depend, on the revenue side, on expected sales, expected prices, *ad valorem* taxation on sales (t^Y) and specific tax on production (τ).[8] On the cost side, it depends on expected unit costs (UC^e).

Producers of commodities, however, know that all production not consumed domestically will be exported, and hence the uncertain variables are expected prices ($p^{W,e}$) and expected nominal exchange rate (e^e). Therefore, expected gross profitability is given by:

$$r_r^e = \frac{Y_r^P[\frac{p_r^{W,e} e^e}{1+t_r^Y} - \tau_r - UC_r]}{K_r p^K} \tag{9}$$

where p^K is the current price of capital.

Producers of non-traded and other goods and services are price-makers. The expected gross profitability will account for future expected sales as following:

$$r_{j'}^e = \frac{Y_{j'}^{e,f} \frac{p_{j'}}{1+t_{j'}^Y} - (Y_{j'}^{e,f} + I_{j'}^V)(UC_{j'} + \tau_{j'})}{p^K K_{j'}} \tag{10}$$

For all productive sectors, unit costs depend on labour and input costs as a proportion of production. Unit labour costs are given by wages (w), and input prices and the technical

[8] Carbon taxes may be interpreted as specific taxes if one assumes that carbon emissions per unit of production remain constant.

coefficients give labour productivity and unit input costs. In matricial terms, we have

$$\begin{bmatrix} UC_r \\ UC_n \\ UC_m \end{bmatrix} = \begin{bmatrix} w/a_r \\ w/a_n \\ w/a_m \end{bmatrix} + \begin{bmatrix} c_r^{r,IM} & c_n^{r,IM} & c_m^{r,IM} \\ c_r^{n,IM} & c_n^{n,IM} & c_m^{n,IM} \\ c_r^{m,IM} & c_n^{m,IM} & c_m^{m,IM} \end{bmatrix}^T \begin{bmatrix} p_r^{IM} \\ p_n^{IM} \\ p_m^{IM} \end{bmatrix} + \begin{bmatrix} c_r^r & c_n^r & c_m^r \\ c_r^n & c_n^n & c_m^n \\ c_r^m & c_n^m & c_m^m \end{bmatrix}^T \begin{bmatrix} p_r \\ p_n \\ p_m \end{bmatrix}$$

or considering only the inputs different from zero:

$$UC_j = \frac{w}{a_j} + c_j^r p_r^W e + c_j^n p_n + c_j^m p_m + c_j^{m,IM} p_j^{IM} \tag{11}$$

A.1.2. Foreign trade and actual sales

Natural-resource exporters produce for intermediate consumption and the external market and sell all their production at a given price as they produce commodities. Export revenue (X) is given by production (Y^P) discounted by the demand for intermediate consumption), world price (p^W) and the nominal exchange rate (e):

$$X_r = \left(Y_r^P - \sum IC_j^r\right) p_r^W e \tag{12}$$

where the subscript r refers to operations of natural-resource exporters.

Non-tradable goods and services produce only for the domestic market, and these goods are not imported. Actual sales in this sector are given by the summation of intermediate consumption of all three sectors and final demand. Because this sector does not export and does not produce capital goods, only government and household consumption contributes to the final demand:

$$Y_n^D = \sum IC_j^n + C_n + G_n \tag{13}$$

Besides competing with imports, other traded goods and services are produced for the domestic market and exports. The share of world exports is a function of price and non-price competitiveness, as follow:

$$\sigma_m^X = \zeta_X \left(\frac{p_m}{p_m^W e}\right)^{\eta_X} \left(\frac{a_m}{a_m^W}\right)^{\varepsilon_X} \tag{14}$$

where η_X is the price elasticity of demand for exports, which measures the price competitiveness, and $\varepsilon = \frac{a_m}{a_m^W}$ measures the impact of the productivity gap on non-price competitiveness.

Exports revenue of m are thus given by

$$X_m = \sigma_m^X Y^W p_m \tag{15}$$

where Y^W is the world GDP measured in constant prices.

Real world GDP evolves according to world productivity growth and population growth:

$$\dot{Y^W} = Y^W(\alpha_a + \alpha_{Pop}) \tag{16}$$

Import propensity (σ_m^{IM}) is the share of imports in total demand, excluding exports, which includes domestic absorption and intermediate consumption. Import penetration depends on relative prices and the price elasticity of demand for imports (η_{IM}):

$$\sigma_m^{IM} = \zeta_{IM} \left(\frac{p_m^{IM}}{p_m} \right)^{\eta_{IM}} \tag{17}$$

The price of imported goods in national currency (p_m^{IM}) is given by its world price, the exchange rate and the import tax (t_m^{IM}):

$$p_m^{IM} = (1 + t_m^{IM}) p_m^W e \tag{18}$$

Total imports are, therefore, the summation of the import share of domestic absorption and imported intermediate consumption:

$$IM_m = (\sigma_m^{IM} Y_m^A + \sum IC_j^{m,IM}) p_m^W e \tag{19}$$

where absorption includes demand from household consumption (C_m) and the summation of capital investment of productive sectors:

$$Y_m^A = C_m + \sum I_j \tag{20}$$

Domestic intermediate consumption is given by the domestic technical coefficients, which depend on the import penetration and the technical coefficient:

$$c_j^m = (1 - \sigma_m^{IM}) c_j^{m,T} \tag{21}$$

and

$$c_j^{m,IM} = \sigma_m^{IM} c_j^{m,T} \tag{22}$$

where T stands for total.

Import penetration also determines the price of capital since it is the weighted price of domestic and imported goods:

$$p^K = \sigma_m^{IM} p_m^{IM} + (1 - \sigma_m^{IM}) p_m \tag{23}$$

Actual sales of domestic producers in other traded goods and services sector (Y^D) is, therefore, given by final demand absorbed by domestic producers and demand for domestic inputs:

$$Y_m^D = \frac{X_m}{p_m} + (1 - \sigma_m^{IM}) Y_m^A + \sum_j IC_j^m \tag{24}$$

A.1.3. Demand, expectations and pricing

In the case of natural resources, total production is given by:

$$Y_r^P = \frac{K_r \bar{u}}{b_r} \tag{25}$$

In the other two sectors, however, capacity utilization is not constant. Firms will produce (constrained by the stock of capital) according to expected sales (Y^e), current inventories (V) and desired rates of inventories (v^d):

$$Y_{j'}^P = \text{min}[Y_{j'}^e + I_{j'}^V, \frac{K_{j'}}{b_{j'}}] \tag{26}$$

where

$$I_{j'}^V = (Y_{j'}^e + \dot{Y}_{j'}^{e,f})v_{j'}^d - V_{j'} \tag{27}$$

is the investment in inventories.

Expected sales follow a backwards-looking process where firms adjust their expectation according to actual demand. However, knowing that the economy is growing, they also account for a historical growth rate of sales, which has a long-term factor, given by the historical growth rate of capital (g^K) and a medium-term factor, given by the historical growth rate of capacity utilization (g^u):[9].

$$\dot{Y}_{j'}^e = \beta_e(Y_{j'}^D - Y_{j'}^e) + Y_{j'}^e(g_{j'}^K + g_{j'}^u) \tag{28}$$

where

$$\dot{g}_{j'}^K = \beta_g \left(\frac{\dot{K}_{j'}}{K_{j'}} - g_{j'}^K \right) \tag{29}$$

and

$$\dot{g}_{j'}^u = \beta_g \left(\frac{u_{j'}}{u_{j'}^h} - 1 \right) \tag{30}$$

Actual and historical change in capacity utilization rates are given respectively by:

$$u_{j'} = \frac{b_{j'} Y_{j'}^P}{K_{j'}} \tag{31}$$

where

$$\dot{u}_{j'}^h = u_{j'} - u_{j'}^h \tag{32}$$

Expected gross profitability depends on prices and expected sales. Firms have a desired price based on their mark-up (μ_n) over unit costs:

$$p_{j'}^d = (1 + \mu_{j'})UC_{j'} \tag{33}$$

[9] In the case of investment in fixed capital and inventories, the short-term adjustment is not considered once firms invest with a focus on medium- and long-term expected demand. Therefore, we have $\dot{Y}_{j'}^{e,f} = Y_{j'}^e(g_{j'}^K + g_{j'}^u)$

Mark-ups adjust to reduce the distance between current and desired inventories:[10]

$$\mu_{j'} = \mu_0 + \mu_1 \left(\frac{Y^e_{j'} v^d_{j'}}{V_{j'}} - 1 \right) \tag{34}$$

Producers price adjusts towards the desired price according to a speed of adjustment that depends on the probability of firms' to remark prices:

$$\dot{p}^p_{j'} = \beta_p (p^d_{j'} - p^p_{j'}) + \pi^e \tag{35}$$

where π^e is expected inflation ($\pi^e = \frac{\dot{p^{C,e}}}{p^{C,e}}$).

Sales price is given by producers price and taxation, which includes ad valorem and specif taxes:

$$p_{j'} = (1 + t^Y_{j'})(p^p_{j'} + \tau_{j'}) \tag{36}$$

A.1.4. Firms financing

Firms borrow only to invest (we abstract from working capital lending). Total Financial Needs (TFN) of firms is given by the investment multiplied by the price of capital (p^K) discounted by non-distributed profits, which is given by the difference between net profits (NF) and dividends.

$$TFN_j = p^K I_j - (1 - \sigma_D) NF_j \tag{37}$$

where σ_D is the share of profits distributed as dividends.

Net profits are calculated as total sales discounted by all costs (taxation, wages, input costs and interest payments):

$$NF_j = Y^D_j p^p_j - Y^P_j UC_j - i^L L_j - (i^{FX} + \mu^{FX}) L^{FX}_j e \tag{38}$$

Dividends are distributed according to the share of investors in total equity (EQ), and it is proportional to net profits, as follows:

$$Div^i_j = \sigma_D NF_j \frac{EQ^i_j}{\sum_i EQ^i_j} \tag{39}$$

where i stands for the different investors (H, G and F stand for households, government and foreign, respectively).

Firms will first try to finance their financial needs by the equity market, and then, they will try to do it by foreign lending, and the remaining financial needs are closed by domestic lending. Assuming that firms will use foreign lending to avoid a mismatch between revenues and

[10] As discussed by Yilmaz and Godin (2020), even though there is the possibility of counter-cyclical mark-ups due to collusion by good producers, we assume that mark-ups work as equilibrators, and hence they are pro-cyclical.

costs in foreign and domestic currency, but they have a zero lower bound, we have that

$$\sigma_j^{FX,D} = \max\left[0, \sigma_j^X - \sigma_c^{IM} c_j^m\right] \tag{40}$$

where σ_c^{IM} is the share of traded inputs that firms believe to be affected by the exchange rate path-through and

$$\sigma_j^X = \frac{X_j}{Y_r p_j e} \tag{41}$$

Therefore, lending in foreign and domestic currencies evolves as follows:

$$\dot{L_j^{FX}} = \sigma_j^{FX}\left[\frac{TFN_j - (DDI_j + PDI_j + FDI_j)}{e}\right] \tag{42}$$

and

$$\dot{L_j} = (1 - \sigma_j^L)[TFN_j - (DDI_j + PDI_j + FDI_j)] \tag{43}$$

where DDI, PDI and FDI are, respectively, household domestic direct investment, direct public investment and foreign direct investment.

A.2. Institutional sectors

A.2.1. Households

Households consume non-tradable and other tradable goods based on their disposable income, wealth, and access to new loans. Households' disposable income (YD_H) includes wages, dividends (Div), interest on their deposits (i^D) and social transfers from the government (ST). However, they have to pay income taxes (t^H), social contributions (sc) and interest on their loans (i^L).

$$YD_H = (1 - t^H)[(1 - sc)wN + \sum_{j,B} Div_j^H + i^D D_H] + ST \tag{44}$$

where dividends includes those received from productive sectors (j) and banks (B), and

$$N = \sum N_j \tag{45}$$

Households will decide how much they will consume and then distribute between the two sectors. Furthermore, consumption takes time to adjust to income and wealth, and hence target consumption is given by

$$C^T = p^C \gamma_0 Pop + \gamma_1 YD_H + \gamma_2 D_H \tag{46}$$

where

$$\dot{Pop} = \alpha_{Pop} Pop \tag{47}$$

Actual consumption adjusts towards target consumption as follows:

$$\dot{C} = \beta_C(C^T - C) \tag{48}$$

The difference between disposable income and consumption gives households available funds for investing. Based on the share of firms' investment in total investment, households will distribute the composition of their investment as follow:

$$DDI_{j,B} = \sigma^H_{j,B}(YD_H - C) \tag{49}$$

The remaining funds are saved as deposits:

$$\dot{D_H} = YD_H - C - \sum DDI_{j,B} \tag{50}$$

Household equity evolves due to new investments, as discussed before, but also due to non-distributed profits. Thereby, it is given by:

$$\dot{EQ^H_{j,B}} = DDI_{j,B} + (1 - \sigma_D)NF_{j,B}\frac{EQ^H_{j,B}}{EQ_{j,B}} \tag{51}$$

The spending on non-traded goods has two components: an autonomous and one that depends on relative prices. Following a Linear Expenditure System (LES) with no autonomous consumption of m[11], we have that consumption of in real terms (C_n) is given by:

$$C_n = C_{n,0} + \gamma^n\left(\frac{C}{p_n} - C_{n,0}\right) \tag{52}$$

where

$$\gamma^n = \gamma^n_1 + \gamma^n_2\left(\frac{p_n}{p^{C,e}}\right)^{\gamma^n_3} \tag{53}$$

and

$$C_{n,0} = \gamma^n_0 Pop \tag{54}$$

The remaining consumption is then spent on other tradable goods and services (C_m):

$$C_m = \frac{C - C_n p_n}{p^K} \tag{55}$$

The lower the employment rate, the lower the wage bargaining power; hence, real wages can grow at a different rate of productivity growth. Moreover, nominal wages grow according to expected inflation. Thereby, we have that:

$$\dot{w} = w\left[\frac{\dot{a}}{a} + \frac{\dot{p^{C,e}}}{p^{C,e}} + \gamma_w\left(\frac{N}{Pop} - \gamma_N\right)\right] \tag{56}$$

[11] A LES for two goods has the following structure: $C_n p_n = C_{n,0}p_n + \gamma_n(C - C_{n,0}p_n - C_{m,0}p_m)$ and $C_m p_m = C_{m,0}p_m + (1-\gamma_n)(C - C_{n,0}p_n - C_{m,0}p_m)$. In this case we assume $C_{m,0} = 0$.

where γ_N is the employment rate in which bargaining power is capable of guaranteeing that all expected consumers inflation and productivity growth is transferred to wages, p^C is the average consumer prices, and $p^{c,e}$ is the expected consumer prices:

$$p^C = \sigma_n^C p_n + (1 - \sigma_n^C) p^K \tag{57}$$

and

$$\dot{p^{C,e}} = \beta_{pC}(p^C - p^{C,e}) + p^{C,e}\lambda_p \tag{58}$$

where λ_p is the target inflation defined by the Central Bank.

A.2.2. Government

Assuming that government has a strict fiscal rule for its consumption, where it changes according to expected inflation and real output growth (g^Y), we have that:

$$\dot{G} = G\left(g^Y + \frac{\dot{p^{C,e}}}{p^{C,e}}\right) \tag{59}$$

where

$$g^Y = \frac{Y_r^P \frac{\dot{K_r}}{K_r} + Y_n^P\left(\frac{\dot{K_n}}{K_n} + g_n^u\right) + Y_m^P\left(\frac{\dot{K_m}}{K_m} + g_m^u\right)}{Y_r^P + Y_n^P + Y_m^P} \tag{60}$$

Government consumes only non-traded goods and services, which includes all governmental activities (public health, public education and public administration):

$$G_n = \frac{G}{p_n} \tag{61}$$

The government also pays a basic revenue for unemployed people (social transfers), and the value grows with consumers' inflation and output per capita growth:

$$ST = st(Pop - N) \tag{62}$$

where

$$\dot{st} = st\left(g^Y - \alpha_{Pop} + \frac{\dot{p^{C,e}}}{p^{C,e}}\right) \tag{63}$$

As a source of revenue government taxes household income and firms' sales and production, imports and social contributions:

$$T_G = t^H[(1-sc)wN + Div^H + i^D D_H] + \sum t_j^Y \frac{p_j}{1+t_j^Y} Y_j^D + \sum \tau_j Y_j^P + t_m^{IM} M_m + scNw \tag{64}$$

Government invests directly in productive activities and banks (PDI). Public Direct Investment is a proportion of government expenses, whilst its distribution follows the current distribution of government equity:

$$PDI_{j,B} = \sigma_{j,B}^P G \tag{65}$$

Government equity evolves due to new investments, as discussed before, and due to non-distributed profits:

$$\dot{EQ}^{G}_{j,B} = PDI_{j,B} + (1 - \sigma_D) NF_{j,B} \frac{EQ^{G}_{j,B}}{EQ_{j,B}} \tag{66}$$

Besides the primary deficit, the government must also finance its bonds' interest spending. Central bank profit and dividends received from firms, on the other hand, reduce Government Financial Needs as follow:

$$GFN = G + ST + PDI + i^{B}(B^{B} + B^{F}) + i^{FX} B^{FX} e - T_G - NF_{CB} - Div^{G} \tag{67}$$

where B^B is government bonds with banks, B^F is government bonds with foreigners in domestic currency and B^{FX}_G in foreign currency,

$$Div^{G} = Div^{G}_{r} + Div^{G}_{n} + Div^{G}_{m} + Div^{G}_{B} \tag{68}$$

and

$$PDI = PDI_r + PDI_n + PDI_m + PDI_B \tag{69}$$

To finance its deficit, the government issues bonds. Firstly, the government decides how much bonds are issued in foreign currency (the foreign financial markets will absorb them), which is exogenous to the model:

$$\dot{B^{FX}} = \lambda_B GFN \tag{70}$$

The total supply of bonds in domestic currency (B^S) will be given by the GFN discounted by bonds issued in foreign currency added by the difference between the target and the actual Operating Account (OA):

$$B^{S} = GFN - \dot{B^{FX}} e + (\lambda_O GDP - OA) \tag{71}$$

where λ_O is the target operating account that government want to keep to guarantee liquidity as a share of GDP.

Bonds issued by the government and absorbed by banks are given by:

$$\dot{B^{B}} = \frac{B^{S} - \dot{B^{F}}}{\exp[\gamma_B \, (i^{B,d} - i^{B})]} \tag{72}$$

where $i^{B,d}$ is the desired interest rate by which the market accepts to absorb all supply of bonds.

The desired interest rate is given by the policy rate plus a risk of default premium, which depends on the government's gross debt (DG) to GDP ratio.

$$i^{B,d} = i^{P} + \gamma_{Bd} \frac{DG}{GDP} \tag{73}$$

where

$$DG = B^{B} + B^{F} + B^{FX} e \tag{74}$$

GDP is calculated from a demand perspective:

$$GDP = C + I + G + X_r + X_m - IM_m \tag{75}$$

where

$$I = (I_r + I_n + I_m)p^K \tag{76}$$

Government operating account and the bonds interest rate evolve as follows:

$$\dot{OA} = \dot{B^B} + \dot{B^F} + \dot{B^{FX}}e - GFN \tag{77}$$

The government adjusts the actual interest rate towards the desired interest rate at the speed β_{iB}:

$$\dot{i^B} = \beta_{iB}(i^{B,d} - i^B) \tag{78}$$

A.2.3. Commercial Banks

Interest rates are given by the policy rate (defined by the Central Bank) and a constant mark-up:

$$i_j^L = \mu_j^B + i^P \tag{79}$$

Banks are obligated to keep compulsory deposits with the central bank according to the required reserves ratio (σ_{rr}) and their total deposits:

$$R_B = \sigma_{rr} D_H \tag{80}$$

If deposits and own funds are insufficient to cover their lending and reserves, they need advances from Central Bank. If there is an excess of liquidity, they borrow it to the Central Bank, which pays the policy rate as interest rate

$$\dot{A_{CB}} = \sum \dot{L_j} + \dot{B^B} + \dot{R_B} - \dot{D_H} - \dot{OF_B} + \dot{R_B^{FX}}e \tag{81}$$

Banks distribute profits according to the share of equity:

$$Div_B^i = \sigma_D NF_B \frac{EQ_B^i}{EQ_B} \tag{82}$$

where

$$EQ_B = EQ_B^H + EQ_B^G + EQ_B^F \tag{83}$$

For simplification, we assume that the deposits interest rate is equal to the policy rate,

$$i^D = i^P \tag{84}$$

and, hence, banks profits (excluding capital gains) can be written as:

$$NF_B = i^L \sum L_j + i^B B^B + i^P R_B - i^P A_{CB} - i^D D_H \tag{85}$$

and

$$r_B = \frac{NF_B}{OF_B} \tag{86}$$

The summation of distributed profits is given by

$$Div_B = \sum Div_B^i \tag{87}$$

Banks' own funding (OF) evolves according to new investments and retained profits

$$\dot{OF_B} = DDI_B + PDI_B + FDI_B + (1 - \sigma_D)NF_B \tag{88}$$

A.2.4. Central Bank

The central bank is responsible for the monetary policy, besides guaranteeing liquidity through advances to commercial banks. Central bank profit is given by the difference between revenue from these advances and the interest of compulsory deposits:

$$NF_{CB} = i^P A_{CB} - i^P R_B + i^{FX} R_{CB}^{FX} e \tag{89}$$

Policy rate follows a simplified Taylor rule, where the distance between expected inflation and the inflation target is used as a reference:

$$i^P = \max\left[0, \iota_0 + \iota_1 \left(\frac{\dot{p^{C,e}}}{p^{C,e}} - \lambda_p\right)\right] \tag{90}$$

where λ_p is the inflation target. (distance between the current and the capital utilisation rate the CB think is adequate can also be used to have the complete Taylor rule)

The central bank also does open market operations with foreign reserves (R_{CB}^{FX}) to reduce the volatility of the nominal exchange rate. If Central Bank wants to keep the nominal exchange rate fixed, it absorbs all excess foreign currency supply (FX^S) over demand (FX^D), thereby increasing its FX reserves. If it wants to let it float, it only keeps a constant share of the country's nominal GDP as reserves to guarantee liquidity. Thereby, we have that:

$$\dot{R_{CB}^{FX}} = \sigma_0^{FX}(FX^S - FX^D) + R_{CB}^{FX}\left(g^Y + \frac{\dot{p^{C,e}}}{p^{C,e}}\right) \tag{91}$$

where the value of σ_0^{FX} determines the Central Bank's intention to keep e fixed or floating.

A.2.5. Rest of the World

Firms can be financed either by portfolio or foreign direct investments (FDI)[12]. A share of world financial flows gives the flow of new foreign equity investments (direct and indirect)

[12] FDI is defined here as equity investments because there is no other type of equity in the model.

according to the profitability and the actual share of equity in total equity:

$$FDI_{j,B} = \phi_{j,B}(r^e_{j,B} - i^{FX})WFF \tag{92}$$

Foreign capital flows also finance the government by buying bonds. In the case of bonds in domestic currency, what determines the flow is the difference between the interest rate paid by the government and the world interest rate added by the external risk premium (limited by the supply of bonds):

$$\dot{B^F} = \text{min}\{B^S, [\phi_0^F + \phi_1^F\left(i^B - i^{FX}\right)]WFF\} \tag{93}$$

The world financial depends on world growth rate in nominal terms, which is given by population and productivity growth, and international inflation (α_p):

$$WFF = \phi^W(Y^W p_m^W)(\alpha_a + \alpha_{Pop} + \alpha_p)e \tag{94}$$

Change in equity is, therefore, the summation of new investments and retained profits:

$$\dot{EQ^F_{j,B}} = FDI_{j,B} + (1 - \sigma_D)NF_{j,B}\frac{EQ^F_{j,B}}{EQ_{j,B}} \tag{95}$$

The nominal exchange rate is determined by the adjustment of supply and demand for foreign currency, as follows:

$$\dot{e} = e\beta_{eN}\frac{FX^D + \dot{R^{FX}_{CB}} - FX^S}{FX^S} \tag{96}$$

where

$$FX^D = IM_m + (L_r^{FX} + L_m^{FX})(i^{FX} + \mu^{FX})e + Div^F + i^B B^F + i^{FX}B^{FX}e \tag{97}$$

and

$$FX^S = X_r + X_g + (\dot{L_r^{FX}} + \dot{L_m^{FX}})e + FDI + \dot{B^F} + \dot{B^{FX}}e \tag{98}$$

where

$$Div^F = Div_r^F + Div_n^F + Div_m^F + Div_B^F \tag{99}$$

and

$$FDI = FDI_r + FDI_n + FDI_m + FDI_B \tag{100}$$

Expected exchange rate depreciation and expected commodities prices follow a typical backwards-looking expectation structure:

$$\dot{e^e} = \beta_{ee}\left(e - e^e\right) \tag{101}$$

and

$$\dot{p_r^{W,e}} = \beta_{pr}\left(p_r^W - p_r^{W,e}\right) + p_r^{W,e}\alpha_p \tag{102}$$

Banks will allocate the remaining foreign currency as reserves:

$$\dot{R_B^{FX}} = \frac{FX^S - FX^D}{e} - \dot{R_{CB}^{FX}} \tag{103}$$

B. Balanced growth path

B.1. Sectoral demand and supply

Sectoral output has to be equal to total demand for guaranteeing a balanced growth path. In a classical Leontief system, we need to have $\mathbf{Y} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{FD}$, where **Y** is a vector of sectoral production, **A** is the matrix of domestic technical coefficients, and **FD** is a vector of final demand (including changes in inventories).

However, because investment in fixed capital and changes in inventories are induced by demand growth, we need to consider a dynamic Leontief system, where the inverse matrix embodies the capital-flow matrix and the desired changes in inventories. Therefore, we have that

$$\mathbf{Y^P} = \mathbf{d}[(1 - \sigma^{\mathbf{IM}})\mathbf{C} + \mathbf{G} + \mathbf{X}] \tag{104}$$

where $\mathbf{Y^P}$, **C**, **G**, **X** are vectors of production, final consumption, government expenditure and exports, respectively, $\sigma^{\mathbf{IM}}$ is a diagonal vector of import propensity, and **d** is the dynamic Leontief matrix, which is given by:

$$\mathbf{d} = [\mathbf{I} - \mathbf{A} - g\hat{\mathbf{v^d}} - (1 - \sigma^{\mathbf{IM}})(g + \delta)\mathbf{B}]^{-1}$$

B, in turn, is the capital-flow coefficient matrix (considering that only the sector m produces capital goods):

$$\mathbf{B} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ b_r/u_r & b_n/u_n & b_m/u_m \end{bmatrix}$$

and g is exogenously given by the summation of productivity growth and population growth: $g = \alpha_{Pop} + \alpha_a$.

B.2. Investment function

The assumption of a linear investment function implies that only for a linear combination of the parameters, the model will be stable in the long run. Therefore, one need to determine these parameters, otherwise there will be either over-investment or under-investment leading the economy to explosive growth or economic collapse.

From an accumulation perspective, if there is no change in capital-output ratio, economic growth has to be equal to capital accumulation:

$$g = \frac{\dot{K}}{K} = \frac{I - \delta K}{K}$$

However, from a demand perspective, investment in all sectors depends on the investment propensity parameters and on expected profitability discounted by interest payments:

$$I = (\kappa_0 + \kappa_1 r^{e'} + \delta)K$$

Demand for investment and its capacity creation have to equal, and hence, replacing one equation on the other we have that:

$$\kappa_1 = \frac{g - \kappa_0}{r^{e'}} \tag{105}$$

B.2.1. Profitability for price-takers

Net profitability ($r^{e'}$) depends on expected prices, historical unit costs and expected sales, besides the interest payments.

In the case of price takers, all production is sold, but they are not aware of the price received by their sales, as they sell their products at international prices, which are exogenous. For these sectors, as $K = \frac{Yb}{u}$, expected net profitability is given by

$$r_r^{e'} = [p_r^e e(1-t) - UC]\frac{u_r}{p^K b_r}$$

given that $e = e^e \; p_r^{W,e} = p_r^e$ and $HUC = UC$ in the balanced growth path.

If one assumes $p^K = 1$ as the numerator, expected net profitability for these sectors can be written as:

$$r_r^{e'} = \Pi_r^e \frac{u_r}{b_r} - l_r i_r^{L,a} \tag{106}$$

where Π_r^e is the expected profit margin, given by:

$$\Pi_r^e = (1-t)p_r^W e - \frac{w}{a_i} + \sum c_r^j p_j$$

B.2.2. Productivity and mark-up in other sectors

Once profitability after interest payments has to be equal in all sectors to guarantee a balanced growth path, productivity in these sectors is given by:

$$a_i = \frac{w}{(1-t^Y)p_i - \sum c_i^j p_j - (r^{e'} + i_i^{L,e} l_i) b_i / u_i} \tag{107}$$

The mark-up is composed of two factors: one autonomous, μ_0, which depends on an exogenous price-elasticity of demand for the product, and is sector-specific, and another that varies according to the difference between desired and current inventories. Given that in the long run, desired inventories are equal to current inventories, we have that the autonomous component of the mark-up is given by

$$\mu_{0i} = \frac{1}{1 + UC_i} \tag{108}$$

where

$$UC_i = \frac{w}{a_i} + \sum c_i^j p_j$$

B.3. Debt Sustainability

In a balanced growth path, all variables have to grow at the same rate. The growth rate of nominal variables (g_N), such as lending, deposits and consumption, has to be equal to the summation of real growth and inflation, therefore,

$$g_N = \alpha_{Pop} + \alpha_a + \alpha_p$$

B.3.1. Firms

Investment can be financed by retained profits, loans or by direct investment. The summation of direct investment needed to fulfill firms' financial needs is, therefore:

$$DI_i = I_i - (1 - \sigma_D)NF_i - \dot{L}_i$$

To guarantee that firms leverage ratio, l, will be constant, and given the dividends distribution as a share of profits, σ_D, total direct investment is given by:

$$DI_i = K_i[(g + \delta) - (1 - \sigma_D)r' - l * g_N] \tag{109}$$

where, r' is equivalent to $r^{e'}$ in the balanced growth path.

Given the equity structure of firms, we have that

$$DDI_i = DI_i \frac{EQ_i^H}{EQ_i}$$

,

$$PDI_i = DI_i \frac{EQ_i^G}{EQ_i}$$

and

$$FDI_i = DI_i \frac{EQ_i^F}{EQ_i}$$

B.3.2. Banks

Banks' debt sustainability depends on their own funding growing at the rate of nominal GDP, otherwise either they will need proportionally more Advances from Central Bank or they will have an excess of liquidity. Because own funds evolve as the summation of new equity investments and retained profits, we have that:

$$DI_B = [g_N - (1 - \sigma_D)r_B]OF \tag{110}$$

where

$$r_B = \frac{(i^L \sum l_i K_i (1 - \sigma_i^{FX}) + i_B B_B - i_P A_{CB}}{OF_B}$$

Based on the equity distribution, we have that:

$$DDI_B = DI_B \frac{EQ_B^H}{EQ_B}$$

,

$$PDI_B = DI_B \frac{EQ_B^G}{EQ_B}$$

and

$$FDI_i = DI_B \frac{EQ_B^F}{EQ_B}$$

B.3.3. Households

In the case of households, the variable that closes their current balance is deposited (D_H). Household deposits evolve as

$$\dot{D_H} = YD_H - C - DDI$$

Given total consumption and total domestic direct investment, and knowing that D_H has to grow at the nominal growth rate, we have that

$$YD_H = C + g_N D_H + DDI$$

The income tax that guarantees that expenditures are equal to revenues is, therefore, given by:

$$t_H = 1 - \frac{C + g_N D_H + DDI - st(Pop - N)}{(1 - sc)wN + \sum Div_{j+B}^H + i^D D_H} \tag{111}$$

Total consumption is determined by population, disposable income and deposits. One of these sensitivity parameters has to adjust in order to guarantee the sustainability of consumers' debt. Here we will assume that the propensity to consume deposits (γ_2) is the one that adjusts to guarantee a balanced growth path.

Consumption adjusts to target consumption according to β_C, and hence it is given by:

$$\exp\left(\frac{g_N}{\beta_C}\right) C = \gamma_0 p^C Pop + \gamma_1 YD_H + \gamma_2 D_H$$

Isolating γ_2, which is the consumption out of deposits, we have that it will be given by the actual consumption per capita discounted by the autonomous real consumption per capita and the real disposable income per capita, we have that

$$\gamma_2 = \frac{1}{D}\left[\exp\left(\frac{g_N}{\beta_C}\right) C - \gamma_0 Pop - \gamma_1 YD_H\right] \tag{112}$$

B.3.4. Government and External

Besides households, banks and firms, balanced growth also depends on the stabilization of external and public accounts.

Because we are assuming the same inflation domestically and abroad, it implies that the nominal exchange rate is constant, and hence the supply of foreign currency is equal to its demand and the demand for FX of the Central Bank, which is satisfied.

Therefore, supply and demand of FX will be equal when

$$B^F = \frac{FX^{S'} - FX^{D'} - \dot{R}^{FX}_{CB} e}{i^B - g_N} \tag{113}$$

where $FX^{S'}$ is FX^S discounted by the nominal growth of B^F and $FX^{D'}$ is FX^D discounted by the interest payments of B^F.

Government debt has to be stable as a share of nominal GDP and the Operating Account has to grow at this same rate. It implies that Government Financial Needs (GFN), which are financed by bonds (government debt), will determine the debt sustainability. Therefore,

$$\lambda_O = \frac{(B^B + B^F + B^{FX} e) g_N - GFN}{GDP g_N} \tag{114}$$

B.4. Propensity to invest

Households, public and foreign direct investment is defined by firms' debt sustainability. However, for the spending to be equal to the amount receipted by firms, the propensity out of disposable income the share of government spending and the propensity out of World Funding Flows need to be consistent. Therefore we have that:

- The propensity to invest out disposable income after consumption in each sector is given by:

$$\sigma^H_{j+B} = \frac{DDI_{j+B}}{YD_H - C} \tag{115}$$

- The propensity to invest as a share of government expenditures in each sector is given by:

$$\sigma^P_{j+B} = \frac{PDI_{j+B}}{G} \tag{116}$$

- And FDI sensitivity to profitability is given by:

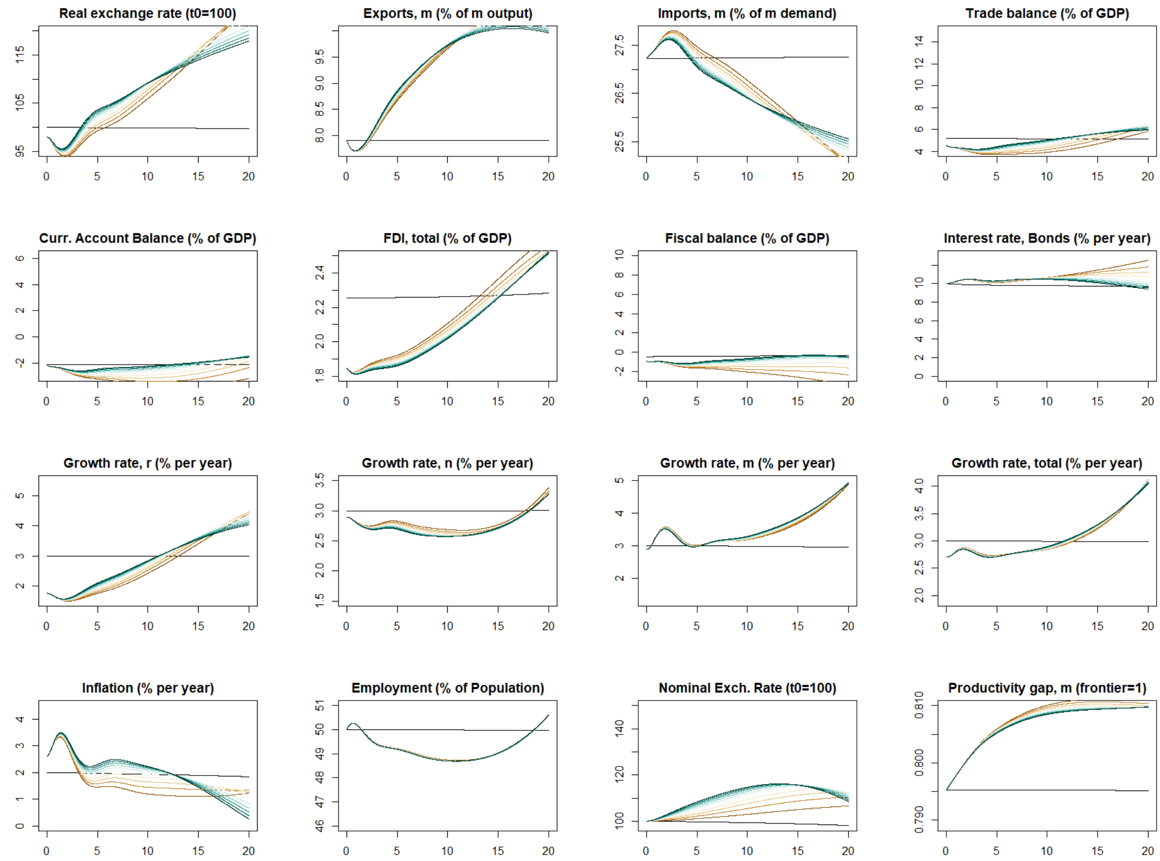
$$\phi_{j+B} = \frac{FDI_{j+B}}{(r^e_{j+B} - rsk - i^{FX}) WFF} \tag{117}$$

C. Sensitivity analysis

As this is a theoretical model, parameters such as the speed of adjustments are not calibrated for any specific economy. However, some of these parameters may be essential in determining the trajectories described above. Thus, it is important to test the model for some of these parameters.

Real exchange rate misalignment plays a crucial role in the model. As exports and imports are associated with price competitiveness, this is a key variable in determining possible paths in different scenarios. We then tested the sensitivity of changes in the nominal exchange rate in relation to the difference between supply and demand for foreign exchange, which is given by β_{e^N}. In the original simulation, it is set to 1, which is relatively high sensitivity. We simulate, in Figure 5, what would be the consequence of having a lower sensitivity.

Figure 5: Simulation with different exchange rate sensitivity



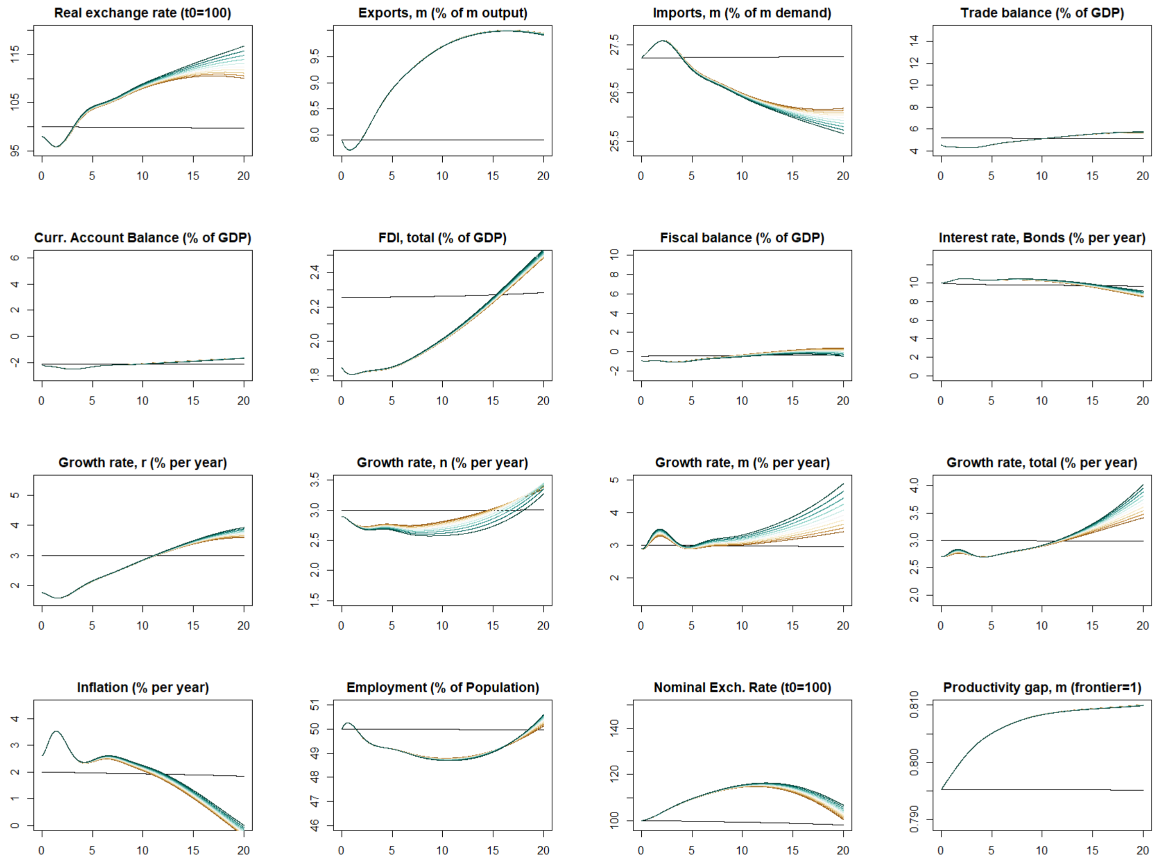
10% carbon tax on sales recycled as infrastructure investment with β_{e^N} reduced from 1 (green) to 0.4 (yellow).

This sensitivity analysis is also important to understand which variables drive the others. First, it can be seen that short-term appreciations and depreciations of the real exchange rate are not caused by changes in the nominal exchange rate, but in prices. However, after period 3, there is a divergent pattern, which indicates that the nominal exchange rate starts to determine the trajectory of the real rate. If sensitivity is low, depreciation is slower. It also implies that exports and imports will react more slowly, and the current account deficit will take longer to reverse. As a consequence, in the long term, the real exchange rate will continue to depreciate (it does not stop in period 10 with 40% depreciation).

Despite these differences, as well as their long-term consequences on foreign capital flows and fiscal balance, the impact on growth rates is negligible. There will be a slightly slower recovery in the growth rate of natural resource-based industries in the medium term and a slightly faster recovery in the longer term (since these industries are very sensitive to the real exchange rate), but this has almost no impact on total growth. Therefore, the model results are not sensitive to this (supposed) key variable.

As investment is led by expected profitability, and expected demand plays an important role in this variable, another variable that can be very important for the model is the speed of adjustment of expected demand to current sales. In the model, this adjustment speed is given by β_g and, in the original simulation, it is fixed at 0.3, which means that, on average, the demand for the last 3.3 years is considered to form expectations (characteristic time). We simulate what happens if longer-term demand is considered to form expectations by reducing this adjustment speed from 0.3 to 0.03 (characteristic time increases to 33 years). Figure 6 presents these results.

Figure 6: Simulation with different demand expectation speed of adjustment



10% carbon tax on sales recycled as infrastructure investment with β_g reduced from 0.25 (green) to 0.1 (yellow).

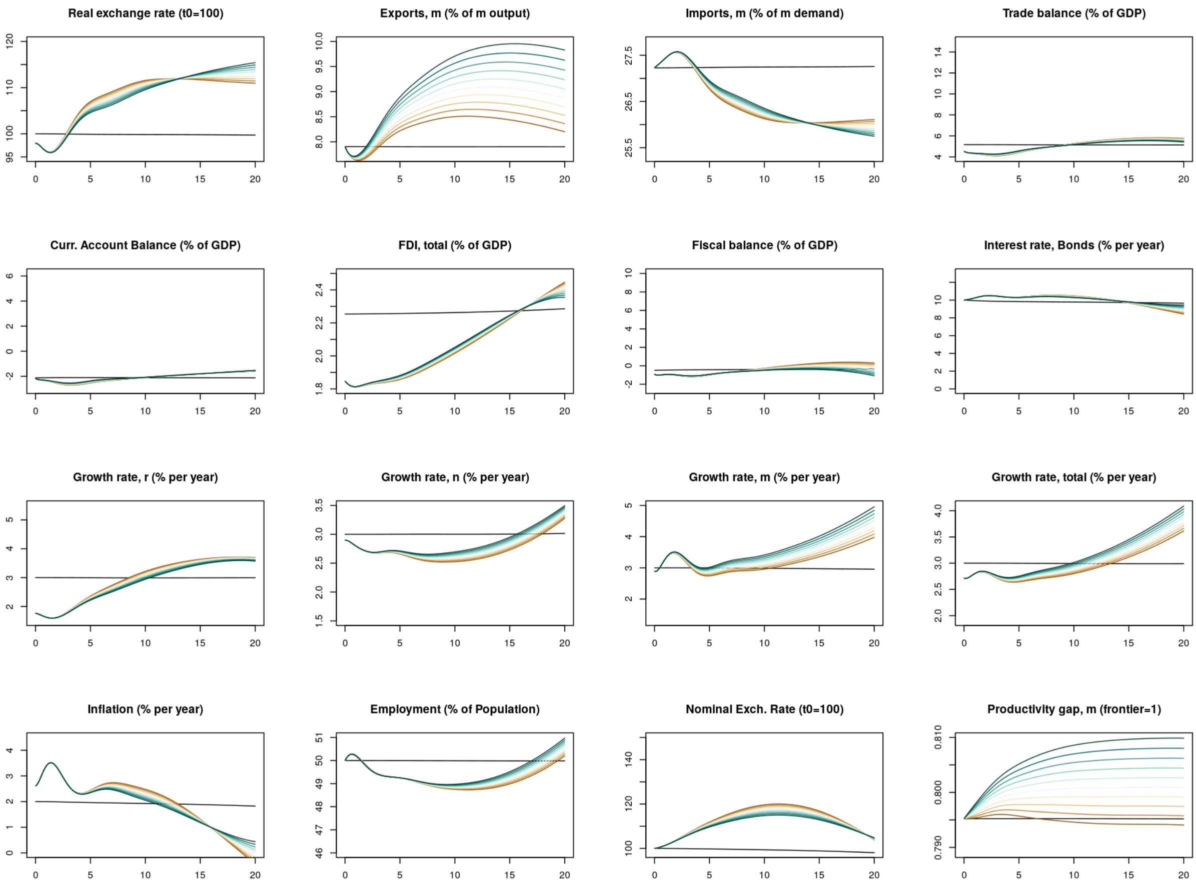
In this case, the short and medium-term trajectories are very similar. Only after 15 years of simulation, changing this parameter will have some impacts on the real exchange rate, exports, imports, FDI, fiscal balance and bond interest rates. However, as demand expectations play an important role in investment decisions, the long-term trajectory is very different in sectors where investment is demand-led. In manufacturing, a low speed of adjustment implies almost no impact on long-term growth. This means that the transition to low-emission industries is highly determined by how companies incorporate demand expectations into their investment decisions.

The increase in exports and the decrease in imports from periods 2 to 15 are almost independent of expected demand. However, in the case where current demand drives investment through the perception of new market opportunities, manufacturing and non-tradable industries start to invest more. It creates a cumulative process of causality, where more investment leads to greater demand, and therefore greater demand leads to more investment. This result is relevant because it shows how demand dynamics play an important role in the long run and is a determinant of the transition path. Even in the case where *m* productivity is driven by more investment in carbon tax recycled infrastructure, demand is expected to drive more investment in low-emission industries.

One of the key findings of the analysis highlights the pivotal role of other tradable sectors in driving the transition toward low-emission industries through re-industrialization. This result relies on the positive impact of infrastructure investment on the productivity of this sector. The magnitude of this effect is contingent upon the sensitivity of tradable goods productivity to public investment in infrastructure (γ^{IG}), which is currently set at 0.001. This indicates that a 1.0 percentage point increase in GDP allocated to public infrastructure investment leads to a 0.1% increase in the productivity of the tradable goods sector. While this sensitivity may seem modest (Perez-Montiel and Manera, 2021), we conduct sensitivity tests by reducing this value to 0.01% (highlighted in yellow) to assess the significance of this parameter.

The diminished influence of public investment in infrastructure on productivity growth yields markedly different outcomes. Firstly, the country fails to close the productivity gap in the directly impacted sector, namely other tradable goods. Consequently, the export of these goods cannot fuel the recovery via the non-price competitiveness effect, and the growth rate of the directly affected sector fails to accelerate, impeding its ability to drive growth in the non-tradable sector. As a result, both sectors experience slower growth rates, prolonging the overall recovery process. Conversely, natural resource exports rebound more swiftly, albeit insufficiently compensating for the sluggish recovery of other industries.

Figure 7: Simulation with different productivity growth sensitivity



10% carbon tax on sales recycled as infrastructure investment with γ^{IG} reduced from 0.001 (green) to 0.0001 (yellow).

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