Recycling carbon taxes for reindustrialisation: addressing structural rigidity and financialisation in natural resource exporting countries

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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 décarbonisation durable en renforçant l'innovation et la compétitivité dans les industries à faibles émissions.

Mots-clés: Transition bas-carbone, Stock-Flow Consistent Model, Exportateurs de ressources naturelles, Pays en développement et émergents, Changements structurels, Industrialisation.

Abstract

The inclusion of developing and emerging countries in the low-carbon transition agenda is necessary to achieve climate goals, and policies must be designed according to their idiosyncrasies. Despite the relevance of these countries, their structural specificities are often overlooked in low-carbon transition models. With the aim of building a suitable framework for this analysis, this article develops a Structural Stock-Flow Consistent (Structural SFC) model for open developing economies, categorising production into three sectors: resource-based exports, non-tradable goods and services, and other tradable sectors.

Although SFC models are important for highlighting financial constraints, they are rarely multisectoral and fail to account for structural specificities. The contributions of our model are twofold: (1) it provides a versatile framework that captures varying country characteristics and balances short-term demand with long-term structural strategies, and (2) it demonstrates that sole reliance on carbon pricing is insufficient for economies anchored in carbon-intensive sectors.

By accounting for structurally different sectors in a truly monetary framework, the model allows us to understand how financial constraints derived from structural rigidities play a decisive role in determining the dynamics of the low-carbon transition. The model provides evidence that the effectiveness of carbon pricing depends on countries' commercial, financial and production structure. It also shows that carbon tax recycling is essential to avoid recessions and promote sustainable decarbonization by strengthening innovation and competitiveness in low-emissions industries.

Keywords: Low-carbon transition, Stock-Flow Consistent Model, Natural resource exporting countries, Developing and emerging countries, Structural changes, Industrialization.

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1. Introduction

The Paris Agreement laid out a global goal to limit climate change to well below 2°C (and aim for 1.5°C) and called for targeted policies to achieve net zero carbon emissions (UNFCCC, 2015). While developing and emerging nations contribute to 63% of emissions, it is essential to integrate them into the low-carbon transition strategy tailored to their unique characteristics. Yet, many economic models overlook the distinct features of these economies, neglecting the interaction between finance and inherent structural constraints. As low-carbon transition policies impact industries in varied ways (Savona and Ciarli, 2019), distinct dynamics emerge, based on the productive, commercial, and financial frameworks of nations (IMF, 2020; Peszko et al., 2020; Magacho et al., 2023). This oversight can hinder 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 shed light on the implications and dynamics of a low-carbon shift in open developing economies. Our model breaks down the production aspect into distinct industries to account for the heterogeneity of the productive structure of developing and emerging countries. In this prototype version, we account for three structurally different sectors: resource-based commodities export industries, non-tradable goods and services, and other tradable goods and services, which competes internationally in terms of 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. investment loans) (Borio and Disyatat, 2015). However, multi-industry representation in these models is uncommon, with a few notable exceptions (Jackson and Jackson, 2021; Dunza et al., 2021; Berg et al., 2015). By incorporating sectors with structural differences within a genuinely monetary model, we can then grasp how financial limitations stemming from structural rigidness critically influence the low-carbon transition path.

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 besides this introduction. The next section discusses the importance of considering finance in a structural model to understand the impacts of low-carbon transition policies in developing and emerging countries. Section 3 describes the sectoral and financial structure of the model. Section 4 presents the simulations intending to show the applicability of the model. Finally, the concluding remarks discuss the advances and contributions of this approach.

2. Literature review

The green transition has become a focal point in global discussions, with numerous developing nations pledging to reduce their greenhouse gas (GHG) emissions in line with the Paris Agreement (UNFCCC, 2015). This renewed commitment adds an extra challenge to economies that already struggle with other aspects related to economic and social sustainability. To achieve their development goals, emerging economies must also promote economic growth and simultaneously cultivate an inclusive system that confronts poverty and inequality (Porcile et al., 2023).

Macroeconomic models have been widely used to advise policymakers at both national and international levels on the implications of climate policies. These models aim to determine how these policies impact economic growth, public debt, employment and other relevant macroeconomic variables (Stern, 2007). In typical multisectoral macroeconomic models, such as the Computable General Equilibrium (CGE) often downplay the significance of finance and its interplay with real-world factors. Only a handful of CGE models that touch upon climate concerns incorporate finance (Liu et al., 2017; Paroussos et al., 2020). However, even in these models, finance has a limited impact on long-term dynamics, as it is essentially treated as a technological or sectoral friction in accessing funding sources. Due to assumptions like market-clearing interest rates where all savings are inevitably invested, any financial constraints in one sector can result in excessive investments in others, leading to a prevalent *crowding-out* effect. Nevertheless, this scenario doesn't always reflect real-world situations, especially in climate change. For instance, during times of elevated systemic risks, where default risks soar, banks typically curtail lending across sectors. Conversely, during periods of economic buoyancy, when anticipated profits rise, and default risks recede, banks are more liberal with their lending (Mercure et al., 2019).

Equilibrium models are founded on the rational choice theory, where incentives guide the behaviour of individual agents. Within this framework, individual agents make rational decisions to maximise their objectives and interact in market dynamics. This web of agent interactions weaves a system characterised by checks and balances, culminating in a stable equilibrium, which serves as a self-regulating mechanism anchoring economic behaviour. The interrelationship between different types of interdependent markets results in a general equilibrium. The New Keynesian school (Mankiw, 1995; Stiglitz, 1989) discusses some frictions that can occur. Through this lens, system stability may not be achieved in the presence of market failures (a fundamental failure concerns the presence of externalities). Government intervention is then justified in the presence of these failures to achieve a second-best situation. Externalities, such as GHG emissions, must be addressed by creating incentives that penalise the industries responsible for their generation (carbon-intensive activities). By penalising activities with high emissions, the system would rebalance itself to create new incentives to invest in carbon-saving activities. Financial institutions in this system neither crate nor destroy money, as there is no credit creation. Savings are, therefore, always available to turn into new investments in the most profitable activities (Mercure et al., 2019). The system then relies on this automatic mechanism that readjusts the economy and creates incentives, such as carbon pricing, to foster 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) offers valuable perspectives on the issue of structural rigidity. Developing economies need more capabilities and absorptive capacity to adapt and diffuse cutting-edge technologies to their productive structures (Lee and Lim, 2001; Silverberg and Verspagen, 1995). The development of an innovative economy, able to move across sectors and quickly re-adapt and upgrade, requires a significant economic and social effort in building the supply conditions for it through a strong and dynamic national innovation system (Lundvall, 2007). In this context, catching up is far from automatic. It requires strong investments in physical and human capital and 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, the restricted access to funding and steep borrowing expenses are considerable obstacles in garnering resources for these ventures, especially for small and medium-sized enterprises (SMEs) (Sánchez & Rungi, 2016).

Addressing these obstacles requires developing nations to implement policies that endorse structural change. Examples include industrial strategies that encourage technological education and progression, and trade policies that assist in embedding SMEs within global value chains (GVCs) (UNCTAD, 2018). Such policies can help to address the lack of absorptive capacity and the limited availability of finance that prevent developing countries from effectively catching up with developed economies. Additionally, international cooperation and partnerships can play an essential role in providing financial and technical assistance to developing countries in their efforts to achieve sustainable and inclusive economic growth (OECD, 2018).

The second significant obstacle to sustainable and inclusive economic growth in developing nations is demand deficiency, especially in relation to balance of payments challenges. In a monetary economy, investment decisions account for expectations. During periods of high uncertainty, agents tend to move their assets towards liquid assets, which reduces spending decisions, leading to a lack of demand. Supply adjusts by reducing production capacity, hindering growth and causing unemployment (Pasinetti, 2001). For open developing economies, constrained by limited foreign currency access, they must draw foreign exchange for essential imports for consumption and investment. This is even more pressing for those countries that lag in technological innovation, dependent on importing advanced tech and historically plagued by external restrictions and crises (Thirlwall, 1979; Cimoli and Porcile, 2014). Balance-of-payments constraints exert significant pressure on the economy to adjust towards the availability of foreign currency when imports are a central requirement for the structural change process. Currency devaluations cannot persist indefinitely to compensate for this lack of foreign exchange. The economic adjustment is, therefore, *via* quantity rather than prices. This adjustment means that growth is constrained by demand through the balance-of-payments channel, so exports and imports can be balanced in the long run, avoiding an explosion of foreign debt.

To navigate balance of payments constraints, developing countries need to amplify their export potential through diversifying production, technologically advancing, and enhancing product and service quality. Furthermore, policy initiatives supporting local industries – encompassing infrastructure investment, educational initiatives, and R&D – can curtail import demand while bolstering domestic production (Botta et al., 2023; Porcile et al., 2022).

The third barrier is financialisation, which hinders sustainable and inclusive growth. The current global economic framework relies heavily on open financial accounts that pressure national economies to align their domestic macroeconomic policies with the rules and demands of international capital markets. Consequently, monetary policies fixate on inflation control and foreign portfolio attraction, with pronounced implications on real economies (Frankel, 2010; Borio and Disyatat, 2015). This focus prompts developing nations to favor short-term financial equilibrium over enduring growth (Ghosh et al., 2016). This orientation risks volatile capital movements, potential financial unrest, and economically detrimental crises (Stiglitz, 2002). Moreover, the reliance on foreign capital inflows can lead to an overreliance on short-term finance rather than long-term investment in productive capacities, undermining growth prospects (Reinhart and Rogoff, 2009).

Therefore, it is essential for developing countries to carefully manage their capital accounts and develop financial policies that prioritise long-term sustainable growth over short-term financial stability. This might encompass capital controls, regulatory oversight, and cultivating domestic financial ecosystems that support enduring productive investments (Ghosh et al., 2016). It is also essential for developing countries to have greater agency in shaping the rules of the international financial system to ensure that they align with the needs and priorities of the real economy rather than the demands of international capital markets.

The three barriers described above cannot be easily captured using a CGE framework. In this approach, due to market clearing mechanisms, financial constraints and structural rigidities play a negligible role in the economy. As an alternative framework, using Stock-Flow Consistent (SFC) modelling allows us to understand the links between structure, demand, and finance dynamics. This approach allows us to connect short-run macroeconomic dynamics with long-run economic paths. In that sense, this framework highlights the key challenges faced by countries aiming to achieve a green transition regarding macroeconomic constraints. The SFC approach allows money creation and feedback loops between finance and the real side of the economy. Short-term disequilibrium and imbalances between different economic sectors can significantly affect economic growth and sustainability in the long run.

Incentive mechanisms in a CGE framework tend to have recessive effects that hinder development and exacerbate economic crises instead of driving a structural shift towards sustainability. On the other hand, mechanisms that create disincentives for investments in one industry automatically incentives investment in others. For instance, in a CGE framework, a negative shock, such as carbon pricing, create incentives for reallocating resources towards renewable energy. In a SFC framework, conversely, a negative shock in the energy sector may have unintended consequences, such as reducing overall demand, leading to a contraction in other sectors and ultimately to a recession. Crowding-out effects predominate in a CGE framework, whilst SFC models allow for both crowding-in and crowding-out effects. Furthermore, in the latter framework, the financialisation module reveals that negative shocks - such as a drop in exports - may exacerbate the contractionary effects, leading to a deeper recession. This view contrasts with the CGE framework, which predicts an exchange rate reduction and compensation on the current account (either by import reduction or by increases in exports).

Thus, the limitations of the CGE framework highlight the need for more comprehensive and integrated models to capture the complex feedback mechanisms between the real and financial sectors and the interplay between environmental and economic outcomes. Such models could provide policymakers with a more accurate understanding of the impact of policy measures on economic and environmental sustainability. The role of policy is particularly different in this newly proposed framework. Instead of a pure mechanism to address market failures, the policy has an active development role in fostering structural change while maintaining macroeconomic stability in the sensitive context of financialisation, open financial accounts, and financial dominance (Botta et al., 2023).

The proposed framework underscores the crucial role of policy in tackling the triad of barriers impeding sustainable and inclusive economic growth. Policy intervention becomes necessary to foster structural change and maintain macroeconomic stability in financialisation and open financial accounts. Rather than merely addressing market failures, policies need to play an active role in promoting sustainable growth and development. Such policy shifts can span various domains, from fostering innovation and bolstering education to infrastructure enhancement and strategic industrial directions, aiming to birth new industries and fortify existing ones. Additionally, macroeconomic policies should align with long-term development objectives while safeguarding short-term macroeconomic stability, especially when factoring in external influences like capital flows, exchange rate volatility, and global financial crises. Nevertheless, the effectiveness of these policies depends on the specific characteristics of each country. That includes their institutional frameworks, political will, and the availability of financial resources. Hence, tailoring policies to fit individual country contexts becomes paramount in ensuring they effectively bolster sustainable and inclusive growth.

3. The structural SFC model

The dynamics of the structural transformation process in resource-exporting countries need to consider at least three structurally different sectors (Skott, 2021). First, it is necessary to divide the economy into tradable and non-tradable sectors, as the impacts of global dynamics affect them through different channels. While both sectors benefit from booms due to the lower cost of accessing credit, inputs and capital goods and higher domestic demand, the impact on traded goods is ambiguous. As these industries compete with imports for the domestic market and with other economies for export, they may not profit from booms due to exchange rate dynamics. In addition, it is necessary to account for a specific sector within tradable goods: the sector that produces goods based on natural resources. During cycles, these industries are particularly impacted because they predominantly export commodities. Unlike other tradable sectors, these industries can be positively over-impacted in booms due to rising commodity prices. Furthermore, as these industries depend directly on environmental services and their production is closely related to environmental impacts, they are fundamental to understanding how the green transition can impact countries that export natural resources.

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]. However, this model needs to consider sectoral differences, as it considers only one productive sector, which is essential to understand the structural rigidity of these economies.

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
- 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

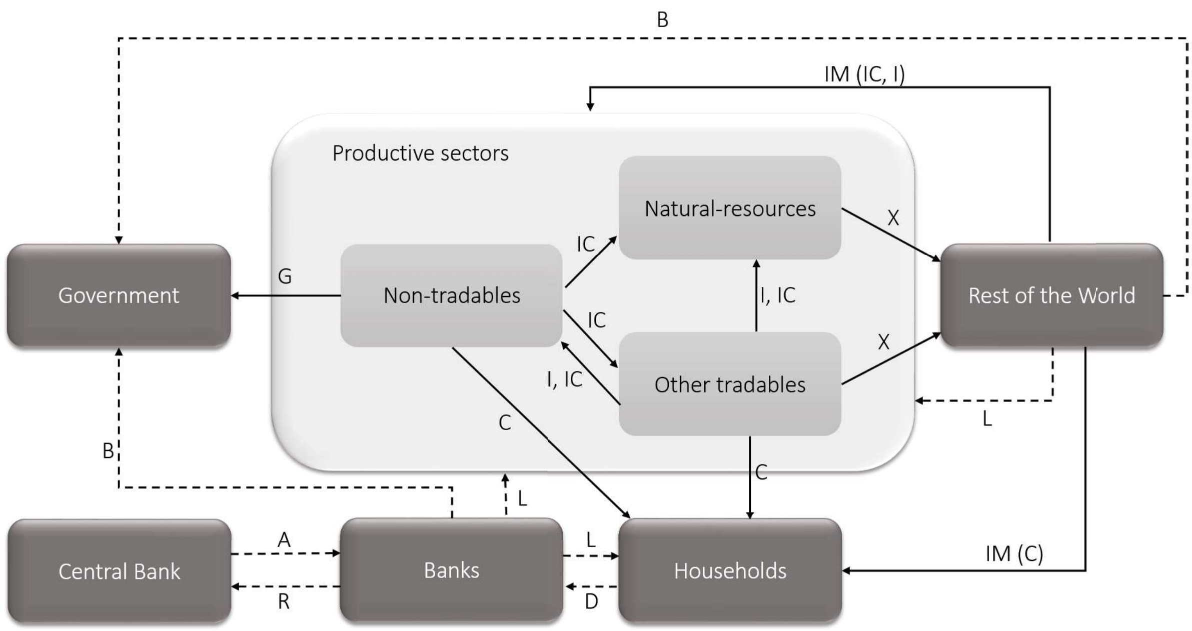
[1]For a detailed discussion of the advantages of using a continuous-time model over a discrete-time model, see Gandolfo (2012) and Yilmaz and Godin (2020)

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 on 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; absorbs Central Bank profits; invests in firms and banks and receives dividends
- Banks (B): finance firms and households by loans and government debt through 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 finance firms and banks by loans and FDI and government debt through 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.

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. Specific features of the model

Appendix A presents all model equations. Here we detail the most important characteristics, highlighting the structural differences between the sectors.

Table 1: Transactions Flows Matrix (TFM)

	NR exporters		Non-traded G&S		Other G&S		HH	Gov	Commercial Banks		Central Bank	Rest of the World	$\sum$
	curr	cap	curr	cap	curr	cap			curr	cap			
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.

3.1.1. Productive sectors

In most developing economies, even when the unemployment rate is low, the labour shortage is not an important constraint 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 desired inventories (which is necessary to guarantee their sales in the case of volatility). (Charpe et al., 2011).

In all sectors, investment is determined by the 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, it depends 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, 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. Unlike natural resources, they are price makers; hence, 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.

Firms borrow to produce and invest. For simplicity, however, we will abstract from lending for production (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, discounted by income tax and social contributions.

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 product 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 value grows with consumer inflation and growth in per capita production.

The public primary deficit evolves according to taxation, social contributions, public consumption and social transfers. In addition to the primary deficit, the government must also finance expenditure with interest on its obligations. To finance its deficit, the government issues bonds. Firstly, it decides how many bonds are 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 household 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 ratio. 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 profit is 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

[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

currency in relation to demand, increasing its reserves.

3.1.4. Rest of the world

International capital flows are attracted to finance companies in the productive sectors (by portfolio or foreign direct investment) and public debt. In the case of capital flows attracted to finance public debt, they will reduce the government's dependence on banks, as we saw previously. In the case of portfolio and FDI, they reduce companies' internal loans.

International liquidity determines global financial flows. The flow of new foreign capital investments (direct and indirect) also depends on the expected profitability of these investments in foreign currency. In addition to equity investments, foreign capital flows also finance the government through the purchase of bonds in both domestic and foreign currencies. Foreign currency bonds, as discussed earlier, are a government decision (a low-risk investment for foreign investors, but a risky debt for the government). In the case of bonds in national currency, what determines the flow is the difference between the interest rate paid by the government and the world interest rate plus the external risk premium.

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 a 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 (only due to the use of other industries inputs).

If, on the one hand, the carbon tax penalises relativelly more the production of resource-based industries, on the other hand, it increases tax revenues, which can be an important mechanism to promote structural changes concerning other industries. We looked at three different uses of these features. First, we assess the impact of the retention of these revenues by the government, increasing the public surplus and, therefore, positively impacting public debt and interest rates. We then simulated what would happen if the government redistributed this carbon fund to households through Social Transfers. In this case, there is no direct impact on the fiscal balance. Still, the government is not draining money from the economy - it is just redirecting resources from high-emitting industries to consumption by other industries. Finally, we tested what would happen if the government invested directly in social infrastructure instead of transferring to households to create capacities for low-emission industries to gain competitiveness in domestic and foreign markets. The idea behind this third type of policy is that, in addition to increasing demand for low-emission industries in the short term, the government encourages this industry by developing the necessary conditions for structural change.

For analytical reasons, the baseline scenario (without carbon tax) is set on a balanced growth trajectory, as presented in Appendix A. The carbon tax can therefore be interpreted as a shock that will lead to a new dynamic, which is not necessarily a new equilibrium. Depending on the size and direction of the shock, it can generate structural transformations in the economy that can lead to a catching-up or an economic setback that feeds back. Table 2 presents some key variables which are stable in the baseline scenario but may be impacted by the carbon tax shock.

Table 2: Value of key variables in the baseline scenario

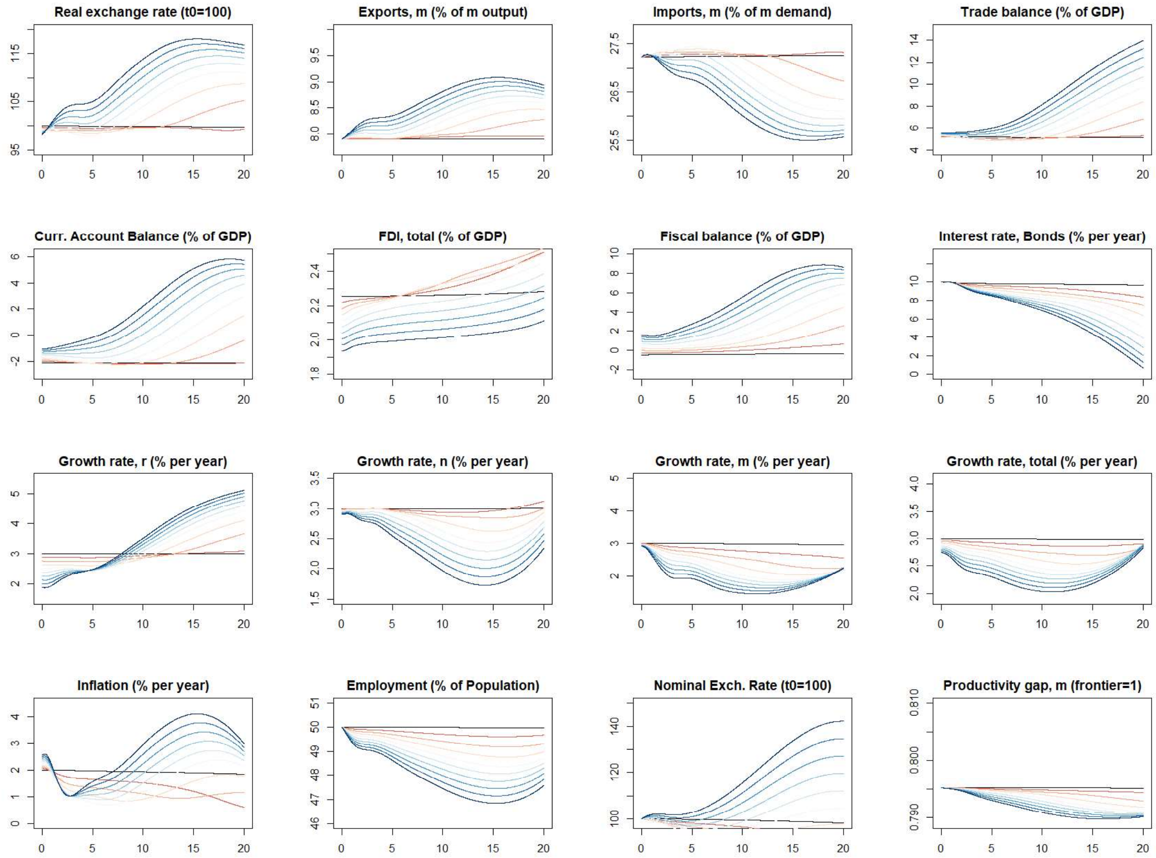
Variable	Measure	Value	Variable	Measure	Value
Household Consumption	% of GDP	50.0%	Leverage ratio, r	% of K_r	20.0%
Government Expenditure	% of GDP	20.0%	Leverage ratio, n	% of K_n	20.0%
Fixed investment, r	% of GDP	4.8%	Leverage ratio, m	% of K_m	25.0%
Fixed investment, n	% of GDP	11.5%	Productivity 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%

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

4.1. Carbon taxation

Figure 2 presents graphics selected for the first simulation, which is the imposition of a carbon tax without recycling. The direct impacts of the carbon tax are inflation and the drop in the profitability of resource-based industries, which leads to a decrease in its investments. As this industry works at full capacity, the growth rate decreases due to this drop in investment, leading to an overall drop of the economic growth from 3.0% to less than 2.0% per year.

Figure 2: Simulation of Carbon tax



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

The economic impacts of carbon taxation go beyond the impacts on this industry. Because industries are connected through input and capital demand, and the income generated in one industry is the demand for others, the carbon tax is a recessive measure. The increase in the fiscal surplus (and the fall in interest rates) is not enough to offset these negative impacts. The fall in investments in natural resource industries reduces the demand for industries producing capital goods (in the case of the model, m). As a result, the economy's growth rate as a whole slows down continuously, as well as the employment rate.

Even though the immediate impact on the real exchange rate is negative (appreciation) due to price domestic increase, low demand for all goods leads to real depreciation in the short run. The drop in demand increases inventories and, consequently, the mark-up decreases. As a consequence, price-competitiveness increases and boosts exports of manufactured goods. Imports are also impacted by these price competitiveness gains, and declines as a share of demand. Imports decline even faster due to declining demand for capital goods and other inputs. Due to these impacts on trade, a current account surplus is generated.

The accumulation of current account surpluses prevents a continuous real exchange rate depreciation. A few periods after the adoption of the carbon tax, the economy presents positive results from the financial and fiscal point of view in spite of a recession from the productive point of view. Employment keep dropping in the medium run, as well as overall growth (it reaches 2.0%), mainly due to the drop in tradables other than natural resources. Fiscal and current account surpluses and dropping interest rates don't revert this cycle, and only after almost 15 years employment start increasing led by the recovery in natural resources and it's capacity to push non-traables due to its demand and income effects.

The long-term consequences, however, can be devastating. As the decline in investment in resource-based industries (r) did not lead to an increase in other tradables goods and services (m), the expected structural shift towards low-emission industries did not occur. Insufficient demand, financialisation and structural rigidity played important roles in preventing this process. First, because demand has declined, imports have also declined, leading to a better current account position despite the decline in exports from resource-based industries. Alongside a fiscal surplus, this process generates a positive financial situation, leading to FDI inflows, which sustain this dynamic. The negative conditions on the productive side (despite the decline on interest rates) are not enough to reverse the positive financial cycle, and the economy faces a prolonged period of financial *bonanza* with decline of manufacturing and tadable services. This process is similar to a Financial Dutch Disease, where, despite the loss of competitiveness in manufacturing, due to self-reinforcing financial mechanisms, current account deficits do not lead to reversion of exchange rate appreciation (Botta, 2015).

In this context, it is clear that the carbon tax without recycling mechanisms is recessive both in the short and medium/long-run. Despite the positive impacts on the fiscal and financial sides, it has strong negative impacts on production and employment. Essentially, because the government is draining resources from the economy, demand is decreasing and falling interest rates are not offsetting these negative shocks. Incentives to invest diminish, and their decline feeds back demand, leading the country to lag behind in terms of income and the transition to low-carbon industries.

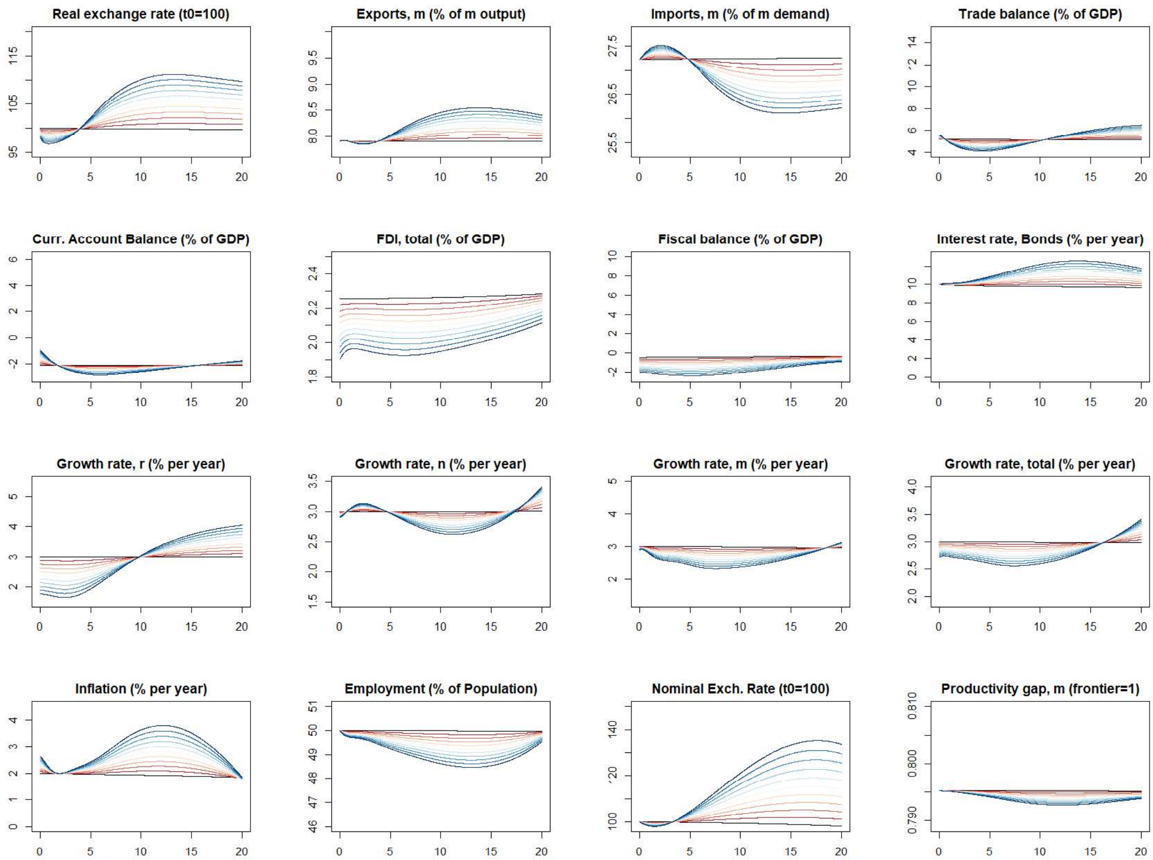
4.2. Carbon taxation recycled as social transfers

In the latter case, tax revenues from the carbon tax are used to increase the fiscal surplus. The fiscal surplus increases in the short term, allowing a fall in the interest rate on government bonds. Despite this low interest rate and the increase in public savings, insufficient demand led to a generalized fall in investment. Alternatively, we simulate two cases where these tax revenues are used to stimulate the economy. In the first, we look at what happens if they are recycled as social transfers, and in the second, they are used to invest in infrastructure.

Figure 3 presents the case where the fiscal revenue from the carbon tax is transferred to households to increase their disposable income through social transfers. The immediate impacts are similar: inflation and drop in natural resources profitability and investments, leading to an overall drop in economic growth rate. The difference is that, in this case, rather than a fiscal surplus, the fiscal deficit is intensified.

In the short run, we can observe that, because government is not draining resources from the economy as before, high demand for non-tradables prevents a continuous decline in overall growth rate, which stabilises at 2.7%. Employment rate keep dropping because productivity is growing at 2.0% per year and population at 1.0%. However, in this case, current account deteriorates, as well as fiscal deficit, leading to increasing interest rates despite disinflation.

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.

This dynamics, however, is rapidly reverted. Fiscal and current account deficits keep increasing, and it turns to be a inflationary environment in the medium run. The increase in interest rate prevents inertial inflation by reducing demand and attracting foreign capital to compensate for the current account deficit, but it is recessive. Non-tradables and tradables other than natural resources face 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 - in the simulation it happens only after period 10, when the growth rate of this sector exceeds 3%. The impact of the measure on employment is not as high as in the 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.

Thereby, recycling the carbon tax by transferring these resources to households (and consequently increasing their disposable income and consumption), can be an interesting instrument to avoid the problems of insufficient demand and the contradiction of the financial and productive cycles that we saw in the previous simulation. Furthermore, despite being a recessive measure in the short term, the social costs of the carbon tax in terms of employment are compensated by an increase in social spending. Nevertheless, due to structural rigidities, the sectors that benefit from the transition are not the tradable ones (m), but non-tradables (n). As real depreciation is slow (due to inflation) and price competitiveness is not sufficient to lead to a significant increase in tradable sectors' exports, the growth of these sectors do not compensate for the decline of natural resources, which are high-emission industries. Conversely, in the long term, as shown in the simulation, the natural resources sector (r) recovers due to macroeconomic conditions unfavorable to other sectors, and the economy returns to a process of specialization in natural resources, and hence on high-emission industries.

4.3. Carbon taxation recycled as infrastructure investment

Finally, Figure 4 presents the third simulation, where, instead of recycling carbon taxation through social transfers, the government invests in infrastructure with the aim of creating the necessary technological and productive capacities to effectively increase 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 m related to government 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.

In the short term, a jump in inflation lead by high demand for capital goods lead to an appreciation of the real exchange rate. It leads to a reduction in exports and an increase in imports, which causes an increase in current account deficit. The increase in imports is also driven by the increase in domestic demand for imported manufactured goods. In the medium term, the current account deficit leads to a real exchange rate depreciation and, due to the impacts on price competitiveness, exports grow and imports decline.

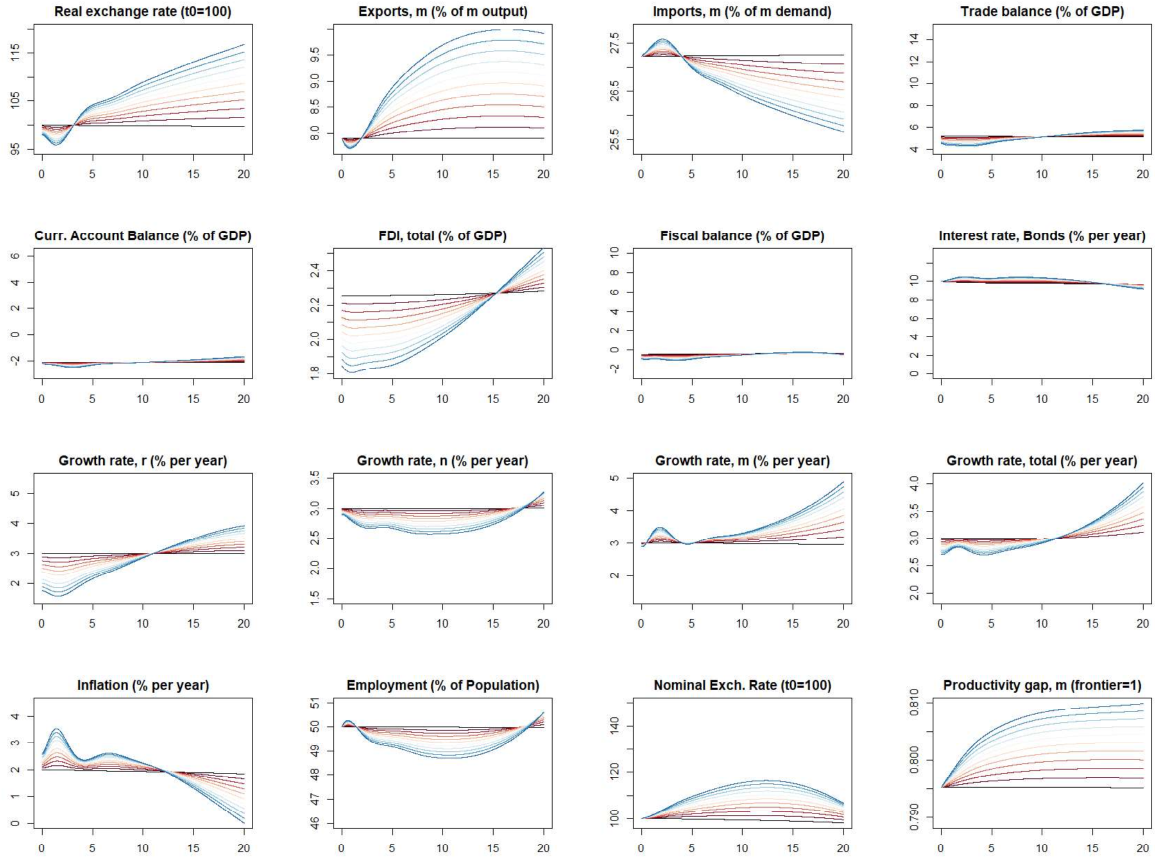
The most important difference between recycling carbon tax revenues through infrastruc-

[4] The new productivity function becomes:

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

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.

ture investments and social transfers is their medium to long-term impacts. As low-emission industries gain competitiveness in domestic and international markets due to productivity growth, exports recover more quickly and imports begin to decline sooner. This leads to a faster recovery of these industries (after simulation period 4, the growth rate of *m* starts to increase), leading to a faster transition from high to low-emission industries. Different from the other scenarios, employment and growth rate recovery is not driven by natural resources. Instead, it is the low-emission industries that pushes the economy up preventing it of facing both insufficient demand, as in the case of non-recycling, and deterioration of fiscal and current accounts, as in the case of recycling via social transfers.

In addition to avoiding contradictory patterns between financial and production dynamics and problems of insufficient demand, one of the main bottlenecks for carbon tax to promote the transition is overcome through these investments in infrastructure. Developing countries tend to face structural rigidities that can restrict (or slow down) the transition to low-emission industries. However, as we could see in this last simulation, combining demand and supply policies is important to promote the transition in these economies. If government is able to use these resources to build technological and productive capabilities in the key industries for the transition, these industries will not only grow at the expense of carbon-intensive ones but will create a positive cumulative process of structural transformation and economic catching up.

5. Concluding remarks

The inclusion of developing countries in the decarbonisation agenda is necessary to achieve net zero emissions in the coming decades. Currently, these countries account for 63% of global emissions, and their importance is increasing (Abubakar and Dano, 2020). There is a need, however, to think about their idiosyncrasies when proposing policies. Traditional macroeconomic models are built on the basis of developed economies and therefore fail to address some of the key issues facing developing and emerging countries to promote a sustainable and just transition. Structural rigidities, for example, is one of the main problems these countries face when trying to move from high-emitting industries to low-emitting industries. Therefore, there is a need to develop tools that take into account these specificities, and these tools need to address the main constraints that may arise in this process.

This paper develops a Structural Consistent Stock and Flow (Structural-SFC) model for natural resource exporting countries. As these economies have a heterogeneous productive structure and sectors are different in many dimensions, such as market structure, productivity and investment dynamics, a one-sector model or a multi-sector model where sectors are structurally the same can be misleading when analyzing macroeconomic factors. Furthermore, finance plays an important role in the transition because there is nothing to guarantee that falling investment in high-emitting industries will boost investment in low-emitting industries. In this sense, SFC models are important tools, as they allow money creation and destruction via credit and, therefore, banks and other financial institutions are central to the transition dynamics.

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.

The results show that, if there is no recycling of carbon tax revenues, this is an ineffective measure. 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. One of the main mechanisms that can be expected to occur, which is the increase in exports and decrease in imports of other industries (to compensate for the drop in exports of high-emitting industries), fails to happen. As imports also fall in other sectors, there are no current account persistent deficits and no real exchange rate depreciation. Consequently, falling profitability in high-emission industries does not lead to an automatic increase in investment in low-emission industries. In addition, financial dynamics may reinforce a process of falling investment in low-emission industries despite the drop in interest rates. As financial conditions are positive (low inflation, fiscal and current account surpluses), foreign capital continues to flow into the country, despite the problems faced by the productive sectors. The reversal of the financial cycle, after a long period of bonanza, may lead to an intensification of the problems faced by the productive sectors, especially low-emission tradable, and the economy fails to promote the transition.

Recycling carbon tax revenues can, however, create better macroeconomic dynamics that can favour the low-carbon transition. In the case of using these revenues as social transfers, the problem of insufficient demand is solved and the profitability of other industries does not fall with the reduction of profitability of high-emission industries. In this case, however, the transition is very slow due to 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. In addition, these gains in competitiveness can leverage a cumulative process of causality, where export growth leads to high profitability in low-emission industries, increasing investment and generating more demand and competitiveness gains.

As the model is built on a theoretical calibration, not representing any specific country, the simulations are explanatory. However, the sensitivity analysis shows that the results can be generalized to many countries with similar production structures. Furthermore, the model is a prototype version and, as it is relatively simple (despite having hundreds of equations, most of which are accounting equations), it can be used and applied to specific countries. As it is built on a multisectoral framework, environmental issues specific to sectors in different countries can be considered, such as the impact of climate change on key industries for a country, the impact of biodiversity loss due to inadequate land use and dependence on activities that use water in countries with high 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, $Y_j^P = \min(a_j N_j, u_j K_j / b_j)$.[5]. 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):

$$N_j = \frac{Y_j^P}{a_j} \tag{2}$$

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

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

and

$$\begin{bmatrix} IC_r^{r,IM} & IC_n^{r,IM} & IC_m^{r,IM} \\ IC_r^{n,IM} & IC_n^{n,IM} & IC_m^{n,IM} \\ IC_r^{m,IM} & IC_n^{m,IM} & IC_m^{m,IM} \end{bmatrix} = \begin{bmatrix} c_r^{r,IM} & c_n^{r,IM} & c_m^{r,IM} \\ c_r^{n,IM} & c_n^{n,IM} & c_m^{n,IM} \\ c_r^{m,IM} & c_n^{m,IM} & c_m^{m,IM} \end{bmatrix} \begin{bmatrix} Y_r^P & 0 & 0 \\ 0 & Y_n^P & 0 \\ 0 & 0 & Y_m^P \end{bmatrix} \tag{4}$$

where c_j^i and $c_j^{i,IM}$ are the domestic and imported inputs of i necessary to produce one unit of j.[6] 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:

$$\dot{K}_j = I_j - \delta_j K_j \tag{5}$$

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:

$$\dot{V}_{j'} = Y_{j'}^P - Y_{j'}^D \tag{6}$$

[5]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.

[6]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:

$$I_j = \max[0, K_j(\kappa_0 + \kappa_1(r_j^e - l_r i_j^{L,e}) + \delta)] \tag{7}$$

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

$$l_j = \frac{L_j + L_j^{FX} e}{K_j p^K} \tag{8}$$

and

$$i_j^{L,e} = \sigma_j^{FX}(i^{FX} + \mu_j^{FX})e^e + (1 - \sigma_j^{FX})i_j^L \tag{9}$$

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).[7] 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:

$$r_r^e = \frac{Y_r^P[\frac{p_r^{W,e}e^e}{1+t_r^Y} - \tau_r - UC_r]}{K_r p^K} \tag{10}$$

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:

$$r_{j'}^e = \frac{Y_{j'}^{e,f}\frac{p_{j'}}{1+t_{j'}^Y} - (Y_{j'}^{e,f} + I_{j'}^V)(UC_{j'} + \tau_{j'})}{p^K K_{j'}} \tag{11}$$

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

[7] 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:

$$UC_j = \frac{w}{a_j} + c_j^r p_r^W e + c_j^n p_n + c_j^m p_m + c_j^{m,IM} p_j^{IM} \tag{12}$$

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):

$$X_r = \left(Y_r^P - \sum IC_j^r\right) p_r^W e \tag{13}$$

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:

$$Y_n^D = \sum IC_j^n + C_n + G_n \tag{14}$$

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:

$$\sigma_m^X = \zeta_X \left(\frac{p_m}{p_m^W e}\right)^{\eta_X} \left(\frac{a_m}{a_m^W}\right)^{\varepsilon_X} \tag{15}$$

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

$$X_m = \sigma_m^X Y^W p_m \tag{16}$$

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

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

$$\dot{Y^W} = Y^W(\alpha_a + \alpha_{Pop}) \tag{17}$$

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}):

$$\sigma_m^{IM} = \zeta_{IM} \left(\frac{p_m^{IM}}{p_m} \right)^{\eta_{IM}} \tag{18}$$

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}):

$$p_m^{IM} = (1 + t_m^{IM}) p_m^W e \tag{19}$$

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

$$IM_m = (\sigma_m^{IM} Y_m^A + \sum IC_j^{m,IM}) p_m^W e \tag{20}$$

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

$$Y_m^A = C_m + \sum I_j \tag{21}$$

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

$$c_j^m = (1 - \sigma_m^{IM}) c_j^{m,T} \tag{22}$$

and

$$c_j^{m,IM} = \sigma_m^{IM} c_j^{m,T} \tag{23}$$

where T stands for total.

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

$$p^K = \sigma_m^{IM} p_m^{IM} + (1 - \sigma_m^{IM}) p_m \tag{24}$$

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:

$$Y_m^D = \frac{X_m}{p_m} + (1 - \sigma_m^{IM}) Y_m^A + \sum_j IC_j^m \tag{25}$$

A.1.3. Demand, expectations and pricing

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

$$Y_r^P = \frac{K_r \bar{u}}{b_r} \tag{26}$$

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):

$$Y_{j'}^P = \text{min}[Y_{j'}^e + I_{j'}^V, \frac{K_{j'}}{b_{j'}}] \tag{27}$$

where

$$I_{j'}^V = (Y_{j'}^e + \dot{Y}_{j'}^{e,f})v_{j'}^d - V_{j'} \tag{28}$$

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):[8].

$$\dot{Y}_{j'}^e = \beta_e(Y_{j'}^D - Y_{j'}^e) + Y_{j'}^e(g_{j'}^K + g_{j'}^u) \tag{29}$$

where

$$\dot{g}_{j'}^K = \beta_g \left(\frac{\dot{K}_{j'}}{K_{j'}} - g_{j'}^K \right) \tag{30}$$

and

$$\dot{g}_{j'}^u = \beta_g \left(\frac{u_{j'}}{u_{j'}^h} - 1 \right) \tag{31}$$

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

$$u_{j'} = \frac{b_{j'} Y_{j'}^P}{K_{j'}} \tag{32}$$

where

$$\dot{u}_{j'}^h = u_{j'} - u_{j'}^h \tag{33}$$

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

$$p_{j'}^d = (1 + \mu_{j'})UC_{j'} \tag{34}$$

[8] 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:[9]

$$\mu_{j'} = \mu_0 + \mu_1 \left(\frac{Y^e_{j'} v^d_{j'}}{V_{j'}} - 1 \right) \tag{35}$$

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

$$\dot{p}^p_{j'} = \beta_p (p^d_{j'} - p^p_{j'}) + \pi^e \tag{36}$$

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:

$$p_{j'} = (1 + t^Y_{j'})(p^p_{j'} + \tau_{j'}) \tag{37}$$

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.

$$TFN_j = p^K I_j - (1 - \sigma_D) NF_j \tag{38}$$

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):

$$NF_j = Y^D_j p^p_j - Y^P_j UC_j - i^L L_j - (i^{FX} + \mu^{FX}) L^{FX}_j e \tag{39}$$

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

$$Div^i_j = \sigma_D NF_j \frac{EQ^i_j}{\sum_i EQ^i_j} \tag{40}$$

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

[9] 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

$$\sigma_j^{FX,D} = \max\left[0, \sigma_j^X - \sigma_c^{IM} c_j^m\right] \tag{41}$$

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

$$\sigma_j^X = \frac{X_j}{Y_r p_j e} \tag{42}$$

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

$$\dot{L_j^{FX}} = \sigma_j^{FX}\left[\frac{TFN_j - (DDI_j + PDI_j + FDI_j)}{e}\right] \tag{43}$$

and

$$\dot{L_j} = (1 - \sigma_j^L)[TFN_j - (DDI_j + PDI_j + FDI_j)] \tag{44}$$

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).

$$YD_H = (1 - t^H)[(1 - sc)wN + \sum_{j,B} Div_j^H + i^D D_H] + ST \tag{45}$$

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

$$N = \sum N_j \tag{46}$$

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

$$C^T = p^C \gamma_0 Pop + \gamma_1 YD_H + \gamma_2 D_H \tag{47}$$

where

$$\dot{Pop} = \alpha_{Pop} Pop \tag{48}$$

Actual consumption adjusts towards target consumption as follows:

$$\dot{C} = \beta_C(C^T - C) \tag{49}$$

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:

$$DDI_{j,B} = \sigma^H_{j,B}(YD_H - C) \tag{50}$$

The remaining funds are saved as deposits:

$$\dot{D_H} = YD_H - C - \sum DDI_{j,B} \tag{51}$$

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

$$\dot{EQ}^H_{j,B} = DDI_{j,B} + (1 - \sigma_D)NF_{j,B}\frac{EQ^H_{j,B}}{EQ_{j,B}} \tag{52}$$

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[10], we have that consumption of in real terms (C_n) is given by:

$$C_n = C_{n,0} + \gamma^n \left(\frac{C}{p_n} - C_{n,0}\right) \tag{53}$$

where

$$\gamma^n = \gamma^n_1 + \gamma^n_2 \left(\frac{p_n}{p^{C,e}}\right)^{\gamma^n_3} \tag{54}$$

and

$$C_{n,0} = \gamma^n_0 Pop \tag{55}$$

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

$$C_m = \frac{C - C_n p_n}{p^K} \tag{56}$$

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:

$$\dot{w} = w\left[\frac{\dot{a}}{a} + \frac{\dot{p^{C,e}}}{p^{C,e}} + \gamma_w\left(\frac{N}{Pop} - \gamma_N\right)\right] \tag{57}$$

[10] 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:

$$p^C = \sigma_n^C p_n + (1 - \sigma_n^C) p^K \tag{58}$$

and

$$\dot{p^{C,e}} = \beta_{pC}(p^C - p^{C,e}) + p^{C,e}\lambda_p \tag{59}$$

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:

$$\dot{G} = G\left(g^Y + \frac{\dot{p^{C,e}}}{p^{C,e}}\right) \tag{60}$$

where

$$g^Y = \frac{Y_r^P \frac{\dot{K_r}}{K_r} + Y_n^P\left(\frac{\dot{K_n}}{K_n} + g_n^u\right) + Y_m^P\left(\frac{\dot{K_m}}{K_m} + g_m^u\right)}{Y_r^P + Y_n^P + Y_m^P} \tag{61}$$

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

$$G_n = \frac{G}{p_n} \tag{62}$$

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

$$ST = st(Pop - N) \tag{63}$$

where

$$\dot{st} = st\left(g^Y - \alpha_{Pop} + \frac{\dot{p^{C,e}}}{p^{C,e}}\right) \tag{64}$$

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

$$T_G = t^H[(1 - sc)wN + Div^H + i^D D_H] + \sum t_j^Y \frac{p_j}{1 + t_j^Y} Y_j^D + \sum \tau_j Y_j^P + t_m^{IM} M_m + scNw \tag{65}$$

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:

$$PDI_{j,B} = \sigma_{j,B}^P G \tag{66}$$

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

$$\dot{EQ}^G_{j,B} = PDI_{j,B} + (1-\sigma_D) NF_{j,B} \frac{EQ^G_{j,B}}{EQ_{j,B}} \tag{67}$$

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:

$$GFN = G + ST + PDI + i^B(B^B + B^F) + i^{FX} B^{FX} e - T_G - NF_{CB} - Div^G \tag{68}$$

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,

$$Div^G = Div^G_r + Div^G_n + Div^G_m + Div^G_B \tag{69}$$

and

$$PDI = PDI_r + PDI_n + PDI_m + PDI_B \tag{70}$$

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:

$$\dot{B^{FX}} = \lambda_B GFN \tag{71}$$

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):

$$B^S = GFN - \dot{B^{FX}} e + (\lambda_O GDP - OA) \tag{72}$$

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:

$$\dot{B^B} = \frac{B^S - \dot{B^F}}{\exp[\gamma_B \left(i^{B,d} - i^B\right)]} \tag{73}$$

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.

$$i^{B,d} = i^P + \gamma_{Bd} \frac{DG}{GDP} \tag{74}$$

where

$$DG = B^B + B^F + B^{FX} e \tag{75}$$

GDP is calculated from a demand perspective:

$$GDP = C + I + G + X_r + X_m - IM_m \tag{76}$$

where

$$I = (I_r + I_n + I_m)p^K \tag{77}$$

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

$$\dot{OA} = \dot{B^B} + \dot{B^F} + \dot{B^{FX}}e - GFN \tag{78}$$

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

$$\dot{i^B} = \beta_{iB}(i^{B,d} - i^B) \tag{79}$$

A.2.3. Commercial Banks

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

$$i^L_j = \mu^B_j + i^P \tag{80}$$

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

$$R_B = \sigma_{rr} D_H \tag{81}$$

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

$$\dot{A_{CB}} = \sum \dot{L_j} + \dot{B^B} + \dot{R_B} - \dot{D_H} - \dot{OF_B} + \dot{R^{FX}_B}e \tag{82}$$

Banks distribute profits according to the share of equity:

$$Div^i_B = \sigma_D NF_B \frac{EQ^i_B}{EQ_B} \tag{83}$$

where

$$EQ_B = EQ^H_B + EQ^G_B + EQ^F_B \tag{84}$$

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

$$i^D = i^P \tag{85}$$

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

$$NF_B = i^L \sum L_j + i^B B^B + i^P R_B - i^P A_{CB} - i^D D_H \tag{86}$$

and

$$r_B = \frac{NF_B}{OF_B} \tag{87}$$

The summation of distributed profits is given by

$$Div_B = \sum Div_B^i \tag{88}$$

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

$$\dot{OF_B} = DDI_B + PDI_B + FDI_B + (1 - \sigma_D)NF_B \tag{89}$$

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:

$$NF_{CB} = i^P A_{CB} - i^P R_B + i^{FX} R_{CB}^{FX} e \tag{90}$$

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

$$i^P = \max\left[0, \iota_0 + \iota_1\left(\frac{\dot{p^{C,e}}}{p^{C,e}} - \lambda_p\right)\right] \tag{91}$$

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) concerning demand (FX^D), increasing its reserves. If it wants to let it float, it only keeps a constant share of the country's imports or nominal GDP as reserves to guarantee liquidity. Thereby, we have that:

$$\dot{R_{CB}^{FX}} = \sigma_0^{FX}(FX^S - FX^D) + R_{CB}^{FX}\left(g^Y + \frac{\dot{p^{C,e}}}{p^{C,e}}\right) \tag{92}$$

where σ_0^{FX} varies from zero to one according to the Central Bank intention to keep e fixed or floating, and, if it is zero (the country is in a floating exchange rate regime).

A.2.5. Rest of the World

Firms can be financed either by portfolio or foreign direct investments (FDI)[11]. A share of world financial flows gives the flow of new foreign equity investments (direct and indirect)

[11] 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:

$$FDI_{j,B} = \phi_{j,B}(r^e_{j,B} - i^{FX})WFF \tag{93}$$

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):

$$\dot{B^F} = \min\{B^S, [\phi^F_0 + \phi^F_1 \left(i^B - i^{FX}\right)]WFF\} \tag{94}$$

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

$$WFF = \phi^W (Y^W p^W_m)(\alpha_a + \alpha_{Pop} + \alpha_p)e \tag{95}$$

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

$$\dot{EQ^F_{j,B}} = FDI_{j,B} + (1 - \sigma_D)NF_{j,B}\frac{EQ^F_{j,B}}{EQ_{j,B}} \tag{96}$$

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

$$\dot{e} = e\beta_{eN}\frac{FX^D + \dot{R^{FX}_{CB}} - FX^S}{FX^S} \tag{97}$$

where

$$FX^D = IM_m + (L^{FX}_r + L^{FX}_m)(i^{FX} + \mu^{FX})e + Div^F + i^B B^F + i^{FX} B^{FX} e \tag{98}$$

and

$$FX^S = X_r + X_g + (\dot{L^{FX}_r} + \dot{L^{FX}_m})e + FDI + \dot{B^F} + \dot{B^{FX}} e \tag{99}$$

where

$$Div^F = Div^F_r + Div^F_n + Div^F_m + Div^F_B \tag{100}$$

and

$$FDI = FDI_r + FDI_n + FDI_m + FDI_B \tag{101}$$

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

$$\dot{e^e} = \beta_{ee}\left(e - e^e\right) \tag{102}$$

and

$$\dot{p^{W,e}_r} = \beta_{pr}\left(p^W_r - p^{W,e}_r\right) + p^{W,e}_r \alpha_p \tag{103}$$

Banks will allocate the remaining foreign currency as reserves:

$$\dot{R_B^{FX}} = \frac{FX^S - FX^D}{e} - \dot{R_{CB}^{FX}} \tag{104}$$

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

$$\mathbf{Y^P} = \mathbf{d}[(1 - \sigma^{\mathbf{IM}})\mathbf{C} + \mathbf{G} + \mathbf{X}] \tag{105}$$

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:

$$\kappa_1 = \frac{g - \kappa_0}{r^{e'}} \tag{106}$$

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:

$$r_r^{e'} = \Pi_r^e \frac{u_r}{b_r} - l_r i_r^{L,a} \tag{107}$$

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:

$$a_i = \frac{w}{(1-t^Y)p_i - \sum c_i^j p_j - (r^{e'} + i_i^{L,e} l_i) b_i / u_i} \tag{108}$$

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

$$\mu_{0i} = \frac{1}{1 + UC_i} \tag{109}$$

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:

$$DI_i = K_i[(g + \delta) - (1 - \sigma_D)r' - l * g_N] \quad (110)$$

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:

$$DI_B = [g_N - (1 - \sigma_D)r_B]OF \quad (111)$$

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:

$$t_H = 1 - \frac{C + g_N D_H + DDI - st(Pop - N)}{(1-sc)wN + \sum Div_{j+B}^H + i^D D_H} \tag{112}$$

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

$$\gamma_2 = \frac{1}{D}\left[\exp\left(\frac{g_N}{\beta_C}\right) C - \gamma_0 Pop - \gamma_1 YD_H\right] \tag{113}$$

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

$$B^F = \frac{FX^{S'} - FX^{D'} - \dot{R}_{CB}^{FX} e}{i^B - g_N} \tag{114}$$

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,

$$\lambda_O = \frac{(B^B + B^F + B^{FX} e) g_N - GFN}{GDP g_N} \tag{115}$$

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:

$$\sigma_{j+B}^H = \frac{DDI_{j+B}}{YD_H - C} \tag{116}$$

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

$$\sigma_{j+B}^P = \frac{PDI_{j+B}}{G} \tag{117}$$

- And FDI sensitivity to profitability is given by:

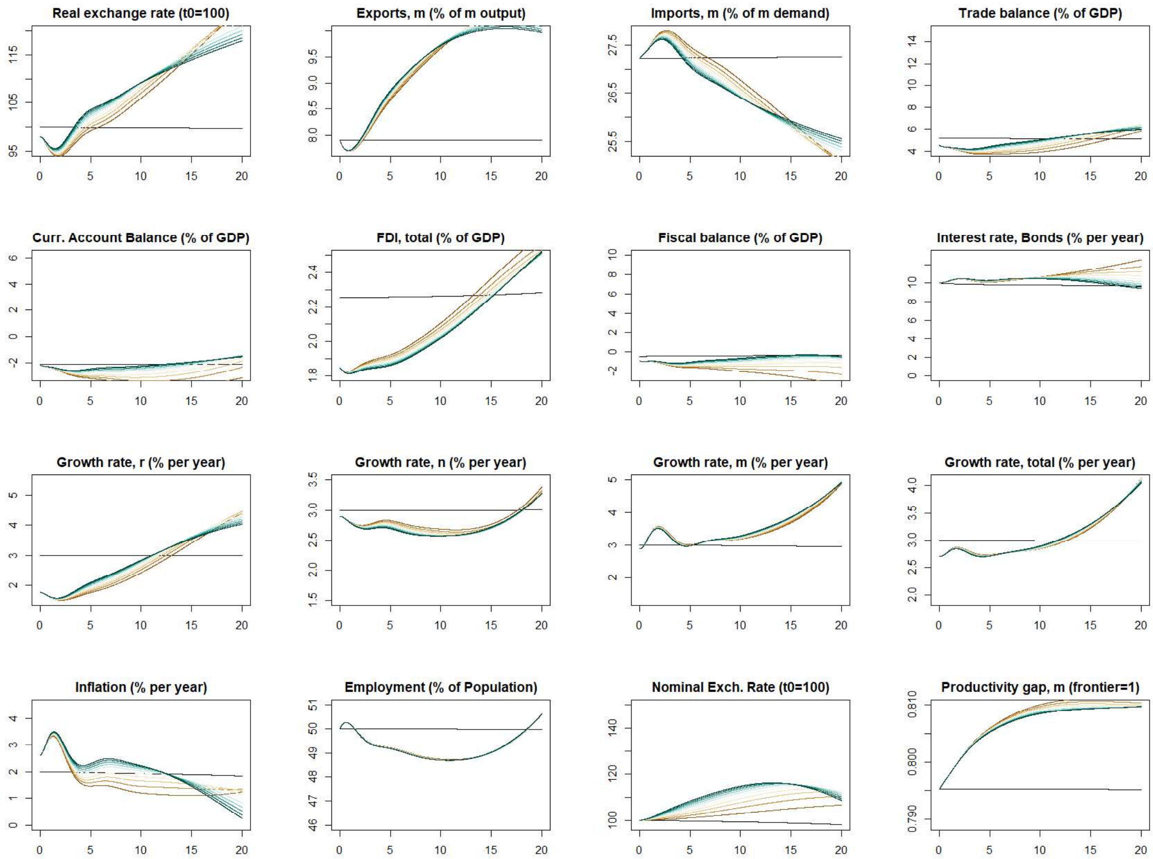
$$\phi_{j+B} = \frac{FDI_{j+B}}{(r_{j+B}^e - rsk - i^{FX}) WFF} \tag{118}$$

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



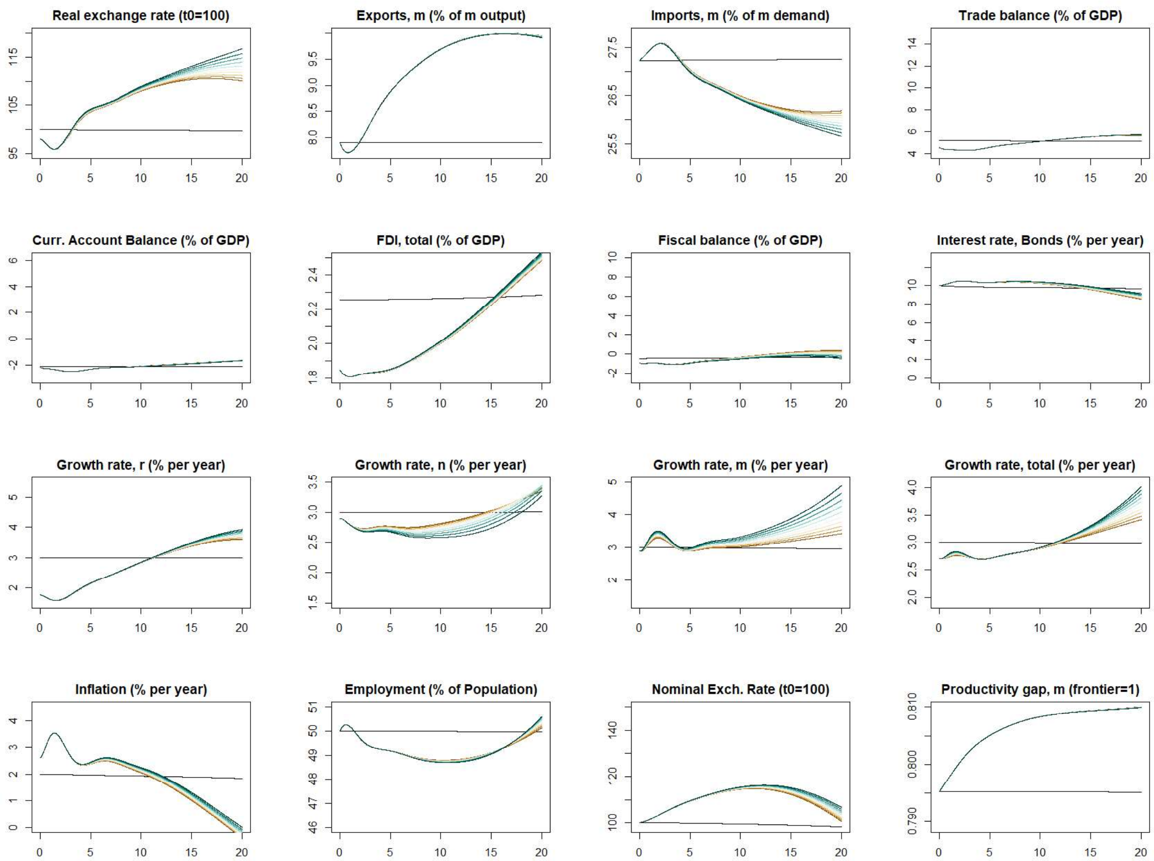
10% carbon tax on sales recycled as infrastructure investment with β_{e^N} reduced from 1 (green) to 0.4 (yellow).

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.