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Green innovation in a balance-of-payments constraint growth model for developing economies with capital inflows: The Latin America scenario

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Abstract:

The main purpose of the paper is to build a balance of payments constraint model with capital inflows, where green innovations are inducers of the structural change process. The main results indicate that green R&D can reduce the growth rate of natural resource use. On the other hand, green structural change will only occur if foreign direct investment has spillover effects on green R&D.

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The Stockholm conference in 1972 marked the beginning of the debate on unlimited growth and its possible consequences. Later, in 1987, the Brundtland report of the World Commission on Environment and Development intensified the debate on how to reconcile growth, development, and sustainability. This report also introduced the concept of sustainable development, defined as the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987).

Since this first milestone, a number of countries have invested in research and actions to mitigate the effects of human activity on the environment, with the aim of achieving balance and preserving the conditions of existence. In recent years, there has been a move towards incorporating environmental aspects in a range of economic models and under the most diverse theoretical frameworks, both orthodox and heterodox (Guarini and Porcile, 2016; Dafermos et al., 2017; Argentiero et al., 2018; Lamperti et al., 2018; Dunz et al., 2021).

One of these theoretical frameworks is the new Latin American structuralist (N-LAS) approach, which follows the tradition of post-Keynesian models based on balance of payments (BoP) constraint and seeks to understand structural change (Gabardo et al., 2017). Thirlwall's (1979) BoP constraint model establishes that the ratios between the income elasticities of demand for exports and imports define the pace of domestic growth relative to the pace of external growth (Thirlwall, 1979; Thirlwall and Hussain, 1982).

The N-LAS contributed by adding technology as a key element to increase the income elasticity ratio and to continue the development process (Cimoli and Porcile, 2014). The addition of the technology variable is usually done through the technological gap between peripheral and centre countries and/or through the internal capacity to develop a national innovation system, hence combining post-Keynesian macroeconomics with the principles of evolutionary economics (Missio and Gabriel, 2016; Ribeiro et al., 2016).

Literature on the N-LAS also presents advances in transition models for sustainable development, showing how the production and export of more environmentally efficient products can increase the level of growth (Guarini and Porcile, 2016). However, the N-LAS has made little progress in linking the impact of capital flows, both in the process of structural change and in relation to sustainable development. This paper aims to fill this gap. The new developmentalism (ND) literature – the Brazilian view of the N-LAS (Bresser-Pereira, 2020a) – highlights the vulnerabilities of capital flow movements and income growth through an increase in external savings (Bresser-Pereira, 2020b; Bresser-Pereira et al., 2020).

Nevertheless, there are significant econometric results showing that capital inflows have different effects on output growth depending on their type: portfolio inflows have a negative impact on growth and Foreign direct investment (FDI) has a positive impact (Aizenman et al., 2013). For Latin America, there are important results showing that FDI increases the BoP constraint (Alencar et al., 2019), which should have a negative impact on growth. Other results show a positive impact of FDI on high income countries in Latin America, such as Chile and Uruguay, and a negative impact on low- and middle-income countries (Alvarado et al., 2017).

In this sense, the present paper proposes a BoP constraint model with capital movements, where green innovations are inducers of structural change. In other words, green innovations induced by FDI can generate structural changes that reduce the BoP constraint condition and contribute to a lower growth rate in the use of natural resources. For this purpose, the paper is divided into three sections: the first is dedicated to the development of a state-of-the-art BoP constraint model with structural change by N-LAS; the second is dedicated to the development of the proposed model of green structural change with capital inflows, and the third shows the scenario simulations of the model, confirming the model's premises, as well as explaining the current Latin American scenario.

1. The New Latin American structuralism theory and economic-environmental channels

The original Latin American structuralism approach asserts that there is an asymmetrical relationship in the pattern of trade and international integration between Latin American developing countries and the developed countries of North America and Europe. This asymmetry is the central argument of the centre-periphery model, in which centre economies produce and export capital-intensive and high-technology products, achieving greater dynamism and high growth, while peripheral economies produce and export labor-intensive and low-technology products, focused on the production of natural resources, achieving less dynamism and low growth (Prebisch, 1950; Singer, 1950; Porcile, 2021).

Prebisch's (1950) initial ideas, although consistent with the observation of reality at that time, lacked a macroeconomic model capable of explaining the growth differential between the centre and the periphery based on the different patterns of international integration. These models were created in the 1970s and 1980s by post-Keynesian authors and consist in understanding the growth differential between the centre and the periphery based on the differences between the ratio of income elasticities of exports to imports (Thirlwall, 1979; Thirlwall and Hussain, 1982):

$$y_{bt} = \frac{\varepsilon(z_t)}{\pi} \tag{1}$$

where y_{bt} is the growth rate of the balance of payments equilibrium, $z_t$is the growth rate of external demand, ε is the income elasticity of demand for exports, and π is the income elasticity of demand for imports. Equation 1 states that the larger the ratio of ε/π, the larger the domestic growth is relative to growth in the rest of the world. Thus, it is assumed that countries in the periphery would have $\varepsilon/\pi < 1$ and countries in the centre would have $\varepsilon/\pi > 1$. However, the model leading to equation (1) assumes that the balance of payments equilibrium occurs only through the trade balance.

Recent N-LAS literature has focused on understanding the determinants of structural effects that generate changes in income elasticities, also called structural change (Gabardo et al., 2017), focusing on two main effects: technological progress and the exchange rate (Porcile and Yajima, 2019; Porcile, 2021). The effects of cyclical fluctuations of capital flows are not widely studied in the N-LAS literature, thus highlighting a gap that this paper aims to fill. In addition, capital inflows in the form of foreign direct investment can have structural effects that affect income elasticities, as shown in the empirical literature (Alencar et al., 2019), but not in the theoretical literature.

$$\frac{\varepsilon}{\pi} = \beta_0 + \beta_1 \frac{W}{P_d a} + \beta_2 \frac{S_d}{S_f} \tag{2}$$

$$\frac{\varepsilon}{\pi} = \frac{(\delta_0 + \delta_1 E_r + \delta_2 NIS)}{(\gamma_0 + \gamma_1 E_r + \gamma_2 NIS)} \tag{3}$$

Equations (2) and (3) are two examples from the current literature on the subject, where $W/(P_d)$ is the domestic real wage, a is the level of productivity, S_d/S_f is the ratio of domestic technology to foreign frontier technology, E_r is the real exchange rate, and NIS is a technological variable that measures the development of the national innovation system; and the exogenous coefficients comprise: $\beta_0 > 0$, $\beta_1 > 0$, $\beta_2 > 0$, $\delta_0 > 0$, $\delta_2 > 0$, $\alpha_0 > 0$, $\delta_1 > 0$ if $E_r > E_{ri}$, or $\delta_1 < 0$ if $E_r < E_{ri}$, and $\gamma_1 > 0$ if $E_r < E_{ri}$ or $\gamma_1 < 0$ if $E_r > E_{ri}$, where E_{ri} is the industrial equilibrium real exchange rate.

In equation (2), elaborated by Ribeiro et al. (2016), the structural change – the increase in the ratio of income elasticities of exports to imports – is caused by (i) the growth in the real wage level above labor productivity, which enables the substitution of labor for capital, increasing domestic technology; and (ii) the increase in the domestic technology relative to the foreign frontier technology. In equation (3), elaborated by Missio and Gabriel (2016), the same effect occurs when the real exchange rate is above the industrial equilibrium real exchange rate level and the national innovation system is better developed domestically.

The addition of technology and exchange rate variables have different origins. Fajnzylber (1983) highlighted the importance of technology as a variable in his critique of the model of industrialization by import substitution adopted in Latin America. According to the author, Latin American industrialization lacked international competition and was unable to develop a highly technological domestic sector and local companies with innovative potential. Exchange rate is an important variable in Bresser-Pereira (2012, 2020), where it is stated that it is necessary for developing countries to present a higher exchange rate (price of the domestic currency in terms of the foreign currency) for the industrial sector of these countries to achieve international competitiveness.

The logic developed by Fajnzylber (1983) has aspects derived from evolutionary microeconomic theories (Porcile, 2021), so that only the emergence and growth of firms with innovative potential at an international level can enable the process of structural change. In evolutionary theory, innovation essentially depends on the development of public and private research and development (R&D) programs capable of generating different technological trajectories that modify products, production processes and industrial chains, generating sectoral and even global productivity gains (Nelson and Winter, 1977; Dosi, 1982, 1988).

In equations (2) and (3), these R&D programs that generate productivity gains are represented by the variables S_d/S_f and NIS. In equation (2), the growth of S_d relative to S_f is driven by an R&D program capable of replicating a technological path that brings domestic technology closer to frontier technology (already developed in the centre economies). In equation (3), the local development of a national innovation system will be able to generate different R&D programs responsible for domestic structural transformation. It is important to emphasize that the R&D variable, relevant in the evolutionary literature, enters the N-LAS models in the form of a proxy, characterized by the technological frontier differential and the national innovation system, and thus highlights another gap in the literature.

The logic developed by Bresser-Pereira (2012, 2020) is derived from post-Keynesian, profit-led and wage-led growth regimes (Lavoie, 2017), combined with Thirlwall's (1979) balance of payments constraint condition. Bresser-Pereira (2012, 2020) notes that developing countries such as Latin America suffer from Dutch disease, where the production and export of natural resources stimulate the inflow of additional foreign currency, keeping the exchange rate (price of the domestic currency in terms of the foreign currency) at a very low level. In this way, these countries need their real exchange rate to be high enough – above the industrial equilibrium real exchange rate (real exchange rate level that neutralizes the Dutch disease) – to favor the functional redistribution of income in favor of profits (reducing the participation of wages in income), which will increase investment and industrial exports, allowing sustained growth with balance of payments equilibrium.

$$\varepsilon/\pi = \frac{(\varphi\varepsilon_{HT}+(1-\varphi)\varepsilon_{LT})}{(\theta\pi_{HT}+(1-\theta)\pi_{LT})} \tag{4}$$

$$\varphi = \frac{\varphi_{max}}{\left[1+\varphi_1 e^{(-\varphi_{min}E_r)}\right]} \tag{5}$$

$$\theta = \frac{\theta_{max}}{\left[1+\theta_1 e^{(\theta_{min}E_r)}\right]} \tag{6}$$

where ε_{HT} and ε_{LT} are the income elasticities of exports of high and low technology products; π_{HT} and π_{LT} are the income elasticities of imports of high and low technology products; and the coefficients φ and θ vary according to logistic curves (equations 5 and 6) modified by the level of the real exchange rate E_r; and e is the mathematical constant based on a logarithm function (Euler's number) specific to a logistic curve. The use of logistic curves to understand technology diffusion is supported by arguments on evolutionary economics developed by Marchetti (1980) and Modis and Debecker (1988). In this case, the logistic curves show how technological dispersion and structural change occur, stimulated by the rise in the real exchange rate. In equations 4 to 6, developed by Ferrari et al. (2013), the higher the exchange rate, the closer φ is to φ_{max} and θ to θ_{min}, allowing the ε/π ratio to grow.

From an evolutionary perspective, the idea of an ecological structural change is not new, especially regarding the design of policies that force markets to create and use green technologies (Ring, 1997). Nevertheless, heterodox macroeconomic models guided to analyze the ecological structural change are largely restricted to ecological macroeconomics models (in the post-Keynesian tradition), and multi agent and evolutionary models (agent-based models) (Ciarli and Savona, 2019). Most ecological macroeconomics models of the post-Keynesian tradition (EMPK) are stock-flow consistent and do not necessarily address structural change. Guarini and Porcile (2016) are two of the first to propose a BoP constraint model of EMPK tradition applied to emerging economies with structural change, modifying the original Thirlwall Law:

$$y_{bt} = \frac{(\varepsilon z_t + \xi v_{gd} - \mu v_{df})}{\pi} \tag{7}$$

where v_{gd} and v_{df} are the growth rates of domestic and external environmental efficiencies; and ξ and μ are the green income elasticities of exports and imports. Since environmental concerns are greater in developed countries, which tend to impose restrictions on international trade in non-green goods, implying that$\mu/\xi < 1$, creating an opportunity to increase growth in developing countries through increased production and export of more environmentally efficient green goods. The authors argue that there is room for green innovation to increase domestic environmental efficiency, but they do not explain this relationship in an equation that includes a technology variable. Therefore, green structural change must involve the growth of domestic environmental efficiency over ecological efficiency, although it is not explicit how this process occurs.

Thus, three points that are missing in the literature can be identified: (i) modeling the structural effects of capital inflows on the balance of payments of developing countries, (ii) explicitly incorporating the R&D variable in the N-LAS models, and (iii) considering how the advancement of green technology (green R&D) can facilitate the process of structural change of developing economies. These three central points will be the theoretical advances proposed by the model given in this paper.

2. The model

The model starts from a balance of payments equilibrium with capital movements, following Thirlwall and Hussain (1982):

$$y_{bt} = \frac{((E/R\eta + \psi + 1)(p_{dt} - e_{rt} - p_{ft}) + E/R\varepsilon(z_t) + C/R(c_t - p_{dt}))}{\pi} \tag{8}$$

where η is the price elasticity of exports, ψ is the price elasticity of imports, p_{dt} is the growth rate of domestic tradable prices, e_{rt} is the growth rate of the exchange rate, p_{ft} is the growth rate of foreign tradables, c_t is the growth rate of capital inflows, E is the total resources from exports, C is the total resources from capital inflows, and R is the total resource from all inflows ($R = E + C$). If relative prices do not vary in the long term (p_{dt}= e_t= p_{ft}= 0), we have:

$$y_{bt} = \frac{E/R\varepsilon(z_t)+C/Rc_t}{\pi} \tag{9}$$

According to equation (9), a peripheral country with an income-elasticity ratio of exports to imports of less than one must go through a process of structural change that involves increasing this income-elasticity ratio and, at the same time, attracting capital movements to finance this process. Moreover, this process of structural change must be managed in such a way as to reduce the environmental impact of more robust economic growth. In this sense, the process of structural change should be guided by the absorption and generation of technologies that allow changes in the income elasticities of exports and imports, as follows:

$$\varepsilon_t = \theta\varepsilon_t^G + (1-\theta)\varepsilon_t^T \tag{10}$$

$$\pi_t = (1-\vartheta)\pi_t^G + \vartheta\pi_t^T \tag{11}$$

where ε_t^G and ε_t^T are the income elasticities of green and traditional exports; π_t^G e π_t^T are the income elasticities of green and traditional imports; and $0 < \theta < 1$ and $0 < \vartheta < 1$ are coefficients that will behave in the form of logistic curves similar to the one presented by Ferrari et al. (2013), as can be seen in equations (12) and (13). It is assumed that $\varepsilon^G > \varepsilon^T$ and $\pi^G > \pi^T$, since green products represent the more technological products and the traditional products represent natural resource-based products. The values of θ and ϑ rise as the structural change process takes place, increasing green exports with higher income elasticity and increasing traditional imports with lower income elasticity.

The assumption that the income elasticity of demand for green exports and imports is higher than for traditional exports and imports reflects the high technological intensity of green products. In this sense, Boleti et al. (2021) find a positive correlation between the Economic complexity index (ECI) and the Environmental performance index (EDI), highlighting that the empirical results indicate that higher technology is associated with better environmental performance. Romero and Gramkow (2021) present empirical evidence on the relationship between economic complexity and a reduction in GHG emission intensity, showing that ECI has a negative relationship with GHG emissions.

In this respect, the model uses the same premise as Guarini and Porcile (2016), according to which the export of green goods expands the equilibrium growth rate of the balance of payments. However, unlike the authors, the model does not rely on exogenous parameters of environmental efficiency (v_{gd} and v_{df}) but makes structural change endogenous by modifying the income elasticities of exports and imports. In this way, the change in income elasticities will be due to changes in θ and ϑ according to the equations:

$$\theta = \frac{\theta_{max}}{1+\theta_1 e^{-(RDGY_{t-1}E_r)}} \tag{12}$$

$$\theta_{min} = \lim_{RDGY\to 0} \frac{\theta_{max}}{1+\theta_1 e^{-(RDGY_{t-1}E_r)}} = \frac{\theta_{max}}{1+\theta_1} \tag{12.1}$$

$$\vartheta = \frac{\vartheta_{max}}{1+\vartheta_1 e^{-(RDGY_{t-1}Er)}} \quad (13)$$

$$\vartheta_{min} = \lim_{RDGY \to 0} \frac{\vartheta_{max}}{1+\vartheta_1 e^{-(RDGY_{t-1}Er)}} = \frac{\vartheta_{max}}{1+\vartheta_1} \quad (13.1)$$

where $RDGY_t$ is the proportion of green research and development in GDP ($R\&D_{Gt}/Y_t$); Er is the real exchange rate level; e is the mathematical constant based on logarithm function (Euler's number) specific to a logistic curve; $0 < \theta_{max} < 1$ is the highest value θ can reach, considering that it will not be possible to export only green high technological goods; θ_1 is an exogenous factor to limit the value of θ in θ_{min} (equation 12.1), considering that it is not possible to export only traditional natural resources; $0 < \vartheta_{max} < 1$ is the maximum value of ϑ, considering that it is not possible to import only traditional natural resources goods; $\vartheta_1$is an exogenous factor to limit the value of ϑ in ϑ_{min} (equation 13.1), considering that it is not possible to import only green high technological goods.

Equations (12) and (13) are similar to those developed by Ferrari et al. (2013), in which the authors assume that the structural change, the expansion of ε_t and contraction of π_t, are only achieved by an increase in the exchange rate, while the proposal presented here assumes that this effect is also dependent on the level of research and development in the economy.

Volz et al. (2020) illustrate that climate policies adopted by countries, technological change, and both internal and external consumption patterns can significantly affect exports and imports. Among the various ways in which physical and transitional impacts can affect international trade, it is worth highlighting the position of commodity-dependent countries, which may be more vulnerable to environmental risks (as is discussed in equations 19 and 22). In addition, the materialization of these possible impacts may affect international prices, terms of trade and exchange rates. For the model proposed here, equations (12) and (13) consider the capacity of technological change to influence exports and imports without incorporating changes in the price system, as highlighted by Volz et al. (2020).

The premise of using R&D in green technologies is similar to Fontana and Sawyer (2016), the difference being that in their model, which is aimed at a centre economy, green R&D only reduces the depreciation of natural capital generated by economic growth. This paper follows this line of thought, with the additional premise that technological progress of green R&D also changes the income elasticities of exports and imports, a hypothesis that does not constitute a centre economy model.

The growth rate of natural resource use (g_n) or natural resource depreciation is given by:

$$g_n = \frac{(1+y_{bt})^{\tau}}{(1+r\&d_{Gt})^{\rho}} - 1 \quad (14)$$

where τ represents how much the increase in growth will cause an increase in consumption of natural resources, and ρ represents the environmental efficiency gain as a result of a lower use of natural resources caused by the increase in green R&D. We assume that a higher growth rate of use of natural resources means higher use of non-renewable energy sources, higher emissions of greenhouse gas (ghg), and a higher waste production. Thus, an increase in y_{bt} that is not accompanied by the process of structural change through the growth of green R&D will lead to an increase in the use of natural resources with bigger environmental impacts. In addition, the increase in g_n will be captured by international financial markets and interpreted as an increase in physical and transitional risks, which will affect capital inflows determined by international portfolio choices.

In short, physical risks arise from the relationship between climate hazards and human and environmental vulnerability to adverse events, including adaptive capacity. Transitional risks, in turn, are related to human activities towards a greener economy to prevent carbon lock-in, which may generate a process of capital and labor mobility, in addition to a technological structural change that may have negative impacts on the economy (Batten et al., 2016). Batten (2018) clarifies that the effects of the two risks, which are dynamic and imbued with uncertainty, can affect the economy on both the supply and demand sides. The shocks associated with supply affect the variables related to the factors of production of an economy, while the demand shocks are related to the variables and economic agents that constitute the aggregate demand of an economy. The model presented here does not include demand and supply shocks, but does include a form of financial pricing of both risks that affects capital flows (FDI and portfolio choices).

On the other hand, within the framework of N-LAS models, with a focus on the impact of capital movements on the process of green structural change, three factors are relevant for understanding this dynamic: (i) the change in income elasticities of exports and imports caused by the green transition, (ii) investments related to green innovation (green R&D), including those of external origin (foreign direct investment), and (iii) portfolio financial inflows.

Factor (i) is already modeled by equations 10 to 13. Factor (ii) is partially modeled by equations 12 and 13, excluding the impact that foreign direct investment may have on the green innovation process (to be explored in equations 16 to 18). Factor (iii) is developed in equations 19 to 22. Thus, with respect to capital inflows, the model proposed here divides them into two types:

$$c_t = \frac{FDI}{C} fdi_t + \frac{PORT}{C} port_t \qquad (15)$$

In equation (15), the growth rate of capital inflows will be divided between the growth rate of foreign direct investment fdi_tweighted by its share of total inflows ($\frac{FDI}{C}$) and the growth rate of portfolio investments $port_t$weighted by their share of total entries ($\frac{PORT}{C}$). This is important because the empirical literature has shown that capital inflows in the form of FDI have a positive impact on economic growth, while capital inflows in the form of portfolio have no relevant impact on growth and may even be a source of instability (Aizenman et al., 2013). It is important to note that while the results of Aizenman et al. (2013) confirm this for a wide range of countries, the results found for Latin America show that FDI does not always have a positive impact on economic growth (Alvarado et al., 2017; Alencar et al., 2019).

In this sense, Magacho et al. (2023), when analyzing the degree of macroeconomic exposure of countries to a process of structural change towards a low carbon transition, reiterate the risks of transitioning to countries with a balance of payments constraint that can generate imbalances capable of not only constraining growth but also of constraining the transition per se and that advances towards specific international financing and technology transfers can be justified. In the model proposed here, these elements are incorporated given the potential expansionary effects of FDI on R&D (equation 16), and the incorporation of environmental risks as a repulsion factor of FDI (equations 17 and 18) and a financial risk that changes international portfolio choices (equations 19 to 22).

FDI inflows in the context of a low-carbon transition and in support of structural change in developing countries will follow an inverse logistic function similar to function of innovation presented in Dosi et al. (2010) and imitation effects of R&D:

$$r\&d_{Gt} = \alpha_0 y_{bt-1} + \left(1 - e^{-\alpha_1 r\&d_{Gt-1}}\right) fdi_{t-1} \tag{16}$$

$$\lim_{r\&d_{t-1}\to 0}\left[\left(1 - e^{-\alpha_1 r\&d_{Gt-1}}\right) fdi_{t-1}\right] = 0 \tag{16.1}$$

$$\lim_{r\&d_{t-1}\to \infty}\left[\left(1 - e^{-\alpha_1 r\&d_{Gt}-1}\right) fdi_{t-1}\right] = fdi_{t-1} \tag{16.2}$$

where $\alpha_0 > 0$ is the Kaldor-Verdoorn coefficient applied to investments on innovation, and $\alpha_1 > 0$ is the size of the positive spillover effect of FDI on R&D. An inverse logistic function, as in Equation 16, creates a similar result of a non-linear technology transfer of a logistic curve, as presented in equations 12 and 13. The main difference is that equation 16 represents a non-linear function of technology transfer, and equations 12 and 13 represent the domestic technology diffusion. R&D will also create an attraction factor of new FDI, following the equation:

$$FDI_t = \frac{Y_{bt-1}^{\alpha_2} R\&D_{Gt-1}^{\alpha_3}}{EMBI_{t-1}^{\alpha_4}} \tag{17}$$

$$fdi_t = \alpha_2 y_{bt-1} + \alpha_3 r\&d_{Gt-1} - \alpha_4 embi_{t-1} \tag{18}$$

where $EMBI_t$ is the value of the emerging market bond index measure in a point-based system (presented below), or country risk premium, and $\alpha_2 > 0$, $\alpha_3 > 0$, $\alpha_4 > 0$ are exogenous parameters that represent the extent to which each variable is important to attract FDI. Equation 17 is a gravity equation to explain FDI (Anderson, 1979, 2010) and equation (18) is the logarithmical time difference of equation (17) to represent growth rates. Gravity equations are useful tools to explain international trade and FDI, since they assume that FDI will gravitate towards countries with higher income (y_{bt}) and higher levels of R&D ($r\&d_t$), and is less likely in countries with higher macroeconomic instability or financial risks ($embi_t$) (Archibugi and Michie, 1995; Moosa and Cardak, 2006; Canh et al., 2020; Kaczmarczyk and Flassbeck, 2023).

Portfolio investments, on the other hand, will follow the logic of carry trade operations applied to balance of payments constraint models:

$$PORT_t = \left(\frac{i_{t-1}}{i_{t-1}^{*} EMBI_{t-1}}\right)^{\alpha_5} \tag{19}$$

$$port_t = \alpha_5 (g_{it} - g_{it}^{*} - embi_t) \tag{20}$$

$$port_t = -\alpha_5 embi_t \tag{21}$$

where i_t is the domestic interest rate (measured in a one plus point-based decimal system); i_t^{*} is the international interest rate – both are measured in a one plus point-based decimal system –; with g_{it} and g_{it}^{*} being the respective growth rates of both interest rates; and $\alpha_5 > 0$ the exogenous coefficient that represents the liquidity of the domestic currency in the international hierarchy (de Paula et al., 2017).

Equation (19) defines what international financial markets understand as a carry trade, in which the ability to attract portfolio investment depends on the domestic and international interest rates differential and the country risk of emerging markets (Barbosa-Filho, 2021). Equation (20) is the logarithmical time difference of equation (19), and in equation (21) we assume that there are no significant changes in the interest rate differential; in this sense the growth rate of portfolio investment will be explained by changes in $embi_t$ (equation 22 above).

In carry trade operations, international investors finance themselves by borrowing in foreign currency – paying the international interest rate (i_t^*) –, and lending to emerging markets, receiving the domestic interest rate (i_t), covering their risks in the financial derivatives markets by buying the emerging market bond index as a form of protection ($EMBI_t$). Emerging market bond indexes are usually a credit default swap contract, where the seller assures the buyer that there is a monetary compensation in case of default or credit degradation in risk rating agencies. To sustain this operation the buyer pays the seller a value based on the EMBI periodically (usually monthly payments in a five-year contract).

Thus, in general, emerging markets will always have higher domestic interest rates than the international interest rate plus the country risk to attract capital and finance the current account deficit. The necessary domestic interest rate will depend on the size of α_5. Countries whose currencies are in a higher liquidity hierarchy will have a higher α_5, so a smaller difference between the domestic interest rate and international interest rate to attract more capital is possible. On the other hand, countries with less internationally liquid currencies will have a lower α_5 and will need higher domestic interest rates to attract capital movements.

The $embi_t$ is associated with different risk perceptions formulated in the global financial markets; the main component being the risk of default or risk of credit rating degradation of public debt. However, in the model proposed here, the balance of payments constraint condition – defined by the ratio of the income elasticity of exports to imports – must be added to the risk calculation, given the restrictions it imposes on the establishment of fiscal policies involving the expansion of deficits and public debt (Ocampo, 2016). In addition, the perception of environmental risks will also be incorporated into the $embi_t$.

Semieniuk et al. (2021) present an analytical scheme of the drivers of environmental transition risks and their relationships with the real and financial sectors of an economy, as well as with macroeconomic variables. Among the transition risks, the author highlights the technological paradigm shift as an innovative process leading to cost reduction and consequent diffusion of new, more environmentally efficient technologies through prices. Credit and market risks are the main implications for the financial sector of the phenomena associated with the low-carbon transition. In the context of portfolio investments, market risks may negatively affect institutional investors and other investors holding financial assets due to the process of evaluating the prices of assets that are related to and may be affected by the transition processes. This happens given that agents begin to incorporate transition risks into prices, which may lead to a reduction in the current value of financial assets, and this phenomenon may be catalyzed by the deep interconnectedness of assets, both directly and indirectly (Semieniuk et al., 2021).

Within the macroeconomic risks and their possible effects, it should be noted, according to Semieniuk et al. (2021), that the spillover effects of financial instability can affect foreign investment, exchange rates and debt crises mainly for developing countries. In this sense, the synthetic inclusion of the previously explained channels within the N-LAS analytical scheme can be given by:

$$embi_t = \varphi_0 + \varphi_1(\varepsilon/\pi)_{t-1} + \varphi_2 g_{n-1} \quad (22)$$

where $\varphi_0 > 0$ is the initial exogenous country risk defined by international investor preferences; $\varphi_1 < 0$ is the balance of payments risk coefficient; and $\varphi_2 > 0$ is the environmental risk coefficient – both define the pattern of evolution of country risk from the process of structural change that corrects the balance of payments constraint and the increase in the depreciation of natural resources, which imply greater environmental risks, as mentioned by Semieniuk et al. (2021). In this sense, the process of structural change stimulated by green R&D, in addition to contributing to the increase in ε/π, also reduces $embi_t$, facilitating the growth of capital inflows (c_t) and the expansion of y_{bt}. On the other hand, maintaining an extremely high domestic interest rate may attract more capital and expand y_{bt} without structural change, which may lead to a greater depreciation of natural resources.

Chen et al. (2022), when analyzing the relationship between FDI inflows and environmental risks through a panel analysis with data from 108 countries, find a robust negative correlation between FDI and environmental risks. This effect is captured in this paper's model through the process of green structural change that can be facilitated by FDI. FDI inflows with a high impact on green R&D (equation 16) will accelerate the green structural change process, increasing the income-elasticity ratio ε/π (equations 12 and 13) and reducing country risk as measured by $embi_t$; both effects will increase the attraction of FDI (equation 18) and portfolio investment (equation 21), generating new impacts on R&D and income-elasticity ratio.

Equations (16) to (22) are consistent with recent findings about Latin America, where an increase in FDI does not result in significant increases in the income-elasticity ratio, rather a relevant increase in income-elasticity of imports was noted, indicating that the opposite occurred (Alvarado et al., 2017; Alencar et al., 2019). In the model presented here, this scenario is possible if $\alpha_1 < 0$, implicating that FDI does not reinforce R&D sectors, but natural resources sectors, resulting in decreases in the balance of payments equilibrium growth rate y_b and increases in country risk, that will decrease future FDI, generating a vicious cycle towards stagnation.

First, this scenario is consistent with the middle income trap in Latin America: FDI that reinforces specialization in natural resources and increases country-risk means that those countries need to increase their interest rates ($g_{it} > 0$) to attract more capital inflows in the form of portfolio investment and increase balance of payments equilibrium growth rate y_b with external savings (Bresser-Pereira, 2020b; Bresser-Pereira et al., 2020). Second, it is also consistent with evolutionary and post-Keynesian literature. As pointed out by Archibugi and Michie (1995) FDI combined with R&D is globally organized to reinforce the countries specialization patterns; in this sense, if Latin America is specialized in producing and exporting natural resources, it will receive FDI in R&D sectors of natural resources. The model concludes that green R&D can change this scenario but needs to be domestically developed by countries to change the attractiveness of FDI in green production technologies.

3. Simulation and analysis of results

The proposed model is innovative on three fronts: (i) modelling the structural impact of capital movements in the form of FDI on the balance of payments of developing countries; (ii) explicitly incorporating the R&D variable in the N-LAS models; and (iii) considering how the development of green technology (green R&D) combined with FDI can facilitate the process of structural change in developing countries. Therefore, this section is devoted to a series of computer simulations aimed at better understanding the model's possible conclusions.

Two simulations – baseline and scenario – were performed using the R-cran programming language. All parameter values are referenced in the appendix (tables A1 and A2). Changes in initial values mean no change in the result, but too high values of z_t can make the model unstable. The system of equations comprised one-thousand-time steps and several univariate or local sensitivity tests were applied to evaluate the influence of key parameters on the model (tables A3 and A4 of appendix). In addition, the augmented Dickey-Fuller test was applied to verify the stability of the model (table A5 of the appendix). Since there is no reference in the literature to equation 22 or a proxy estimation, we carried out univariate or local sensitivity tests on the parameters of this equation (table A6, appendix).

Univariate sensitivity analysis is a fundamental approach to assessing the impact of parameters in complex models. In this study, we used this technique to investigate how variations in the parameter α_1 affect the main variables of a simulated economic model (Borgonovo and Plischke, 2016). Parameter α_1 is important since it represents a key measurement within the context analyzed that can change the baseline simulation for the Latin American scenario. To perform the analysis, we implemented the model in R, where parameter α_1 was varied within a predefined range, as described in the appendix. A total of 300 simulations were performed, each with a different value of α_1, generating a set of results for each variable of interest. The variables considered include $embi$, fdi, $port$, y_b, $r\&d_G$, among others, which are fundamental to the model in question.

In the context of a numerical simulation, the F-test is used to evaluate the overall significance of the regression model, which in this case was implemented to evaluate the variables of interest in relation to the parameter under analysis, indicating the extent to which the independent variable explains the variance of the dependent variable. Specifically, the F-test compares the full model that includes the independent variable of interest with a reduced model that omits this variable. If the F-test results in a significant value, it indicates that the inclusion of the independent variable in the model significantly improves the ability to explain the variance of the dependent variable. Scientifically, a high and significant F-value indicates that the variation in the independent variable contributes significantly to the prediction of the dependent variable, thus reinforcing the validity of the econometric model in the simulation and the relevance of the relationship between the variables analyzed.

The baseline simulation makes it possible to understand the structural effects that capital inflows, in the form of FDI, can have on green structural change. FDI combined with domestic R&D in the form of global technological cooperation and global technology generation can induce structural change (Archibugi and Michie, 1995), where global firms transfer technology to domestic markets, in this case green technologies (Johnson, 2017). The scenario simulation shows that the model is consistent with the Latin American scenario, where FDI and R&D lead to global technological exploration (Archibugi and Michie, 1995; Kaczmarczyk and Flassbeck, 2023). In this latter process, the combination of FDI and domestic R&D is aimed at increasing global market share and market concentration, where firms learn with domestic R&D and export knowledge to their national export platforms.

In this sense, for the baseline simulation, FDI has spillover effects on green R&D (equation 16), which leads to a reduction in the depreciation rate of natural resources (equation 14) and changes in the income elasticities of exports and imports (equations 10 to 13). This in turn alters the balance of payments equilibrium growth rate (equation 9), with cumulative effects on portfolio capital inflows due to the reduction of balance of payments risks and environmental risks (equations 19 to 22) and FDI attraction (equations 17 and 18), reinforcing the growth process. These effects can be observed in the first simulation.

Figure 1 – *Baseline simulation ($\alpha_1 = 4$) results for y_{bt}, $r\&d_G$ ε_t, π_t, g_n, c_t, $embi_t$*

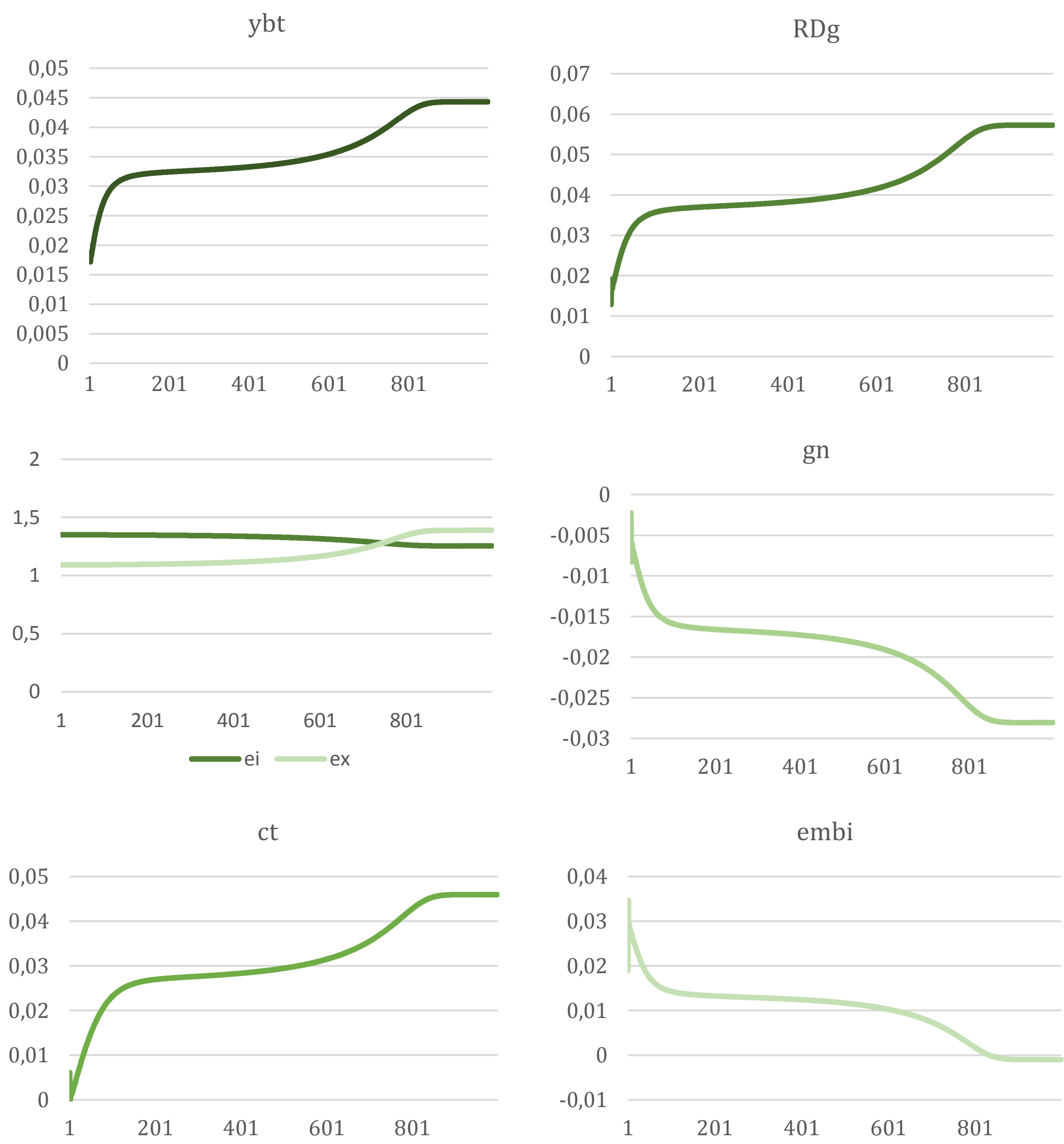


Figure 1 shows the baseline simulation, where FDI will transfer technology to domestic R&D and accelerate structural change by inverting the income elasticities ratio of exports to imports from $\varepsilon/\pi < 1$ to $\varepsilon/\pi > 1$. The balance of payments equilibrium growth rate will stabilize in a growth rate above that of the rest of the world, with a consistent fall in natural capital depreciation and decreasing risks in the financial markets. Thus, figure 1 shows the cumulative results of the three innovative elements of the model: (i) the structural effect of capital inflows in the form of FDI, (ii) the impact of domestic R&D on income growth and natural capital depreciation, and (iii) the green structural change process.

Figure 2 – *F-Test for variations in* α_1 *values for the baseline simulation*

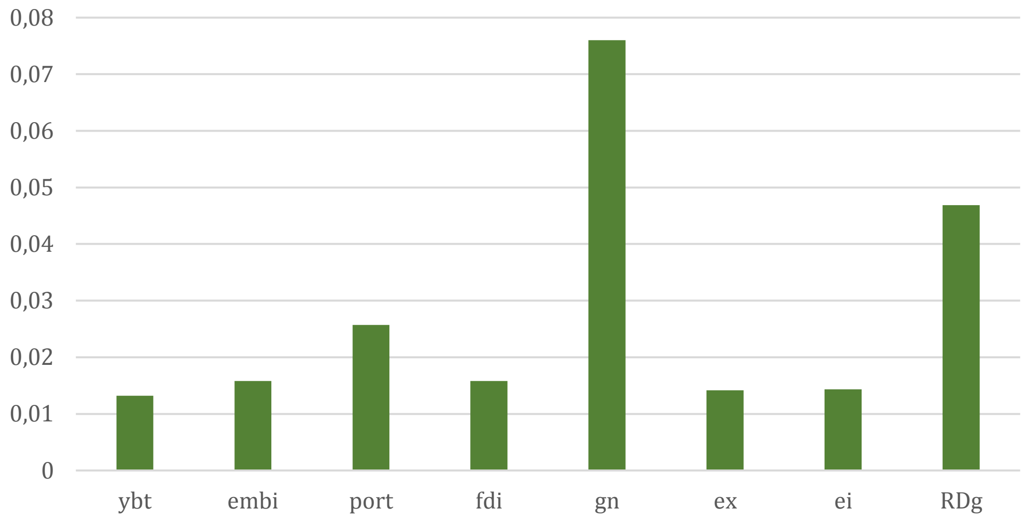


Figure 2 shows the F-test applied to α_1 volatility, considering $1 < \alpha_1 < 10$. The applied literature shows no non-linear estimation similar to equation 16, therefore we ran a F-test to show the model's consistency. Figure 2 presents the results of the F-test for variations in the value of α_1 in the baseline simulation. It is observed that the variation of α_1 has a significant impact on the dependent variables of the model, with high F-values and p-values indicating high statistical significance. This suggests that parameter α_1 is crucial in explaining the variances of the simulated variables, emphasizing the importance of its accurate estimation and interpretation within the econometric model. Specifically, an increase in α_1 is associated with increases in the variables y_{bt}, $r\&d_G$ ε_t, g_n, c_t, and decreases in $embi_t$ and π_t.

The F-test results statistically confirm the simulation baseline for a wide range of values of α_1, meaning that a higher α_1 will lead to a faster structural change process, since the impacts of FDI on R&D will be greater. A higher R&D will also mean a higher income elasticity of exports and a lower income elasticity of imports, increasing the balance of payments equilibrium growth rate, with different impacts on capital inflows (FDI and portfolio choices).

Figure 3, on the other hand, shows the current scenario in Latin America, where FDI does not create cumulative effects on domestic R&D. In this scenario, R&D will be capable of reducing natural capital depreciation, but no structural change will occur. The balance of payments growth rate will be lower than the external growth rate, the income elasticities ratio of exports to imports will remain unchanged, at$\varepsilon/\pi < 1$, and the financial risks will stabilize because of g_n, leading to an increase in capital inflows. This scenario can be categorized as growth with external savings without structural change, which is the current scenario that Latin America is trapped in as suggested by the empirical literature (Alvarado et al., 2017; Alencar et al., 2019).

Figure 3 – *Scenario simulation* ($\alpha_1 = -4$) *results for* y_{bt}, $r\&d_G$ ε_t, π_t, g_n, c_t, $embi_t$

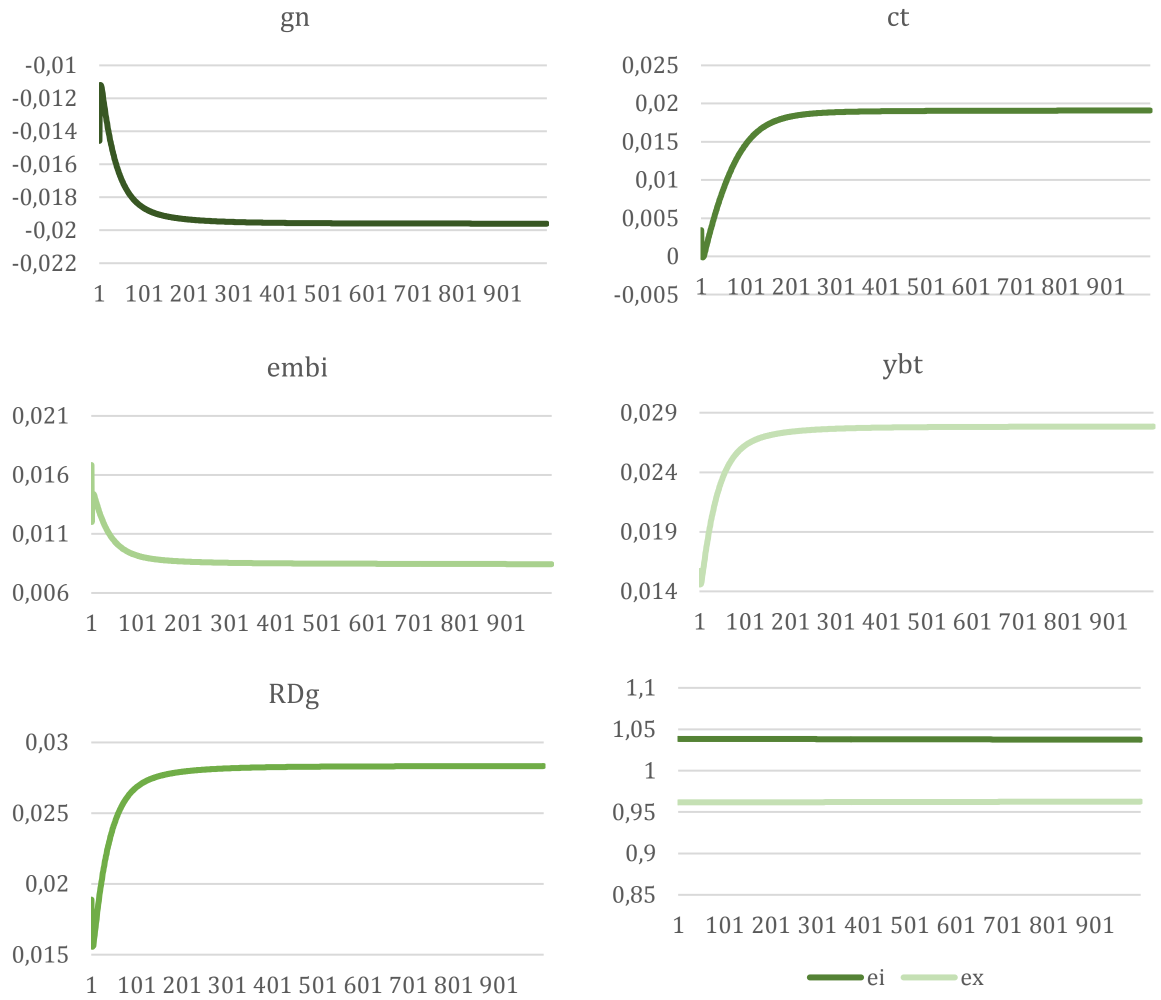
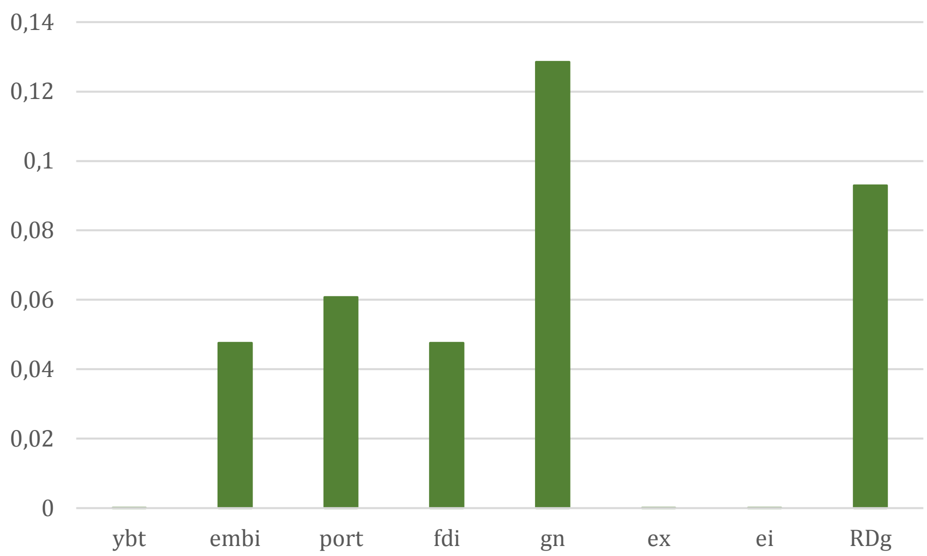


Figure 4 shows the statistical test applied to α_1 volatility, considering $-10 < \alpha_1 < -1$. In the scenario simulation, the results of the F-test for variations in α_1 confirm the case scenario of Latin America. Figure 4 confirms that α_1 plays a fundamental role in the dynamics of the model's variables, a higher α_1 (closer to -1) means a higher $r\&d_G$, creating a decreasing tendency of g_n; $r\&d_G$ is not high enough (bigger than y_{bt}) however to initiate a process of structural change. The small, almost negligible, effects on y_{bt}, ε_t, $embi_t$, fdi_t and π_t confirm the consistency of the scenario previously described.

To improve the status of Latin America as shown in the scenario simulation to a more favorable scenario in the baseline simulation, some regulatory reforms should be implemented. In this case, the regulatory reforms should ensure that the extraordinary profits from R&D are temporary and create permanent incentives for firms to innovate, that FDI cannot be concentrated on the receiver country's previous specialization pattern alone, and that the domestic economy has access to the knowledge and information generated by FDI to create spillover effects on the whole domestic economy (Kaczmarczyk and Flassbeck, 2023).

Figure 4 – *F-Test for variations in α_1 values for the scenario simulation*



Final remarks

Despite the synthetic and simplistic nature of the model presented here, it aims to consider aspects from two perspectives that have only recently been explored together when it comes to the incorporation of FDI in R&D and the possibility of green structural change. These two different perspectives arise from conflicting data. On one hand, there is strong data that suggests a positive impact of FDI on growth for developing economies in general (Aizenman et al., 2013). On the other hand, the data on Latin America suggests that FDI does not have a significant impact on growth (Alvarado et al., 2017), nor does it increase the balance of payments constraint (Alencar et al., 2019).

The N-LAS literature can be useful for these type of analyses, anchored in balance of payments constrained growth models, since it shows that the process of structural change takes place by changing the income elasticities of exports and imports through technological progress and the establishment of a competitive exchange rate regime (Porcile, 2021). Given recent climate change and natural resource degradation, models in the literature have begun to include the possibility of implementing a green structural transformation (Guarini and Porcile, 2016).

The model proposed in this article contributes to the advancement of the literature on green structural change by adding the possibility of structural effects of capital flows in the form of FDI, and the incorporation of green R&D in the structural change process to the model. The main results indicate that we can reduce natural resources depreciation with R&D, but to achieve green structural change in an open economy with capital flows, it is necessary to create cumulative effects of FDI on R&D. This reinforces the conclusions presented by Kaczmarczyk & Flassbeck (2023) regarding the need for regulatory changes to assure technological transfer on FDI inflows.

Appendix

Table A1 – *List of Variables*

Variable	Description	Initial Value
y_{bt}	growth rate of the balance of payments equilibrium	–
z_t	growth rate of external demand	5%
ε	income elasticity of demand for exports	–
π	income elasticity of demand for imports	–
E_r	level of the real exchange rate	4
c_t	growth rate of capital inflows	–
E	total resources from exports	1/3 of R
C	total resources from capital inflows	2/3 of R
R	total resources from all inflows	–
ε_t^G	income elasticities of green exports	–
ε_t^T	income elasticities of traditional exports	–
π_t^G	income elasticities of green imports	–
π_t^T	income elasticities of traditional imports	–
g_n	growth rate of the use of natural resources	–
$r\&d_G$	green research and development	–
fdi_t	growth rate of foreign direct investment	–
$port_t$	growth rate of portfolio investments	–
i_t	domestic interest rate	–
i_t^*	international interest rate	–
$embi_t$	growth rate of emerging market bond index	–
$EMBI_t$	level of the emerging market bond index	–
Y_{bt}	level of balance of payments equilibrium income	–
$R\&D_{Gt}$	level of green research and development	1% of Y_{bt}

Table A2 – *List of Parameters*

Parameters	**Description**	**Value on Simulation I**	**Value on Simulation II**	**Reference**
ε_t^G	income elasticities of exports of green technology	2.14	2.14	Proxy parameter built by the average income elasticities of exports of developing countries with $\varepsilon/\pi > 1$ and strong results extract from Perraton (2003)
ε_t^T	income elasticities of exports of traditional technology	1.16	1.16	Proxy parameter built by the average income elasticities of exports of developing countries with $\varepsilon/\pi < 1$ and strong results extract from Perraton (2003)

π_t^G	income elasticities of imports of green technology	2.72	2.72	Proxy parameter built by the average income elasticities of imports of developing countries with $\varepsilon/\pi < 1$ and strong results extracted from Perraton (2003)
π_t^T	income elasticities of imports of traditional technology	0.75	0.75	Proxy parameter built by the average income elasticities of imports of developing countries with $\varepsilon/\pi > 1$ and strong results extracted from Perraton (2003)
θ_{max}	maximum value of θ	0.5	0.5	Highest percentage of exports of non-natural resources based on the same countries as in (Perraton, 2003) extracted from Unctad for the same period
θ_1	create the minimum value of θ $\left(\theta_{min} = \frac{\theta_{max}}{1+\theta_1}\right)$	1	1	Value that creates the lowest percentage of exports of non-natural resources based on the same countries as in Perraton (2003) extracted from Unctad for the same period
ϑ_{max}	maximum value of ϑ	0.7	0.7	Highest percentage of imports of non-natural resources based on the same countries as in Perraton (2003) extracted from Unctad for the same period
ϑ_1	Create the minimum value of ϑ $\left(\vartheta_{min} = \frac{\vartheta_{max}}{1+\vartheta_1}\right)$	0.2	0.2	Value that creates the lowest percentage of imports of non-natural resources based on the same countries as in Perraton (2003) extract from Unctad for the same period
τ	parameter that measures how much of income growth becomes depreciation of natural resources	0.32	0.32	Proxy number extracted from correlation between GDP increase and CO2 emission (Wang et al., 2023)
ρ	environmental efficiency gain that saves the use of natural resources caused by the increase in green R&D	0.46	0.46	Proxy number extracted from correlation between R&D increase and CO2 emission (Wang et al., 2023)
α_0	Kaldor-Verdoorn effect of income on R&D	0.95	0.95	Estimated coefficient for developing economies (Deleidi et al., 2023)
α_1	positive spillover effect of FDI on R&D	Simulated: $1 \leq \alpha_1 \leq 10$	Simulated: $-10 \leq \alpha_1 \leq -1$	Statistical analysis on figure 2 and figure 4
α_2	attraction factor of income on FDI	0.68	0.68	FDI flow from north to south explained by gravity model by income (Guerin, 2006)
α_3	attraction factor of R&D on FDI	0.31	0.31	FDI flows explained by gravity model with higher R^2 using patents as a proxy of R&D (Cuadros et al., 2022)

α_4	repulsion factor of EMBI on FDI	0.37	0.37	FDI flows explained by gravity model with higher R^2 using financial distance as a proxy of financial risk (Dellis, 2024)
α_5	liquidity of the domestic currency in the international hierarchy	0.16	0.16	Proxy number that explains international capital movements by carry trade operations (Jylhä and Suominen, 2011)
φ_0	country risk defined by international investor preferences	Simulated: $0.02 \leq \varphi_0 \leq 0.05$	Simulated: $0.02 \leq \varphi_0 \leq 0.05$	Statistical analyses on table A6
φ_1	balance of payments risk coefficient	Simulated: $-0.04 \leq \varphi_1 \leq -0.01$	Simulated: $-0.04 \leq \varphi_1 \leq -0.01$	Statistical analyses on table A6
φ_2	environmental risk coefficient	Simulated: $0.01 \leq \varphi_2 \leq 0.09$	Simulated: $0.01 \leq \varphi_2 \leq 0.09$	Statistical analyses on table A6

Table A3 – *Regression analysis for the α_1 impact on the main variables for baseline simulation*

Model	**Term**	**Estimate**	**Std. Error**	**Statistic**	***P*-value**
$\boldsymbol{ex}$	α_1	0.0004067	2.13E–05	19.11712	0
$\boldsymbol{embi}$	α_1	–0.000399	6E–07	–617.864	0
$\boldsymbol{ei}$	α_1	–0.000407	0.000023	–17.7136	0
$\boldsymbol{port}$	α_1	0.0001993	3E–07	617.8649	0
$\boldsymbol{ybt}$	α_1	0.0000226	1.5E–06	14.77153	0
$\boldsymbol{RDg}$	α_1	0.0004786	1.4E–06	335.6184	0
$\boldsymbol{fdi}$	α_1	0.0003595	1.4E–06	260.3503	0

Table A4 – *Regression analysis for the α_1 impact on the main variables for scenario simulation*

Model	**Term**	**Estimate**	**Std. Error**	**Statistic**	***P*-value**
$\boldsymbol{ex}$	α_1	0.0227858	0.0002779	81.990948	0
$\boldsymbol{embi}$	α_1	–0.4916561	0.0215462	–22.818733	0
$\boldsymbol{ei}$	α_1	–0.003102	0.0002646	–11.722243	0
$\boldsymbol{port}$	α_1	0.245828	0.0107731	22.818733	0
$\boldsymbol{ybt}$	α_1	0.0040093	0.0002014	19.905099	0
$\boldsymbol{RDg}$	α_1	0.069671	0.0004825	144.398299	0
$\boldsymbol{fdi}$	α_1	0.2065874	0.0083368	24.780037	0

Table A5 - *ADF test analysis for the α_1 impact on the main variables*

Baseline simulation		Scenario simulation	
Variables	*P*-Value	Variables	*P*-Value
$\boldsymbol{gn}$	0.01	gn	0.01
$\boldsymbol{ybt}$	0.01	ybt	0.01
$\boldsymbol{RDg}$	0.01	RDg	0.01
$\boldsymbol{port}$	0.01	$port$	0.01
$\boldsymbol{fdi}$	0.01	fdi	0.01
$\boldsymbol{embi}$	0.01	$embi$	0.01
$\boldsymbol{FDI}$	0.01	FDI	0.01
$\boldsymbol{PORTt}$	0.01	$PORTt$	0.01
$\boldsymbol{Y}$	0.01	Y	0.01
$\boldsymbol{C}$	0.01	C	0.01
$\boldsymbol{RDG}$	0.01	RDG	0.01
$\boldsymbol{E}$	0.01	E	0.01
$\boldsymbol{R}$	0.01	R	0.01
$\boldsymbol{ct}$	0.01	ct	0.01

Table A6 – *F-Test for variations in φ_0, φ_1, φ_2 values for the baseline and scenario simulation*

Sim 2	$\boldsymbol{ybt}$	$\boldsymbol{gn}$	$\boldsymbol{ex}$	$\boldsymbol{ei}$	$\boldsymbol{RDg}$
$\boldsymbol{\varphi_0}$	6.22E-02	4.84E+01	1.96E+00	4.84E+01	5.98E-04
$\boldsymbol{\varphi_1}$	3.31E-03	2.74E-02	2.67E-08	2.74E-02	1.65E-05
$\boldsymbol{\varphi_2}$	1.22E-05	7.89E-03	1.77E-05	1.52E-05	2.84E-03
Sim 1					
$\boldsymbol{\varphi_0}$	0.00444	4.87E-02	1.53E-02	1.82E-02	4.43E-03
$\boldsymbol{\varphi_1}$	0.0155727	2.68E-01	3.64E-02	3.41E-02	1.54E-01
$\boldsymbol{\varphi_2}$	0.0076	0.034381	0.009777	0.009891	0.02551

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