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Ecological Transition and Structural Change: A New-Developmentalist Analysis

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Ecological Transition and Structural Change: A New-Developmentalist Analysis*

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Abstract: The article aims to analyze the ecological transition and the structural change by considering the role of Medium-Income Trap (MIT) with respect to exchange rate overvaluation and (re)industrialization, according to the structuralist-New Developmentalist Approach. The ecological challenges can be faced by an ecological transition based on Ecological Technological Progress and Ecological Structural Change (ESC). The ESC can be represented by the increase of the share of green activities in output for increasing the environmental efficiency of the economy. The theoretical core of the new developmentalism is the tendency of overvaluation of real exchange rate for middle income countries whose sources are the Dutch disease (and the growth with external saving strategy). This fact generates the MIT concerning the negative impact of overvaluation real exchange rate on the industrial development. Thus, we analyze how the ESC interact with the drivers of overvaluation exchange rate by carrying out a post-Keynesian model based the Structuralist-New Developmentalist features. In this perspective, we integrate the issue of the achievement of the environmental targets as indicated by the Climate International Conferences and by the UN initiative of the Sustainable Developments Goals, to the structural change necessary for the economic catching-up of the middle income (and/or developing) countries.

Keywords: Ecological Transition, Structural Change, Dutch-Disease, New-Developmentalism.

JEL-Code: Q56, Q57, O11, O14

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1.Introduction

The beginning of Industrial Revolution in Great Britain in the second half of XVIII century had two long-term effects over the world. The fist effect was the occurrence of the so-called "great divergence", defined as a cumulative process of international dispersion of per-capita incomes (Pomeranz, 2000). According to Prichett (1997) the ratio of GDP per-capita of the richest to poorest countries rose from 8.7 in 1870 to 51.6 in 1985. In 2008, for a sample of 87 countries, Ros (2013) showed that the ratio of the richest country (Norway) to the poor country (Zimbabwe) was 274:1.

The second long-term effect was the cumulative increasing of CO_2 levels in the atmosphere. According to Aghion et al. (2021, p. 173) until the beginning of the nineteenth century the concentration of carbon dioxide in the atmosphere was stable, at levels of 280 parts per million (ppm). In 2018 the atmospheric concentration of carbon dioxide had reached 410 p.m. This rapid increase in the CO_2 levels created the *greenhouse effect*, which is the source of global warming and climate change that will have devastating economic effects in the next decades if it was not controlled in time.

After the end of Second World War many countries that had fallen behind in economic development relative to European countries and the United States had started a process of state-led industrialization by import substitution. Countries as Brazil, Mexico and South Korea industrialized at a very fast rate reaching the status of middle-income countries at the end of 1970´s and the beginning of the 1980´s. From that time on, however, Latin American Countries become stuck in a middle-income trap (MIT hereafter) while East Asian countries continued its development path, reducing their income gap to the developed economies.

According to new-developmentalist theory (NDT hereafter) the main reason for the stagnation of Latin American Economies compared to the East-Asian countries is that the former experienced a process of *premature deindustrialization*[1], i.e., a reduction of the share of manufacturing industry in output and employment before the "Lewis's point" is reached (Lewis, 1954), that is, before all labor force is transferred from the traditional or subsistence sector to the modern sector of the economy (Bresser-Pereira, Oreiro and Marconi, 2015). In other words, the MIT was a result of *an incomplete structural change* of Latin American economies.

One of the causes of premature deindustrialization for NDT is the overvaluation of real exchange rate caused by the Dutch-Disease (DD hereafter), that means the exchange rate overvaluation caused by the production and export of commodity goods that are intensive in the use

[1] This concept was prionerely defined by Palma (2005).

of natural resources. Exchange rate overvaluation reduced the price competitiveness of Latin-American manufacturing firms in both external and domestic markets thus reducing the profitability of investment in manufacturing sector and hence increasing the technological gap[2] with manufacturing firms of developed economies since new technologies are, in general, embedded in new machines and equipment (Kaldor, 1957). Over time the combined effects of real exchange rate overvaluation and increasing technological gap reduced the share of Latin-American manufacturing firms both on world exports of manufacturing goods and in GDP.

If industrialization was the cause of climate change and premature deindustrialization was the cause of stagnation of Latin-American countries how it is possible for then to resume growth without converting into "pollution havens"? East Asin economies would have to stop their development process based in structural change toward the manufacturing sector to contribute to the global fight against climate change?

The first objective of this article is to show that the necessary transition from a fossil fuel-based economy to a low-carbon economy - which the European Commission (2019) denominates as *ecological transition* - is compatible not only with industrialization but also with reindustrialization of the countries that get stuck in the MIT due to DD. Economic development is structural change, and what is needed now is an *Ecological Structural Change* defined by the increase of the share of green activities in output to reduce the emissions of CO_2 into the atmosphere by each unit of output produced, that is to increase the environmental efficiency of the economic system.

Until recently New-Developmentalism had nothing to say about the problem of climate change and ecological transition. The first step in order to fulfill this gap was made by Guarini and Oreiro (2022) whom argued that the real exchange rate overvaluation due to DD can act as a barrier for ecological structural (ESC hereafter) due to the possibility that "green industries" can be the most damaged ones, because they have a higher technological intensity the brown industries, requiring more trained and educated workforce (that is relatively scarce in middle-income countries) which demand high real wages. In this context, exchange rate overvaluation will act as an additional pressure for increasing unit labor costs for these industries, thereby reducing their price competitiveness" (p.248). In other words, DD can act in order to make developing economies in "pollution havens".

Despite this initial effort, these ideas are not yet integrated in a formal new-developmentalist model, as the one made by Oreiro et al (2020). The second objective of this article is precisely to

[2] This concept is due to Fagerberg (1988).

develop a formal new-developmentalist model, based in the original model of Oreiro et al (2020), that incorporates the ESC in its basic structure to analyze the relation of DD with ecological transition as well as the relation of the former with the manufacturing share. This analysis is required for answering some important questions as what is the effect of ecological transition for the manufacturing share in developing economies? What are the mechanisms by which DD can hamper ecological structural change? Neutralization of DD is the only way to achieve the goals of ecological transition and reindustrialization for developing economies or there are other policies that can be used to accomplish these goals? New developmentalism can also be useful for developed economies to make the ecological transition?

The article is organized as follows. Section 2 analyzes the main elements characterizing the relationship between structural change and ecological issues within the developmentalism approach by introducing a macroeconomic interpretation of *inclusive and sustainable industrial development*, and by specifying the concepts of "structural complementarity" and "twin structural change". Section 3 introduces the issue of green activities and Dutch disease within the developmentalist structural change analysis. Section 4 carries out the dynamic of the relationship between the ecological standard structural change by pointing out the effects of devaluation, an improvement of technological gap and a stringency of green targets. Section 5 contains concluding remarks.

2. Structural change and environmental sustainability: a general view.

We can consider that the ecological transition is a combination of Ecological Technical Progress and Ecological Structural Change. The former is based on a general reduction of the environmental pression in terms of impact (for instance pollution intensity) and/ or use of natural resources (for instance, raw material intensity, ecological footprint), while the latter is represented by the shift of labor/value added from economic activities with high environmental pressure intensity, that we can call shortly *brown activities,* to economic activities with a low environmental pressure intensity, that we can call *green activities*. We can classify natural resources in plantations (e.g., coffee, cocoa, rice, soyabeans) and minerals (e.g., oil, gas, coal, iron ore). Obviously, green activity is a latent variable that can assume different specific definitions according to the level of detail. A wide version of green sector concerns all economic activities with a significant commitment for environmental sustainability in terms of processes and products related to green or circular economy (Loiseau et al., 2016). A narrow version can concern the concept of eco-industries used by OECD/Eurostat (OECD/Eurostat, 1999): "*activities which produce goods and services to measure, prevent, limit, minimize or correct environmental damage to water, air, and soil, as well as problems* *related to waste, noise, and eco-systems. This includes cleaner technologies, products and services that reduce environmental risk and minimize pollution and resource use*". Their activities can concern "pollution management", "cleaner technologies and products" and "resources management".

The first step to build a theoretical framework is to define the index of *environmental pressure intensity* as the ratio of the flow of pollution and environmental degradation (per year) and GDP. This index presents the negative externality over environment of the economic activities performed by a country over some definite time (say, one year).

Defining as EPED the flow of environmental pollution /or environmental degradation and Y as the GDP, we had:

$$EPED = Y\left(\frac{EPED}{Y}\right) = \left(\frac{EPED_1}{Y_1}\frac{Y_1}{Y} + \frac{EPED_2}{Y_2}\frac{Y_2}{Y}\right)Y = \left(\frac{EPED_1}{Y_1}.\varepsilon + \frac{EPED_2}{Y_2}(1-\varepsilon)\right) = [EP_1.\varepsilon + EP_2(1-\varepsilon)]Y \ (1)$$

Where: 1 and 2 are subscripts indicating green and brown activities respectively, EP_1 is the environmental pressure of green activities, EP_2 is the environmental pressure of brown activities, ε is the share of green activities in GDP. It is important to notice that $EP_1 < EP_2$.

In equation (1) we can see that pollution flow/environmental degradation is an increasing function of GDP but a decreasing function of the share of green activities in GDP. So, economic growth can be made compatible with a reduction of environmental pollution /or environmental degradation if a structural change in the direction of green activities occurs at the same time. In other words, economic growth can be sustainable if it is the result of an ecological structural change.

Let us define $\hat{\varepsilon}$, as the growth rate of the share of green activities, ε. To reduce the environmental pressure is necessary to increase the *general green productivity* (the inverse of environmental pressure intensity) and to move the economy towards green economic activities that can be composed of organic agriculture, manufacturing industry and services sector.

We aim to introduce ecological structural change (ESC) into a new-developmentalist framework to analyze the interaction between industrialization and ESC. Indeed, the goal 9 of the Sustainable Development Goals strategy of UN Agenda 2030 is "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation". Specifically, target 9.2 is "Promote inclusive and sustainable industrialization and, by 2030, significantly raise industry's share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries" and target 9.4 is "By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities" (UN, 2015).

The relationship between industrialization and ecological structural change can be studied within the new-developmentalism framework[3]. Starting with the modified *technological progress function* of Kaldor (1957), Oreiro et al. (2020) define the function of technical progress as:

$$g_y = \alpha_0 + \alpha_1 \gamma \hat{k} \ (2)$$

where: g_y is the growth rate of output per-worker, $\hat{k}$ is the growth rate of capital per worker, γ is the manufacturing share in output, $\alpha_0 > 0$ Is the autonomous component of the technical progress function and $0 < \alpha_1$<1 is the coefficient of induced technical progress.

The growth rate of labor productivity depends positively upon both the growth rate of capital per-worker and the share of the manufacturing share in output, since in manufacturing industry is the source of increasing returns in the economy there are sources of increasing returns in the economy (Thirwall, 2013, pp. 43-50)

In the long run growth, we can assume, as usual, $g_y = \hat{k}$, then the long run growth rate of labor productivity is

$$g_y = \frac{\alpha_0}{1 - \alpha_1 \gamma} \ (3)$$

In equation (3) we can see that growth rate of labor productivity is an increasing function of the manufacturing share.

One of the main propositions of new-developmentalism is that industrialization is an important driver for the long-run growth. However, a sustainable and inclusive economic development must also consider the environmental effects of industrialization. In order to achieve this result, we had to consider a macroeconomic definition of the *Inclusive and Sustainable Industrial Development* that is an initiative of UNIDO to promote industrialization by limiting the potential environmental and social effects, through a cleaner production, efficient resource management and a reduction in waste and pollution (UNIDO, 2013a; Yuan et al. 2020; Li, 2015).

We can integrate the environmental side of economic development into the new developmentalist framework by means of equation (1). Defining $z = \frac{1}{E_p}$ where E_p is the average

[3] See Bresser-Pereira, Oreiro and Marconi (2015).

environmental pressure of the economy, taking logs in both sides of the equation and time derivative, we get:

$$\widehat{EPED} = \hat{y} - \hat{z} \ (4)$$

The growth rate of the environmental pollution and degradation is equal to the growth rate of output $\hat{y}$ minus the growth rate of environmental efficiency (the inverse of average environmental pressure $\frac{E_P}{Y}$), $\hat{z}$. Since the average environmental pressure is a decreasing function of the share of green activities in the economy, then we can easily show that the growth rate of environmental efficiency is a positive function of the growth rate of the share of green activities as in equation (5) below:

$$\hat{z} = \alpha_2 \hat{\varepsilon} \ (5)$$

Where: $\alpha_2 > 0$

What can be said about the growth rate of share of green activities in GDP? First, we had to acknowledge that the share of green activities cannot grow forever since it has a maximum value of $\varepsilon = 1$. So, after some threshold level of the share of green activities in the economy is reached, then decreasing returns will begin to reduce the rate of growth rate of the share of these activities in the economy. However, it can take many decades until this point is reached, so we will suppose that growth rate of the share of green activities is given by equation (5a) below:

where in turn $\hat{\varepsilon}$ can depend positively upon the share of green activities

$$\hat{\varepsilon} = \alpha_3 \varepsilon \ \ (5a)$$

Where $\alpha_3 > 0$ is a coefficient that measures the impact of institutional arrangements regarding environmental issues over the growth rate of the share of green activities in GDP.

From equation (4), we can derive *a weak sustainability condition*, where $\widehat{E_P} = 0$

$$\hat{y} = \hat{z} \ \ (6)$$

In equation (6), growth is said to be **sustainable** (in the weak sense) if the growth rate of GDP is equal to the growth rate of environmental efficiency.

In a balanced growth path, the growth rate of real output must be equal to the growth rate of output per-worker and the growth rate of labor force, according to equation (7) below:

$$\hat{y} = \ g_y \ + \ n \ (6)$$

where: n is the growth rate labor force (which will be taken as an exogenous variable)

Substituting (3) in (6) we get:

$$\hat{y} = \frac{\alpha_0}{1-\alpha_1\gamma} + n. \text{ (6a)}$$

For balanced growth to be (environmentally) sustainable than is required that:

$$\frac{\alpha_0}{1-\alpha_1\gamma} + n = \hat{z} \leftrightarrow \frac{\alpha_0}{1-\alpha_1\gamma} + n = \alpha_2\alpha_3\varepsilon \quad \leftrightarrow \varepsilon = \frac{1}{\alpha_2\alpha_3}\left[\frac{\alpha_0}{1-\alpha_1\gamma} + n\right] \quad (8)$$

Equation (8) presents the relation between the share of green activities in GDP and the share of manufacturing industry in GDP for which the balanced growth path is (environmentally) sustainable. Taking the derivative of (8) in relation to ε and γ, we get:

$$\frac{\partial\varepsilon}{\partial\gamma} = \frac{\alpha_0\alpha_1}{\alpha_2\alpha_3}\frac{1}{(1-\alpha_1\gamma)^2} > 0 \quad (9)$$

Equation (9) shows the existence of a positive relation between the share of green activities in GDP and the share of manufacturing industry in GDP along the environmentally sustainable balanced growth path.

3.Structural change, Dutch disease, and green activities

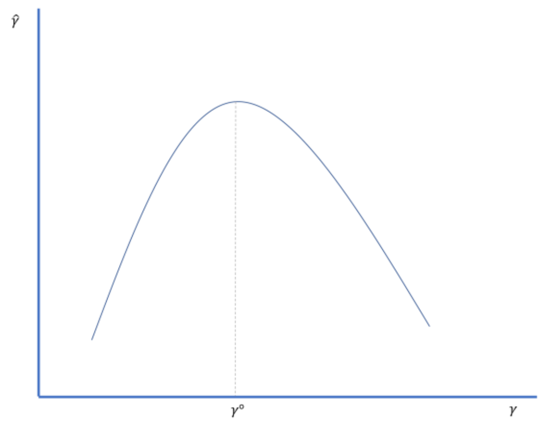
The core of both old and new developmentalist approach is that the pattern of development concerns the structural change from traditional or subsistence sector (typically centered in exploitation of natural resources) to the modern or capitalist sector (typically, the manufacturing industry) with more opportunities for productivity gains.

We start by considering that the dynamics of manufacturing sector in output is given by the following equation

$$\hat{\gamma} = \beta_0 + \beta_1\gamma - \beta_2\gamma^2 - \beta_3 G^T + \beta_4\varepsilon + \beta_5 q \text{ (10)}$$

where: γ, G^T, ε, q are respectively the share of manufacturing industry in output, the technological gap, the share of green activities in output and the exchange rate. With respect to the traditional version of the new-developmentalism (Bresser-Pereira, Oreiro and Marconi, 2015; Oreiro et al. 2020), there are two novelties: the non-linear relationship between the manufacturing share and its growth rate, and the green activities share. First novelty is the result of the combination of Lewis (1954) and Rosenstein-Rodin (1943) models [See Ros 2013, chapters, 6 and 7]. In the initial stages of the process of industrialization, the increasing in the manufacturing share generates increasing rates of profit and capital accumulation due to both external economies and real wages constant at subsistence level [It was the phase of growth acceleration that Brazil, Italy, and Spain had in the period (1950-1970)]. As *Lewis point* is reached with all labor force transferred to the modern (industrial sector) the real wages start to increase and the profit rate starts to decline, resulting in a reduction of the growth rate of capital accumulation and in the growth rate of the modern sector which is, in our model, the manufacturing sector. So γ° is the manufacturing share for which economy reaches "Lewis Point" (See figure 1).

Figure 1: The Inverted - shape relationship between the share of manufacturing industry in output γ and its growth rate $\hat{\gamma}$: The Lewis Point



The second novelty is that the share of green activities can be considered a new driver of industrialization. The structural change can depend positively upon the weight of green activities thanks to many channels. Technological green activities can increase the *price competitiveness* of the industries by reducing the unit raw material and energy costs of production and they can increase the *non-price competitiveness* of manufacturing industries, thanks to the fact that the environmental sustainability of goods production increase the quality perceived by international consumers (Galindo et al. 2020; Guarini and Porcile, 2016; Althouse et al. 2020). There are also important technological advantages that can derive from green activities concerning the technological complementarities between standard and green technologies (Horbach, 2008; Guarini, 2015), economies of scope (Johnstone et al., 2008), knowledge spillovers generated from green activities, typically high knowledge intensive (Jaffe et al., 2003; Rennings, 2000). Green activities can open the room for new sources of competitiveness and business for activities driven by innovation and high added valuing (ECLAC, 2016), but also for sectors such as "ecotourism": it can represent a stimulus for industrialization in developing countries that give double externalities in terms of protection of natural resources, but at same time to develop important businesses (Jones, 2018). Higher is the share of green activities and higher is the demand for new goods and services generated by backwards and forwards linkages theorized by Hirschman and that can be reinterpreted by a green perspective (Lenzen, 2003). Green innovations stimulate the networking and open innovations process, favoring linkages across sectors and in turn increasing returns (Fabrizi et al., 2018; Ghisetti et al., 2015). Eco-industries generate territorial economic spillovers because the installation and maintenance of appliances is strictly linked at local context (Görlach et al., 2014). Investments in renewable energy activities has a multiplier effect on value chain, and reduces the external vulnerability of economy for the substitution of the fossil fuel imports, this also reduces the uncertainty of the refueling in terms of the international prices volatility of fossil energies due to financial speculations in the energy market (Kyritsis & Serletis, 2018; Creti & Nguyen, 2015; Ahmad, 2017; Rizvi, 2021) and the unpredictable supply interruptions due to political instability (ECLAC, 2020). Circular economy favors industrialization by promoting a production diversification in the activities of as waste management, repair, maintenance, remanufacturing, and recycling and by reducing the raw material unit costs (Abelaideio et al. 2021). Share of green activities represents the preference for capital investment with respect of financialized speculation because green innovations reflect the strategic long-term goals, instead of short-term strategies typical of corporate financialization (Huang, 2021). The green activities can also have a positive impact on current account of the balance of payments: they can increase international both price and non-price competitiveness (Guarini and Porcile, 2020) as well as they can cause import substitution concerning fossil sources (ECLAC, 2020), and finally they can enlarge the exports opportunities by producing secondary raw materials and high value-added industrial waste (Abeladeio et al., 2021).

We are in a new industrial revolution driven by *eco-capitalism* (Robert Gutmann 2018). This means that the *only chance for a country to reindustrialize is by means of increasing the share of green industries in manufacturing industry*.

Finally, the evolution of manufacturing share depends negatively upon the level of technological gap which reduce the non-price competitiveness of industrial firms, while it depends positively upon the exchange rate, that rise the price competitiveness of them.

We define with γ° the level of γ for which the economy reaches "Lewis Point", $\frac{\partial \hat{\gamma}}{\partial \gamma} = 0$. This level is given by

$$\frac{\partial \hat{\gamma}}{\partial \gamma} = \beta_1 - 2\beta_2\gamma \ = \ 0$$

With: $\gamma^{\circ} = \frac{\beta_1}{2\beta_2}$ (i)

We redefine equation (10) by inserting $\beta_1\gamma^{\circ} - \beta_1\gamma^{\circ}$ and $-\beta_2\gamma^{\circ 2} + \beta_2\gamma^{\circ 2}$

$$\hat{\gamma} = \bar{\beta} + \beta_1(\gamma - \gamma^{\circ}) - \beta_2\left(\gamma^2 - \gamma^{\circ 2}\right) - \beta_3 G^T + \beta_4\varepsilon + \beta_5 q \quad (11)$$

With $\bar{\beta} = \left[\beta_0 + \beta_1\gamma^{\circ} - \beta_2\gamma^{\circ 2}\right]$.

As in the standard new-developmentalist analysis we derive the exchange rate compatible with the industrial equilibrium q^{IND}, namely the exchange rate for which there is constant long-run share for manufacturing industry in output (Oreiro et al. 2020):

$$q^{IND} = -\frac{\bar{\beta}}{\beta_5} - \frac{\beta_1}{\beta_5}(\gamma - \gamma^{\circ}) + \frac{\beta_2}{\beta_5}\left(\gamma^2 - \gamma^{\circ 2}\right) + \frac{\beta_3}{\beta_5}G^T - \frac{\beta_4}{\beta_5}\varepsilon \quad (12)$$

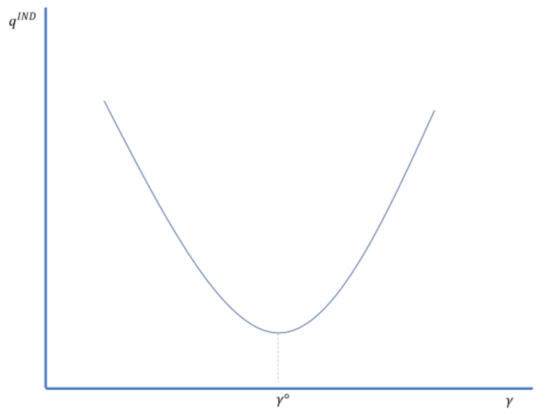
From equation (12) we consider firstly the relationship between q^{IND} and the manufacturing share and after between q^{IND} and the green activities share.

$$\frac{\partial q^{IND}}{\partial \gamma} = -\frac{\beta_1}{\beta_3} + 2\frac{\beta_2}{\beta_3}\gamma = -\frac{\beta_1}{\beta_3} + \frac{\beta_1}{\beta_3}\frac{\gamma}{\gamma^{\circ}} = -\frac{\beta_1}{\beta_3}\left[1 - \frac{\gamma}{\gamma^{\circ}}\right] \quad (13)$$

In this case we have substituted $2\beta_2$ with $\frac{\beta_1}{\gamma^{\circ}}$, thank to equation (i).

If $\left[1 - \frac{\gamma}{\gamma^{\circ}}\right]$>0 the country is a *dual economy*, before reaching the maturity level in terms of the manufacturing share in output; industrial equilibrium exchange rate is a decreasing function of the manufacturing share $\frac{\partial q^{IND}}{\partial \gamma} < 0$; while if $\left[1 - \frac{\gamma}{\gamma^{\circ}}\right]$<0 the country is a *mature economy*, that have overcame the "Lewis point", so industrial equilibrium exchange rate is a increasing function of the manufacturing share $\frac{\partial q^{IND}}{\partial \gamma} > 0$. Figure 2 displays this U shape relation between industrial equilibrium exchange rate and manufacturing share.

Figure 2 The U-shape relation between industrial equilibrium exchange rate q and manufacturing share γ.



The U-shape relation between industrial equilibrium exchange rate and manufacturing share is the result of the *transition from a dual economy to a mature economy*. In a dual economy, the increasing in manufacturing share results in a growing average productivity of labor with constant real wages in home currency. This means that unit labor costs in home currency are decreasing which allowed real exchange rate to appreciate without jeopardizing price competitiveness of home manufacturing firms. After the Lewis point is reached, however, the economy enters in a mature stage where real wages in home currency increases with capital accumulation. At this stage any further increase in the manufacturing share requires an increase in price-competitiveness, holding non-price competitiveness constant, by means of a more depreciated exchange rate**.** For mature economies, the only way to increase the manufacturing share without a more depreciated industrial equilibrium exchange rate and hence with lower real wages is to increase the non-price competitiveness by means of an increase in the share of green activities in the manufacturing industry.

Taking the derivative of equation (12) relative to the share of green activities we get:

$$\frac{\partial q^{IND}}{\partial \varepsilon} = -\frac{\beta_4}{\beta_5} < 0 \ (14)$$

Equation (14) says that lower is the share of green activities, higher will be the industrial equilibrium exchange rate required to prevent deindustrialization, because firms need to compensate their lack of environmental competitiveness with more price competitiveness which means, other variables constant, lower real wages.

We will suppose that the economy is operating with full capacity utilization, that is with a capacity utilization equal to the normal long-run level. Moreover, we will also assume that the economy is operating with a current account equilibrium of the balance of payments, which means that the actual level of real exchange rate is equal to the current account equilibrium level of the new-developmentalist model: $q = q^{CAB}$(ii). Considering equation (12) and condition (ii) we can analyze in static terms the relationship between green activities share and Dutch disease[4] usually defined as a situation where the industrial equilibrium real exchange rate is higher than the current account equilibrium real exchange rate; i.e $(q^{IND} - q^{CAB}) > 0$. (Bresser-Pereira, Oreiro and Marconi, 2015, pp. 59-62).

Figure 3 The relationship between green activities share ε and Dutch disease

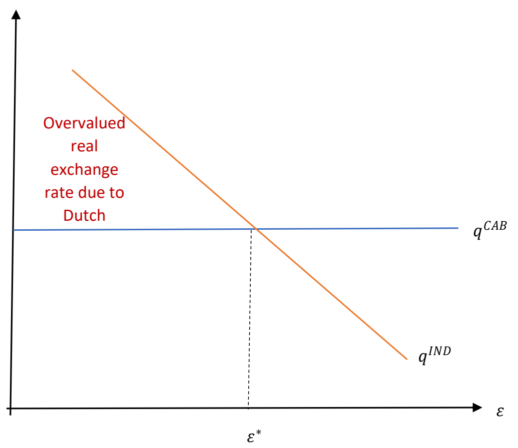
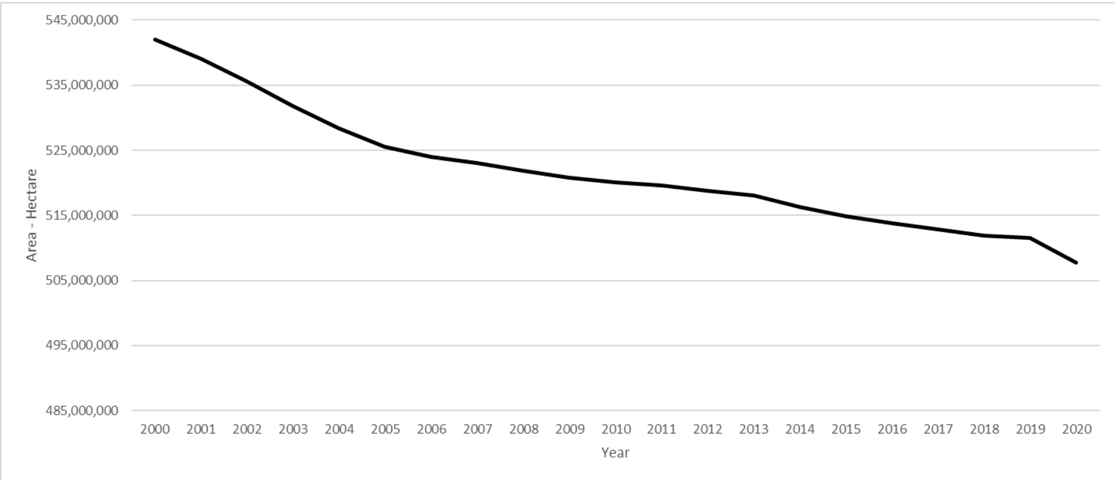


Figure 3 above shows that an overvalued real exchange rate due to Dutch Disease is clearly associated with a low share of green activities in output. In other words, Dutch Disease is not only harmful for the manufacturing sector and hence economic development, but also for the environment. The Dutch disease had a *clear environmental side* that is, up to now, not considered by new-developmentalism. This is precisely the case of Brazil. We explain. Production of soybeans and cattle are land intensive, but extremely profitable in Brazil because land is abundant. The increasing production of soybeans and cattle leaves to the expansion of land used by this kind of production to the borders of amazon forest. Marginal producers had no option instead of putting down the forest to occupy new spaces for soybeans and cattle which had a clear and negative effect over the CO2 emissions. The traditional economic solution to the problem is to reduce the profitability of such kind of activities - this where the export tax over primary goods fits in. Another solution is what we designed in the model: to increase the share of green industries to reduce industrial equilibrium exchange rate at the level compatible with the elimination of Dutch disease. And this can be done without a devaluation of actual exchange rate and consequently without having a negative, although

[4] Dutch disease is defined by Bresser-Pereira, Oreiro and Marconi (2015, p. 57) as the "chronic exchange rate overvaluation caused by the exploitation of abundant and cheap resources, whose exports is compatible with clearly higher exchange rate than the rate that makes internationally competitive other business enterprises in the tradeable sector (….)"

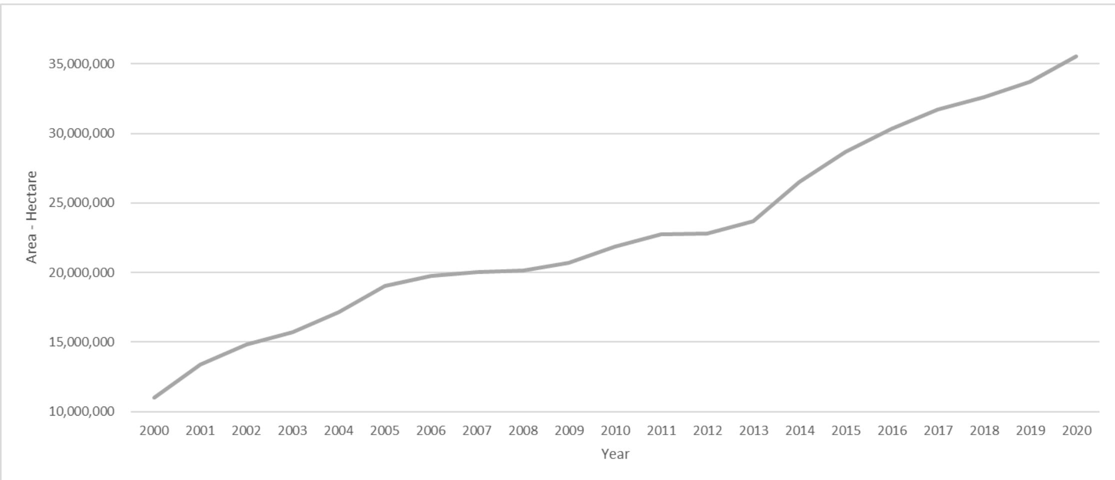
temporary effect over real wages. According to Oreiro et al. (2021), data show the premature deindustrialization of Brazil in the period 1998-2017 caused by the overvaluation of real effective exchange rate, while Figure 4.a and Figure 4.b show the green side of the Dutch disease: a slow Brazilian land cover structural change: a decrease of land cover by forests and an increase of land cover by soybean.

Figure 4.a Land Cover by forests in Brazil (2000 – 2020), Area-Hectare millions.



Source: Project MapBiomas, 2022. Collection 6.0 of Brazilian Land Cover and Use Map Series. Elaborated with the assistance of Daniel Moura (UnB/SDMRG).

Figure 4.b Land Cover by soybean in Brazil (2000 – 2020), Area-Hectare millions



Source: Project MapBiomas, 2022. Collection 6.0 of Brazilian Land Cover and Use Map Series. Elaborated with the assistance of Daniel Moura (UnB/SDMRG).

We will endogenize the current account equilibrium exchange rate starting from equation (27) of Oreiro et al (2020) new developmentalist model:

$$d = \varphi_0 - \varphi_1 q$$

Where: d is the current account deficit as a ratio to GDP, q is the actual level of real exchange rate and φ_0 and φ_1 are positive parameters.

We will add another term to this equation, the share of green activities in GDP, as can be seen in equation (15) bellow:

$$d = \varphi_0 - \varphi_1 q - \varphi_2 \varepsilon \quad (15)$$

In equation (15) the current account deficit as a ratio to output depends on both of price and non-price competitiveness of home exports. The share of green activities in output in now a proxy for non-price competitiveness of exports. We can now calculate the real exchange rate compatible with a zero current account deficit, which is the current account equilibrium exchange rate, by:

$$q^{CAB} = \frac{\varphi_0}{\varphi_1} - \frac{\varphi_2}{\varphi_1}\varepsilon \quad (16)$$

The effect of a change of share of green activities over the size of Dutch disease is given by:

$$\frac{d(q^{IND} - q^{CAB})}{d\varepsilon} = -\frac{\beta_4}{\beta_5} + \frac{\varphi_2}{\varphi_1} \quad (17)$$

The sign of partial derivative in equation (17) is ambiguous, which means that an increase in the share of green activities can increase or decrease the size of exchange rate overvaluation and hence the size of Dutch disease. This occurs because an increase in the share of green activities can increase both $q^{CAB}$and q^{IND}. For reducing the exchange rate overvaluation and the size of Dutch Disease is necessary that the the eco-structural change should have a higher impact over industrial equilibrium exchange rate than over current account equilibrium exchange rate , otherwise there is a sort of *rebound effect*: the openness to the global market for green activities will reinforce the premature deindustrialization.

4. Ecological structural change and the dynamics of manufacturing share

So far, we considered the share of green activities in output constant over time. Now it is the time to present the dynamics of ecological structural change, that is, the dynamics of the share of green activities in output. This is done by equation (18) bellow:

$$\hat{\varepsilon} = -\theta_0(q^{IND} - q^{CAB}) - \theta_1 G^T + \theta_2(\bar{\varepsilon} - \varepsilon) \quad (18)$$

Where: θ_0 is a coefficient that captures the influence of the size of Dutch Disease (measured by the difference between industrial equilibrium exchange rate and current account equilibrium exchange rate with a positive value representing the existence of Dutch Disease) over the rate of change of the share of green activities in output, θ_1 is a coefficient that captures the influence of the size of the general technological gap over the dynamics of ecological structural change and θ_2 is a coefficient that captures the influence of the size of the "ecological gap" [5]over the dynamics of ecological structural change .According to equation (18) ESC has three main drivers: the macroeconomic driver represented by the term $[\theta_0(q^{IND} - q^{CAB})]$, the technological driver represented by the term $[\theta_1 G^T]$ and the institutional driver represented by the term $[\theta_2(\bar{\varepsilon} - \varepsilon)]$

Dutch disease affects the ESC. Dutch disease reduces the price-competitiveness of green activities and increase the Ricardian rents of natural resources owners, the purchasing power of workers and revenues for entrepreneurs in non-tradeable sectors; these mechanisms weaken the social and political support to the ecological structural change and reinforces the image of the country at international as a "raw material country", reducing the room for green competitiveness. This element points out a potential *Ecological Macroeconomic Trap* between Dutch disease and low green activities share: a hifh size of Dutch disease reinforce the political conditions for the expansion of environmental pressure intensive activities and a low share of green activities makes manufacturing industry to be more dependent of a higher level of q^{IND} to be competitive, rising even further the size of Dutch disease. Moreover, ESC can be negatively affected by an insufficient level of technological capabilities with respect to the international standards, because green activities are knowledge and technology intensive and the distance from the international technological frontier reduce the technological opportunities for ecological conversion (Fabrizi et al., 2018). This element generates an *Eco-Technological Trap*: a high technological gap reduces the rate of technological transfer necessary to enlarge the green activities share and a low share of green activities makes manufacturing more dependent of high levels of q^{IND} to be competitive, rising the size of Dutch disease. Finally, ESC can be positively influenced by the result of the institutional green efforts to achieve the sustainable development goals: $\bar{\varepsilon}$ represents the national green target coherent with the international standards, for instance, a target related to the Sustainable Development Goals. Thus, the ecological gap $(\bar{\varepsilon} - \varepsilon)$ stimulates a green reaction. The effectiveness of institutional green efforts represents the factor that can make country able to overcome the abovementioned ecological macroeconomic and eco-technological traps. Equation (18) shows the complexity of ecological structural change due to the varieties of factors that play a relevant role.

[5] Ecological gap will be defined as the difference between some target or desired level for the share of green activities $(\bar{\varepsilon})$ in output and the actual level of the share of green activities (ε).

In steady-state or long-run equilibrium the share of green activities in output must be constant; i.e, $\hat{\varepsilon} = 0$. Thus, we get:

$$-\theta_0(q^{IND} - q^{CAB}) - \theta_1 G^T + \theta_2(\bar{\varepsilon} - \varepsilon) = 0 \qquad (18a)$$

For simplicity let us consider $\varphi_2 = 0$ in equation (16). In this case the current account equuilibrium exchange rate is constant. Equation (18a) presents the loci of combinations between industrial equilibrium exchange rate and the share of green activities in output for which the last one is constant through time.

Substituting equation (12) in (16) we get:

$$-\theta_0\left[-\frac{\bar{\beta}}{\beta_5} - \frac{\beta_1}{\beta_5}(\gamma - \gamma^{\circ}) + \frac{\beta_2}{\beta_5}\left(\gamma^2 - \gamma^{\circ 2}\right) + \frac{\beta_3}{\beta_5}G^T - \frac{\beta_4}{\beta_5}\varepsilon - q^{CAB}\right] - \theta_1 G^T + \theta_2(\bar{\varepsilon} - \varepsilon) = 0 \quad (18b)$$

Notice that in our model we had two sectors, Modern and Subsistence. Modern sector had two kinds of activities: green and brown. An ecological transition means to transfer labor from the subsistence sector to modern sector (industrialization and/or capitalist production and export of primary goods) and increasing the share of green activities in the modern sector. A modern economy can be one with a higher share of brown activities in the modern sector (as is the case of Brazil) and hence with Dutch Disease problems. The economic issue is how to increase the share of green activities in the modern sector without reducing the size of the manufacturing share, i.e., without promoting deindustrialization. So, we must perform some comparative statics exercises to evaluate the effect over the stable equilibrium point of changes in some of the parameters of the model: G^T, q^{CAB} and $\bar{\varepsilon}$. But first, we must calculate the steady-state values of γ *and* ε.

4.1 The steady state values

Let us to study the dynamic relationship between rate of change of manufacturing share $\hat{\gamma}$ and ecological structural change represented by $\hat{\varepsilon}$.

To this end, we introduce equation (12) of q^{IND} in equation (18) and we obtain

$$\hat{\varepsilon} = -\theta_0\left(-\frac{\bar{\beta}}{\beta_5} - \frac{\beta_1}{\beta_5}(\gamma - \gamma^{\circ}) + \frac{\beta_2}{\beta_5}\left(\gamma^2 - \gamma^{\circ 2}\right) + \frac{\beta_3}{\beta_5}G^T - \frac{\beta_4}{\beta_5}\varepsilon - q^{CAB}\right) - \theta_1 G^T + \theta_2(\bar{\varepsilon} - \varepsilon) \quad (19)$$

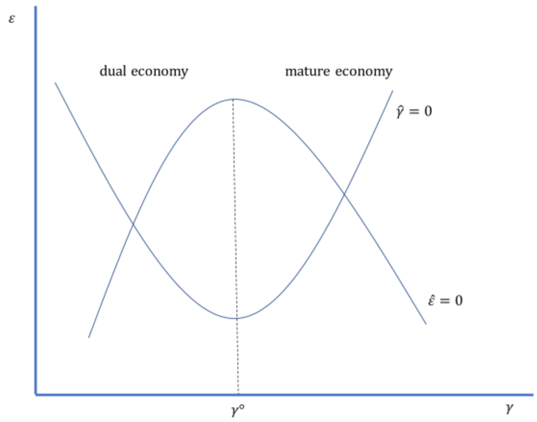
The dynamics of the manufacturing share is given by equation (11)

$$\hat{\gamma} = \bar{\beta} + \beta_1(\gamma - \gamma^{\circ}) - \beta_2\left(\gamma^2 - \gamma^{\circ 2}\right) - \beta_3 G^T + \beta_4\varepsilon + \beta_5 q \quad (11)$$

In the Appendix A is carried out the stability analysis of the system composed of equation (11) and (19). According to the calculations, the dynamic system can be stable only at the mature phase of economic development. This result deserves further explanation. As stated by Lewis (1954) economic development in an economy with unlimited supply of labor is essentially an unbalanced growth process in which the savings ratio, the profit share and the manufacturing-share are all increasing overt time, so the ratios between variables are ever changing, which characterizes an unbalanced growth.

Figure 4 shows the existence of two steady-states for the economy at hand, one for a dual economy and the other for a mature economy.

Figure 4 Steady states for dual and mature economy



We will focus our analysis over the mature economy equilibrium because it is is stable one,. Firstly, we simplify the equation of the rate of change of manufacturing share to :

$$\hat{\gamma} = \beta_0 - \beta_1\gamma - \beta_3 G^T + \beta_4\varepsilon + \beta_5 q^{CAB} \quad (20)$$

Then we calculate $\hat{\gamma} = 0$ loci:

$$\varepsilon = \frac{-\beta_0 + \beta_1\gamma + \beta_3 G^T - \beta_5 q^{CAB}}{\beta_4} \quad (20a)$$

To analyze the ecological structural change in this case we have

$$q^{IND} = -\frac{\beta_0}{\beta_5} + \frac{\beta_1}{\beta_5}\gamma + \frac{\beta_3}{\beta_5}G^T - \frac{\beta_4}{\beta_5}\varepsilon \quad (21)$$

$$\hat{\varepsilon} = -\theta_0\left(-\frac{\beta_0}{\beta_5} + \frac{\beta_1}{\beta_5}\gamma + \frac{\beta_3}{\beta_5}G^T - \frac{\beta_4}{\beta_5}\varepsilon - q^{CAB}\right) - \theta_1 G^T + \theta_2(\bar{\varepsilon} - \varepsilon) \quad (22)$$

Taking $\hat{\varepsilon} = 0$ we get after some mathematical manipulations[6]:

$$\varepsilon = \frac{\theta_0}{\sigma} q^{CAB} + \sigma_0 - \sigma_1 \gamma - \sigma_2 G^T + \frac{\theta_2}{\sigma} \bar{\varepsilon} \ (22a)$$

With $\sigma = \theta_2 - \theta_0 \frac{\beta_4}{\beta_5}\, \sigma_0 = \frac{\theta_0}{\sigma}\frac{\beta_0}{\beta_5};\ \sigma_1 = \frac{\theta_0}{\sigma}\frac{\beta_1}{\beta_5};\ \sigma_2 = \frac{\theta_0}{\sigma}\ \frac{\beta_3}{\beta_5}$

$\sigma, \sigma_0, \sigma_1, \sigma_2$ are positive when the green institutional effectiveness is higher than green Dutch disease effect $\theta_2 > \theta_0 \frac{\beta_4}{\beta_5}$

Combining equation (20a) and (22a) we can obtain the steady-state values. The steady state value of γ is given by:

$$\gamma^* = \frac{\left[\frac{\beta_0}{\beta_4} - \left(\frac{\beta_3}{\beta_4} + \sigma_2\right) G^T + \left(\frac{\beta_5}{\beta_4} + \frac{\theta_0}{\sigma}\right) q^{CAB} + \sigma_0 + \frac{\theta_2}{\sigma} \bar{\varepsilon}\right]}{\frac{\beta_1}{\beta_4} + \sigma_1} =$$

$$\gamma^* = \frac{\left[\frac{\beta_0}{\beta_4} - \sigma_3 G^T + \sigma_4 q^{CAB} + \sigma_0 + \frac{\theta_2}{\sigma} \bar{\varepsilon}\right]}{\sigma_5} \qquad (23)$$

Where: $\sigma_3 = \left(\frac{\beta_3}{\beta_4} + \sigma_2\right) > 0$, $\sigma_4 = \left(\frac{\beta_5}{\beta_4} + \frac{\theta_0}{\sigma}\right) > 0$, $\sigma_5 = \frac{\beta_1}{\beta_4} + \sigma_1 > 0$

The steady-state value of ε is given by:

$$\varepsilon^* = \frac{\theta_0}{\sigma} q^{CAB} + \sigma_0 - \sigma_1 \frac{\left[\frac{\beta_0}{\beta_4} - \sigma_3 G^T + \sigma_4 q^{CAB} + \sigma_0 + \frac{\theta_2}{\sigma} \bar{\varepsilon}\right]}{\sigma_5} - \sigma_2 G^T + \frac{\theta_2}{\sigma} \bar{\varepsilon}$$

$$\varepsilon^* = \left(\frac{\theta_0}{\sigma} - \sigma_1 \frac{\sigma_4}{\sigma_5}\right) q^{CAB} + \sigma_0 + \left(\frac{\sigma_1 \sigma_3}{\sigma_5} - \sigma_2\right) G^T + \frac{\theta_1}{\sigma} \bar{\varepsilon} \left(1 - \frac{\sigma_1}{\sigma_5}\right) - \frac{\sigma_1}{\sigma_5}\frac{\beta_0}{\beta_4} \quad (24)$$

6

$$\varepsilon = \frac{\theta_0}{\sigma} q^{CAB} + \frac{\theta_0}{\sigma}\frac{\beta_0}{\beta_5} - \frac{\theta_0}{\sigma}\frac{\beta_1}{\beta_5}\gamma - \frac{\theta_0}{\sigma}\ \frac{\beta_3}{\beta_5} G^T - \frac{\theta_1}{\sigma} G^T + \frac{\theta_2}{\sigma}\bar{\varepsilon} = \frac{\theta_0}{\sigma} q^{CAB} + \sigma_0 - \frac{\theta_0}{\sigma}\frac{\beta_1}{\beta_5}\gamma - \left(\frac{\theta_0}{\sigma}\ \frac{\beta_3}{\beta_5} + \frac{\theta_1}{\sigma}\right) G^T + \frac{\theta_2}{\sigma}\bar{\varepsilon}$$

4.2 The impact of a devaluation of real exchange rate

A devaluation of current account equilibrium real exchange rate (obtained by the imposition of an export taxes over primary goods) will have unambiguous positive impact over the steady-state value of the manufacturing share γ^* as we can see below:

$$\frac{\partial \gamma^*}{\partial q^{CAB}} = \frac{\sigma_4}{\sigma_5} > 0 \; (25a)$$

For ecological structural change to be positive the following condition must be met

$$\frac{\partial \varepsilon^*}{\partial q^{CAB}} = \left(\frac{\theta_0}{\sigma} - \sigma_1 \frac{\sigma_4}{\sigma_5}\right) > 0 \leftrightarrow \theta_0 > \; \sigma\sigma_1 \frac{\sigma_4}{\sigma_5} = \theta_0^c \; (25b)$$

Equation (25b) states that a devaluation of current account equilibrium exchange rate will have a positive effect over the share of green activities in output if θ_0 defined as the coefficient that captures the influence of the size of Dutch Disease is higher than a certain threshold level $\theta_0^c = \sigma\sigma_1 \frac{\sigma_4}{\sigma_5}$. The economic interpretation is straightforward. As we had seen, Dutch Disease had a negative impact over the share of green activities in output. The size of the Dutch Disease is measured as the difference between industrial equilibrium exchange rate and current account. A devaluation of current account equilibrium exchange rate (due to the introduction of export taxes over primary goods) will reduce the size of Dutch Disease. The dynamic effect of a reduction in the size of Dutch Disease over the share of green activities is captured by θ_0: the higher is this coefficient the greater will be the impact of the reduction of Dutch Disease over the rate of change of ε. Equation (25b) shows the minimum value for θ_0 that allowed a positive impact of the steady-state value of ε of a reduction in the size of Dutch Disease produced by the devaluation of current account equilibrium exchange rate, keeping all other variables constant.

4.3 The impact of a change in the technological gap

The effects of a change in the technological gap over the steady-state values of the manufacturing share and green share activities over output are given below:

$$\frac{\partial \gamma^*}{\partial G^T} = -\frac{\sigma_3}{\sigma_5} < 0 \; (26a)$$

$$\frac{\partial \varepsilon^*}{\partial G^T} = \left(\frac{\sigma_1\sigma_3}{\sigma_5} - \sigma_2\right) < 0 \leftrightarrow \sigma_1 < \frac{\sigma_2\sigma_5}{\sigma_3} \leftrightarrow \theta_0 < \frac{\beta_4}{\beta_5}\sigma\frac{\sigma_2\sigma_5}{\sigma_3} = \theta_0^{cc} \; (26b)$$

In the expression (26a) we can see that a reduction in the level of technological gap will increase the steady-state value of the manufacturing share, all other variables remaining constant. This happens because technological gap represents the non-price competitiveness of the home country manufacturing share; with a reduction in the level of this gap increasing non-price competitiveness of the home country manufacturing firms and hence expanding their size in the economy.

In expression (26b), however, we see that the reduction in the technological gap will only had a positive impact over green activities if θ_0 is lower than a critical value $\theta_0^{cc} = \left(\frac{\beta_4}{\beta_5}\sigma\frac{\sigma_2\sigma_5}{\sigma_3}\right)$. This happens because the reduction in the level of technological gap had two opposite effects over the share of green activities according to equation (ESC). The fist effect is given by $-\sigma_1\gamma$: a decrease in the level of technological gap will increase the share of the entire manufacturing share, due to the reduction of the Dutch Disease because of the appreciation of industrial equilibrium exchange rate, increasing both green and brown activities. This will have a negative effect over the share of green activities in the output. The second effect is given by $-\sigma_2 G^T$: a decrease in the technological gap will increase the economic complexity of the productive structure which favors green activities.

4.4 The impact of a change in the green target

The effects of a change in the green target over the steady-state values of the manufacturing share and green share activities over output are given below:

$$\frac{\partial\gamma^*}{\partial\bar{\varepsilon}} = \frac{\theta_2}{\sigma}\sigma_5 > 0 \; (27a)$$

$$\frac{\partial\varepsilon^*}{\partial\bar{\varepsilon}} = \frac{\theta_2}{\sigma}\bar{\varepsilon}\left(1 - \frac{\sigma_1}{\sigma_5}\right) > 0 \leftrightarrow 1 > \frac{\sigma_1}{\sigma_5} \; (27b)$$

As we can see in equation (27a) an increase in the target level for the share of green activities in output will have a positive effect over the manufacturing share, because such an increase will demand institutional and policy changes that will increase non-price competitiveness of home country manufacturing firms, expanding their share on output (sophistication spillovers). The impact over green activities, however, is ambiguous: since the manufacturing industry had both green and brown activities is possible that an increase in the size of manufacturing sector will result in a decrease of the share of green activities in the economy. Equation (27b) defines the range of parameter values that make $\frac{\partial\varepsilon^*}{\partial\bar{\varepsilon}} = \frac{\theta_2}{\sigma}$ positive. Moreover, the sign of condition (27b) could strictly depend on the sign of σ: it will be positive $\sigma > 0$ when the green institutional effectiveness is higher than size of potential Dutch disease effect $\theta_2 > \theta_0\frac{\beta_4}{\beta_5}$. Thus, with a low value of θ_2 could be a policy paradox: an increase of green target generates a reduction of green activities share. When green targets are too ambitious with respect to institutional green capability can worsen the sustainability. Instead, when the green targets are combined with a stringency of the green policy, green regulation can increase the competitiveness of industries, as asserted by the strong version of Porter Hypothesis (Porter and Linde, 1995; Guarini, 2020), and in turn it can promote industrialization.

5. Final Remarks

Throughout this article we developed a Post-Keynesian/Structuralist-New Developmentalist model to illustrate the relationship between ecological transition and structural change and to analyze the effects of ecological structural change (ESC) over Middle Income Trap (MIT) caused by Dutch disease. As show in the article an increase in the share of green activities in output had the potential to reduce the size of Dutch disease since it can produce an appreciation of industrial equilibrium exchange rate. We also show that Dutch disease had a clear environmental side which is not considered in the new-developmentalist literature: environmental pressure is a byproduct of the production of primary goods which are the source of Dutch disease in countries with abundance of natural resources. This means that environmental devastation and premature deindustrialization that results in the MIT are the result of the same negative structural change.

For countries like Brazil that are sunk in Middle-Income Trap (MIT) due to premature deindustrialization caused by the Dutch disease, ESC can be the only real option for reindustrialization and resume economic development. A simultaneous increase in the manufacturing share and the share of green activities in output is possible by means of a proper combination of macroeconomic, industrial, and institutional policies. Regarding macroeconomic policies, a real exchange rate devaluation by means of the introduction of an export tax over primary goods will increase the manufacturing share and, under certain conditions, also the share of green activities. Industrial policies must be designed to reduce the level of the technological gap will also be an important complement to the exchange rate devaluation, probably reducing the real exchange rate depreciation required for a green reindustrialization and therefore reducing the temporary losses of real wages produced by the exchange rate depreciation. Finally, institutional policies aimed to increase the target of the share of green activities in output can reinforce the positive effects of real exchange rate devaluation and the reduction of technological gap.

Appendix: Stability Analysis

Given the equations

$$\hat{\gamma} = \beta^{*} + \beta_1(\gamma - \gamma^{*}) - \beta_2\left(\gamma^2 - \gamma^{*2}\right) - \beta_3 G^T + \beta_4 \varepsilon + \beta_5 q^{CAB}(IND)$$

$$\hat{\varepsilon} = -\theta_0\left(-\frac{\bar{\beta}}{\beta_5} - \frac{\beta_1}{\beta_5}(\gamma - \gamma^{*}) + \frac{\beta_2}{\beta_5}\left(\gamma^2 - \gamma^{*2}\right) + \frac{\beta_3}{\beta_5}G^T - \frac{\beta_4}{\beta_5}\varepsilon - q^{CAB}\right) + \theta_2(\bar{\varepsilon} - \varepsilon) \quad (ET)$$

We obtain the following Jacobian Matrix

$$\begin{bmatrix} \hat{\gamma} \\ \hat{\varepsilon} \end{bmatrix} = \begin{bmatrix} \frac{\partial \hat{\gamma}}{\partial \gamma} & \frac{\partial \hat{\gamma}}{\partial \varepsilon} \\ \frac{\partial \hat{\varepsilon}}{\partial \gamma} & \frac{\partial \hat{\varepsilon}}{\partial \varepsilon} \end{bmatrix} \begin{bmatrix} \gamma - \gamma^{ss} \\ \varepsilon - \varepsilon^{ss} \end{bmatrix}$$

$$\begin{bmatrix} \beta_1 - 2\beta_2\gamma & \beta_4 \\ \frac{\beta_1}{\beta_5} - 2\frac{\beta_2}{\beta_5}\gamma & \theta_0\frac{\beta_4}{\beta_5} - \theta_2 \end{bmatrix}$$

To obtain the stability trace should be negative $TR\ |J| < 0$ and determinant DET positive, $DET\ |J| > 0$. Let us to calculate both.

$$TR\ |J| = \beta_1 - 2\beta_2\gamma + \theta_0\frac{\beta_4}{\beta_5} - \theta_2$$

$$TR\ |J| < 0 \leftrightarrow 2\beta_2\gamma > \beta_1 + \theta_0\frac{\beta_4}{\beta_5} - \theta_2$$

By considering

$$\gamma^{\circ} = \frac{\beta_1}{2\beta_2} \quad (2)$$

We obtain

$$TR\ |J| < 0 \leftrightarrow \gamma > \gamma^{\circ} + \left[\frac{\theta_0\frac{\beta_4}{\beta_5} - \theta_2}{2\beta_2}\right]$$

$$DET\ |J| = \left(\beta_1 - 2\beta_2\gamma\right)\left(\theta_0\frac{\beta_4}{\beta_5} - \theta_2\right) - \left(\frac{\beta_1}{\beta_5} - 2\frac{\beta_2}{\beta_5}\gamma\right)(\beta_4)$$

We consider equation (2) then we have

$$DET\ |J| = \left(\beta_1\theta_0\frac{\beta_4}{\beta_5} - \beta_1\theta_2\right) - 2\beta_2\gamma\theta_0\frac{\beta_4}{\beta_5} + 2\beta_2\gamma\theta_2 - \frac{\beta_1}{\beta_5}\beta_4 + 2\frac{\beta_2}{\beta_5}\gamma\beta_4$$

$$DET\ |J| = 2\beta_2\left[-\theta_0\frac{\beta_4}{\beta_5} + \theta_2 + \frac{\beta_4}{\beta_5}\right]\gamma + \beta_1\left[\theta_0\frac{\beta_4}{\beta_5} - \theta_2 - \frac{\beta_4}{\beta_5}\right]$$

$$DET\ |J| > 0 \leftrightarrow 2\beta_2\left[-\theta_0\frac{\beta_4}{\beta_5} + \theta_2 + \frac{\beta_4}{\beta_5}\right]\gamma > \beta_1\left[-\theta_0\frac{\beta_4}{\beta_5} + \theta_2 + \frac{\beta_4}{\beta_5}\right]$$

$$DET\ |J| > 0 \leftrightarrow 2\beta_2\gamma > \beta_1 \leftrightarrow \gamma > \gamma^{\circ} = \frac{\beta_1}{2\beta_2}$$

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