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the Impossible (?) Quest for Prosperity of South American Economies

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The Green Transition Dilemma

The Impossible (?) Quest for Prosperity of South American Economies

Paper issued from the International Research Conference: **“Strong Sustainability: How sustainable are Net Zero trajectories?”**

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Abstract
This paper explores the tensions that the transition toward a zero-carbon economy entails for countries relying on natural resources exploitation as the main drivers of (net) exports, as is the case of most South American economies. Given their relatively low diversification and high technology gaps compared to advanced economies, attaining higher prosperity levels driven by sustained economic growth has recurrently been hampered by balance of payments crises. Using a simple long-run demand-led theoretical model with balance of payments constrained growth we show that if the structural limitations in their productive structure are not overcome, the decarbonization of the economy, be it exogenously imposed by the rest of the world or sovereignly decided by each South American country, will be exposed to the dilemma of increasing growth or reducing greenhouse gas emissions. Underpinning this dilemma is the essential role of exports and their associated carbon intensity. Finally, we show that to solve this green transition dilemma, even a process of structural change like the one proposed by the old Latin American structuralist school might not be sufficient – it is only through a “big environmental push” that the long-lastingly desired prosperity of South American countries can cease to be an impossible quest.

Keywords
Green Transition, South America, Environmental Sustainability, Balance of payments constrained growth

JEL codes
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Résumé

Cet article explore les tensions que la transition vers une économie à neutre en carbone entraîne pour les pays dont l'exploitation des ressources naturelles est le principal moteur des exportations (nettes), comme c'est le cas de la plupart des économies sud-américaines. Compte tenu de leur diversification relativement faible et de leurs écarts technologiques élevés par rapport aux économies avancées, l'atteinte de niveaux de prospérité plus élevés grâce à une croissance économique soutenue a été régulièrement entravée par des crises de la balance des paiements. À l'aide d'un modèle théorique simple à long terme axé sur la demande, avec une croissance limitée par la balance des paiements, nous montrons que si les limites structurelles de leur structure productive ne sont pas surmontées, la décarbonisation de l'économie, qu'elle soit imposée de manière exogène par le reste du monde ou décidée souverainement par chaque pays d'Amérique du Sud, sera exposée au dilemme suivant : augmenter la croissance ou réduire les émissions de gaz à effet de serre. Ce dilemme est sous-tendu par le rôle essentiel des exportations et de l'intensité en carbone qui leur est associée. Enfin, nous montrons que pour résoudre ce dilemme de la transition verte, même un processus de changement structurel comme celui proposé par l'ancienne école structuraliste latino-américaine pourrait ne pas être suffisant - ce n'est que par le biais d'une "grande poussée environnementale" que la prospérité longtemps désirée des pays d'Amérique du Sud peut cesser d'être une quête impossible.

Mots-clés

Transition verte, Amérique du Sud, Soutenabilité environnementale, Croissance contrainte par la balance des paiements

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Introduction

It is now widely accepted that the "green transition" is a process of structural change, where cleaner and more energy-efficient industries, both newly created and other already existing ones will gain importance in the economy, while more traditional activities (mostly the ones related to fossil fuels) will progressively disappear (Semieniuk et al., 2021). Even if the contribution of South American countries to global greenhouse gas emissions is low (while their share of global GDP is 4.5%, their share of global emissions is 3%) their reliance on natural resource-intensive activities entails a series of risks. This is because in most of them macroeconomic stability relies on primary commodity exports, which in many cases are related to the so-called "sunset industries", i.e., those that will be negatively affected by the series of policies that the global green transition entails. Even if some "sunrise industries" can provide big opportunities in some cases (like the case of lithium in Argentina, Bolivia and Chile), recent empirical analysis has shown that the region's exposure to the green transition is significant (Espagne et al, 2021)[1].

Seventy years after Prebisch (1950) and Singer (1950) seminal contributions about the problems that a productive structure based on commodities entailed for long-run development, the specialization pattern of South American countries has not changed much. Consequently, the sustained growth of income levels that are required (at least as a necessary condition) to increase the standard of living of their populations has been repeatedly interrupted by the external constraint originally identified by Diamand (1972) and Rodríguez (1977) and later one defined and formalized by Thirlwall (1979) as the balance of payments equilibrium growth rate.

Now that humanity has finally accepted the unescapable need to decarbonize the economy (IPCC, 2022) South American countries face a double challenge. Not only do they have to go through a sustained growth process that enables higher income levels such that the population living in poverty is better off, but this growth must take place in a global context where the world's demand for

[1] Espagne et al (2021) break down macroeconomic risks into three categories: external, fiscal and socio-economic exposures, each of them defining the net potential losses of foreign exchange, government revenue and employment as a result of the global move toward more sustainable ways of production and consumption. To quantify each country´s exposure they rely on input-output data to see the relevance that "sunset industries" have in each of the three dimensions. Their analysis shows varying levels of exposure across the region. First, Bolivia and Venezuela exhibit a high exposure in all three dimensions because exports, government revenue and employment rely heavily on "sunset industries". Brazil, Paraguay, Ecuador, Guyana and Suriname are more susceptible to socio-economic exposure, meaning that an important part of the employment in their economies is directly or indirectly related to "sunset industries", while exports and government revenue are more diversified. Chile, Peru and Colombia, for their part, are more subject to external exposure, implying that exports are strongly related to "sunset industries", while employment and government revenue are less dependent on them. According to their analysis, only Argentina and Uruguay show low levels of exposure to the green transition.

high carbon-intensive commodities will be reduced. The challenge is even bigger when multidimensional poverty is considered, requiring even higher income growth to tackle all the related dimensions such as access to health, education and infrastructure.

As mentioned before, this more complex scenario for South America has to be faced with the same tools (namely the productive structure) that proved insufficient to close prosperity gaps in the previous decades. The existing specialization pattern and, more specifically, the natural-resources-based (net) export basket of South American economies, therefore, puts them in a dilemma. The attempt to preserve external sustainability so that the economy can finance all the investments that increasing prosperity requires would need the sustained exploitation of natural resources, which would, in turn, imply the demise of the environmental sustainability goal. On the other hand, compliance to decarbonize the economy would require a lower growth rate of exports (or even a decrease in them) which would make the external constraint more binding, thereby limiting the room for increasing prosperity. Thus, given the existing productive structure South American countries can either choose to increase income (by increasing exports, which might not even depend on their will) or environmental sustainability (by reducing exports). In other words, these two goals are, as of today, mutually exclusive.

At the center of this dilemma faced by South American countries is the combination of a natural resource-intensive productive structure with a high technological gap with advanced economies. The Rio+ 20 Conference on Sustainable Development in 2012 saw a series of proposals for solutions to this dilemma, most based on the notion of "green growth" (Hickel and Kallis, 2019). Underpinning "green growth" is the idea of decoupling GDP growth from natural resource use (UNEP, 2011). The possibility of aligning economic growth with environmental sustainability, if possible, would make the prospects of South America less dismal. In line with this possibility, ECLAC, which since the 1950s has been calling for structural change to allow Latin America to overcome its pending tasks in terms of development, has updated its proposal to acknowledge the planetary boundaries. Now, the way to prosperity consists of a "big environmental push" (ECLAC, 2016). However, the available research on the feasibility of "green growth" strategies is pessimistic, to the extent that achieving the targets set in the sustainable development goals is highly unlikely (Hickel and Kallis, 2019).

This paper presents a simple long-run demand-led theoretical model with balance of payments constrained growth to show that if the aforementioned structural limitations are not solved, the decarbonization of the economy, be it exogenously imposed by the rest of the world or sovereignly decided by each South American country, will be exposed to the green transition dilemma. The remaining of the paper is organized as follows. After this introduction, in the next section we present a benchmark model representing the historical features exhibited by South American countries. In section 3 we present an export-led model closure to assess the pathways associated with the pursuit of sustained income growth. Two scenarios are analyzed, a hypothetical one where there are no limits to export growth and the other one, more likely, where the world economy embarks on a green transition. Section 4 presents a closure where the country decides to become carbon neutral in the long run and analyzes the implications for prosperity and its determinants. Section 5 builds on the nationally determined carbon neutrality closure to explore how long-run prosperity could be affected by two types of structural change, the first one an “old school” type where the productive matrix is diversified, and the second one along the lines of the “big environmental push” proposed by ECLAC (2016), where Rosenstein-Rodan’s (1943) proposal of planned coordinated investments leading to a more complex productive structure is followed with an environmental sustainability criterion. Section 6 compares the main findings of the different closures and scenarios. Finally, section 7 concludes the paper.

1. An Environmental Lewis-Prebisch-Thirlwall model

The last years have seen important developments in ecological macroeconomics and, more specifically, in the development of models consistently integrating economy-environment linkages. Most of these attempts describe the world economy[2], thereby leaving aside the specificities that small open economies face in the context of the green transition. However, there have also been attempts to incorporate ecological considerations into models describing the perspective of a peripheral economy (Dunz and Naqvi, 2016; Guarini and Porcile, 2016; Althouse et al., 2020; Gramkow and Porcile, 2022). The model presented in this section is closely related to the latter strand of the literature.

The model builds on Porcile and Spinola (2018), who in turn draw on the framework developed by Setterfield (2011). Being a long-run framework, the goal is to explore the properties of the position where the economy would tend to be when the short-run-related noise is absent. Thus, the equilibrium rates derived from the model can be interpreted as those attainable in a sustainable way, i.e., in a situation where all the constraints embedded in the model are being fulfilled. In particular, the aim of Porcile and Spinola (2018) is to explore the alternative closures that ensure that long-run demand-driven growth is consistent with the balance of payments constraint and with supply-side conditions (in other words, they define different adjustment mechanisms through which the natural, the effective and the balance of payments equilibrium growth rates are equalized in the long-run).

In this paper, we take the Lewis-Prebisch-Thirlwall closure proposed by Porcile and Spinola (ibid), implying that long-run economic growth is determined by the balance of payments equilibrium as suggested by Thirlwall (1979) for the reasons originally laid down by Prebisch (1950). Thus, the long-run aggregate demand growth will find an upper limit in the balance of payment equilibrium. Following Lewis' (1954) contributions, a two-sector economy is assumed: a modern sector with high wages and a traditional and predominantly informal with a large "reserve army" and, hence, with low wages. The Lewisian element of the model is given by the way the supply side adjusts to demand. It is assumed an infinite elasticity of labour supply to the relative wage between sectors, implying that the labour supply (and hence the natural rate of growth) is endogenous such that long-run equilibrium between supply and demand is ensured. Porcile and Spinola propose other interesting closures where, for instance, productivity is endogenized so that the supply-side adjustment to demand can be made through a process of structural change. However, given the motivation of this paper it seems more reasonable to assume a static productive structure such that the starting point of South American economies' green transition, as well as the trajectory that brought them to it, is best represented.

[2] For instance, Taylor et al. (2016) build a demand-driven growth model involving capital accumulation and the dynamics of greenhouse gas concentration to examine the macro-economic issues raised by global warming, while Dafermos et al. (2018) build a fully-fledged stock-flow consistent model with a coherent integration of economic and environmental processes to analyze the effects of climate change on financial stability.

The short-run growth rate is demand determined and given by the growth rates of exports x, and the growth rate of domestic demand a, each weighted by the parameters α and β, which are a function of their share of aggregate demand, as proposed by Setterfield and Cornwall (2002). The derivation of this equation can be found in the appendix.

$$y^E = \alpha a + \beta x \tag{1}$$

The growth rate of exports normally depends on the growth rate of the rest of the world y^W multiplied by the income elasticity ε, the rate of depreciation of the real exchange rate $\dot{q}$ and the price elasticity of exports ψ_x. In the long run the real exchange rate is in equilibrium, implying that $\dot{q} = 0$ and that the exports equation can be simplified to $x = \varepsilon y^W$. Since the growth rate of the rest of the world is exogenous and assuming a static productive structure (ε constant), the growth rate of exports can be assumed to be exogenous in the long run.

Balance of payments constrained growth implies, as defined in Thirlwall (1979), that the long-run growth rate of GDP is given by the growth rate of the rest of the world multiplied by the ratio of exports and imports income elasticities (ε and π, respectively). As many authors of the Neo-structuralist school have claimed, the ratio $\frac{\varepsilon}{\pi}$ is a function of the technological capabilities of the economy or, in other words, the complexity of its productive structure. The higher the technological capabilities, the more effectively the economy will respond to the rest of the world´s demand (Araujo and Lima, 2007; Cimoli and Porcile, 2014).

$$y^{BP} = \frac{\varepsilon}{\pi} y^W \tag{2}$$

Being y^{BP}, as suggested by Blecker (2013), the long-run "attractor" of the growth rate of GDP, it is necessary to define how aggregate demand converges to it. Porcile and Spinola (2018) assume that the growth rate of domestic demand converges to the balance of payments equilibrium growth rate at a speed ϕ, as shown in equation (3).

$$\dot{a} = \phi(y^{BP} - y^E) \tag{3}$$

Assuming a production function comprising labour and technology and an unlimited stock of natural resources3, the natural growth rate y^N can be defined as the sum of the growth rate of labour supply n and the growth rate of technology z. The Lewisian closure implies that labour supply is infinitely elastic, thereby closing any gap between production (in turn given by aggregate demand as shown in equation 1 with the binding balance of payments constraint (2)) and productivity growth. A more detailed description of the endogenous adjustment of the supply side, including the determinants of technology growth, can be found in the appendix.

[3] The assumption of limitless natural resources is not realistic. However, it is kept to simply the analysis because, for the period for which the green transition is being debated (need to achieve carbon neutrality by 2050), Latin American countries are not expected to be subject to natural resource depletion. The impact of relaxing this assumption is left for future research.

$$n = y^E - z \tag{4}$$

Net greenhouse gas emissions growth g is given by the growth rate of aggregate demand components (x and a) and their carbon intensity (v_x for exports and v_a for autonomous demand) relative to the average carbon intensity of the economy (v), weighted by their share in output (β_1 and $\tilde{\alpha}$, respectively). The change in greenhouse gas absorptions made by the country's carbon sinks, θ, is also considered in the growth of net greenhouse gas emissions. If the country's carbon sinks absorption capacity is constant, then $\theta = 0$. If the absorption capacity is declining (for instance, due to deforestation), then $\theta < 0$. On the other hand, if the absorption capacity is increasing (for instance, as a result of reforestation or, in the future, geoengineering techniques), then $\theta > 0$. The complete derivation of equation (10) can be found in the appendix.

$$g = x\beta_1 \frac{v_X}{v} + a\tilde{\alpha}\frac{v_A}{v} - \theta \tag{5}$$

Inspired by Jackson and Victor (2020), who claim that a broader measure of wellbeing should be considered instead of per capita GDP, we define a simplified measure of prosperity $P = \frac{(Y/N)^{\sigma}}{(G/N)^{1-\sigma}}$ as a function of income per capita Y^E/N and pollution, which we proxy by per capita greenhouse gases emitted by the country, G/N[4]. The parameter $0 < \sigma < 1$ represents the country's weight of the material and environmental dimensions of prosperity in determining total prosperity. If $\sigma = 0.5$ both dimensions are given the same importance. Equation 6 presents the growth rate of prosperity, p, as an increasing function of the growth rate of demand, and decreasing in the growth rate of population and pollution. Considering equations 1 and 5, the growth rate of prosperity ultimately depends on the growth rates of the components of aggregate demand, their share in it, and their greenhouse gas intensity. As long as the economy has not reached carbon neutrality ($v_X = v_A = 0$, implying that $G = 0$) there will be a trade-off between growth and environmental sustainability – the higher the growth rate of aggregate demand, the higher the resulting pollution levels. The derivation of equation 6 can be found in the appendix.

$$p = \sigma y^E - (1-\sigma)g + n(1-2\sigma) \tag{6}$$

Given the structure of the model the green transition dilemma that South American countries face is already visible. To converge to higher levels of prosperity in the long run a higher growth rate of prosperity is needed in the medium run. Given the population growth rate, this requires that income levels grow at a high rate ($\uparrow y^E$) which, according to Thirlwall's law, would need an increase in the growth rate of exports ($\uparrow x$). Since the carbon intensity of exports of Latin American countries is higher than the one of domestic demand ($v_X > v_A$), the increase in the growth rate of exports would lead to an increase in the rate of growth of greenhouse gas emissions ($\uparrow g$), ultimately undermining the

[4] The sustainable prosperity index constructed by Jackson and Victor (2020) includes GDP per capita, the Gini index, hours worked, households' loan-to-value ratio, the government debt-to-GDP ratio, and the unemployment rate. To make the model as simple as possible the proposed prosperity index is limited to income per capita and domestic greenhouse gas emissions. The reason why only domestic emissions (instead of global) are considered is that to focus on the development policy trade-offs and dilemmas we focus on the variables that the country can directly or indirectly affect.

growth rate of prosperity (or eventually reducing it) and backfiring on the whole development strategy.

On the other hand, the goal of attaining carbon neutrality ($G = g = 0$) would imply, under the current productive structure (given by $\alpha, \beta, \varepsilon$ and π), its carbon intensity (given by υ_X and υ_A) and the absorption capacity (Θ), the need to reduce the growth rate of exports, thereby putting a low upper limit on y^{BP} and, therefore, on y^E and p. Thus, given their productive structure it seems that South American economies cannot simultaneously achieve both higher levels of prosperity and carbon neutrality. At the core of "Gordian knot" is the balance of payments constraint.

3. Closure 1: Exogenously determined Exports

The traditional way South American countries took to obtain the resources they need to finance domestic consumption and, eventually, the investment required to pursue a process of structural change has been the exports of commodities[5]. As mentioned before, it is a feature of natural resources-based activities, especially extractive ones, to have an above-average carbon intensity. Hence, a development strategy based on commodities exports, such that the country can increase its prosperity without hitting the balance of payments constraint, seems to be at odds with the transition toward a zero-carbon economy.

Assuming that the country's exports are exogenously determined by the rest of the world's growth rate times the income elasticity of exports, $x = \varepsilon y^W$, as specified in the previous section. In this case, given the parameters β and v_X there is no mechanism taking the economy to carbon neutrality in the long run. The convergence of the demand-driven output growth to the balance-of-payments equilibrium growth rate is given by equation (3). Still, nothing in this closure caps emissions (like, for instance, NDCs) and, therefore, the growth rate of exports. Note, however, that if the rest of the world embarks in a green transition (either through a de-growth process, represented by a fall in y^W, or by a change in production and consumption patterns, which impacts on the country's exports would be seen through a fall in ε) the country's exports growth could also be negatively affected, thereby making the external constraint more binding and limiting the space to increase prosperity.

In such a situation, where exports grow at an exogenous rate, the country's greenhouse gas emissions growth rate is endogenous, as defined in equation (5). This situation is, as a matter of fact, a description of how the joint evolution of the dynamics of exports and greenhouse gas emissions have been until now. Therefore, the dynamic system consists only of one equation (equation 3). Given that both $\phi, \alpha > 0$, stability will always be attained.

Figure 1 shows the main elements needed to analyze the implications of the export-led prosperity closure. We first use the figure in the left panel and leave the one in the right for later when changes in the societal preferences regarding environmental issues are explored. In the upper quadrant we plot the growth rates of exports, x, and the rest of the elements of aggregate demand, a. The growth rate of exports is exogenously given by ε and y^W. Together with the income elasticity of imports, ε, these two parameters determine the balance of payments equilibrium growth rate which, in turn, defines the long-run equilibrium growth rate of the rest of the components of aggregate demand, $a^* = \frac{x\left(\frac{1}{\pi}-\beta\right)}{\alpha}$. The $\dot{a} = 0$ locus shows the range of possible long-run equilibria. As the expression of a^* shows, the higher the growth rate of exports, the higher the possible growth rates of the rest of the components of aggregate demand, thereby leading to a higher level of total aggregate demand y^E. The slope of the $\dot{a} = 0$ locus is given by the composition of aggregate demand (parameters α and β)

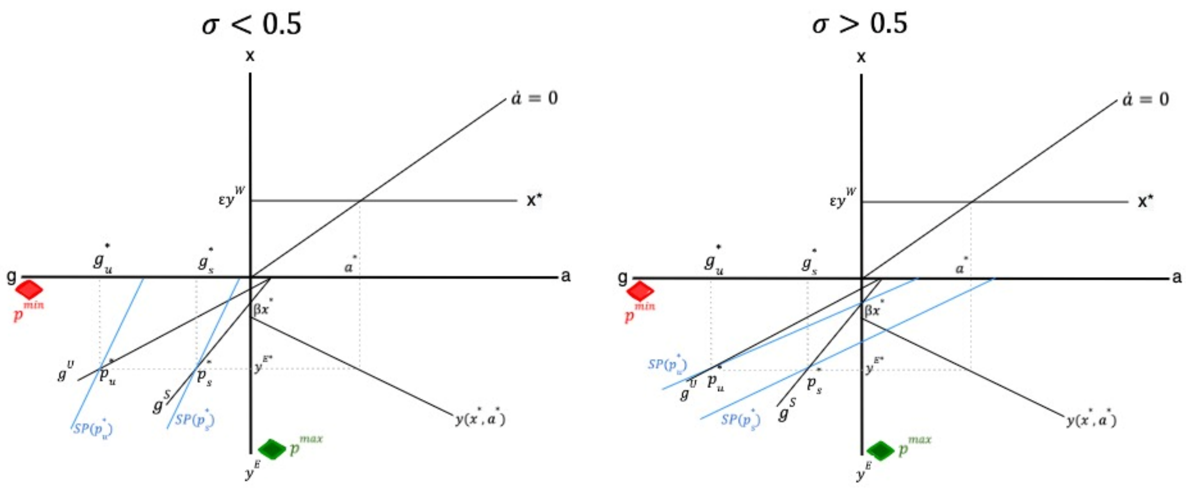
[5] In the last decades capital inflows have become an increasingly important source of financing current account deficits, but as some authors have shown these inflows were to a large extent related directly or indirectly to the country's status of commodity exporters.

and the income elasticity of imports, π. For instance, an economy where exports are not only crucial for growth as a source of foreign exchange but also as a direct source of demand (a high β) would exhibit an $\dot{a} = 0$ locus with a smaller slope, i.e., rotated clockwise compared to the one plotted in Figure 1, and implying a higher possible long-run growth rate of aggregate demand.

Based on the equilibrium growth rates of exports and the domestic demand, the long-run equilibrium growth rate of income is obtained, y^{E^*}. The bottom-right quadrant plots the income growth function as defined in equation 1. The intercept of the function is given by the equilibrium growth rate of exports weighted by β, which is a function of their share on aggregate demand. The higher the growth rate of exports, the higher the possible attainable growth rate of income, as the balance of payments constraint becomes less binding. The slope of the function is positive and given by α, showing that for a given equilibrium growth rate of domestic demand, the overall growth rate of income will tend to be higher the larger the share of domestic demand on aggregate demand.

Based on the long-run equilibrium growth rate of demand obtained in the bottom-right quadrant it is possible to derive the associated growth rate of pollution (emissions) using equation 5. This is represented in the bottom-left quadrant, where the two varying arguments of the prosperity growth function, $y^E$and g (we will let n be constant all over the subsequent experiments), are defined in the axes. For illustrative purposes two alternatives are shown. The first one is the more environment-friendly or sustainable, which we call g^S, is given by either low levels of the carbon intensity of exports, v_X, or of the domestic demand, v_A, by a high absorption capacity of the country's carbon sinks, Θ, by a high weight on aggregate demand of carbon-intensive activities, or by a combination of all these elements. The second pollution function, which we call g^U, has the opposite features, thereby representing an environmentally unfriendly or unsustainable structure. The intercept of these two functions is negative (the exact value given by $-\theta$) because if output growth were zero, emissions growth would be negative (if $\dot{\Theta} > 0$). Projecting the long-run equilibrium growth rate of aggregate demand y^E into the bottom-left quadrant we find the long-run growth rate of pollution, which is g_S^* for the sustainable case and g_u^* for the unsustainable one. As it can easily be observed, $g_S^* < g_u^*$, implying that for the same long-run growth rate of aggregate demand, prosperity growth will be higher in the (y^{E^*}, g_S^*) equilibrium, as higher greenhouse gas emissions are negatively related to prosperity.

Figure 1. Equilibrium prosperity with exogenous export growth



Source: self-elaborated.

Recalling that prosperity growth was defined as dependent on income and pollution growth rates (equation 6), the level curves of the prosperity growth function can also be drawn in the bottom-left quadrant. Following Jackson and Victor (2020) we call these curves *SP*, standing for sustainable prosperity. From equation (6) it is derived that these level curves are linear, as illustrated in the blue lines. Their intercept depends on the growth rate of prosperity and the societal preferences regarding the weight of the material and environmental dimensions of prosperity. Higher (desired) prosperity growth rates (like, for instance, p_S^*) would be located in more rightward curves (like $SP(p_S^*)$), showing that for a given growth rate of income (y^{E^*}) lower (even negative) growth rates of greenhouse gas emissions would be required. On the contrary, a low growth rate of prosperity (like p_U^*) would mean that the same growth rate of income could coexist with higher growth rates of greenhouse gas emissions. In a similar vein, if society prioritizes income growth over pollution reduction ($\sigma > 0.5$), the growth rate of income per capita y^{E^*} can be attained tolerating higher growth rates of emissions, as the steeper level curves in the right panel show. Conversely, when society weighs more on environmental sustainability ($\sigma < 0.5$) the income growth rate y^{E^*}needs to be attained with lower pollution growth, as the flatter curves in the left panel show. The sustainable prosperity curves are drawn for both equilibrium levels of prosperity, g_S^* and g_u^*, which correspond to two different economic structures. As mentioned before, $p_S^* > p_u^*$, implying that the combinations of income and pollution growth comprised in the $SP(p_S^*)$ curve are higher than the ones contained in the $SP(p_u^*)$ curve.

Maximum prosperity growth is achieved when long-run income growth is high (implying that the country has enough room to catch up with developed countries) and greenhouse gas emissions growth is zero. In a growing economy this would require that carbon intensities υ_X and υ_A are zero or, if they are not, that the growth rate of absorption θ fully compensates the growth rate of gross emissions. This scenario is represented by the p^{max} point[6], which is located slightly to the right of the axis to show that in the best-case scenario the growth rate of emissions could be mildly negative. On the contrary, the worst-case scenario is where even extremely low long-run income growth rates produce very high pollution growth rates. This could result from a combination of high carbon intensity with high non-production-related emissions (a negative Θ). This adverse situation is represented by the p^{min} point. Thus, the closer the *SP* curves and their associated equilibrium levels of prosperity locate to p^{max}, the higher the long-run prosperity attainable by the country, because the equilibrium growth rate of prosperity p^* would be higher. However, given their reliance on natural-resources-based activities it is likely that most Latin American economies, mainly those heavily dependent on extractive activities, locate themselves closer to p^{min}.

3.1 Scenario 1: Export-led driven prosperity

From the analysis of Figure 1 it is straightforward that if the country could pursue an export-led growth strategy to increase income levels and, therefore, prosperity, this would come at the cost of increasing pollution. Assume that the country faces an infinitely elastic demand for exports, such that whatever amount of goods the country produces it finds external demand for them. This could be the case for the producers of highly-demanded primary goods such as soy-derived products, critical minerals (copper, lithium, nickel, etc.) and also fossil fuels. If the economy increases its production and, therefore, its exports, the x^*schedule would shift upwards, allowing for a higher growth rate of domestic demand and, consequently, a higher growth rate of income. This would be reflected in a downward shift of the $y(x^*, a^*)$ schedule. The resulting higher y^{E^*}would, in turn, be associated with a higher growth rate of greenhouse gases, regardless of the economy being more or less carbon-intensive (i.e., whether the relevant emissions curve is g^S or g^U). As long as the country's notion of prosperity weighs more on income than on environmental issues ($\sigma > 0.5$) the export-led growth strategy is prosperity-enhancing. But if societal preferences drifted more toward caring for the environment ($\sigma < 0.5$) the export-led growth strategy would end up being detrimental to the goal of increasing prosperity. This can be observed in the figure on the left panel, where the flatter shape of the prosperity curves implies that the resulting equilibrium prosperity levels would be in a SP curve farther from p^{max}.

[6] The possibility of a permanently high prosperity growth rate, as the one in the surroundings of p^{max}implies, might look counterintuitive. If an economy managed to maintain a sequence of high prosperity growth rates, this would gradually converge to the world's standard prosperity levels. As this convergence takes place, the growth rate will necessarily decelerate. Otherwise, there would be ever-increasing, limitless, prosperity. The mechanism that would eventually ensure convergence is the natural rate of growth – if demand permanently grows at high rates eventually the historically abundant labour supply in Latin American countries will become scarce and limit the continued output expansion. This stabilizing constraint was made not binding in the current closure to focus on Latin America's historical barriers to sustained growth (the external constraint).

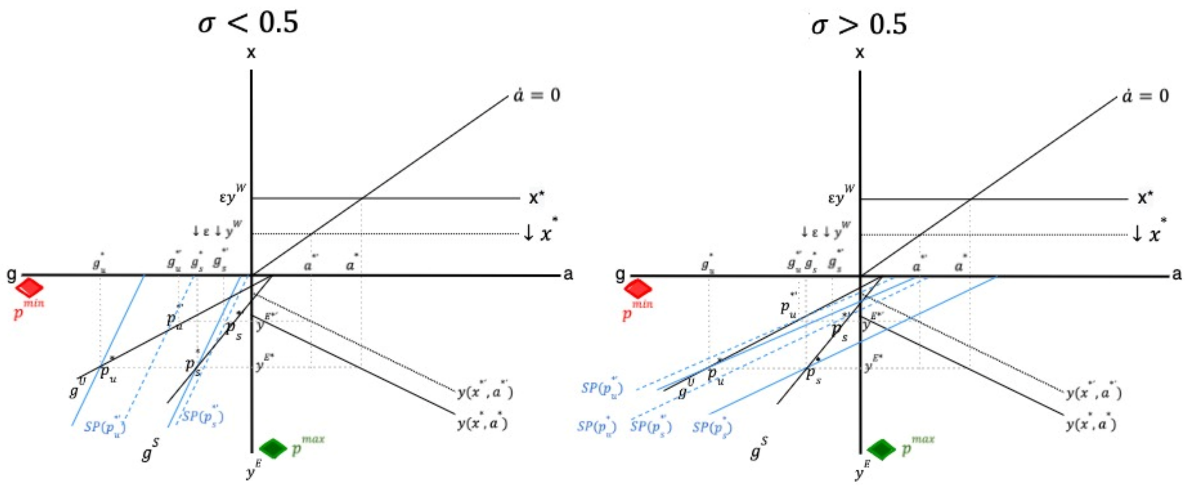
3.2 Scenario 2: Global green transition

To see the tensions that the green transition and the external constraint entail, assume that the growth rate of exports falls as part of the world economy converging to a zero-carbon economy. As mentioned before, this could take the form of either a de-growth process, represented by a fall in y^W, or a change in production and consumption patterns, resulting in a drop of ε. The impact of such a scenario is represented in Figure 2 where, as before, the right panel assumes a social preference of income over the environment when defining prosperity, and the left panel illustrates the opposite case.

First, there is a downward shift in the x^*curve of the top quadrant, implying a tighter balance of payments constraint. This, in turn, shifts the $y(x^*, a^*)$ schedule upwards in the bottom-right panel, implying a reduction in the long-run growth rate of domestic demand and, consequently, of income y^{E^*}. Note that $y^{E^{*'}} < y^{E^*}$, i.e., the economic dimension of prosperity is negatively affected permanently. This lower long-run income growth rate entails a lower growth of production, which, given the structural parameters of the economy, is associated with lower growth of greenhouse gas emissions. Note that this will be the case regardless the economy's productive structure is more or less environmentally sustainable, i.e., whether pollution is defined by the g^S or the g^U lines. The equilibrium prosperity under this new scenario of global green transition would be $p_S^{*'}$ if the emissions function is g^S, and $p_u^{*'}$ if the emissions function is g^U, with the corresponding growth rates of pollution being $g_S^{*'}$ and $g_u^{*'}$, respectively.

Suppose the measure of prosperity gives more weight to income. In that case, the overall effect on the growth rate of prosperity will be negative ($p_S^{*'}$ and $p_u^{*'}$ are located in a more leftward situated SP curve in the right figure). The opposite will happen if society weighs more on environmental sustainability. In this case, the new growth rates of prosperity are found in a more rightward SP curves, as shown in the left panel. The main conclusions drawn from the figure are the following. First, as happened before, prosperity in $p_S^{*'}$ is higher than in $p_u^{*'}$ because income growth is the same while pollution is lower. This result is independent on the societal preferences regarding the material and environmental dimensions of prosperity. Second, if the rest of the world transitions toward a zero-carbon economy, the long-run equilibrium income growth rate will decrease, but so will pollution. This may lead to higher or lower prosperity growth rates depending on society's preferences, but it should be borne in mind that even when $\sigma < 0.5$ and prosperity increases, the economic implications of the situation described in the scenario would go against the need of resolving the region's most pressing pending tasks.

Figure 2. Equilibrium prosperity with exogenous export growth and global green transition



Source: self-elaborated.

4. Closure 2: Carbon Neutrality

In the cases analyzed so far no commitment of the country is assumed regarding achieving carbon neutrality at a specific point in the future. The green transition scenario examined in that case consisted of the consequences the domestic economy would face should the rest of the world embark on a process like this. We now analyze the case where the country deliberately transitions toward a zero-carbon productive structure. Such a scenario would imply that in the long run, $g = 0$. From equation (5) it can be seen that for that to happen something else would have to adjust, i.e., be determined endogenously.

To begin with, let us assume a static productive structure implying fixed values for α, β, v_a and v_x. In this case, it is either exports or domestic demand that have to adjust to the carbon neutrality goal. Since the latter are already defined such that the economy's growth rate is consistent with the balance of payments equilibrium, it is the growth rate of exports the adjustment variable. Let us call ρ the speed of adjustment of this "green transition", i.e., how fast the rate of growth of exports adjusts to the discrepancy between the country's carbon sinks capacity to absorb greenhouse gases from the atmosphere (which is relatively constant) and the economy's emissions resulting from production.

$$\dot{x} = \rho\left(\theta - x\beta_1\frac{v_X}{v} - a\tilde{\alpha}\frac{v_A}{v}\right) \tag{7}$$

Recalling the dynamic equation for the growth rate of autonomous expenditures (3) the following system can be defined:

$$\dot{a} = \phi\left(x(\frac{1}{\pi} - \beta) - \alpha a\right)$$

$$\dot{x} = \rho\left(\theta - x\beta_1\frac{v_X}{v} - a\tilde{\alpha}\frac{v_A}{v}\right)$$

The Jacobian is given by $J = \begin{vmatrix} -\phi\alpha & \phi(\frac{1}{\pi} - \beta) \\ -\rho\tilde{\alpha}\frac{v_A}{v} & -\rho\beta_1\frac{v_X}{v} \end{vmatrix}$

Given that the trace of the Jacobian is negative the first stability condition is satisfied. The second stability condition requires that the determinant is positive. Given the system's structure, this requires that $\frac{1}{\pi} > \beta$. According to the World Bank, in 2021 the average β for Latin American countries hit a historical maximum, reaching 0.276 (the historical average for the period 1960-2021 is 0.2). The various estimates that have been carried out to measure π values range between 1 and 3, implying that

$0.3 > \frac{1}{\pi} > 0.5$. Therefore, it is plausible that the system is stable. The equilibrium values for the growth rates of exports and autonomous demand are given by:

$$x^* = \frac{\theta \alpha \upsilon}{\alpha \beta_1 \upsilon_x + \left(\frac{1}{\pi} - \beta\right) \tilde{\alpha} \upsilon_a}$$

$$a^* = \frac{\frac{\theta \alpha \upsilon}{\alpha \beta_1 \upsilon_x + \left(\frac{1}{\pi} - \beta\right) \tilde{\alpha} \upsilon_a} \left(\frac{1}{\pi} - \beta\right)}{\alpha}$$

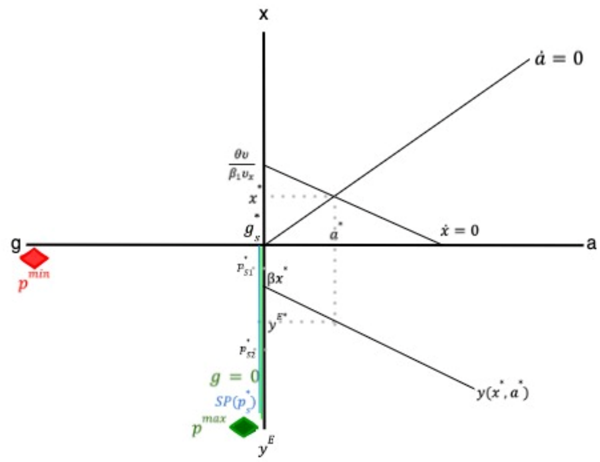
Setting carbon neutrality as a binding constraint implies that all equilibrium values of income will fulfill this environmental condition. This implies that the environmental dimension of prosperity growth will not only be the same for all equilibria but also take the value $g = 0$. In other words, the different prosperity levels associated with different scenarios will be entirely given by the differences in income.

Figure 3 shows the dynamics of the growth rates of exports and autonomous demand when long-run carbon neutrality is imposed. As in the previous closure, the $\dot{a} = 0$ locus is upward sloping because as the growth rate of exports is higher, the balance of payments equilibrium growth rate increases allowing domestic demand to grow faster. Now, the $\dot{x} = 0$ locus is no longer independent of the rest of the system's variables. In line with equation 7, it is downward sloping because the higher the growth rate of domestic demand, the lower the growth rate of exports must be to maintain carbon neutrality. The intercept of the exports growth rate function is no longer given by the Thirlwall's law parameters ε and y^*, but by the country's carbon sinks' absorption capacity growth rate θ, the share of exports in aggregate demand β_1 and exports' GHG intensity relative to the economy's GHG intensity, $\frac{\upsilon}{\upsilon_X}$. For realistic values of the parameters is will be the case that $\varepsilon y^* > \frac{\theta \upsilon}{\beta_1 \upsilon_X}$, implying that that intercept of the export growth function will be lower in the carbon neutrality scenario than in the cases where there is no self-imposed carbon neutrality. This is intuitive, as carbon neutrality would limit the growth of exports to the balance between their carbon intensity and the economy's carbon sinks absorption capacity. Far from implying that the relaxation of the external constraint, these changes in the exports growth function make it even more binding, as the country would limit itself to export to the point consistent with carbon neutrality, even if the rest of the world's demand exceeds that threshold.

Given $g = 0$, we no longer have the different possible g curves in the $y^E - g$ space. Therefore, the $g = 0$ function will overlap with the axis, as shown with the green line next to the y^E axis. The fact that there is only one greenhouse gases emission function does not imply that a single productive structure is allowed for (the parameters $\alpha, \beta, \upsilon_a, \upsilon_x$ can still take different values) – instead, it is imposed that regardless the values of the parameters exports will always adjust to achieve carbon neutrality in the long-run. As shown in equation 7, the economy's structure as reflected by the parameters will determine the dynamics of the convergence to the long-run equilibrium characterized by carbon neutrality.

Since all the possible equilibria in this scenario share the feature $g = 0$, prosperity is determined entirely by the growth of income y^E. Consequently, the level curves of the prosperity function will also overlap with the y^E axis, as shown with the blue line next to (it should actually be overlapping, but for illustrative purposes, it is plotted slightly to the left). Given $g = 0$ and y^{E^*}, the prosperity growth will be given by the subjective parameter σ. A society with a preference for environmental sustainability over income would have an equilibrium prosperity index like p^*_{S2}, consistent with the long-run equilibrium $(y^E, g^*_S = 0)$. A country weighing more on the income dimension would find that the same long-run equilibrium combination of income growth and carbon neutrality is associated with a lower level of prosperity, as p^*_{S1}. The higher the weight of the economic dimension on the notion of prosperity, the stronger the trade-off between carbon neutrality and socio-economic well-being will be. This is likely to be the case in South American countries, for which a notion of prosperity where a sustained increase in income levels is not prioritized seems to be an unaffordable luxury. The green transition dilemma, therefore, appears again as a dead end for most South American countries.

Figure 3. Equilibrium prosperity with carbon neutrality



Source: self-elaborated.

Compared to the prosperity growth rates obtained in the previous closures the ones generated in the carbon neutrality scenario will be far from p^{min}. However, it is not evident that carbon-neutrality-consistent prosperity levels will be close to what countries need to provide their population with a decent life. As shown in Figure 3 and the expressions for x^* and a^*, the long-run equilibrium income growth rate in the zero-carbon scenario is strongly determined by the structural parameters. A higher intercept of the $\dot{x} = 0$ schedule would lead to a higher x^*, and so would a smaller slope. Similarly, a smaller slope of the $\dot{a} = 0$ schedule would also bring about higher x^* and a^* , leading to prosperity growth rates closer to p^{max}. Where each economy locates itself in the $y^E - g$ space and how close it would be from p^{max} under each closure and scenario is an empirical question that requires giving the parameters the values representing the corresponding productive structure.

5. Carbon neutrality with structural change

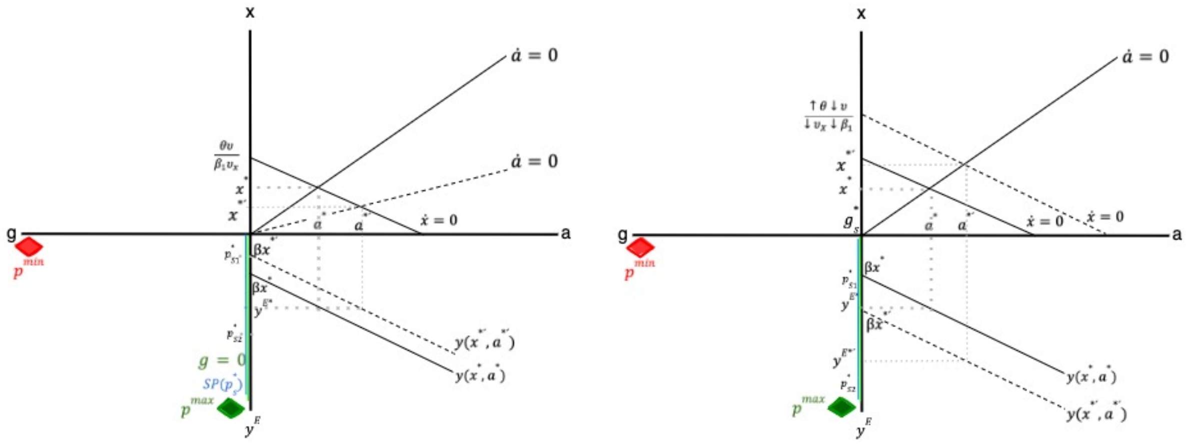
The results so far show that given their current productive structure, heavily based on natural resources-based activities with a high carbon intensity, many South American countries face a dilemma between the long-delayed increase in the living standards of their population and the decarbonization of the economy. The failed attempts to transform their productive structures are at the root of the dilemma. In this section we carry out a few hypothetical experiments to see how the green transition dilemma can be solved if decarbonization is not only pursued by a reduction of carbon-intensive exports (as expressed in equation 7) but also by a process of structural change in the productive matrix.

Assume that the intercept of the $\dot{x} = 0$ locus increases, be it because of an increase in the country's carbon absorption capacity ($\uparrow \theta$), a reduction in the carbon intensity of exports ($\downarrow v_X$), a reduction in a share of exports on aggregate demand ($\downarrow \beta_1$), or a combination of the three. This is represented in the right panel of Figure 4, the result being higher attainable growth rates for both exports and domestic demand, $x^{*'} > x^*$ and $a^{*'} > a^*$. The same result is obtained analytically by computing, for instance, $\frac{\partial x^*}{\partial \theta} > 0$ and $\frac{\partial a^*}{\partial \theta} > 0$. For given values of g (=0) and σ it is straightforward that prosperity increases compared to the scenario with a static productive structure illustrated in Figure 3, thereby getting closer to p^{max} regardless the society's preferences between income and environmental issues. Underpinning this result is the fact that as the country's economic and environmental structure becomes "greener" there is more room for exports to grow faster without jeopardizing the goal of carbon neutrality. In turn, the possibility of increasing the growth rate of exports rises the balance of payments equilibrium growth rate y^{BP}, thereby allowing for a higher growth rate of domestic demand as well, leading to an overall higher y^{E^*}.

However, if neither the country's carbon sinks' absorption capacity nor the carbon intensity of exports and its share on aggregate demand are changed, carbon neutrality would come at the cost of lower prosperity, as the inward (a^*, x^*) point in the right panel of Figure 4 shows when compared to $(a^{*'}, x^{*'})$. In such a scenario, even a positive change in the country's productive structure, which could be represented by a fall in the income elasticity of imports π, could be insufficient to escape the green transition dilemma. As shown in the left panel of Figure 4, a fall in π rotates the $\dot{a} = 0$ locus downwards leading to a higher $a^*$and a lower x^*. These results can be obtained analytically by computing the derivatives $\frac{\partial x^*}{\partial \pi} > 0$ and $\frac{\partial a^*}{\partial \pi} < 0$.

The intuition underlying this result is that the lower income elasticity of imports increases the balance of payments equilibrium growth rate y^{BP}, thereby allowing for a higher growth rate of domestic demand. However, the higher growth of aggregate demand tends to increase the growth rate of greenhouse gases, as none of the factors defining emissions, such as v_a, v_x, θ would have changed. Thus, the fulfilment of carbon neutrality necessarily requires a reduction in the growth rate of exports, thereby leaving the growth rate of aggregate demand unchanged, as shown in the bottom-right quadrant of the left panel. We find that, ultimately, if carbon neutrality is imposed and none of the structural parameters representing the environmental sustainability of the economy is changed, the country is still stuck in the green transition dilemma. In practice, a scenario like this one would require a deliberate attempt of the government to control export-oriented production (for instance, caps on the amount of extracted oil or copper or the stock of animals used in livestock or the surface for agriculture) as the loosening of the balance of payments constraint could tempt the country to increase production to a level incompatible with carbon neutrality.

Figure 4. Equilibrium prosperity with carbon neutrality and structural change



Source: self-elaborated.

6. Discussion

Table 1 summarizes the results that each of the two closures presented in this paper would produce under different scenarios and preferences regarding prosperity's economic and environmental dimensions. The starting point of comparison is the current situation of South American economies. In line with its history, increasing income levels so that the entire population reaps the benefits seems challenging. Suppose this is pursued through an export-led growth strategy like the one that has historically characterized the region. In that case, this will imply the demise of the carbon neutrality goal, even leading to the worst-case scenario regarding environmental sustainability. Still, as is well-known, the continuous growth of exports is beyond the countries' decision. Should the world embark on a green transition, the export-led growth model with its historical specialization pattern would seriously limit the catching up with advanced economies' standards of living.

If, on the other hand, and in line with the commitments undertaken in the Paris Agreements and their recent updates of countries' nationally-determined contributions, South American economies deliberately transition toward a zero-carbon production model, higher long-run prosperity will only be possible if the transition is accompanied by process of green structural change. If no structural change takes place, the decarbonization of the economy will lead to output growth being quickly interrupted by the balance of payments constraint. If structural change occurs following an "old school" style, the focus is on the diversification of the productive matrix and an improvement in technological capabilities. Still, without incorporating environmental sustainability concerns, the result would not be too different from the one found in the cases where the productive structure is static - while the structural change would recede the external constraint, income and output growth would have to be kept within the margins defined by the green transition. Only when structural change includes the decarbonization of the economy, is it possible to simultaneously acquire higher income and environmental sustainability levels and, therefore, increased prosperity. The alternative trajectories that each scenario brings about are illustrated in Figure 5.

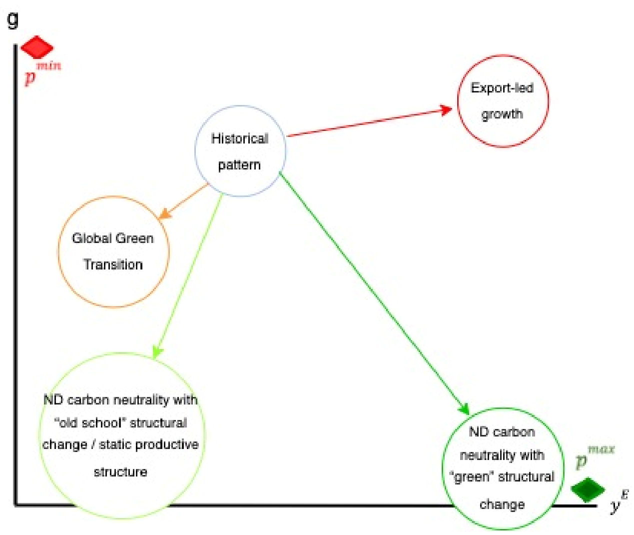
Table 1. Sustainable Prosperity under alternative closures and scenarios

	Export-led Growth		Global Green Transition		Nationally-determined carbon neutrality with static productive structure		Nationally-determined carbon neutrality with "old school" structural change		Nationally-determined carbon neutrality with "green" structural change	
	High σ	Low σ	High σ	Low σ	High σ	Low σ	High σ	Low σ	High σ	Low σ
Economic Prosperity	Higher	Higher	Lower	Lower	Lower	Lower	Lower	Lower	Higher	Higher
Environmental Sustainability	Lowest	Lowest	Higher	Higher	Highest	Highest	Highest	Highest	Highest	Highest
Sustainable Prosperity	Higher	Lowest	Lower	Higher	Lower	Higher	Lower	Higher	Higher	Highest

Source: self-elaborated.

Is there any way South American countries can move along the path leading to sustainable prosperity? One possible alternative could be what ECLAC (2016) has called the "big environmental push", where Rosenstein-Rodan's (1943) proposal of planned coordinated investments leading to a more complex productive structure is implemented following an environmental sustainability criterion. Such a development strategy would require industrial policies that stimulate the dynamic sectors with Keynesian and Schumpeterian7 efficiencies that exhibit can incorporate environmentally sustainable technologies. Ideally, these sectors would also have important forward and backward linkages in the domestic productive structure such that their growth spills over to the entire economy.

Figure 5. Prosperity trajectories in the context of the Green Transition



Source: self-elaborated

According to ECLAC, South America presents advantageous conditions to launch a big environmental push if designed following the principles of the bioeconomy[8].

7 The concept of Keynesian and Schumpeterian efficiencies has been proposed by Dosi et al (1990) and refers to the possibility of changing the income elasticity of exports of a small open economy as a result of two distinct phenomena: demand-side effects of export growth (Keynesian efficiency) and the ability of a country to dynamically adjust to the evolution of demand and technology, as well as to sequentially move towards sectors in which demand grows faster (Schumpeterian efficiency).

8 Which consists of using technological advances to imitate the behavior that organisms have for adapting to different environmental conditions and processing their wastes (Rodríguez et al., 2017; Adamowicz, 2017 y Dubois y Gomez, 2016). This concept was initially proposed by Nicholas Georgescu-Roegen (1977) to highlight the biological origin of economic processes to "spotlight the problem of mankind's existence with a limited store of accessible resources, unevenly located and unequally appropriated" (Georgescu-Roegen, 1977, p. 361). More recently, the European Commission has stated that the bioeconomy includes the "production of renewable biological resources and the conversion of these resources and waste streams into value-added products such as food, feed, biobased products and bioenergy" (European Commission, 2012).

"*The bioeconomy embraces many interconnected value chains: all agricultural, forestry, fishery and aquaculture activities, the food and beverage industries, and the pulp and paper industry, as well as segments of the chemicals, pharmaceuticals, cosmetics, textiles and energy industries. The region has comparative advantages in this area, thanks to the wealth of its biodiversity (genetic potential), its capacity to produce biomass without compromising natural forests, and the great quantities of agricultural and agro-industrial wastes that go unused. The bioeconomy offers options for rural development and job creation through biomass farming, the development of value chains based on non-food biomass and wastes (bio-inputs for agriculture), and the development of knowledge-based SMEs as part of these value chains*" (ECLAC (2016), p. 164).

7. Conclusions

This paper was written based on three historical premises. First, despite the sporadic increases in the standard of living of their population, South American economies have failed to close the gap with developed countries, being their peripheral condition (with both its real and financial implications) a structural barrier in the quest for higher prosperity levels. This limitation has regularly manifested itself through balance of payments crises or, more recently, new forms of external vulnerability (Kaltenbrunner and Painceira, 2018). Second, these structural limitations have not been removed, the export basket of the region still being significantly dependent on natural resources-based products. Third, there is a commitment of countries to transition toward a low-carbon economy.

Based on these premises it is argued that the region faces a green transition dilemma. The attempt to preserve external sustainability so that the economy can finance all the investments that increasing prosperity requires would need the sustained exploitation of natural resources, which would, in turn, imply the demise of the environmental sustainability goal. On the other hand, compliance to decarbonize the economy would require a lower growth rate of exports (or even a decrease of it) which would make the external constraint more binding, thereby limiting the room for increasing prosperity.

Using a theoretical demand-led balance of payments constrained growth model we explored different scenarios representing the green transition. It is shown that as long as the limitations that historically characterized the productive structure of South American countries, the attainment of the so-long-desired increases in prosperity levels will continue to be unfinished business. Only through a process of green structural change, along the lines of a big environmental push or a strategy alike, will the quest for sustainably high living standards become an actual possibility. Its likelihood will depend on the external conditions and the government and the private sector's leaders' dexterity.

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There are no relevant financial or non-financial competing interests to report.

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Appendices

A. Derivation of the effective rate of growth

Aggregate demand is composed of domestic demand A and net real exports $X - eM$, where $e = \frac{EP^W}{P}$ is the real exchange rate, E is the nominal exchange rate, P^W is the foreign price index and P is the domestic price index.

$$Y = A + X - eM \tag{A.1}$$

The demand for exports and imports are given by:

$$X = e^{\mu_X} Y^{W^{\varepsilon}} \tag{A.2}$$

$$M = e^{\mu_M} Y^{\pi} \tag{A.3}$$

Where μ_X and μ_M are the price elasticities of exports and imports, and ε and π the income elasticities, respectively, and Y^W is the foreign income level. Taking logs and differentiating with respect to time, and assuming a constant real exchange rate in the long run, we get:

$$y = \tilde{\alpha} a + \beta_1 x - \beta_2 m \tag{A.4}$$

Where y, a, x and m are the growth rates of aggregate demand, domestic demand, exports and imports, respectively, $\tilde{\alpha} = A/Y$, $\beta_1 = X/Y$ and $\beta_2 = M/Y$. Using the definition of X and M in the equation for y we get:

$$y = \frac{\tilde{\alpha} a + \beta_1 \varepsilon y^W}{1 + \beta_2 \pi} \tag{A.5}$$

Defining $\alpha = \frac{\tilde{\alpha}}{1+\beta_2\pi}$ and $\beta = \frac{\beta_1}{1+\beta_2\pi}$, and $x = \varepsilon y^*$ the equation for the effective rate of growth can be rewritten as follows:

$$y^E = \alpha a + \beta x \tag{A.6}$$

B. The supply side

The growth of labour supply depends on population growth $\bar{n}$ and the wage rate of the economy W. This wage rate is defined as the ratio of wages in the modern sector of the economy and the wage in the subsistence sector or in other (lower wage) countries.

$$n = \bar{n} + \sigma(W) \tag{B.1}$$

The wage rate depends on the employment rate in the modern sector $E = L/N$, where L and N are labour demand supply, respectively.

$$W = \varpi(E) \tag{B.2}$$

The rate of growth of productivity is given by the Kaldor-Verdoorn law, which Porcile and Spinola (2018) proxy through the rate of employment in the modern sector. Other determinants of productivity growth are complementarities and externalities arising from the flow of knowledge across sectors, which are proxied by the income elasticity of exports, ε, the technology gap, T, and the domestic efforts at technological learning by doing, s.

$$z = z(E, \varepsilon, T, s) \tag{B.3}$$

At every point in time labour demand L is given by effective demand Y^E and the state of technology Z, which defines productivity. Thus, the growth rate of labour demand l can be defined as the difference between the growth rate of effective demand and technology.

$$l = y^E - z \tag{B.4}$$

From the definition of the employment rate $E = L/N$ we know that $e = l - n$, where e is the growth rate of the employment rate, which in the steady state must be zero. Substituting the definition of l into the equation of e we obtain:

$$e = y^E - y^N \tag{B.5}$$

This equation for the growth rate of employment implies that given the rate of growth of technology, labour supply and aggregate demand, at every point of time the rate of growth of the employment rate will adjust such that equilibrium between supply and demand is attained. As mentioned before, since in the long run equilibrium y^E is by definition equal to y^N, the condition stating that $e = 0$ will also hold.

The Lewisian closure implies that labour supply is infinitely elastic ($\sigma = \infty$), thereby closing any gap between production (in turn given by aggregate demand as shown in equation 1 with the binding balance of payments constraint (2)) and productivity growth

$$n = l = y^E - z \tag{B.6}$$

C. Derivation of the rate of growth of greenhouse gas emissions

The flow of net greenhouse gas emissions, G, is given by emissions minus absorptions. Emissions, in turn, depend on the production of domestically demanded goods and services, A, and exports, X, weighted by their respective carbon intensities, $v_A = G_A/A$ and $v_X = G_X/X$. Absorptions are represented by the parameter Θ.

$$G = Xv_X + Av_A - \Theta \tag{C.1}$$

The time change in net emissions is given by:

$$\dot{G} = \dot{X}v_X + \dot{A}v_A - \dot{\Theta} \tag{C.2}$$

Dividing by G the growth rate of net greenhouse gas emissions, g, is obtained:

$$g = \frac{\dot{X}v_X}{G} + \frac{\dot{A}v_A}{G} - \frac{\dot{\Theta}}{G} \tag{C.3}$$

Using the definition of v_X and v_A, and defining $\theta = \dot{\Theta}/G$ as the change in the absorption capacity scaled by the size of emissions, the equation for g can be rewritten as follows. It should be borne in mind that if the country's carbon sinks absorption capacity is constant, then $\dot{\Theta} = 0$, implying that $\theta = 0$ as well. If the absorption capacity declines (increases), then $\dot{\Theta} < 0.$ ($\dot{\Theta} > 0$).

$$g = \frac{xG_X}{G} + \frac{aG_A}{G} - \theta \tag{C.4}$$

Using the initial definition of G and dividing both sides through G we get:

$$1 = \frac{Xv_X}{G} + \frac{Av_A}{G} - \frac{\Theta}{G} \tag{C.5}$$

Defining $v = G/Y$ as the average carbon intensity of the economy we get:

$$1 = \frac{Xv_X}{Yv} + \frac{Av_A}{Yv} - \frac{\Theta}{G} \tag{C.6}$$

Recalling that $\tilde{\alpha} = A/Y$ and $\beta_1 = X/Y$, the equation can be rewritten as follows:

$$1 = \beta_1 \frac{v_X}{v} + \tilde{\alpha} \frac{v_A}{v} - \frac{\Theta}{G} \tag{C.7}$$

The derivations above allow us to express the following two relationships:

$$\frac{Xv_X}{G} = \frac{G_X}{G} = \beta_1 \frac{v_X}{v} \tag{C.8}$$

$$\frac{Av_A}{G} = \frac{G_A}{G} = \tilde{\alpha} \frac{v_A}{v} \tag{C.9}$$

Finally, we can use these relationships to express the equation for the growth rate of net emissions, g, as follows:

$$g = x\beta_1 \frac{v_X}{v} + a\tilde{\alpha} \frac{v_A}{v} - \theta \tag{C.10}$$

D. Derivation of the rate of growth of prosperity

The prosperity index was defined as follows:

$$P = \frac{(Y/N)^{\sigma}}{(G/N)^{1-\sigma}} \quad \text{(D.1)}$$

Taking logs and differentiating with respect to time the growth rate of prosperity is defined as follows:

$$p = \sigma(y^E - n) - (1 - \sigma)(g - n) \quad \text{(D.2)}$$

Where y^E, n and g are the growth rates of effective demand, the population and greenhouse gas emissions, as defined in the paper. Rearranging terms the equation can be expressed as follows:

$$p = \sigma y^E - (1 - \sigma)g - n(1 - 2\sigma) \quad \text{(D.3)}$$

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