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Low-carbon Transition and Macro-economic Vulnerabilities

A Multidimensional Approach in Tracing Vulnerabilities and its Application in the Case of Colombia

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Low-carbon Transition and Macroeconomic Vulnerabilities

A Multidimensional Approach in Tracing Vulnerabilities and its Application in the Case of Colombia

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Abstract
The transition to a low-carbon and climate resilient economy is a process of heavy restructuring of the productive network, during which sunset industries are in decline or even disappear, while sunrise industries emerge and flourish. This process affects all aspects of the economy: the demand and the supply side, the public and the private sector, the financial structure and the informal economy. In this paper, we propose a holistic framework that assesses the macroeconomic vulnerability that emerges from a low-carbon transition, especially in developing economies. We consider vulnerability as a multidimensional phenomenon and, thus, pay attention to all fiscal, social, monetary, financial and external dimensions of the economy. We, then apply this framework to the Colombian economy. We use indicative variables of vulnerability, in all its aspects, and a stock-flow consistent growth model in order to monitor their evolution across time. We consider two scenarios related to a reduction of real fossil fuel exports of Colombia and a global rise in the interest rates. Results indicate that the more delayed is the global transition, the higher the vulnerability of the Colombian economy. Similarly, global monetary tightening becomes an obstacle in the transition process, as it induces vulnerability stemming from the financial and external side of the economy.

Keywords
Low carbon transition, Macroeconomic Vulnerabilities, Development trajectories, Stock-flow Consistent, Colombia

Jel codes
E60, Q58, F18

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Résumé
La transition bas carbone et résiliente au changement climatique implique un processus de restructuration profond du tissu productif, au cours duquel les industries émissives déclinent ou même disparaissent, tandis que les industries en plein essor dites « sunrise » émergent et prospèrent. Ce processus affecte tous les aspects de l'économie : la demande et l'offre, le secteur public et le secteur privé, la structure financière et l'économie informelle. Dans cet article, nous proposons un cadre holistique qui analyse la vulnérabilité macroéconomique qui émerge d'une transition bas carbone, en particulier dans les économies en développement. Nous partons du principe que la vulnérabilité est un phénomène multidimensionnel et, par conséquent, nous prêtons attention à toutes les dimensions fiscales, sociales, monétaires, financières et externes de l'économie. Nous appliquons ensuite ce cadre à l'économie colombienne. Nous utilisons des variables indicatives de la vulnérabilité, sous tous ses aspects, et un modèle de croissance stock-flux cohérent afin de suivre leur évolution dans le temps. Nous partons de deux scénarios liés à une réduction des exportations réelles de combustibles fossiles de la Colombie et à une hausse mondiale des taux d'intérêt. Les résultats indiquent que plus la transition globale est tardive, plus la vulnérabilité de l'économie colombienne est élevée. De même, le durcissement monétaire mondial devient un obstacle au processus de transition, car il induit une vulnérabilité provenant du côté financier et externe de l'économie.

Mots-clés
Transition bas carbone, vulnérabilités macroéconomiques, trajectoires de développement, Modélisation stock-flux cohérente, Colombie

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Introduction

The pressing issue of climate change has expanded the relevant research agenda, covering not only its impact on physical and biological systems, but also its socio-economic implications. The rising global temperature and the intensification of extreme weather events are expected to affect the economy in multiple manners. The productive capacity of the economies, investment and the balance sheets of the institutional sectors are likely to deteriorate. In addition, they will disrupt trade flows, boost the volatility of prices and financial markets and exacerbate poverty and inequality, especially in developing economies (see, e.g., Semieniuk et al. 2021).

In this sense, the transition strategies, established in the COP21 commitments (UNFCC 2015), aiming to mitigate greenhouse gases (GHG) emissions and enhance the resilience and capacity of societies to cope with climate change are essential for any development agenda. Being a complex process, the transition to a low-carbon economy generates tensions and conflicts on both micro and macro levels and imposes constrains to growth. Macroeconomic policies should aim to minimize or solve such tensions in a way that the adaptation to a clean economy becomes a socially just, intra and intergenerational productive transformation. Nevertheless, the degrees of freedom of policymakers to achieve this policy objective are heavily affected by climate-related risks and their impact on the macro-financial conditions. Macroeconomic policies must on the one hand promote favorable conditions for an orderly adjustment to a low carbon path, and on the other to respond to the negative effects that climate events and transition policies might have on the economy.

In this context, vulnerability assessments are a key tool in analyzing how climate-related stressors and transition strategies affect the economy. They, further, assist in understanding how the exposure and the coping capacity of the economy is amplified, or diminished, by non-climatic factors. These non-climatic factors could be related to the level of economic development, the structure of the economy and its pattern of international insertion, the orientation and role of the State within the economy, and the level of priority of environmental issues within the hierarchy of objectives and management of economic policy.

This approach is essentially multifactorial, as vulnerability is not a univocal and directly observable characteristic. It cannot rely on an aggregate indicator or exclusively on quantitative considerations. Instead, there is a multiplicity of potential risks on macro-economic and social conditions, which require deliberation about weighing and prioritizing objectives and evaluating possible intra and intertemporal trade-offs.

This paper aims to propose a multidimensional approach in monitoring the vulnerability of the macro-financial system, emphasizing three major aspects of the economy: a) the fiscal and social conditions, b) the monetary and financial conditions and c) the vulnerability of

the economy *vis-à-vis* the external sector. The proposed approach provides an explicit framework for understanding and evaluating the associated constraints and leeway in terms of policymaking, aiming for a socially fair and smooth transformation. Many similar attempts have been proposed at the service of the same, or similar, goal (see, e.g., Naude et al. 2008; Semieniuk et al. 2021; BIS 2021; Magacho et al. 2023). Our approach differs in that it provides a more holistic view in assessing macroeconomic vulnerability, in a dynamic framework.

We further apply the proposed approach to the Colombian economy. With the use of a continuous time stock-flow consistent growth model we examine how the Colombian economy would respond in two external shocks. In the first case, we examine how the economy would respond in a gradual decrease of its oil exports vs. a sudden decrease, though of the same cumulative magnitude. In the second case, we further assume a global rise of interest rates, due to monetary tightening in the Global North and a simultaneous increase of the interest rate and the country risk, as perceived by the rest of the world. We utilize radar plots in order to manifest how multiple vulnerability indicators evolve in each case. Our results indicate that the Colombian economy would experience a larger, yet temporal, shock if the transition process is delayed, while it would become more vulnerable if the global monetary conditions are tight.

The paper is organized in the following manner. Section two provides a rigorous and analytic definition of macroeconomic vulnerabilities, also highlighting the importance of multifactorial analysis in monitoring vulnerabilities. Section three exposes the factors that are taken under consideration and provides a brief description of the analytical framework employed in order to estimate the evolution of the vulnerability indicators across time. Section four presents and discusses the associated results, while the ultimate section concludes.

1. Vulnerability and macroeconomic policies in a multidimensional framework

The vast majority of the relevant literature is focused on the impact of green policies, such as taxes, subsidies, or public investment, on GDP and employment (see, e.g., Stern 2007; Bezdek et al. 2008; Rayment et al. 2009; Pollin 2015; Hafstead and Robertson 2018). Financial repercussions of transition policies are also taken into account, as well as other factors such as the feasibility of degrowth policies, State-led innovation and the transformation of the energy sector (see, e.g., Batten, 2018; Feyen et al., 2020). Nonetheless, in most cases the analytical framework addresses specific research questions, thus not providing a socio- and economy-wide view on vulnerabilities.[1]

As noted by Magacho et al. (2023), transition strategies implemented both domestically and globally could affect macroeconomic conditions on multiple fronts, inducing risks at the external, monetary, financial, and fiscal levels. These potential risks affect the implementation and effectiveness of transition policies, amplify tensions between the public and the private sector and impose further financing and political constraints. Therefore, as a first step it is important to define with rigor and analytical clarity the term vulnerability and its potential application in macroeconomics. Despite the wide variety of analytical approaches regarding the definition and measurement of vulnerability, there seems to be a kind of semi-agreement on the determinants of vulnerability (Cardona Arboleda 2001). Below follow two generic definitions presented in Marre (2013) that can be useful in this analysis:

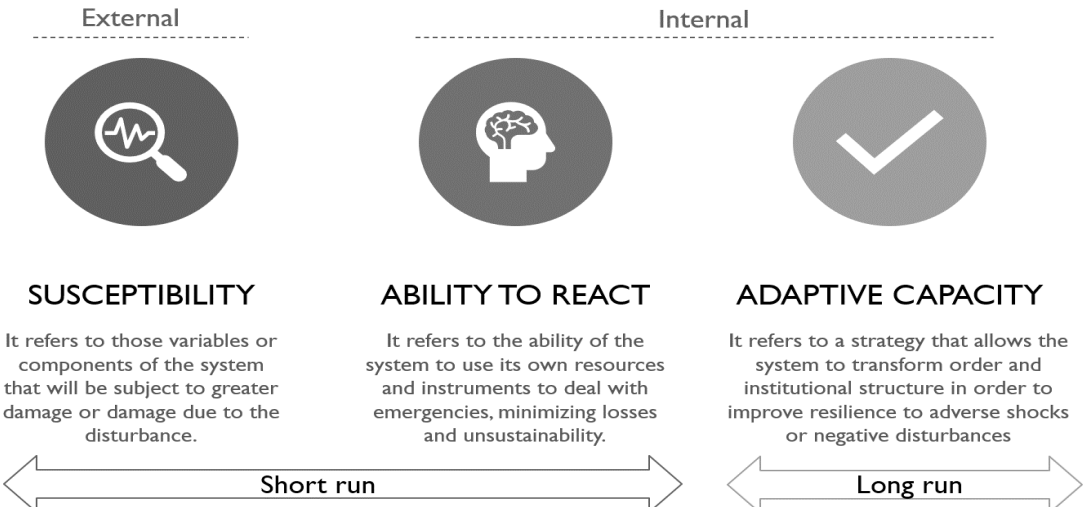
> "Vulnerability is usually defined as the ability of a system to be affected by a disturbance or tension. It is a function of the probability of occurrence of the disturbance and its magnitude, as well as the ability of the system to absorb and recover from it" (Suarez 2002).

> "Vulnerability is the degree to which a system, subsystem, or system components are likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor" (Turner et al. 2003).

According to Welle et al. (2013), vulnerability can be associated with three conditions: susceptibility, ability to react and adaptive capacity. The first one has an external origin and is determined by the exposure to an external threat or danger (disturbance). The second and third ones have an internal nature and capture the capacity of the system to respond to the exposure, either in the short or in the long-run. Figure 1 demonstrates the internal components or vulnerability drivers of a system.

[1] Several macroeconomic vulnerability indicators have been proposed in the literature though very few are strictly related to climate-adaptation risks (see, e.g., Ndirangu et al. 2014; Aikman et al. 2016).

Figure 1. Vulnerability components



Source: Own elaboration based on (Welle, et al. 2013)

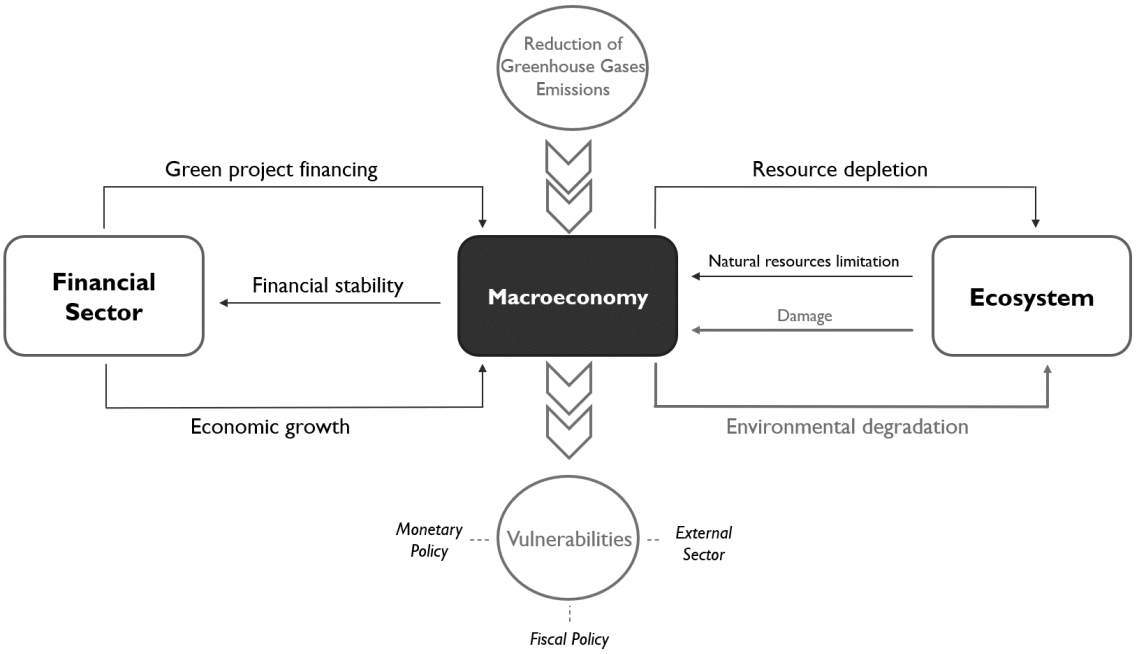
Susceptibility and reaction abilities are short-run system properties. The former refers to those variables or components of the system that will be subject to greater damage or disruption. The latter indicates the capability of the system to use its resources and instruments so as to face emergencies, minimize losses and correct any imbalances. Finally, adaptive capacity refers to a long-term strategy that allows the system to transform its order and its institutional structure, so as to improve its resilience against adverse or negative shocks.

Carley et al. (2018:1) define three interrelated dimensions, similar to the above definition, and apply them to the case of the US energy policies. They define 'vulnerability as a function of where and when these policies go into effect (exposure); the susceptibility of different communities to the impacts of these policies (sensitivity); and the capability of communities to attenuate, cope or mitigate the negative effects (adaptive capacity)'. In this fashion, it would be feasible to construct vulnerability functions, which could highlight the intensity of a shock that hits the system (IDEA 2005).

Figure 2 presents a macroeconomic scheme that integrates the financial sector, the national macro-economy and the ecosystem. We extend the original concept of Dafermos et al. (2017) by adding two elements. The first corresponds to the shock or threat associated with the GHG emissions reduction agreement, which is supposed to affect both the economy as a whole and the ecosystem (through lower damage and environmental degradation). The second indicates that the fulfilment of those commitments affects and puts strain on monetary, fiscal and external sector conditions. The top white

arrows show the impact on the macroeconomy and the bottom white arrows indicate the connection between vulnerability and the respective dimensions.[2]

Figure 2. Vulnerability analysis under macroecological interactions



Source: Own elaboration based on Dafermos et al. (2017)

Policies aiming to mitigate GHG emissions are determined outside the system and depend on political preferences and goals. Their implementation and magnitude, however, depend on specific dimensions and features of the economy, including the feedback of the macro-financial risks that could emerge as a response of the different transition drivers: policies and regulation, technological and structural change, shifts in consumers and investors' preferences. Thus, this approach is not just useful to analyze macroeconomic vulnerabilities linked to the low-carbon transition, but also for proposing environmentally effective mitigation policies with reduced risks and costs.

Ultimately, such an approach would allow reducing the macro-financial risks that could arise during and after the transition, with risk, as exposed in eq. (1), understood as a function of threat and vulnerability (Cardona Arboleda 2001). Despite the merit of simplicity, eq. (1) comes with two main drawbacks. Firstly, the internal and external factors affecting the degree of vulnerability cannot be fully quantified, because certain latent elements have not yet been realized. Other factors are qualitative, and some are simply not comparable. Secondly, focusing on an aggregate indicator would downplay the individual trends of each of the vulnerability drivers. For instance, it could be the

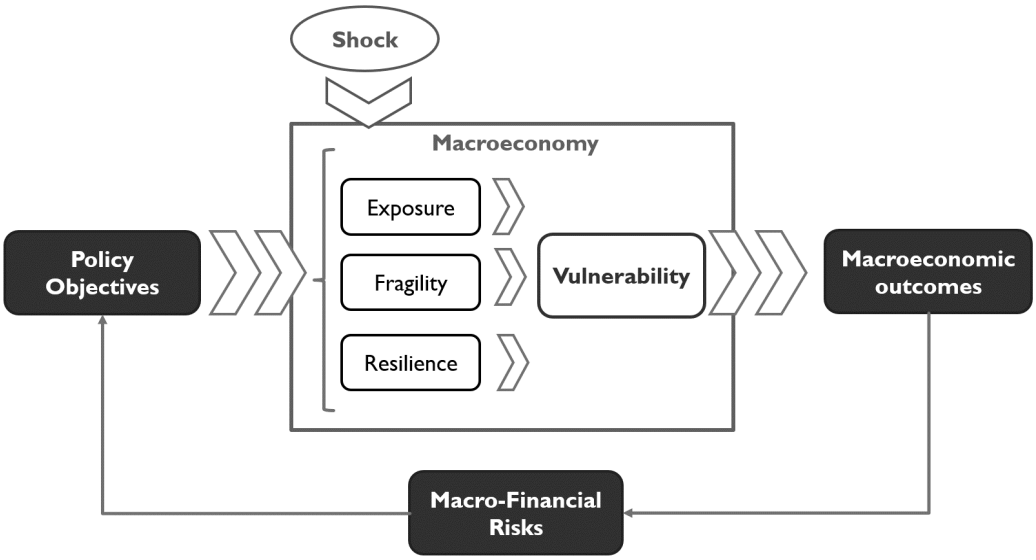
[2] It should be stressed that the reduction of GHG emissions is to some extent endogenous to green financing and will likely fade out as resource depletion and environmental degradation targets are gradually met. The figure provides a simplified view of the overall process.

case where the aggregate indicator does not change significantly, but there are opposite and offsetting movements in the exposure and the resilience of the different dimensions (external, fiscal, monetary, social), not reflected on the aggregate indicator.

$$Risk = f(Threat, Vulnerability) \quad (1)$$

In reality, multiple potential macroeconomic risks can arise from the transition to a low carbon economy. In this respect, Figure 3 presents a holistic interpretative scheme, which is an adaptation of natural disaster risk models (Suárez 2009; IDEA 2005; Cardona 2005) and serves as a conceptual guide for the analysis. According to the figure, how the transition to a less carbon-intensive economy (shock) is transmitted into the external, fiscal, monetary and social dimensions could lead to macroeconomic outcomes that may differ from policy objectives. Consequently, risks in macro-financial conditions are defined in terms of imbalances in key macroeconomic variables and non-compliance with policy objectives.

Figure 3. Vulnerability drivers and macro-financial risks



Source: own elaboration based on Suárez (2009).

The exposure or susceptibility of the system to a shock is reflected in those macroeconomic and financial variables that will be subject to the greatest impact from the low-carbon transition. However, the economic impacts, derived from domestic and foreign transition policies, could be amplified (or diminished), depending on the fragility of macroeconomic conditions and the resilience of economic policy.

Fragility refers to the high responsiveness of the macro-financial system to external disturbances and the limitations it faces in mitigating or reducing the impact of the shock, at least in the short-term. Resilience is connected to the capacity of macroeconomic policy to respond efficiently to the disturbance with its own resources and instruments. For instance, an effective policy response results in a minimization of costs, a correction of imbalances and the recovery of the system. Thereby, it is possible to assess the vulnerability of macroeconomic conditions by focusing on how some key variables respond to transition-related shocks. In the rest of this section, we propose a set of key indicators that we consider essential for monitoring transition-related macroeconomic vulnerability. We focus mainly on drivers that affect the fiscal, the monetary and financial and the external conditions of the economy. Noteworthy, social conditions are in a direct relation with fiscal conditions, due to the strong impact of fiscal policy on social outcomes.

2. Fiscal Conditions

In most macroeconomic models, fiscal policy is conceptualized in a relatively simple way, including three dimensions: tax revenues, expenditure and the stock of public debt. Emphasis is placed on the interplay between the balance of the fiscal budget, its means of financing and debt dynamics. This is particularly important for developing countries that usually have weak currencies and highly volatile exchange rates, while financial investors and credit rating agencies can restrict their access to financing. Of major significance to the purpose of this paper, are the limitations in conducting fiscal policy as these negatively affect the resilience of the macroeconomic system.

Fiscal authorities define policy objectives that are consistent with economic stabilization and economic growth.[3] Yet, fiscal outcomes are not exogenous to the behavior of the economy, since the latter is heavily influenced by fiscal policy. In this respect, limitations in policy making emerge from the feedback of economic activity to the fiscal balance (e.g., tax flows might decrease after a reduction of public investment, due to lower growth). These limitations are further enhanced by institutional arrangements and the pursuit of self-imposed fiscal rules (e.g., balanced budget rules), which constraint discretionary fiscal policy.

Based on the above, some authors recognize that fiscal conditions must be understood in a vulnerability context (Baldacci et al. 2011; Hayes 2011). Stoian et al. (2018) define fiscal vulnerability as "any kind of intrinsic weakness in the existing fiscal policy or exogenous shocks that lead to a significant deterioration in the level of a public budget balance and/or public debt that will limit the government's ability to achieve its goals" (Stoian et al. 2018, 6). This definition incorporates several elements that can be better identified with the risk analysis proposed above.

For instance, the implementation of a policy to reduce GHG emissions would likely affect the fiscal budget because of the need for higher green investments. In the case of countries relying on carbon-intensive exports, like Colombia, which we use as example in the following sections, the low-carbon transition will further imply a reduction in government revenue. Sovereign risk might further increase by the financial commitments imposed by the transition (Volz et al. 2020). However, at the same time, the reduction of subsidies towards sunset industries and higher environmental taxes would improve the fiscal budget, but could have adverse effects on growth and inequality, especially if taxes are regressive (Goodwin et al. 2018, 663).

Given the above, we consider intrinsic weakness as the conditions of exposure and susceptibility of fiscal policy to the transition risks, while its intensity depends on the magnitude and timing of the transition. Likewise, we associate the limitations of fiscal policy with fiscal fragility, the resilience of

[3] At this point, we do not differentiate between different conceptualizations of fiscal policy and their implications to economic activity (e.g., crowding-out vs. crowding-in), as in all cases, the ostensible goal of the policy makers is the same.

fiscal policy in facing the stress events efficiently, and its capability to bring about a quick recovery. Finally, we regard *risk* as a failure to meet the desired fiscal conditions and targets.

One of the possible vulnerabilities that could emerge during and after the implementation of GHG reduction strategies is public debt sustainability. Although there are no scientifically rigorous criteria to determine the optimal level of public debt, empirical researchers assume arbitrary values defined by market conventions or by the credit rating agencies. Hence, these "standards" can become a potential vulnerability factor because the recent history of financial crises indicates the existence of a pro-cyclical behavior of valuation risk. In those scenarios when more resources are required to sustain counter-cyclical policies, credit rating agencies can restrict the access to credit, which, in turn, amplifies other fiscal and macroeconomic vulnerabilities, especially in developing economies.

In this respect, an implicit relationship between financial risks and fiscal variables emerges. This connection limits the actions of discretionary fiscal policy for addressing exogenous shocks to the system and actions aimed to decrease public finances vulnerability. For example, a fiscal sustainability risk emerges due to the implementation of climate change mitigation and adaptation policies. This reduction in the degrees of freedom because of the discrepancy between fiscal outcomes and policy objectives, would force the fiscal authorities to decrease the intensity of GHG reduction and other complementary policies, to improve fiscal indicators.[4] It, thus, follows that fiscal sustainability risk ought to be mirrored in conventional indicators, namely the fiscal balance over GDP and the public debt over GDP, as they reflect the valuation and the rating of public debt instruments, by financial markets and credit rating agencies, respectively.[5]

Finally, it should be stressed that the concept of fiscal vulnerability exceeds that of fiscal space, which excludes the automatic stabilizers. For instance, the implementation of GHG emissions reduction policies could be hindered by high levels of unemployment. Similarly, poverty rates and wage differentials across sectors induce fiscal risk due to the higher social policy requirements, aiming to bring down poverty and inequality (see, e.g., Magacho et al. 2023). In this regard, fiscal sustainability risk is also related to social conditions. As noted by Green and Gambhir (2020) just transitional policies are constrained by the state capacity to target efficiently the population that will be affected the most.[6] It follows that, apart from social indicators, the institutional governance framework greatly affects the fiscal risk. In turn, social risk, broadly defined as the capacity of social norms to adjust to a low-carbon transition in a justly manner, is closely related with the effectiveness and the capacity of fiscal policy (García-García et al. 2020; Sovacool 2021; Newell et al. 2022).

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[4] The exclusion of net green public investment from the fiscal budget (see, e.g., Darvas and Wolff 2021) could reduce fiscal vulnerability. Nonetheless, off-budget items still weigh on public debt.

[5] Various alternative fiscal sustainability indicators have been proposed in the relevant literature (see, e.g., Tonveronachi 2006; Argitis and Nikolaidi 2014), though they are not usually part of the assessment tools of credit rating agencies and, thus, they are excluded from the key indicators.

[6] They also emphasize the state capacity to combat vested interests. This function is indeed critical in bringing about effective and just transition policies, though its treatment exceeds the scope of this paper.

3. Monetary and financial conditions

Within the so-called New Consensus school of thought, it is established that the most effective tool for stabilizing the economy in the short term is monetary policy. Fundamental in this view is the central bank independence, which isolates monetary policy from interference or ad-hoc interventions of other institutional agents. As noted by Setterfield and Rochon (2007), central bank independence, which practically translates to inflation targeting and the implementation of a Taylor rule, is constrained by supply-side conditions, expectations and the growth of the labor force and technological change. Under this strict policy framework, monetary policy could modify the environmental balance, but only in the short-run, as prolonged interventions could result in central bank missing its policy-objective (Heyes 2000; Lawn 2003). The ecological neutrality of monetary policy (see, e.g., Faria et al. 2022) excludes any concern regarding the impact of climate change and environmental deterioration on the central bank operations.

In line with the above, Bolton et al. (2020) explicitly state that The Green Swan[7] could compromise the implementation of monetary policy, limiting its ability to respond to the challenges of a permanent shock, such as the climate change. This could lead to persistent imbalances on both supply and demand sides. The current central banks' instruments and operational protocols are not properly designed to address the state of climate emergency and its socioeconomic implications. These concerns are consistent with the need for an epistemological break in the monetary policy, financial regulation, and supervision approach.[8] There is a need for more active central banks policies to cope with climate change effects and to encourage the low-carbon transition, or even act as climate rescuers of last resort (Campiglio 2016; Dafermos et al. 2017).

Appropriate interventions and policies require an understanding of the types of climate and transition risks that central banks and the financial system might encounter. Physical risks will have adverse effects on both the micro and the macro level, on society and on natural systems (Batten et al. 2020). At the same time, transition risks will affect the financial structure of the economy through various effects, including e.g. policy changes and technological breakthroughs or limitations. These two risks are interrelated, a fact that signifies the necessity for immediate vis-à-vis delayed or weak action (Bolton et al. 2020, 18-19). In terms of monetary policy, the combination of those risks could induce financial losses and the deterioration of the balance sheet of different institutional sectors. According to the Network of Central Banks and Supervisors for Greening the Financial System (NGFS 2020), financial imbalances related to climate change have potential systemic consequences, to the extent

[7] The idea of 'green swan' came from the concept of 'black swan'. The black swan concept, developed by Taleb (2007), refers to unexpected and rare events, with wide-ranging impacts, that can be understood only after their occurrence (Bolton et al. 2020). Thus, green swans are events of this type related to climate-change risks. These events are "characterised by deep uncertainty and nonlinearity, their chances of occurrence are not reflected in past data, and the possibility of extreme values cannot be ruled out" (Weitzman [2009, 2011] cited in Bolton et al. [2020]).

[8] For an exposition of how European Central Bank green instruments could be used efficiently under such a different conceptualization see Dafermos at el. (2020).

that liquidity and credit access conditions tighten, insurance risk premiums increase, debtors' ability to pay decreases, and asset holders' expectations abruptly change.

A candidate driver of potential financial imbalances is related to the emergence of stranded assets in highly carbon-intensive activities and those that are financially and productively interlinked with them. This is due to the misalignment between current conventional investment patterns and current and future transition policies, which, if carried out in an unplanned and disorderly manner, may induce sharp devaluations in certain assets and reduce their cash flows considerably (Semienuk et al. 2021). For instance, if found reserves of fossil fuels cannot be extracted, they become stranded assets, bearing significant consequences for the financial system and potentially prompting a possible financial crisis, e.g. a climate-related Minsky moment. Transition risks would also indirectly impact sectors dependent on fossil fuels such as the automobile industry or mining companies and deteriorate the macroeconomic prospects for commodity exporting countries (Bernal and Ocampo 2020). Consequently, the transition to a low-carbon and climate-resilient economy can induce financial imbalances, which can be amplified if they are carried out in a disruptive manner and without the involvement of central banks. Ultimately, the timing and type of climate change adaptation and mitigation strategies would affect the operation and fulfilment of objectives of the monetary and financial authorities.

Similarly to fiscal vulnerability, Stoian et al. (2018, 6) define monetary vulnerability as any kind of intrinsic weakness of monetary policy to meet its targets, e.g. financial and price stability, after the occurrence of an external shock. The conceptualization of financial risk has long been discussed in the relevant literature, with the contribution of Minsky (1976, 2008) being the cornerstone of this type of analysis. For our purpose, we merely refer to five types of climate-related financial risks, as exposed by Bolton et al (2020, 19-20), that could serve as key indicators: a) credit risk driven by the deterioration of borrowers' ability to repay their debts due to climate-related risks, b) market risk, reflected in severe capital losses after an abrupt transition scenario, c) liquidity risk, implying a restrained refinancing capacity, d) operational risk, which emphasizes the direct exposure of financial institutions to climate-related risks and e) insurance risk, as reflected in higher expected insurance claim pay-outs resulting from physical risks.

4. External Conditions

In developing economies, the vulnerability of the external sector is assessed through the balance of payments dominance. Domestic economic cycles, as well as the pro-cyclicality of macroeconomic policies, are real and financial shocks transmitted from the current and financial accounts of the balance of payments to the domestic economy. In other words, "[balance-of-payments dominance is] the regime in which the external shocks, both positive and negative, are the essential determinants of short-term macroeconomic dynamics. Under this regime, the balance of payments exercises strong cyclical shocks through trade and the availability and cost of external financing" (Ocampo 2016, 212).

Developing countries have two main characteristics that amplify the impact of external shocks on the internal performance of the economy. The first one is weak currencies, implying a high dependence on external financial flows to meet their external debt obligations. In this case, real and financial cycles in advanced economies are transmitted to peripheral economies, especially if the latter lack of foreign reserves, accumulated by sufficient trade surpluses.

The second one is the structural heterogeneity and the specialization pattern in international trade. Peripheral economies have a productive structure that generates large inter and intra-sectoral productivity differentials. This in turn segments the productive system into two distinct sets of loosely integrated activities, creating a dual economy. The peripheral sector that is characterized by a low level of capitalization, productivity and wages, absorbs most of the workforce, while foreign trade is concentrated in a few primary goods or commodities (Cimoli and Porcile 2014).

Although there has been an extensive discussion concerning the problems derived from Dutch disease in the economic development of peripheral economies, (whether its origin comes from a real or financial balance of payments shocks; see, e.g., Corden and Neary 1982; Wunder 1992; Botta et al. 2014), the literature on the external sector vulnerability is oriented towards other types of issues. It focuses primarily on the economy's short-term performance, especially on the balance of payments crises and the unsustainability of the external debt (Radziunas et al. 2004; Supriyadi 2015).

In this context, external vulnerability is defined as the possibility that the balance of payments could be negatively affected by an external shock (Esser 2015).[9] This in turn would affect the sustainability of the external debt or trigger a balance of payments and financial crisis in the national economy

[9] Ramírez and Díaz (2019) define external vulnerability as the degree of the economy's exposure to withstand a sudden stop. This definition is inconsistent with the international literature, as well as experience. In the first place, the concept of vulnerability contains additional aspects to the exposure of the systems, therefore, features related to fragility and resilience should be included. Secondly, a sudden stop is just a stage of a more complex process as is the currency or balance of payments crisis.

(Kaltenbrunner and Painceira 2015). However, quantifying external vulnerability becomes hazardous due to the lack of scientifically rigorous criteria that determine the optimal level of the country's current account deficit or external debt.

According to Bhering et al. (2019) the external sector vulnerability is associated with creditworthiness or the ability to pay foreign liabilities. In this sense, the ratio of foreign liabilities to the sum of exports plus remittances should not grow indefinitely, as the latter variables are the most sustainable sources of foreign exchange supply and determine an economy's long-term capacity to meet its trade and financial commitments with the rest of the world. Therefore, an unsustainable path of this ratio would manifest an increasing external risk, as export growth would be insufficient relative to the cost of net external liabilities and import growth would yield higher external debt burden and servicing (see, e.g., Kregel 2004).

Critical to the export-growth and external risk connection is the structural competitiveness of the economy and its productive complexity (Haussman et al. 2014, 18). A highly complex economy with less dependence on high-tech imported products for green investment could reduce GHG emissions more efficiently (Romero and Gramkow 2021). Such a productive system: a) produces domestically or holds an important part in the global value chain of the required intermediate or capital goods and b) experiences strong multiplier effects, as green investment in one sector boosts the economic activity in other sectors due to horizontal interlinkages (Lopes et al. 2012). Consequently, the external vulnerability of the economy ought to consider the dependence of the domestic economy on imported intermediate and capital goods and the technological gap that could affect, implicitly, the exchange rate in the long term (Gabriel et al. 2016).

Finally, the fragility of the economy to the external conditions is also critically dependent on the financial fragility of the corporate sector, as the relationship between the exchange rate, the firm size and the leverage structures are highly sensitive to the international financial conditions and the external shocks (Alfaro et al. 2019). For instance, the developing economies were hit by the financial repercussions of the COVID-19 crisis, before the pandemic started to spread in the population. This also explains why a more dynamic analysis is important in understanding the external vulnerabilities of the economy.

All in all, external vulnerability could be reflected on the goods export performance, as it ensures the long-term ability to pay external liabilities. This ability is also subject to the strength of the domestic currency and the currency composition of external debt. Furthermore, a low level of external vulnerability is reflected on: a) lower current account deficit, b) competitive exchange rates, c) a high level of foreign exchange reserves, d) reduced short-term external liabilities, and e) financial account regulations being in place (Ocampo 2016, 224).

5. Operationalizing the multidimensional approach to macroeconomic vulnerabilities of the low-carbon transition

Operationalizing the holistic framework described in the previous section requires two distinct tasks. First, to define a device that easily allows understanding both the overall vulnerability that a country faces regarding a specific shock, as well as the specific stress points. Second, to define a methodological framework through which the prospective analyses about the impacts of the low-carbon transition will be made. Regarding the first issue, while a single indicator like the one presented in equation (1) could provide a synthesis of the different sources of vulnerability, it would lose the richness that simultaneously looking at different dimensions provides. This is important because depending on where the weaknesses of an economy lie, different policy responses would be required. On the other hand, simultaneously looking at different indicators in isolation requires users to make the interpretation and draw the conclusions on their own.

We propose a middle ground between the two alternatives consisting of a radar diagram containing variables that reflect the external, fiscal-social and monetary-financial conditions. The choice of these variables follows from the previous section. Needless to mention, this framework is adequately flexible to add, remove and change indicators as deemed suitable. However, for comparability purposes it is always desirable to set a series of invariant measures.

For the purpose of this paper, we include fourteen variables, with some of them mirroring more than one condition. Their interpretation is quite straightforward and follows from the theoretical discussion laid out above. The per capita income in USD, the inflation and the unemployment rates provide a measure of the overall socio-economic conditions. Households' financial fragility, defined as interest payments over savings, is both a social and financial indicator. Financial indicators include firms' financial fragility, defined as total interest payments over net profits, total private, public and external debt, with all three of them expressed in terms of GDP. Additionally, the share of external private and public debt are taken into account as measures of both financial and external vulnerability. The current account deficit (% GDP) and the country risk, affect negatively the external conditions of the economy, while the FX reserves (% GDP) determine the liquidity risk vis-à-vis the rest of the world. Finally, we include the fiscal deficit (%GDP) as a conventional measure of fiscal vulnerability.

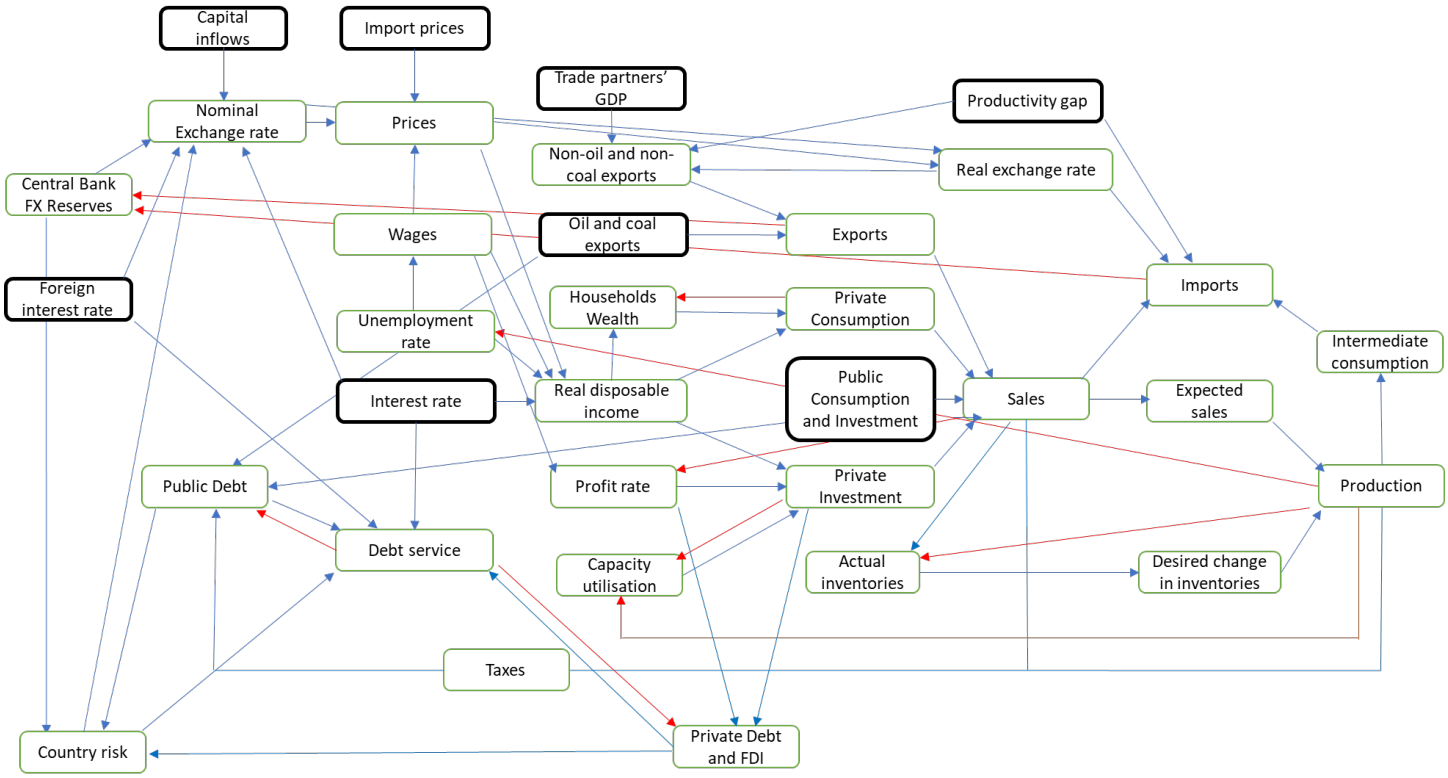
Once the device for analyzing vulnerabilities is built, it is necessary to define a method to project the future trajectory of each of the variables comprising the vertices of a radar diagram, after the economy is hit by a shock. In line with the multidimensional approach in analyzing macroeconomic vulnerabilities, we use a holistic macroeconomic modelling framework, which prioritizes accounting consistency and fitness to the data. The model consists of a monetary and demand-led peripheral economy where the real and financial spheres and their interplay are analyzed explicitly and comprehensively. This implies that banks are not just intermediaries but active players that create

means of payments and therefore have a direct impact on the real sphere. In the same vein, financial flows are analyzed as autonomous processes, following their own behavioral rules rather than merely mirroring real flows. As already mentioned, the specification of the behavioral equations is done on the grounds of empirical regularities and fitness to data rather than on micro-foundations and intertemporal optimization assumptions. Last but not least, the continuous-time specification allows for the emergence of disequilibrium dynamics against the purely equilibrium modelling approaches. The model used to produce the simulations feeding the analysis of vulnerabilities[10] is built upon the benchmark SFC model of a small open economy developed by Yilmaz and Godin (2020).

Following the system of national accounts (SNA), the economy is disaggregated into six institutional agents: non-financial corporations (NFC), households, financial corporations (FC), the central bank (CB), the government and the rest of the world. Using the stock-flow consistent methodology popularized by Godley and Lavoie (2007), we frame all the current and accumulation transactions between these agents in order to determine the budget constraints of each sector and how their savings are allocated between the financial assets. The latter, in turn, can impact the variables of the current accounts (for instance, via interest payments on the holding of financial assets or wealth effects derived from capital gains). The transmission mechanisms of the policies related to the low-carbon transition and the respective dynamic chains of causation can be found in Godin et al. (2023). For the sake of illustrating the multidimensional approach proposed in this article it suffices to lay down the main interactions embedded in the model, of which a visual representation is found in Figure 4. Exogenous variables are indicated by a black border. In the red arrows we highlight the most important feedback effects captured in the model.

[10] The full description of the model can be found in Godin et al. (2023).

Figure 4. The macro-financial framework



Source: own elaboration based on Godin et al. (2023).

Production is determined by both expected sales and the change in inventories, which is given by a ratio of past sales. Sales, in turn, are defined as the sum of the components of aggregate demand. The production process is carried out by NFCs, FCs and the government, who hire labor services from households to whom they pay wages. Production and final consumption also require imports, which as exports, are determined in part by the real exchange rate and the competitiveness of the economy (which we measure through the productivity gap). Additionally, we allow export and import propensities to vary in accordance with movements of the exchange rate. As the primary determinants of the current account, exports and imports play an important role in the analysis of the external dimension of macroeconomic vulnerability. In line with the description made in the previous section, the low-carbon transition will likely increase imports due to the need to acquire machinery and equipment that Colombia (and most peripheral economies) does not produce[11].

Nonetheless, for a country like Colombia, the most important effect of low-carbon transition is going to be on its exports. Oil and coal exports, representing 38.1% of Colombia's exports basket in 2021,[12] would drastically drop if the rest of the world reduces its demand for oil and coal from Colombia, not

[11] As mentioned in section 2, the low-carbon transition could have a positive impact on the external dimension of vulnerability through the channel of imports for countries that rely on imports of fossil fuels.

[12] The estimation is based on data provided by the Observatory of Economic Complexity.

to mention the decreasing stock of these resources and the diminishing capacity for their exploitation. The model can represent this scenario by a reduction in this exogenous component of exports, which is independent of the real exchange rate and productivity (it is assumed that, at least up to now there has been an infinitely inelastic demand for these products). The drop in oil and coal exports not only deteriorates the trade balance, putting upward pressure on the nominal exchange rate (implying a depreciation), but also reduces government revenue in the form of dividends, royalties and income taxes, which would end up either increasing the public debt (the fiscal dimension of macroeconomic vulnerability) or forcing the government to implement austerity policies with harsh consequences in the social dimension of vulnerability. [13]

As a result of the lower availability of foreign exchange, the Central Bank would see its stock of foreign exchange reserves reduced. In conjunction with a worsened budget balance and therefore higher financing needs of the government, the credit risk of Colombia would most likely go up, making its access to external finance more expensive and increasing the cost of servicing debt. This would impact not only on the external dimension of vulnerability but also on the monetary-financial one. The monetary dimension would be more volatile due to the exchange rate depreciation pressures and the lower firepower of the Central Bank, which would bring about a more inflationary scenario. In the financial side, a higher country risk would increase interest rates and, in turn, the debt burden, thereby increasing sovereign risk.

The private sector is also affected in various ways. First, if the resilience of Colombia is not high enough (which we will see shortly), it is likely that the transition related shocks lead to a lower GDP growth path, implying lower income and employment, two key variables of the social dimension. Second, exchange rate depreciation would most likely increase inflation, which together with the decrease in employment would reduce disposable income, the main driver of private consumption. Hence, not only NFC working in the coal and oil sectors would see their sales drop, but also many others. As a result, profits will fall, leading to a lower induced investment. In turn, the overall effect of capital accumulation in demand will be negative, further amplifying the said effects through the exports and consumption channels. In this scenario of lower cash flows firms might face difficulties in honoring past debt commitments and also need to rely more on debt to finance the costs of the transition, increasing the financial risks. Having laid out the main transmission channels, we now illustrate how the multidimensional approach to the macroeconomic vulnerabilities of the low-carbon transition is applied in the Colombian economy.[14]

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[13] The reduction of the investment grade from BBB- to BB+, by the Fitch rating agency, in July 2021, is indicative of how vulnerable the Colombian economy is in its fiscal dimension.

[14] The model described in this section takes the form of a system of non-linear differential equations. Since the model is specified in continuous time, we cannot use standard discrete time econometrics to obtain the parameters of the behavioral equations. To calibrate the model, we compute the values for the parameters that makes the model simulations reproduce, on average, the dynamics of the main macroeconomic variables of the Colombian economy. Due to the dynamic nature of the model, some variables require initial values to carry out the simulations, including the stocks of financial and non-financial assets and other state variables whose behaviour is given by a differential equation (e.g., price indexes, wages, the exchange rate). These initial

6. How vulnerable is the Colombian Economy to the Low-carbon Transition?

In what follows we assess the vulnerability of the Colombian economy, applying two distinct scenarios. In the first scenario we consider a drop in Colombian real fossil fuel exports by 58.1% in a 10-year horizon. We examine how the economy responds whether the reduction is gradual (smooth) or delayed. In the smooth transition scenario real fossil fuel exports decline by 8.5% annually and almost linearly so that after 10 years they are 58.1% below the starting value. In the delayed scenario it is assumed that the drop is sudden and fully takes place in four periods. Panels o and p of Figure 5 show the behavior of fossil fuel exports in these two scenarios, as well as the in the baseline, in which, by assumption, real fossil fuel exports are constant. Figure 6 presents the radar plot illustrating this multidimensional approach in measuring vulnerability. The plots should be read as follows. For the unemployment rate, inflation, the country risk, the current account deficit, total external debt, total public debt, total private debt, the fiscal deficit, the external debt shares and the financial fragility indicators, the higher the variable locates in the respective vertex of the radar the higher the vulnerability. On the contrary, for per capita income in USD and the foreign reserves-to-GDP ratio, vulnerability is higher the closer the variable is to the center of the radar.

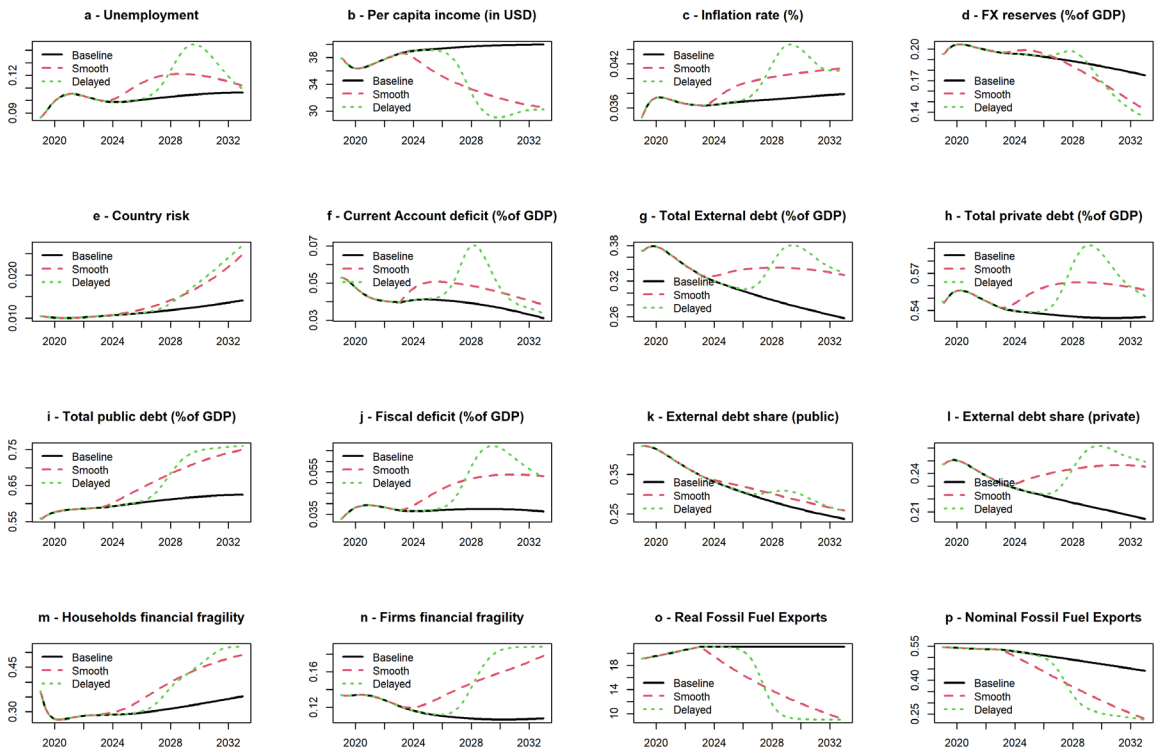
In the second scenario, we further assume a rise in global interest rates, due to monetary tightening in the Global North (smooth – tight) and a rise in both the interest rate and the country risk of the Colombian economy, as perceived by the rest of the world (smooth – risk). These two variants are added to the smooth transition scenario. Again, the results are compared with the baseline scenario.

values were determined by taking 2019 as the reference year. As for the parameters driving the system of equations, these were also calculated from official data sources taking as a reference the period 2014-2019. While a significant number of parameters were calibrated as simple averages, in the case of variables that grow at a constant rate (e.g., labour productivity) or that are a ratio between two known variables (e.g., tax rates), others were calculated considering some reference values in the literature and in some cases by making use of an algorithm for optimising nonlinear continuous-time dynamic systems known as CMA-ES. Finally, the values of some parameters were also determined to be consistent with the assumptions made to build the baseline scenario. Then, once the system of equations with their respective parameters and initial conditions are calibrated, the numerical simulations of the different scenarios can be carried out in the statistical software R for a given time horizon. For this purpose, a numerical solution method known as Runge-Kutta of order 4 is used, which although it does not provide an analytical solution due to the number of variables and the non-linearity of the system, it provides accurate results in a computationally efficient way. For interested readers, the R codes is available from the authors upon request.

7. A Reduction in Real Fossil Fuel Exports

Following the transmission channels defined in Figure 4 we see that the fall in fossil fuel exports leads to a worsening of the current account balance. Although on average the negative effect is almost the same in both scenarios, the long-run effect is slightly stronger in the smooth transition scenario due to the poorer performance of the trade balance in this latter case. In the smooth transition scenario imports are higher and exports are lower, due to a slightly more appreciated real exchange rate. The higher current account deficits registered in the two scenarios lead, in turn, to an also higher issuance of external debt and to a lower stock of foreign exchange reserves (recall that for foreign reserves a lower position in the radar plot implies higher vulnerability). The negative effect on the latter is stronger in the long run in the delayed transition scenario, as shown in the left panel of Figure 6[15].

Figure 5. Vulnerability indicators across time (Scenario 1)



Source: own estimations.

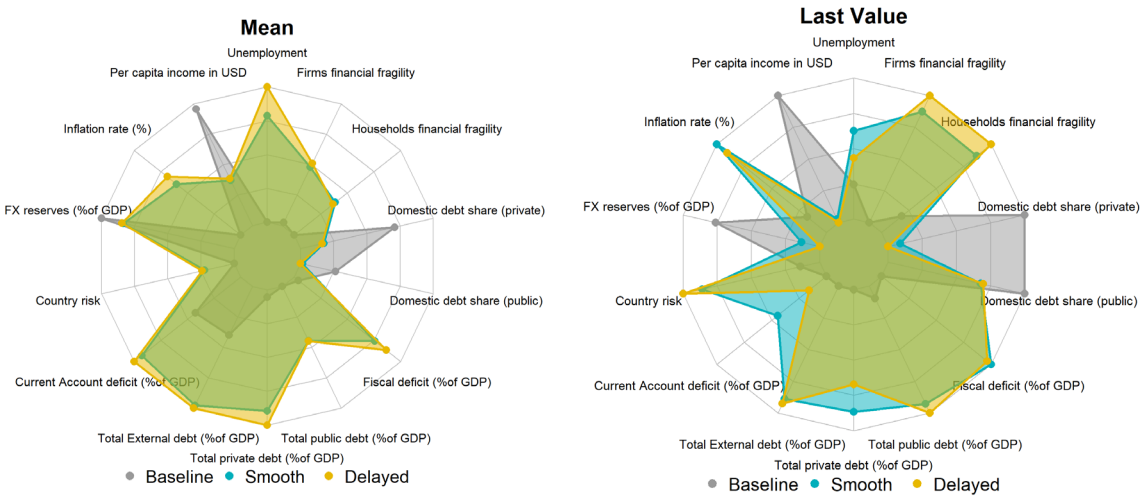
[15] The reason why the stock of foreign exchange reserves is higher in the smooth transition scenario compared to the delayed transition is twofold: first, that while imports are higher the central bank targets a stock of reserves that is a function of imports. Second, that the drop in portfolio and other international inflows is larger in the long-run in the delayed transition scenario, implying a lower supply of foreign exchange.

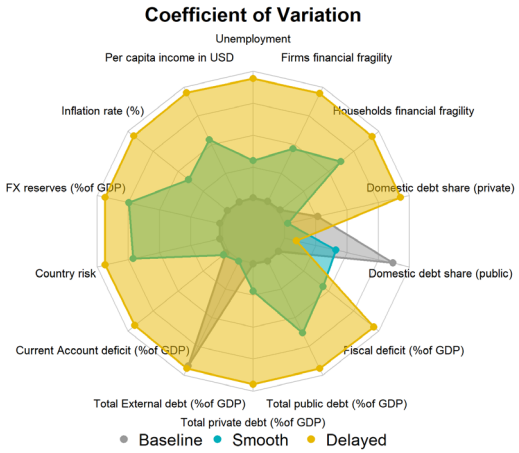
Both the higher external debt and the lower stock of foreign reserves worsen the international investment position, thereby increasing the country risk in both scenarios. The interplay of all these forces results in a lower supply of foreign exchange in the Colombian economy, which leads to a nominal exchange rate depreciation. As the exchange rate depreciates inflationary pressures kick in. Both price and exchange rate dynamics are strongly influenced by the transition path (smooth or delayed), but the end point seems to be the same. Hence, a first conclusion of the implications of the low-carbon transition in Colombia entailing a strong reduction in fossil fuel exports is the deterioration of the economy's overall external position that spreads into the social dimension, as higher inflation tends to increase poverty.

The worsening of the social dimension is not only reflected in the higher inflation, but also in the higher unemployment and lower per capita income. Underlying the poorer performance in the labor market and income is the overall decrease in the activity, which is explained by both exogenous and endogenous factors. The exogenous element is the lower exports, which imply a severe cut to aggregate demand and, therefore, production and income. Lower production brings about weaker labor demand, leading to higher unemployment. The endogenous elements are the lower private consumption and investment brought about by the exogenous negative effect that the transition has on demand, profit rates, disposable income and wealth. All these negative factors are further reinforced by the exchange rate depreciation (which lowers per capita income in USD) and inflation (which reduces disposable income, consumption and, as a result, demand and employment).

As the higher current account deficits generate an increase in the external debt, the higher fiscal deficit resulting from the low-carbon transition leads to a surge in public debt. The weaker state of public finances is given fundamentally by the lower government revenue brought about by both the lower level of activity and, most importantly, the reduced income coming from royalties, while a large share of public expenditures is rigid. This effect highlights the challenges governments, relying heavily on the exports of natural resources-based products, face in the context of the low-carbon transition.

Figure 6. Mean, last values and coefficient variation of vulnerability indicators in Scenario 1
Comparison with baseline scenario





Source: own estimations.

Moving to the financial dimension, the private sector registers an increase in its debt ratios, but this seem to be driven by the drop in GDP rather than a persistent negative net lending position with respect to the baseline, as is the case of the government. External debt shares are higher for both the private and the public sector due to the depreciation of the exchange rate. Finally, fragility indicators are worse for both households and firms due to the increase in the interest rates they pay on their liabilities. Higher interest rates result from the Central Bank's reaction to the increase in inflation, which leads to a permanently higher policy rate which raises the floor for the rest of the interest rates in the economy. Interest rates on foreign currency denominated liabilities are, in turn, also affected by the higher country risk. Financial fragility indicators in the delayed scenario are worse in the long-run due the higher interest rates resulting from the stronger reaction the Central Bank is forced to make following the sudden drop in fossil fuel exports entailed in this transition pathway.

It is important to note here that except the share of domestic public debt, the delayed transition scenario displays very high volatility in all vulnerability indicators compared to the smooth transition, as displayed by the coefficient of variation of these variables. This behavior can also be inferred from Figure 5, particularly for unemployment, inflation, current account deficit, fiscal deficit, total external debt and firms' financial fragility.

The observed 'recovery' in these variables in the long-run (especially in employment, fiscal and current account deficits and external debt) is fundamentally driven by the heavy depreciation of the domestic currency, which leads to lower imports and higher non commodity exports due to the fixed elasticity of import and export functions with respect to relative prices. In essence, such depreciation-driven growth episodes have upper bounds in the absence of sustained productivity gains and the economic growth spurred by currency depreciation displays an S-shape (or even a bell-curve), as beyond a certain level of losses in the value of domestic currency, further depreciations cannot provide increases in exports or lower imports.

Unfortunately, it is very difficult to estimate these upper bounds from observed time series unless the sample contains such episodes that enable the estimation procedure to identify the ceilings and/or turning points. Thus, we did not impose any such unwarranted boundaries in an ad-hoc manner. However, even the so-called 'recovery' comes at the cost of collapsing per-capita income levels measured in $US, which casts doubts on whether these dynamics are indeed desirable outcomes from a policy-making perspective.

In sum, a low-carbon transition consisting of a sharp drop in real fossil fuel exports would find Colombia worse off in all four dimensions. As the radar plots in Figure 6 show, the economy would be approximately twice as vulnerable as it is in the baseline (no transition) taking the mean of a 10-year transition pathway, and roughly three times more vulnerable if the end point is considered.

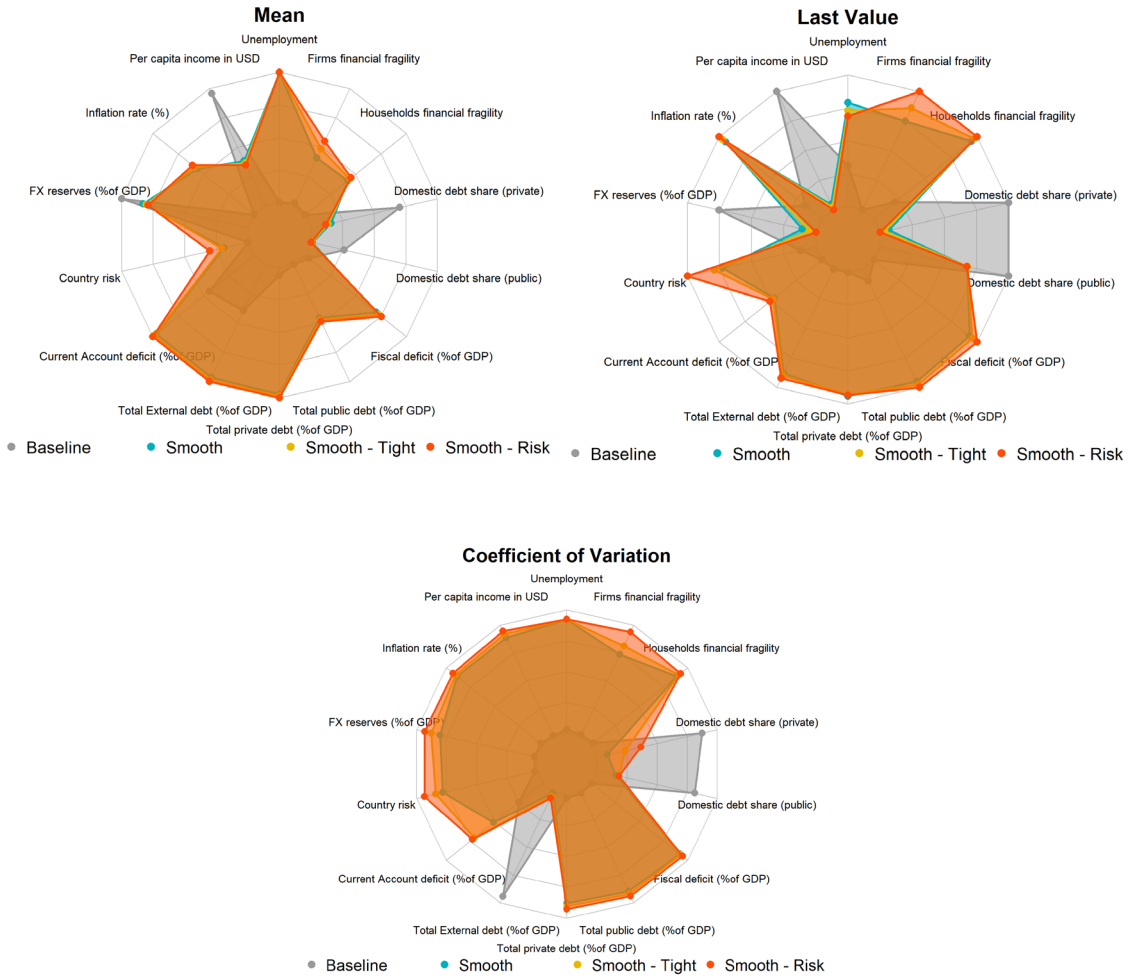
8. Monetary Tightening in the Global North

We now combine the smooth transition scenario with an exogenous monetary shock in the Global North representing tighter conditions for the financing of the low-carbon transition. Two variants are presented. In the first one, which we call 'smooth-tight', there is a permanent 70 base points increase in the interest rate of the rest of the world. In the second one, called 'smooth-risk', we combine the latter with its likely repercussions in the monetary-financial sphere of the Colombian economy: a higher policy rate and country risk.

To some extent, a higher interest rate in the rest of the world reduces portfolio and other investment inflows into Colombia, putting an upward pressure on the nominal exchange rate. This strengthens the effect of the drop in fossil fuel exports observed in the smooth transition scenario, leading to higher exchange rate depreciation and domestic inflation. The Central Bank reacts to this new scenario increasing the policy rate, which raises all the remaining interest rates of the economy. Higher interest rates imply an increase in the debt service and also higher financial fragility. Since the transmission channels of the low-carbon transition described in the 'smooth' scenario are reinforced, the impact on domestic demand is also larger, leading to a worsening of the variables in the social and fiscal dimensions (lower demand leads to lower employment and income per capita, as well as to lower government revenue).

The impact of this transition scenario on Colombia's vulnerability is illustrated in Figure 7. Adding these features to the low-carbon transition slightly increase vulnerability in all dimensions. The firms' financial fragility is the most affected variable compared to the smooth transition scenario, the reason being the resulting higher interest rates in their liabilities (mainly loans). In the 'smooth-risk' scenario the country risk is also higher than in the smooth transition, which is straightforward as this is part of the shock designed in this scenario. As happened in the smooth transition scenario, vulnerability is higher when analyzed at the end-point (10 years after the beginning of the transition) than when taking the whole period average. In sum, adding tighter global financial conditions to the low-carbon transition increases Colombia's vulnerability compared to a scenario of relatively easy conditions. However, the results obtained in these simulations suggest that the differences are marginal compared to the effects inherent to the low-carbon transition.

Figure 7. Mean, last values and coefficient variation of vulnerability indicators in Scenario 2. Comparison with baseline scenario



Source: own estimations.

Conclusions

Recent academic studies have shed light on the socio-economic consequences of climate change and the challenges related to a low-carbon transition process. In principle, it is considered that changes in climate mitigation and adaptation policies, green technological progress, and disruptions in consumption and investment patterns on a global scale may induce non-trivial macroeconomic impacts, especially in developing economies (Magacho et al. 2023). These impacts may exacerbate certain financial and political constraints facing the countries, which have the potential to delay and discourage transition commitments.

Assessments of the different low-carbon transition alternatives and scenarios need to incorporate the concept of vulnerability of the macro-financial system in their analysis. This paper proposes an analytical framework that allows for flexible integration of this facet in fiscal, social, monetary, financial, and external levels, for monitoring and understanding transitions risks that are likely to jointly affect these dimensions. In this way, the restrictions and conditions that any decarbonization and greenhouse gas reduction path must meet to be viable and sustainable in the medium term are made explicit. Ultimately, this approach is useful for understanding the robustness of the macroeconomic policy scheme to climate-related risks and transition stressors.

In this context, we apply a set of fourteen variables, in order to monitor vulnerabilities that arise on all the aforementioned dimensions and use a continuous time stock-flow consistent model so as to examine how these variables evolve across time. We apply the model to the Colombian economy and examine two scenarios. In the first, we assume a smooth reduction of real oil exports and a delayed one. We, then, compare the results to our baseline scenario. The deterioration of the current account balance, increases the liquidity risk of the economy, as reflected in tis holdings of foreign reserves and increases the external debt, both public and private and the household and firm fragility ratios. These negative trends feed back to the social dimension of the economy, portrayed by a rising inflation and unemployment rate and a reduced GDP per capita, denominated in USD. The results, are more adverse in the delayed scenario. Results indicate that the vulnerability of the Colombian economy in the face of a low-carbon transition process, is particularly high and would likely impact on all dimensions under examination. Nevertheless, results are more intense in the delayed scenario, a finding which emphasizes the need for immediate actions aiming to a smooth transition process.

In the second scenario, we maintain the smooth transition assumptions and further introduce monetary tightening in the Global North, as reflected in higher global interest rates. In addition, we examine the vulnerability of the Colombian economy in the event of an induced country risk due to higher interest rates. In this case, the financial repercussions on the real side of the economy are more eminent. This is indicative of how monetary decisions in the Global North induce the vulnerability in the Global South, especially, when the latter implements transition policies.

All in all, our proposed framework provides a multidimensional monitoring of macroeconomic vulnerabilities during a low-carbon transition process. Vulnerability cannot be aggregated in one single variable. In advance, several aspects of vulnerability are interrelated and thus, they cannot be monitored in isolation. In this respect, we propose a middle ground that, in our view, is more efficient in examining simultaneously the fiscal, social, monetary, financial and external vulnerabilities of an economy, especially of a developing country.

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