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Economic complexity and international trade: A case study on the State of Goiás (2010-2019)

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Abstract:
This paper aims to explore the relationship between economic complexity and the productive structure of Goiás, Brazil, particularly in the context of environmental issues within international trade agreements. To this end, the export agenda of Goiás was analysed using the Herfindahl-Hirschman Index to assess the concentration of exports by partners and products. Through the collection of statistical data on the Goiás economy for the calculation of concentration indicators, it is revealed that Goiás' production structure is concentrated in primary products and mining and it has just a few trade partners, exacerbating its vulnerability to evolving environmental challenges and international regulations. This scenario demands a transition towards low-carbon practices and more sustainable technologies while preserving native vegetation and its ecosystem services. For large commodity producers like Goiás, this necessitates continuous diversification and sophistication of the productive structure to enhance economic complexity.

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Since the classical economists, wealth has been intrinsically linked to the division of knowledge and labour, as the technological progress experienced since the Industrial Revolution was made possible by the expansion of productive knowledge. This collective phenomenon results from how economic agents are organised within a given productive structure (Hausmann et al., 2013; Hidalgo, 2021). Depending on the characteristics of this organisation, productive knowledge is generated and disseminated more fluidly, defining its diversification trajectories and shaping possibilities for economic development (Romero and Gramkow, 2021). Thus, economic complexity is the study of the manner in which economic agents are organised within the

productive structure and the consequent amount of productive knowledge that can be incorporated (Hausmann et al., 2013; Hidalgo, 2021; Romero and Gramkow, 2021).

This topic is in line with the economic development literature, and it provides useful insights, not only from a theoretical perspective but also in public policy design. The reason is that the sophistication of production, as measured by economic complexity, is essential for diversifying the economy and widening its trade partners, allowing it to mitigate risks and to create new technologies with economic and environmental benefits (Guarini and Oreiro, 2022; Romero and Gramkow, 2021), the latter is especially important in the current context of climate change. For tropical producers of primary products, such as Brazil and the State of Goiás, in particular, the economic complexity provides a useful framework to deal with the increasing trade requirements at the international level about increased productivity without expanding cultivated areas, while simultaneously increasing areas with native vegetation and their services (Teixeira et al., 2023).

Therefore, sustainable economic growth in the long term necessitates the adoption of various large-scale actions towards low-carbon practices. This transition is inherently linked to the continuous expansion, diversification, and sophistication of the productive structure, enhancing economic complexity. Considering these assumptions, this paper aims to explore the relationship between economic complexity and the productive structure of the State of Goiás in Brazil, particularly in the context of environmental issues within international trade agreements. To this end, the export agenda of Goiás was analysed using the Herfindahl-Hirschman Index (HHI) to assess the concentration of exports by partners and products. So, the contributions of this paper include examining economic complexity within sustainable development and its impact on integrating economies into international trade. It also describes the export profile of a subnational economy in terms of economic complexity and evaluates potential long-term risks to economic growth due to current global rules related to climate change and sustainable development.

The structure of this paper is organized as follows. Section 1 presents the state of the art found in the technical-scientific literature on economic complexity and its relationship with sustainability, economic development, international trade, and the regulation of global markets concerning sustainability. Section 2 outlines the methodology used, corresponding to the HHI for concentration indices. Section 3 presents the findings of the applied method, organized into topics such as “Goiás’ economy profile” and “Environmental issues of Goiás’ exports”. Section 4 summarizes the final considerations of the article’s results and their implications for economic sciences.

1. Literature review

1.1. Economic complexity and sustainability

The complexity approach assumes that industrialisation is fundamentally important for economic development (Hidalgo et al., 2007). The reason is that exporters of technology-intensive goods, which are the most complex and productive, tend to grow and develop further due to their superior techniques and skills. Industrialisation facilitates the generation and adoption of new technologies, which also contributes to accelerated growth (Hidalgo et al., 2007; Lall et al., 2006). It is worth noting that there is empirical evidence that manufacturing activity has significant implications for reducing the technological gap and increasing economic complexity itself (Gabriel et al., 2016).

Hidalgo et al. (2007) indicate that, if certain goods require similar infrastructure, institutions, and technologies (or other properties), they tend to be produced together, whereas those that differ in their respective requirements are less likely to be produced jointly. The lack of interconnection between products produced by a certain region can hinder changes in its productive structure and convergence to the income levels of rich countries and/or regions. In other words, poor countries or regions tend to be located on the 'periphery' of the product space (a kind of map of products that are more likely to be produced together), where changes to new products are difficult to make, especially if large leaps are needed (Hidalgo et al., 2007). On the other hand, Hidalgo and Hausmann (2009) explain the relationship between a country's growth and its level of complexity (and how this level could impact future growth prospects). This, in turn, can be verified by analysing the country's exports, which would be consequences of the country's productive structure. Thus, they measure, through the Method of Reflection, the complexity of a certain good or product and of the economy as a whole.

Corroborating this argument, Felipe et al. (2012) found that high-income economies predominantly export the ten most complex products (machinery, chemicals, etc.) while the ten least complex products (wood, agricultural products, etc.) are mainly exported by middle- or low-income countries. Hausmann and Hidalgo (2011) point out that there is a nonlinear relationship between a country's number of capabilities and the number of products it produces. Furthermore, they show that countries with few capabilities tend to have little incentive to develop new ones, a situation that could leave them in a kind of *low economic development trap*. Another problem is that knowledge is concentrated in a few highly industrialized countries, which are constantly improving technologies, while other countries lag behind, despite greater possibilities for technology transfer – through increased trade, communications, foreign direct investment, public policies promoting cooperation, and other channels (Archibugi and Coco, 2004).

In short, only a few countries are offering the most complex products, due to the difficult conditions necessary to create a favourable environment to produce those goods, such as proper infrastructure, skilled and specialized labour, high-quality institutions, and a fully developed national innovation system.[1] The more capabilities a country acquires, the better its potential for productive diversification. Therefore, these issues are part of the discussion on nonprice competitiveness among economies, which is also necessary as countries advance in their economic development process (Dávila-Fernández et al., 2018).

Several studies have explored the relationship between economic complexity and environmental issues. Lapatinas et al. (2019) have investigated this relationship in 88 countries, both emerging and developed, from 2002 to 2012. The authors found that an increase in economic complexity is associated with better environmental performance. These findings are consistent across various econometric specifications, even with different control variables. However, one aspect of environmental performance, air quality, tends to worsen with increased complexity. Additionally, citizens of countries with higher economic complexity are more inclined to adopt environmentally friendly practices, suggesting that the Economic Complexity Index (ECI) can be a good indicator of this culture.

[1] The concept of a national innovation system (NIS) was initially defined by Freeman (1987), Lundvall (1992), and Nelson and Rosenberg (1993). It corresponds to an articulated group of institutions from the public and the private sectors (funding and financing agencies, financial institutions, public and private companies, educational and research institutions, etc.) whose activities and interactions generate, adopt, import, modify, and disseminate new technologies, with innovation and learning being its crucial aspects. Also, it is the level of articulation among the various factors that make up an NIS that determines the capacity to generate innovation.

Through econometric exercise, Neagu and Teodoru (2019) indicated that European Union countries with higher economic complexity reduce polluting activities more rapidly, likely due to greater efficiency, including in energy use. However, the authors highlight the need to modify the energy profile of countries wishing to increase their complexity, as this tends to increase the emission of polluting gases. They also suggest promoting environmentally friendly practices and investments as a countermeasure.

Romero and Gramkow (2021) demonstrated that economic complexity reduces greenhouse gas emissions intensity, encompassing total emissions per person, commonly referred to as emissions per capita. This is due to the advanced technology used in the production of sophisticated and high-value-added goods, which is common in more complex countries. Productive efficiency is high and increasing, with the adoption of green technologies, resulting in low emissions per unit of product. Using data from 67 countries between 1976 and 2012, the authors conducted a regression with various control variables (such as trade openness, urbanisation, electricity consumption, population, education, the proportion of agriculture, manufacturing, and patents) and adjustments for endogeneity. They concluded that a 0.1 increase in the ECI reduces CO_2 emissions by 2% per billion dollars of output, both in absolute and per capita terms. Additionally, they created an emission intensity index by product, analysing 786 products, and confirmed that more complex products are associated with lower emission intensities.

Mealy and Teytelboym (2022) developed a methodology to measure the productive capacities of a green economy, creating the Green Complexity Index (GCI) and the Green Complexity Potential (GCP). They showed that higher-ranked countries have more environmental patents, lower CO_2 emissions, and stricter environmental policies, highlighting the path of dependence in the accumulation of green capabilities. In turn, Silveira et al. (2023) investigated whether increasing complexity can promote sustainable growth in the Amazon, analysing municipal data from 2006 to 2021. They concluded that there is no guarantee that complexity reduces deforestation but suggested activities that could achieve both goals. The study also highlighted the importance of Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) in protecting the Amazon.

Therefore, there is relevant evidence in the literature that increasing economic complexity is crucial for developing and improving the environmental performance of countries and subnational units, such as the State of Goiás. As is widely known and will be presented with further details in the next sections, this State has a high concentration of exports in low-complexity goods (about 85% of exports[2]), such as the soy complex, meat corn, sugar, gold, and other minerals. Considering this concentration, the policy agenda should move the State away from unsophisticated activities, increasing the relevance of more productive sectors, improving energy efficiency, and reducing pollutant gas emissions. Additionally, the agenda should be implemented alongside other environmental measures, creating investment synergies. Even less complex activities can advance in productivity and technology, becoming less environmentally problematic and more competitive. This can generate resources for more complex activities and advantages in the carbon market.

[2] According to the trade balance of the State of Goiás (see online).

1.2. Economic development and international trade

Economic development corresponds to the process of structural change, in which an economy shifts from focusing on primary, low-productivity, subsistence activities to transferring labour to a higher-productivity industrial capitalist sector. Building on this key concept, the economic literature has expanded to cover various topics related to industrialisation in developed countries, including forms of financing, international issues, savings, and capital accumulation (Agarwala, [1969] 2010). Industry is a critical issue for economic development because it is seen as the sector with the highest economic productivity for several theoretical reasons, all revolving around the common theme of increasing returns of scale. The latter are defined as an economic phenomenon where an increase in the number of inputs or factors of production (capital and labour) causes a more than proportional increase in production levels. In other words, productivity increases with installed productive capacity, and therefore, the average cost per unit produced decreases.

There are various sources for the presence of increasing returns to scale, ranging from discounts offered for large volume purchases to the savings a company can achieve by producing a variety of products (economies of scope). For discussions on economic development, two sources deserve special attention as they are directly related to the factors of production typically considered in theoretical models: (i) the accumulation of physical capital often includes technological innovations that enhance labour productivity. This makes it difficult to distinguish between productivity gains from improved technical knowledge and those from acquiring new machinery (Kaldor, 1957); (ii) worker productivity increases as more hours are dedicated to the same activity, a concept modelled and defined by Arrow (1962) as Learning by Doing through observing that, in the United States, the number of hours spent producing an aeroplane was inversely proportional to the number of planes already produced. In other words, workers gain experience from repeated problem-solving, which increases their productivity.

So, industries are more productive due to their greater access to markets and their potential for increasing returns to scale. Economic development can thus be viewed as a process of disequilibrium, where economic activities concentrate in sectors with higher productivity, such as industry (Berger, 2009). Additionally, the industry's role in international trade is crucial, with extensive literature exploring how trade integration influences economic development, particularly in the context of Latin American Structuralism.[3]

According to this school of thought, economies are categorized as either central or peripheral, rather than simply developed or developing. Central economies are those that have completed the transition of labour from traditional subsistence sectors to modern sectors and have a diverse export agenda, characterized by a homogeneous and diversified productive structure. On the other hand, peripheral economies have a traditional sector that coexists with a modern capitalist sector, resulting in a heterogeneous structure. These peripheral economies primarily engage in international trade through the export of primary goods. This classification seeks to understand underdevelopment as a historical process with its own dynamics, rather than as a stage that will inevitably lead to development (Rodrigues, 2009).

The inadequate integration of peripheral countries into international trade hinders their development for three main reasons. Firstly, industrial sectors can better incorporate technical progress, boosting labour productivity and real wages. Secondly, industrial goods have higher income elasticity compared to primary goods, meaning global income growth may not sufficiently

[3] The Latin American Structuralist school arises from reflection on the economic problems faced by several Latin American countries during the economic crises in the 1930s, and it presents a theory with its own nomenclature to explain the underdevelopment of the region (Rodrigues, 2009).

absorb increased primary sector production, forcing peripheral countries to accept lower growth rates to avoid balance of payments issues. Lastly, peripheral countries often face deteriorating terms of trade, where increased productivity in central countries does not lead to lower prices for their exports relative to primary goods from the periphery. Consequently, the benefits of technical progress are predominantly absorbed by central countries.

In addition to the structuralist perspective, Keynesian arguments also emphasise that demand is the primary driver of economic activity. Kaldor (1970) supports this by proposing that industrial development is influenced more by the growth rate of exports than by factor endowments. He asserts that exports are the autonomous component of demand, not dependent on domestic income levels, and they thus dictate the economy's consumption and investment levels. Consequently, regions with initially more developed industries achieve higher capital accumulation. As technical progress is integrated into new machinery and equipment, these industries become relatively more productive and competitive, further enhancing their export capacity.

The importance of the industry role is also demonstrated by the simplified version of Thirlwall's (1979) model, whose equation (1) is presented as conclusion:

$$y = \frac{\gamma}{\lambda} z \tag{1}$$

where y is the domestic growth rate, γ is the income elasticity of exports, λ is the income elasticity of imports; and z is the growth rate of the rest of the world.

This equation represents the domestic growth rate that is possible without the country experiencing a balance of payments crisis. Therefore, we have that, for $(y > z)$, we need $(\gamma > \lambda)$. In other words, an economy that seeks to develop and reach the same income level as developed economies needs to increase the income elasticity of its exports relative to the income elasticity of its imports. Then, the industry is important because it is a sector that produces goods with a higher income elasticity than what is expected from goods produced by the primary sector. In short, the importance of the industrial sector is due not only to its higher productivity but also to how a given economy positions itself in an international or even inter-regional context. The tendency for terms of trade to deteriorate means that the benefits of technical progress are appropriated by economies that export industrial products, and the higher income elasticity of this sector provides higher demand, which induces greater investments and capital accumulation.

Finally, the factors related to demand and increasing returns to scale interact in such a way that causality is circular, even at a regional level, with demand encouraging industry; and, as this sector grows, its productivity increases, improving its competitive position, which can further increase demand (Krugman, 1991). Besides that, as was corroborated by the economic complexity theory, the industry can become important in the current period, when economies face several kinds of challenges, such as the climate change context, since it is expected that the integration in international trade increasingly requires better environmental performance, while the domestic social demand involves the creation of better jobs.

1.3. International trade regulation and sustainability

In contemporary international trade, a country seeking to impose a blockade on imported goods must justify such actions based on the safety of its residents. For instance, in 2007, Brazil decided to ban the importation of used tyres (Kettunen et al., 2020). The rationale was that these tyres, having a shorter lifespan, are discarded more quickly, becoming breeding grounds for dengue

mosquitoes. Brazil argued that it lacked the capacity to dispose of the accumulated used tyres, which would exacerbate an already severe endemic problem. European countries then appealed to the World Trade Organization, citing specific points of the General Agreement on Tariffs and Trade to accuse Brazil of protectionism. However, it was determined that the used tyres indeed posed a health risk to the Brazilian population.

However, the design of certain trade agreements has evolved over recent years. For the European Union, since the 2011 agreement with South Korea, broader motivations beyond mutual interests have been incorporated as clauses.[4] This agreement introduced the innovation of a specific chapter dedicated to sustainable development, with articles reinforcing each party's commitment to labour and environmental issues. The sustainable development chapter of the EU-South Korea agreement mandates that each party adopt measures in line with the four pillars of the International Labour Organization's Decent Work Agenda: the right to assemble and bargain collectively; the elimination of all forms of forced labour; the abolition of child labour; and the elimination of discrimination in the workplace. Thus, the agreement extends beyond mutual interests between different nations, reinforcing the parties' commitments to international cooperation agreements. In 2018, the European bloc itself requested a review by a panel of experts, which concluded that South Korea was not fulfilling its part of the agreement concerning these fundamental workers' rights (Nissen, 2022).

Regarding Brazil, particularly the State of Goiás, it is important to mention the negotiations for the recently announced Mercosur-European Union agreement. Firstly, when drafting a sustainable development chapter in an economic agreement, the European Commission always relies on a group of independent experts and consultants. These experts elaborate a Sustainability Impact Assessment (SIA) to evaluate the impacts of trade liberalisation on sustainability (both environmental and social). The study for the current agreement concludes positively regarding job creation, increased activity levels, and emission reductions, among other benefits. However, it also highlights some reservations about Brazil's commitment (European Commission, 2021).

The agreement between the European Union and Mercosur, announced on September 9, 2024, still pending signing, does not propose that a country can ban the imports of a specific product due to its non-ecological production chain. Nevertheless, the sustainable development chapter of the agreement stipulates that each party must commit to carbon reduction according to its Nationally Determined Contribution (NDC) under the Paris Agreement, as well as to biodiversity protection, the sustainable management of forests and fisheries, and other social objectives. In its NDC last update (Brazil's NDC, 2024), Brazil announced its goal of reducing greenhouse gas emissions by 37% below 2005 levels by 2025, to reduce them by 50% below 2005 levels by 2030, and to achieve climate neutrality by 2050. The SIA developed by the European Commission notes that Brazil's 2020 NDC removed previously included deforestation-related commitments.

Additionally, the sustainable development chapter of the Mercosur-EU agreement includes commitments from each party to combat illegal deforestation and to respect the rights of indigenous peoples regarding their lands and traditional livelihood.[5] As previously mentioned, the SIA highlighted expressed concerns about removing deforestation reduction commitments from Brazil's NDC. Furthermore, MapBiomas' data shows up that 98% of deforestation alerts in the country lack proper legal authorisation (MapBiomas, 2021), and these alerts increased by 14% between 2019 and 2020 (MapBiomas, 2020). Regarding indigenous lands, the same SIA notes a

[4] European Union–South Korea Free Trade Agreement (2011). Available online.
[5] Mercosur–European Union Free Trade Agreement (2019). Available online.

deterioration in Brazil since 2014, with a reduction in demarcated areas and budget cuts to FUNAI (Brazil's indigenous affairs regulatory body).

It is also worth noting that the Paris Agreement, in its fourth paragraph, allows developing countries to adopt measures to meet carbon emission reduction targets over an extended period. Therefore, while there is a risk for local producers, such as in Goiás, if the country does not commit to the Paris Agreement, the same agreement offers greater flexibility to developing countries.

2. Methods and procedures: concentration indexes

As observed in the previous section, the expansion of foreign trade is paramount for the development of countries and regions, particularly regarding exports. In this regard, it is worth examining the level of concentration of exports from the state of interest in this study, namely Goiás, both in terms of the products exported and their main partners. Based on this, one can discuss the paths the State should take to achieve sustainable growth acceleration. Additionally, from the information on current trade agreements, as observed in the second section, potential risks to Goiás's current strategy can also be indicated.

So, the issue of export concentration in the State of Goiás can be examined. The methodology widely used in the literature refers to the HHI, which first appeared in Hirschman ([1945] 2018) to address market concentration and a potential lack of competitiveness by giving greater weight to larger firms. Herfindahl also used it a few years later in his doctoral thesis on the metal industry in the United States, referencing Hirschman.

Therefore, similar to various studies, such as that of Lee and Zhang (2019), we have adapted the HHI for the case of export concentration in Goiás – both in terms of what is exported and of the number of the State's partners. In this case, the following equation (2) represents the HHI:[6]

$$HHI_t = \sum_{j=1}^{n} \quad S_{jt}^2 \tag{2}$$

In this case, the HHI for the period "t" equals the sum of the share of each partner or each product category, depending on the case, squared to give greater weight to those with a larger share in exports. Thus, if Goiás exported to only one destination, the HHI would be 10000 (100^2), or 1 if using the index in decimals (1^2), both options being used in the literature, which would signify a "monopoly," a total concentration. Conversely, if there are various destinations with small shares, the HHI would tend towards 0, representing almost "perfect competition," i.e., a very low concentration. Typically, an index below 1500 (or 0.15) is considered a competitive market, one between 1500 and 2500 (or between 0.15 and 0.25) is considered moderately concentrated, and one above 2500 (or 0.25) is considered highly concentrated.

With the HHI, one can observe how the productive diversification and the commercial partners of Goiás have behaved over time. Indeed, countries with greater productive diversification and exports tend to be more resilient to shocks, allowing them to achieve stronger economic performance in the medium term (Cavallo et al., 2008; Lee and Zhang, 2019). Another

[6] It is worth noting that there are variants of this equation, such as the one used by UNCTAD for a concentration index of countries' exports. In summary, it is a normalised HHI as follows: the square root of the sum of the squares of the proportion of each product exported by the country, subtracted from the square root of the ratio between 1 and the number of products exported, and all this divided by 1 minus the square root of the ratio between 1 and the number of products exported – with developing countries tending to have more concentrated exports. Lee and Zhang (2019) also use the HHI for the three or five most exported products to compare with other countries. These other variations can be used in the continuation of this article.

effect can be the reduction of volatility, which tends to reduce uncertainty and impact economic growth. To increase diversification, countries or regions must 'reduce distances' through better infrastructure and logistics and also improve governance by reducing trade bureaucracies. Furthermore, raising educational quality can be fundamental for adopting new technologies and their spread throughout the economy; not to mention industrial policy, which has been gaining more traction in recent years.

3. Results and discussion

3.1. Goiás' economy profile

According to data from the Mauro Borges Institute of Statistics and Socioeconomic Studies (IMB, in Portuguese) and the Brazilian Institute of Geography and Statistics (IBGE, in Portuguese), in 2021, the State of Goiás had a gross domestic product (GDP) at current prices of R$ 269,628 billion. Goiás's share of the national GDP was approximately 3%, maintaining the 9th position in the national ranking and the 2nd in the Central-West Region. In terms of GDP per capita in the same period, Goiás reached R$ 37,414, which represented the 11th-highest value in the country; previously, in 2002, the State was in 10th place (Alves et al., 2023).

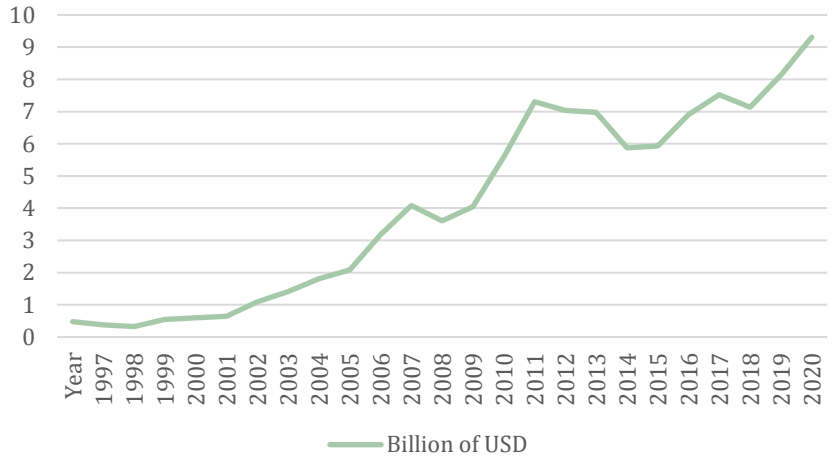
According to IMB (Alves et al., 2023) data, in 2021, the agricultural sector in Goiás accounted for 17.8% of the State's economy, marking an increase of 6.7 percentage points (pp) compared to 2020. The industrial sector's share was 22.3%, a decrease of 1.3 pp, notably due to declines in the electricity and gas, water, sewage, and urban cleaning sectors (-0.8 pp) and in the manufacturing industry (–0.7 pp). Finally, the services sector accounted for 59.9% of the economy (figure 1). It is worth highlighting that the GDP used to have a different calculation methodology before 2010 and the last record available at the time of this paper is 2021.

Figure 1 – *Evolution of sectoral participation in the State of Goiás, in percentage terms, 2010 and 2021*

Source: Alves et al. (2023).

Regarding Goiás' exports, an important aspect to assess the degree of sectoral specialisation of the economy, we can observe their evolution between 1997 and 2021, followed by almost stagnation in the past decade (figure 2). The reason for analysing this period is because Brazil adopted the Harmonised System as the standard good classification in 1997, and the last record available at the time of this paper is 2021.

Figure 2 – *Goiás' exports (billions of USD), 1997-2021*



Source: Own elaboration from data of MDIC (2022).

During this same period, the concentration of exports around Goiás' trading partners was evaluated. Initially, the calculation was done by region – Africa, Central America and the Caribbean, North America, South America, Asia, Europe, Oceania, and the Middle East. Analysing by region is interesting, due to possible interconnections between the countries within each region. For example, for various reasons, one country may import more products and redistribute them among other countries in Europe. Thus, a regional analysis makes more sense, given this possibility and the objective of this paper.

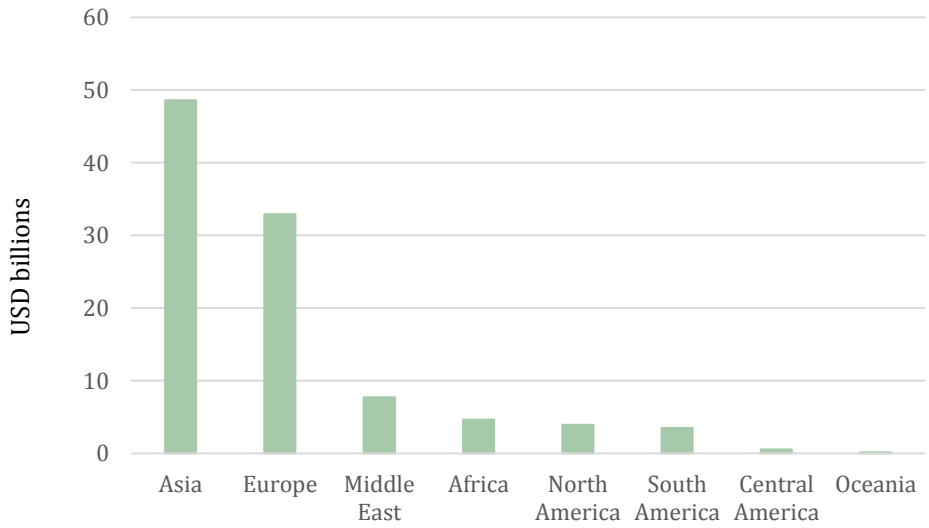
As can be seen in figure 3, the HHI has never been below 0.30, indicating a high concentration in the destinations of Goiás' exports. After a reduction in this concentration until the early 2010s, there was a renewed concentration of the State's trading partners, with the HHI recently reaching values above 0.4, which brings risks and potential volatility for Goiás. The data for the construction of the HHI were the most recent available, with efforts always made to obtain the most up-to-date data possible. The same applies to the following graphs related to the exports of the State of Goiás.

Thus, two regions have been the main destinations for Goiás' exports (figure 4): Europe and Asia – with the former losing relative share to the latter in recent years. As observed, the total exports to Asia throughout the entire period reaches nearly R$ 50 billion, while for Europe the total was lower, around R$ 35 billion. For an average of the years 2015 to 2021, the most recent years, Europe and Asia are the most important regions for Goiás' trade, with an average of R$ 4 billion being exported to Asia and a sum below R$ 2 billion going to Europe.

Figure 3 – *HHI for geographic regions, 1997-2021*

Source: Own elaboration from data of MDIC (2022).

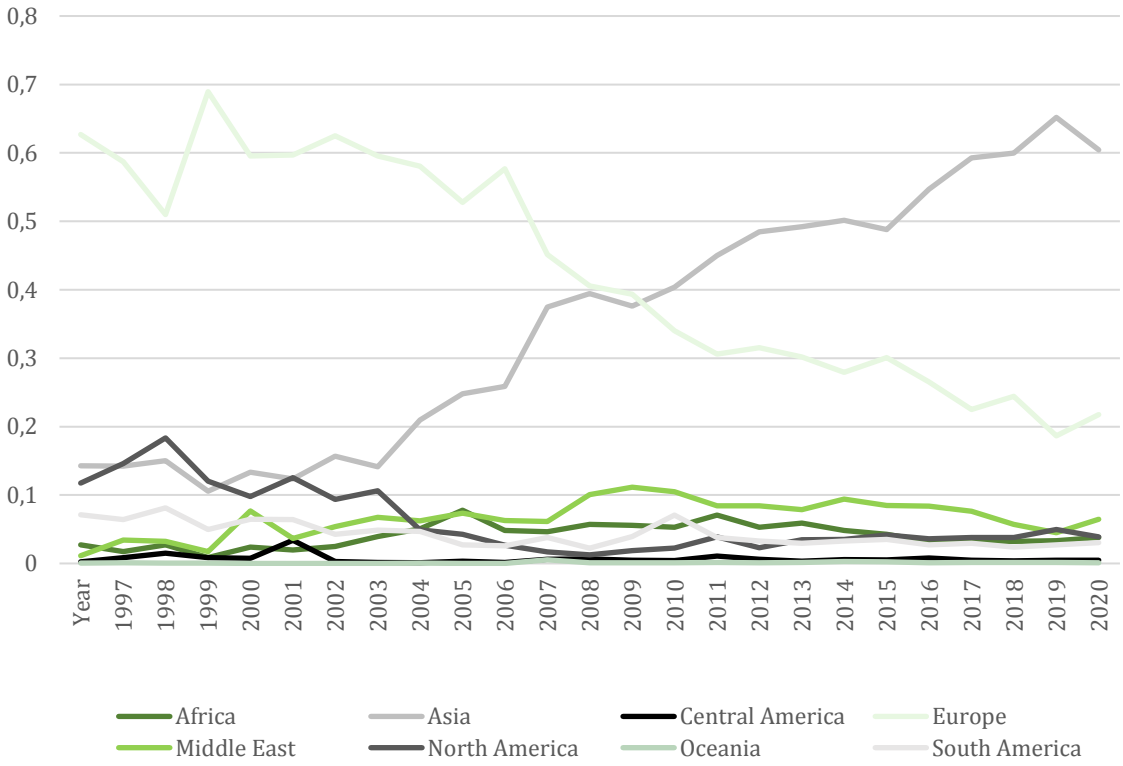
Figure 4 – *Goiás' exports (billions of USD) per region, 1997-2021*



Source: Own elaboration from data of MDIC (2022).

Observing the historical evolution of the participation of some regions, it is clear that the increased importance of Asia has consolidated over the past two decades, with Asia currently being the destination for more than 60% of Goiás' exports. Behind Asia is China, which has increased its imports from the State since the 2000s, during the period of globalisation growth and the country's entry into the World Trade Organization (WTO) in 2001. As a result, China has become the country with the largest share of Goiás' exports, reaching over 40% in 2021 (figure 5).

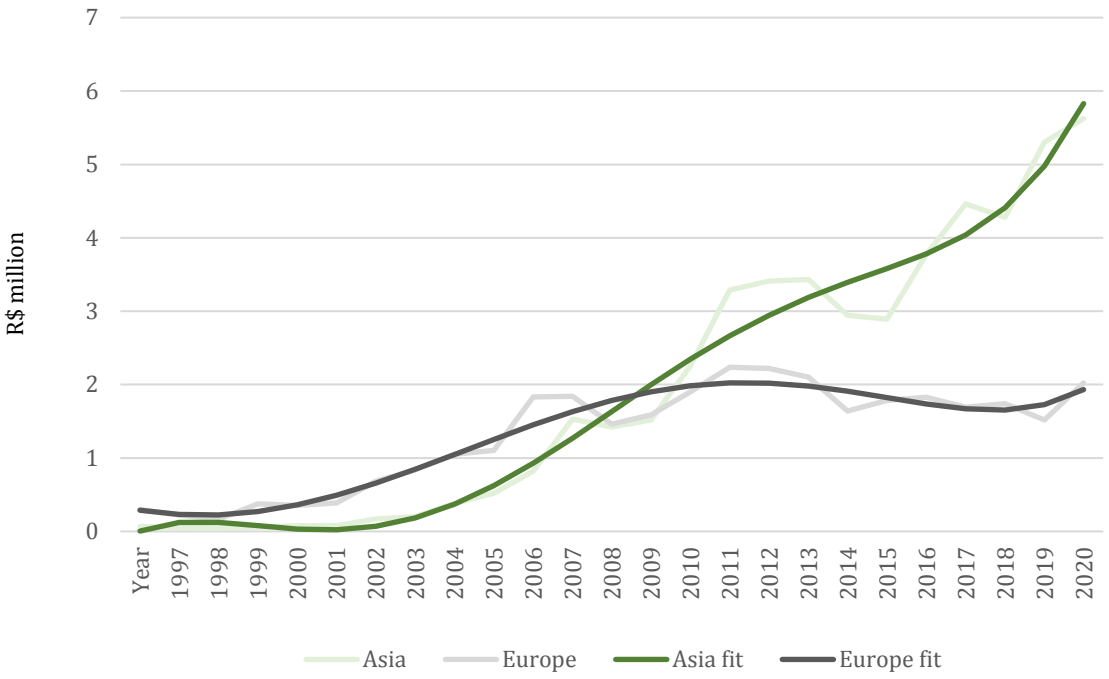
Figure 5 – *Region shares (%) in Goiás' exports, 1997-2021*



Source: Own elaboration from data of MDIC (2022).

In comparison to the growth of exports to China, exports to Europe have shown some stagnation over the past decade, following the end of a growth cycle after the global recession of 2008. As shown in figure 6, the total exported to Europe is close to what it was at the beginning of the decade, without showing a growth trend; the blue line represents the smoothed trend. Apart from a more adverse European economic period, new trends in nontariff barrier measures linked to environmental protection protocols may have some effect on this stagnation. Furthermore, subsidies to European agribusiness are one of the reasons why the Mercosur-European Union agreement has not yet been finalised.

Figure 6 – *Exports from Goiás to Europe and Asia, 1997-2021*



Source: Own elaboration from data of MDIC (2022).

After a period of trade liberalisation and greater economic globalisation, the HHI for countries decreased from over 0.7 to around 0.1, indicating a significant, though not very high, concentration (figure 7). However, it is notable that, from the 2010s onwards, the HHI has increased again, reaching over 0.2, mainly due to the growing share of Chinese participation in Goiás' exports. Thus, it can be concluded that the State of Goiás is increasingly dependent on exporting to Asia, particularly to China, while also maintaining a dependency on Europe as a whole.

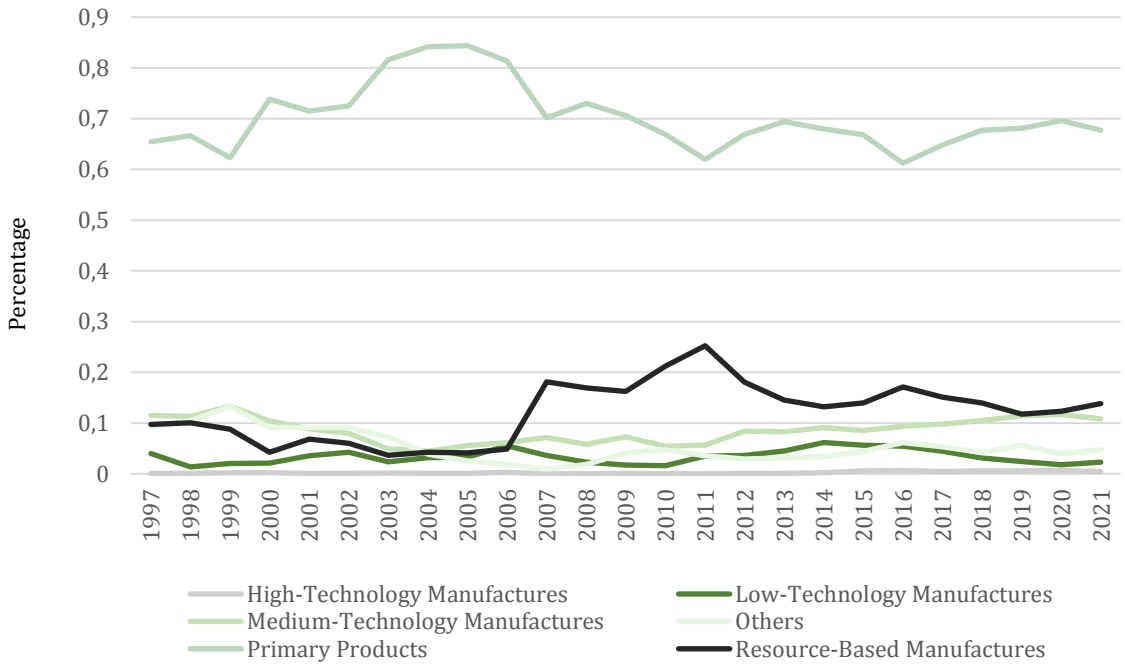
In addition to the concentration of destinations for products exported by Goiás, the HHI was also calculated for the products in question. Initially, a classification of the products exported by the State was made based on technological intensity according to the Lall classification, which is one contribution of the present article. Thus, the products can be divided into: Primary Products (PP), Resource-Based Manufactures (RB), Low, Medium, and High Technology Manufactures (LT, MT, HT), and Others (O).

As can be seen, the State of Goiás concentrates its exports on Primary Products, having maintained over 60% of its exports in PP throughout the period, fluctuating around 70% in recent years (figure 8). This alone demonstrates the lack of productive diversification in the State, as well as the low complexity of its productive structure and, consequently, its exports. Furthermore, it also makes Goiás susceptible to the volatility of the global primary products market, given the high variability of their prices. Therefore, the HHI is calculated considering the economic categories.

Figure 7 – *HHI for Goiás and China, 1997-2021*

Source: Own elaboration from data of MDIC (2022).

Figure 8 – *Exports for technological category, 1997-2021*

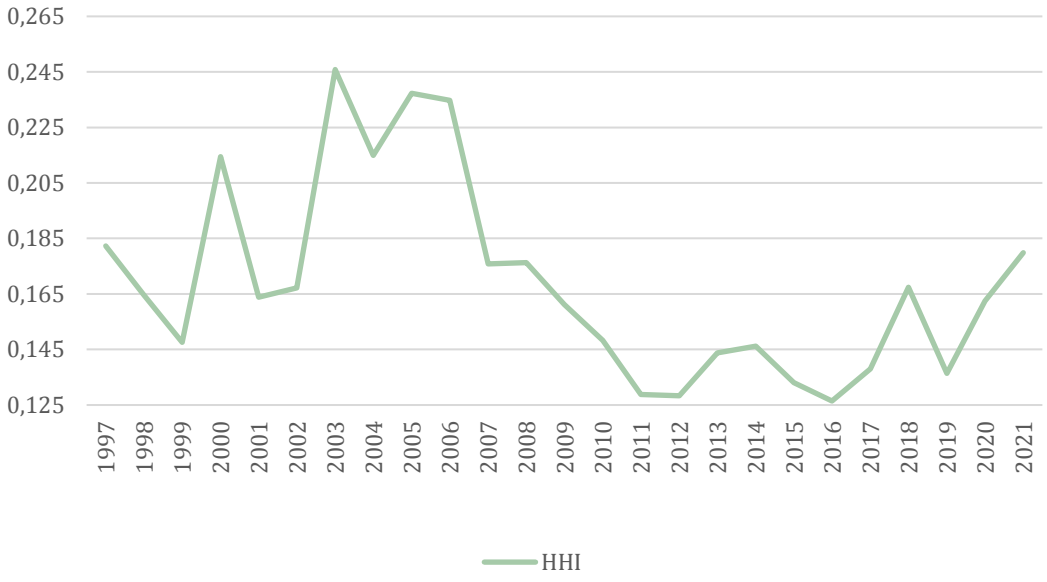


Source: Own elaboration from data of MDIC (2022).

Figure 9 – *HHI for technology categories of exports, 1997-2021*

Source: Own elaboration from data of MDIC (2022).

Figure 10 – *HHI for export products, according to the SH2 level, 1997-2021*



Source: Own elaboration from data of MDIC (2022).

As shown in figure 9, there is indeed a substantial concentration according to the HHI, reaching over 0.7 but generally remaining above 0.5 throughout the period. These data only increase the perception of risk for the economy of Goiás due to the concentration in a few technologically unsophisticated categories.

Finally, an HHI was calculated for the exported products according to the SH2 (Harmonised System 2) level of aggregation. This coding is used to uniformly classify various products worldwide and is used, for example, for the classification of goods in the Mercosur Common Nomenclature (NCM). As shown in figure 10, even for a higher level of disaggregation, with around 97 items, which tends to create an automatic "reduction of concentration" effect, this is not always effective. It would be interesting to compare this index with other countries or entities. The HHI remained mostly above 0.15, suggesting substantial concentration in a few SH2 categories, notably those related to primary production.

3.2. Environmental issues of Goiás' exports

The composition of production, expressed in the sectoral participation in GDP presented, together with the degree of "cleanliness" of the technologies adopted in the production process, is responsible for the types of natural resources consumed and the waste and emissions released into the environment, determining the level of environmental degradation caused by the functioning of the economy (B. Mueller, 2021). The growth of the human population and income observed in the State of Goiás in recent decades has increased production and consumption, raising the demand for water and energy, transport, and sanitation, and it has also generated higher greenhouse gas emissions (GHG) (Castro et al., 2019). In parallel, the concentration of the State's exports around primary agricultural products, notably soybeans, beef, and mining, has led to the expansion of the agricultural frontier over native vegetation to attend to its main trade partners.

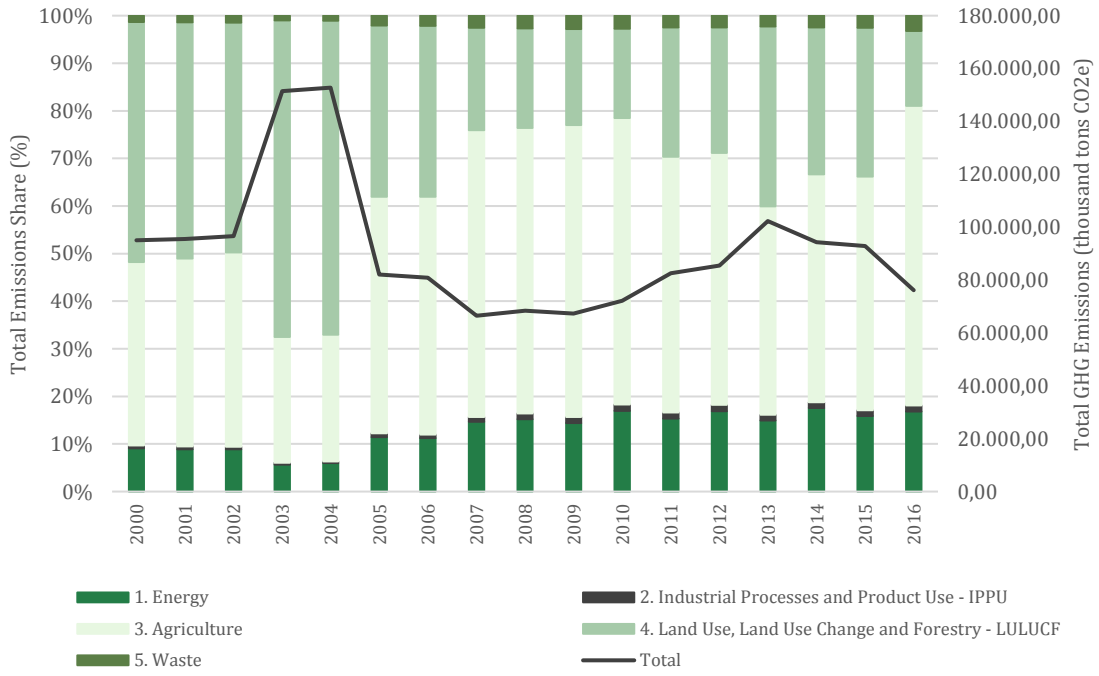
Figure 11 presents the evolution of GHG emissions in the State of Goiás between 2000 and 2016. It can be observed that most emissions are related to agriculture, where 62% of the sector's emissions are due to the enteric fermentation of livestock, and to energy, where 65% of emissions are generated by the transport sector (MCTI, 2021). Additionally, the state's emissions are highly sensitive to land use, land-use change and forestry (LULUCF) activities, like the national trend. The emission data were also the most recent available, due to the considerable lag between the data collected and the data released.

According to projections by OECD/FAO (2023), this trend of specialization in primary products is expected to continue through the decade throughout Latin America, especially for producing regions such as Goiás, due to the increase in global consumption of food in calories and inputs for livestock and aquaculture (Teixeira et al., 2023). Despite the productivity gains obtained over the last decades, the expansion of commodity production would lead to greater conversion of areas with native vegetation (and other uses) for agriculture. Thus, global carbon emissions from agriculture will increase by 7.6%, contributing to the severity of climate risks, as well as the loss of important environmental services for this sector, which include everything from nutrient recycling to watershed protection, soil quality, water resources, biodiversity, and climate stability (Dauvergne and Lister, 2011; Sterner and Coria, 2012; Teixeira et al., 2023).

In response to this situation, trade agreements and other regulations of this nature have increasingly established various provisions on sanitary and environmental issues that are intended to safeguard human well-being while intensifying the flow of goods and services. For

tropical regions and those specialising in primary production, such as Goiás, the major concern of the international community is related to the deforestation of areas with native vegetation. This is the case, for example, with the recent European Union regulation for deforestation-free products, which aims to minimise the contribution of the bloc's commodity consumption[7] to global deforestation and forest degradation and to minimise greenhouse gas emissions and biodiversity loss. To this end, European entities placing these types of goods on the market must certify that the products traded were produced without deforestation, whether legal or illegal, through due diligence declarations and compliance documents with the legislation of the countries of origin (Hoch et al., 2023). It is expected that other countries, such as China, will follow this trend with similar legislation.

Figure 11 – *Evolution of GHG emissions in the State of Goiás between 2000 and 2016, in total values and share by sector of the economy*



Source: Own elaboration from data of MCTI (2021).

Therefore, the specialisation of Goiás's productive structure around agricultural commodities and mining, from the perspective both of environmental risk arising from the cumulative effects of waste generation (including greenhouse gases) and of the increasingly complex regulatory environment, calls into question the sustainability of Goiás's economic expansion in the long term.

[7] It includes cattle, cocoa, coffee, palm oil, soybeans, rubber, and timber and its derivatives.

According to Carlos Bocuhy,[8] maintaining this economic dependence on a few products and trading partners will depend on the environmental capacity to sustain production, despite the disastrous effects of climate change, whose impacts are already being signalled, and Brazil's compliance with environmental regulations, in order to ensure integration into global supply chains of deforestation-free commodities, produced using safe chemicals, among others. For this reason, it is important to increase the participation of economic sectors that adopt "clean" technologies in production, that is, are less intensive in the use of natural resources and the emission of waste and greenhouse gases. This will allow for economic growth at constant, or even decreasing, rates of environmental degradation (C.C. Mueller, 2012; Jones and Vollarth, 2015; Teixeira et al., 2023).

The sophistication of the productive fabric is essential for the creation and introduction of environmentally efficient technologies. However, the necessary investments for this transition do not occur spontaneously, due to the high risk involved and other mechanisms that act as barriers to increasing the environmental efficiency of the economy (Guarini and Oreiro, 2022). Therefore, the role of public policies becomes evident in enabling sustainable development through structural change towards a resource-efficient and low-carbon economy, while allowing productivity gains to be socially inclusive. In this sense, the economic complexity approach, especially the product space, can help guide the design of these public policies.

4. Concluding remarks

Goiás is an important State for the Brazilian economy, particularly due to the contribution of its agribusiness sector to export revenues, which allows it to achieve the ninth-largest GDP among Brazilian states. However, the results of the calculation of concentration indices and other statistical data reveal that Goiás' productive structure is significantly concentrated in primary and mining products, as well as in trading partners, notably China and Europe. This context makes the State vulnerable to climate risk (the impact of extreme environmental events) and the increasing complexity of international trade regulation of products with the potential to cause deforestation or the use of chemical substances (such as agricultural pesticides).

Thus, sustainable economic growth requires the adoption of various large-scale actions towards low-carbon practices, based on more environmentally efficient technologies that reconcile increased productivity without expanding cultivated areas, while simultaneously increasing areas with native vegetation and their services (Teixeira et al., 2023). This process requires a continuous expansion of the diversification and sophistication of the productive structure, in terms of economic complexity, particularly for large commodity producers like Goiás.

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