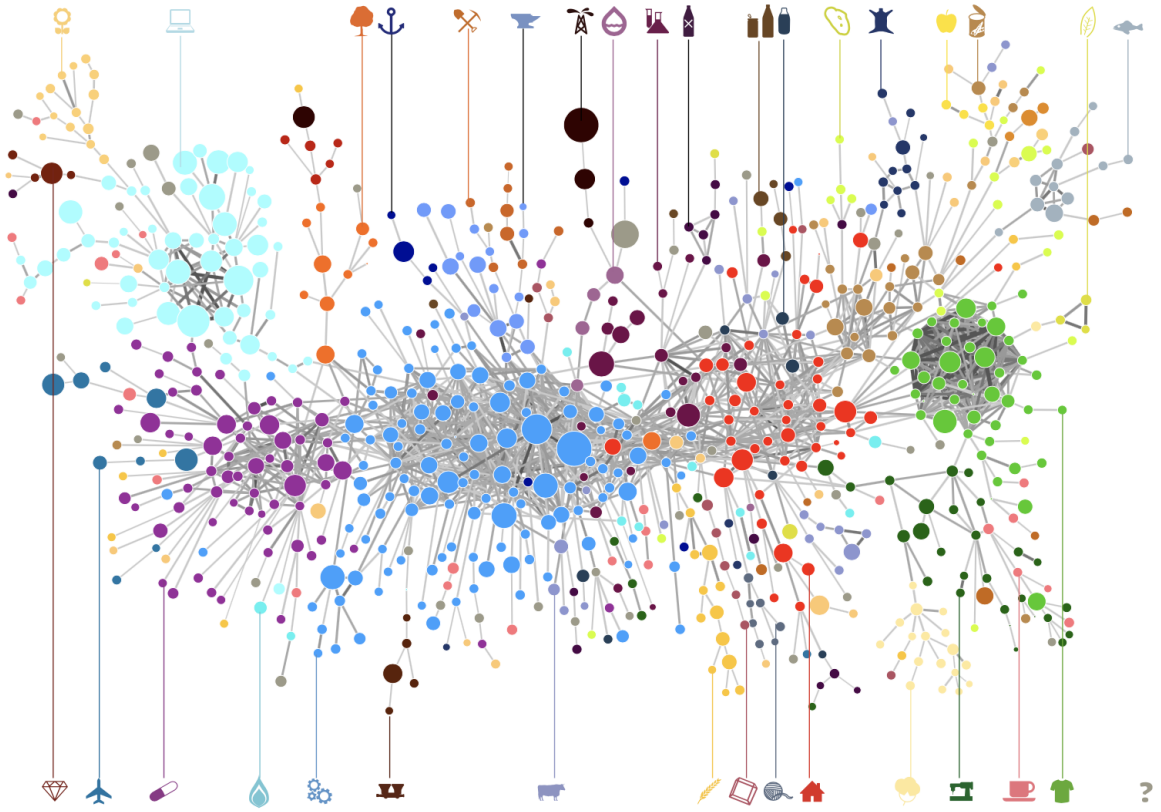

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Optimal Industry Development Strategy Using Economic and Product Complexity

Brazil

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Optimal Industry Development Strategy for Brazil

0. Executive Summary

In this report, we aim to uncover the economic path Brazil went through during the period from 2013 to 2018. Specifically, we dive into the topic through a macroeconomic overview of Brazil from the perspective of Gross Domestic Product (GDP) and Economic Complexity Index (ECI), which reflect countries' production capability and production structure, respectively. We find that during the period of our interest, Brazil demonstrated a stagnant level of economic growth with an annual GDP growth rate of -3.7%, concurrent with a decrease in economic complexity as compared with other major emerging economies.

The level of economic progress during the period, we believe, can be partially explained through analysis of the economic and product complexity structure of Brazil on the industry group level. The product classification system we adopt allows us to measure the realized development for various industry groups and to observe that Brazil aggressively invested in developing Weapons, Clothing and Accessories, Precious Stones during the period, while its emerging peers and developed economies around the globe have adopted paths that were more well-suited to their current stances in the product space.

Based on our analysis of the opportunity gain and a sensitivity analysis of major industry groups, Brazil can further its gains by prioritizing stone, Services and Utilities, and clothing industry groups. We further note that Brazil has an ill-matched development strategy that indicates a particularly low level of structural optimality on the complexity level, having an adjusted R-square of 29.6%. Since a significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, Brazil indeed has a suboptimal growth experience as compared with fast-growing economies both on a regional scale and on a global scale, and has the potential to further its economic gains through industrial structure optimization as suggested in the paper.

1. Report Overview

In this report, we aim to uncover the economic path Brazil went through during the period from 2013 to 2018. Specifically, we dive into the topic through a macroeconomic overview of Brazil from the perspective of Gross Domestic Product (GDP) and Economic Complexity Index (ECI), which reflect countries' production capability and production structure, respectively. We then analyze the industrial framework and changes of Brazil during the period based on quantitative measures such as Product Complexity Index (PCI) and Product Family Complexity Index (PfCI), followed by a detailed analysis of how such changes have matched with development strategies as quantitatively measured by opportunity gains on an industry-level. We conclude our report with macro-level results and predictions of Brazil, as deduced from regression models we have established on a global scale, which take into account countries' stances in their product space.

2. Macroeconomic Results

2.1 GDP Ranking and Changes

As the 9th largest economy in the world by GDP in 2018, Brazil has a GDP of 2.5 trillion USD in 2013 and 1.9 trillion USD in 2018, exhibiting an extraordinary level of economic output. Figure 1 illustrates the time-series GDP results for major emerging economies from 1999-2018, and Brazil demonstrates a high level of consistency in terms of both GDP and GDP growth. However, its growth rate is not as good as compared with many other emerging economies in the world, with an average annual growth of -3.7% during the period from 2013 to 2018. This number is much below the annual growth rates of the other five leading emerging economies, which have a geometric average growth rate of 2.2% and an arithmetic average growth rate of 2.4%. The contrast is particularly significant with China, one of the leading emerging economies in the world, which has an average annual growth rate of 8.2% during the same period. The pace of economic growth in Brazil, we believe, can be reflected through changes in ECI and PCI, and can be further explained by a suboptimal set of production strategies adopted by Brazil from 2013 to 2018, which we will expand at the later stage of the report.

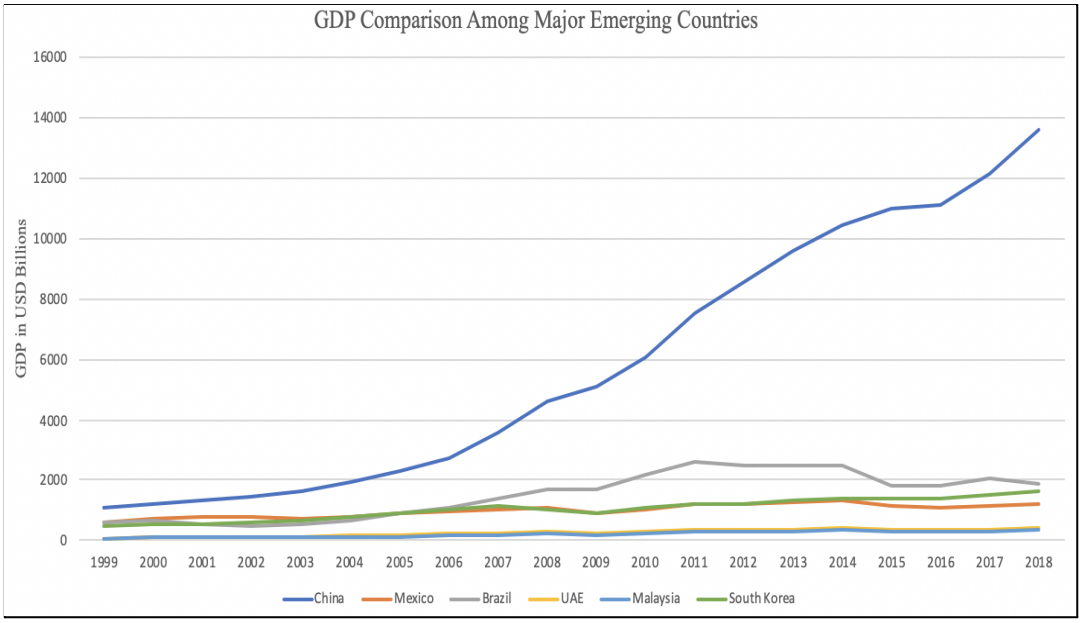


Figure 1: GDP Comparison Among Major Emerging Economies

2.2 ECI Ranking and Changes

The Economic Complexity Index (ECI), as defined by Ricardo Hausmann and Cesar Hidalgo in 2009 to explain the knowledge accumulated in a country's population, exhibits a similar pattern for Brazil. As illustrated in Figure 2 below, Brazil exhibits a slight decrease in terms of its production capability from 2013 to 2018, as measured by ECI. This is in direct contrast to countries such as China and South Korea, which demonstrate an advantage in terms of both the ECI and GDP indexes.

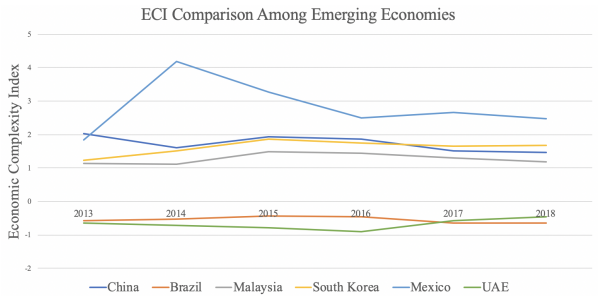


Figure 2: ECI Comparison

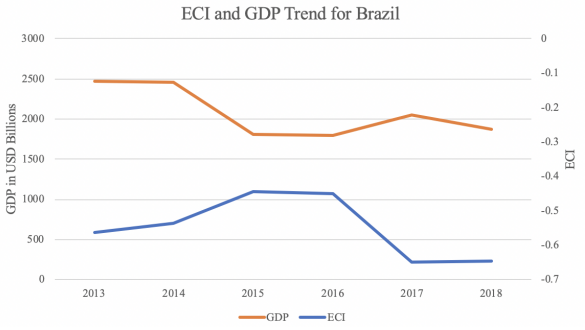


Figure 3: GDP and ECI (Brazil)

Figure 3 offers a further comparison of GDP and ECI over the time span from 2013 to 2018 for Brazil. There's a strong negative correlation between ECI and GDP, indicating the ineffectiveness of the country in developing a competitive product space that helps to accumulate complicated knowledge and technology, and that ECI doesn't have the predictive power to estimate the potential economic development of Brazil. In order to provide a more concrete answer to why this has happened, we will dive into an analysis of Brazil's production structure and its product space designs in the next few chapters.

3. Production Analysis

3.1 Product Categorization

Our main data source in this research is the UN Comtrade Website (https://comtrade.un.org), which provides us with valuable information on countries' export values on an annual basis, including highly specific export data for more than 5000 categories of products. In order to have a holistic vision of the product space of a country, however, a level of categorization is required. Products in our data source are labelled from 010000-999999, with the first two-digits representing a general category to which the product belongs. Based on the 99 categories as extracted from the label, we further group the products into 18 most widely-accepted industries, as summarized in Table 1.

Note that the High-complexity Products industry group is not a distinct industry but rather an aggregated industry that encompasses the most complicated products from the most technologically-advanced industries (as measured by PCI). This industry serves as an indicator for us to quantitatively evaluate how well a country has performed in developing cutting-edge technologies and closing its technical gap with advanced economies, which has become a topic of wide concern today. Indeed, when we rank the 18 categories based on PfCI (an equivalent concept of PCI as calculated based on the 18 categorized product groups), the High-complexity Products industry has the highest PfCI among all industry groups.

Category	Description
Animals and By-products	All kinds of meat, livestock and related by-products
Vegetables, Fruits and Plants	All kinds of plants, edible vegetables and fruits
Food and Preparations	Edible preparations, raw cooking materials and appliances
Clothing and Accessories	All kinds of fabrics, filament, clothing and accessories
Textiles	All kinds of textile articles and related products
Wood Products	Book, paper and other elementary products related to wood
Metals	Mining of all sorts of raw Metals
Refined and Processed Stones	Refined or processed stone products such as pearl and ceramics
Energy Drilling and Mining	Mining industry for energy, minerals, stone materials, etc.
Daily Instruments	Basic daily instruments such as sport requisites, timing and measuring tools
Raw Manufacturing	Basic products made from plastic, rubber, leather, etc.
Chemical Manufacturing	Advanced chemical products and pharmaceutical products
Chemicals	Raw chemical materials and by-products
Machinery and Construction	Machinery and mechanical appliances, including electrical equipment
Transportation	Vehicles and locomotives including aircraft, ship, railway, etc.
Weapons	Explosives, arms and ammunition
Services and Utilities	Financial, business, legal, communication, travel Services and Utilities, etc.
High-complexity Products	Agglomeration of advanced products with highest PCIs

Table 1: Categorization of Products

We further observe a positive correlation between the GDP and the export of High-complexity Products. A higher adjusted R-square exists between GDP and High-complexity Products exports, indicating that more successful economics, as measured by GDP, tend to be those that are capable of producing and exporting High-complexity

Products as we define them. The Figure 3 and 4 show the OLS results in a universe of 107 and 21 typical countries respectively.

	High-complexity Products	Food and Preparations	Animals and By-products
Adj.R-squared	0.075	0.006	0.002
F-statistic	9.556	1.638	1.175
No. Observations	107	107	107

Figure 3: OLS Regression Results of GDP against Percentage Volume of Exports

	High-complexity Products	Food and Preparations	Animals and By-products
Adj.R-squared	0.149	0.003	-0.012
F-statistic	4.510	1.059	0.7542
No. Observations	21	21	21

Figure 4: OLS Regression Results of GDP against Volume of Percentage Exports

3.2 Realized Industry Development

Based on the product categorization aforementioned, we aim to capture Brazil's realized industry production strategy between 2013 and 2018 on a complexity level. In Hausmann and Hidalgo (2009), distance is defined to be a measure of how far a country is from a certain product not in its product space. We extend this concept to all product groups and quantify how technically equipped a country is to develop the corresponding product groups. In other words, the shorter the distance between a country and a product group, the more capable a country is in developing products within that group. Defining this net distance change as the Realized Industry Development (RID), our export data allow us to calculate and compare RID of France and the 18 product groups in 2013 and 2018 through subtraction, where a positive RID indicates a shortening of the distance (i.e., advancement of the industry), and a negative RID indicates the reverse. As ranked in Table 2, during the period from 2013 to 2018, Brazil has focused on products with a moderate level of complexity and those requiring intermediate skills, including Clothing and Accessories, weapons, and Machinery, which are unusual among developed economies.

Rank	Category	RID	Rank	Category	RID
1	Clothing and Accessories	-0.054	10	Metals	0.004
2	Weapons	-0.050	11	Chemical Manufacturing	0.010
3	Machinery and Construction	-0.028	12	Wood Products	0.012
4	Precious Stones	-0.019	13	Food and Preparations	0.016
5	Textile	-0.018	14	Vegetables, Fruits and Plants	0.023
6	Daily Instruments	-0.012	15	Transportation	0.028
7	Animals and By-products	-0.010	16	Energy Drilling and Mining	0.028
8	Services and Utilities	-0.009	17	Chemicals	0.034
9	Raw Manufacturing	-0.004	18	High-complexity Products	0.044

Table 2: Realized Industry Development (RID) of Brazil

3.3 Regional and Global Comparison

Table 3 and 4 below summarize how the production strategy adopted by Brazil compares with leading economies and a selected group of emerging economies in the world, as measured in RID. It can be directly observed that Brazil focused on products with a lower complexity level, when compared against leading economies such as the United States and Germany, which gave a considerable level of attention to more advanced product groups.

Ranking	France	The United States	Germany
1	High-complexity Products	Services and Utilities	High-complexity Products
2	Chemical Manufacturing	Weapons	Transportation
3	Daily Instruments	Raw Manufacturing	Wood Products
4	Animals and By-products	Precious Stones	Metals
5	Food and Preparations	Animals and By-products	Food and Preparations

Table 3: RID Comparison across Leading Economies

Ranking	China	South Korea	Singapore
1	High-complexity Products	Transportation	Transportation
2	Transportation	Textile	High-complexity Products
3	Machinery and Construction	High-complexity Products	Precious Stones
4	Energy Drilling and Mining	Chemical Manufacturing	Daily Instruments
5	Daily Instruments	Machinery and Construction	Services and Utilities

Table 4: RID Comparison across Emerging Economies

Table 4 further examines Brazil's development strategy against those of emerging economies on a global scale. Reasonably, emerging economies such as China, South Korea, Singapore and India have devoted the majority of their efforts into intermediate industry groups while developed economies such as France should have rely more on advanced industry groups. This trend holds true in general, regardless of the continent or the time period, and serves as

an indicator for which phase of development a country is currently in as evaluated from its production strategy. Based on this standard, Brazil is a typical emerging economy that adopts a moderate strategy that seeks development in industry groups with a lower level of complexity than it should.

4. Product Space Design

4.1 Suggested Development Vector

As aforementioned, distance gives us an idea of how far each new product is from a country's current mix of exports. As defined in Hausmann and Hidalgo (2009), distance is "the weighted proportion of products connected to goods p that country c is not exporting, i.e., MCP=0." Based on this definition, the distance between a country and any product that the country is currently exporting (i.e., the country is a significant exporter in the product as compared to global average) is zero. Similarly, opportunity gain quantifies the contribution of a new product in terms of opening up the doors to more and more complex products. Intuitively, a product that a country is currently exporting (i.e., MCP=1) has an opportunity gain of zero. And unreasonable investment on certain product p would lead to a relative decrease in export of more profitable products, and therefore lead to a negative opportunity gain of product p. The opportunity gain is not the only estimator of a country's level of economic development. However, among countries with comparable economics strength, those having higher ECI, or in other words, more reasonable economics structure are often in better shape.

Ranking	Brazil	China	Mexico	United Arab Emirates
1	Machinery and Construction	Raw Manufacturing	Vegetables, Fruits and Plants	High-complexity Products
2	High-complexity Products	Clothing and Accessories	Machinery and Construction	Transportation
3	Transportation	Textile	Transportation	Machinery and Construction
4	Precious Stones	Machinery and Construction	High-complexity Products	Daily Instruments
5	Services and Utilities	Transportation	Services and Utilities	Chemicals
6	Weapons	Weapons	Chemicals	Weapons
7	Daily Instruments	Daily Instruments	Textile	Textile
8	Raw Manufacturing	High-complexity Products	Weapons	Chemical Manufacturing
9	Clothing and Accessories	Precious Stones	Daily Instruments	Raw Manufacturing
10	Chemical Manufacturing	Services and Utilities	Chemical Manufacturing	Energy Drilling and Mining
11	Textile	Chemicals	Clothing and Accessories	Precious Stones
12	Animals and By-products	Energy Drilling and Mining	Raw Manufacturing	Services and Utilities
13	Vegetables, Fruits and Plants	Chemical Manufacturing	Food and Preparations	Metals
14	Food and Preparations	Wood Products	Animals and By-products	Clothing and Accessories
15	Energy Drilling and Mining	Animals and By-products	Metals	Wood Products
16	Chemicals	Vegetables, Fruits and Plants	Wood Products	Animals and By-products
17	Wood Products	Metals	Precious Stones	Vegetables, Fruits and Plants
18	Metals	Food and Preparations	Energy Drilling and Mining	Food and Preparations
ECI	-0.543524462	1.96086598	2.753793255	-0.734459148

Ranking	Brazil	China	Mexico	United Arab Emirates
1	High-complexity Products	Chemicals	Vegetables, Fruits and Plants	High-complexity Products
2	Transportation	Raw Manufacturing	Machinery and Construction	Transportation
3	Machinery and Construction	Clothing and Accessories	Transportation	Machinery and Construction
4	Precious Stones	Textile	High-complexity Products	Daily Instruments
5	Weapons	Machinery and Construction	Services and Utilities	Chemicals
6	Daily Instruments	Transportation	Chemicals	Weapons
7	Clothing and Accessories	Weapons	Weapons	Textile
8	Raw Manufacturing	Daily Instruments	Textile	Chemical Manufacturing
9	Services and Utilities	High-complexity Products	Daily Instruments	Raw Manufacturing
10	Chemical Manufacturing	Precious Stones	Clothing and Accessories	Energy Drilling and Mining
11	Textile	Services and Utilities	Chemical Manufacturing	Precious Stones
12	Animals and By-products	Energy Drilling and Mining	Precious Stones	Services and Utilities
13	Vegetables, Fruits and Plants	Wood Products	Energy Drilling and Mining	Clothing and Accessories
14	Food and Preparations	Animals and By-products	Animals and By-products	Metals
15	Energy Drilling and Mining	Metals	Raw Manufacturing	Wood Products
16	Chemicals	Chemical Manufacturing	Food and Preparations	Animals and By-products
17	Wood Products	Vegetables, Fruits and Plants	Wood Products	Food and Preparations
18	Metals	Food and Preparations	Metals	Vegetables, Fruits and Plants
ECI	-0.677316321	1.700687855	2.527893051	-0.490703037

Table 5: Opportunity Gain Ranking on a Comparable Scale for 2013(up) and 2018(down)

We define the ranking of opportunity gain for a country c, as the Suggested Development Vector (SDV) of c. Table 5 and 6 summarize how the SDV of Brazil compares with a selected group of comparable and leading economies in the world, with the industry groups ranked in decreasing order of significance. Dark blue indicates positive opportunity gain, light blue indicates zero opportunity gains, and white indicates negative opportunity gains. The result shows that leading countries barely have any industries with positive opportunity gain. In other words, those countries are already in the most stable and efficient economic structure. Without the necessity of economic transition, those countries merely need to maintain a steady and balanced economic development. In contrast, developing countries have nearly half of industries with positive opportunity gain, and share common interests in industrial manufacturing and High-complexity Products industries. It can be concluded that Brazil shares the characters of developing countries, with a balanced economics structure that leans towards intermediate-level industries.

Ranking	Singapore	Japan	USA	Germany
1	Chemicals	Chemicals	Energy Drilling and Mining	Chemical Manufacturing
2	Transportation	Metals	Precious Stones	Wood Products
3	High-complexity Products	Machinery and Construction	Animals and By-products	Metals
4	Services and Utilities	Transportation	Vegetables, Fruits and Plants	Machinery and Construction
5	Machinery and Construction	Weapons	Food and Preparations	Transportation
6	Daily Instruments	Daily Instruments	Chemicals	Weapons
7	Weapons	High-complexity Products	Chemical Manufacturing	High-complexity Products
8	Textile	Services and Utilities	Raw Manufacturing	Services and Utilities
9	Chemical Manufacturing	Precious Stones	Wood Products	Energy Drilling and Mining
10	Raw Manufacturing	Energy Drilling and Mining	Machinery and Construction	Precious Stones
11	Clothing and Accessories	Textile	Weapons	Textile
12	Metals	Clothing and Accessories	Daily Instruments	Clothing and Accessories
13	Wood Products	Chemical Manufacturing	High-complexity Products	Chemicals
14	Precious Stones	Animals and By-products	Services and Utilities	Animals and By-products
15	Animals and By-products	Wood Products	Clothing and Accessories	Vegetables, Fruits and Plants
16	Food and Preparations	Vegetables, Fruits and Plants	Metals	Food and Preparations
17	Energy Drilling and Mining	Food and Preparations	Textile	Daily Instruments
18	Vegetables, Fruits and Plants	Raw Manufacturing	Transportation	Raw Manufacturing
ECI	2.751108815	2.154947	1.220401303	1.937171566

Table 6: Opportunity Gain Ranking on a Global Scale

4.2 Budgeted Industry Development Strategy and Interpretation

The optimal budgeted industry development strategy aims to solve the most efficient allocations under the budgeted constraint of different situations of heuristic total export

growth. In order to obtain such an allocation portfolio, we formulate an optimization problem as the following:

$$\begin{aligned} \underset{x \in \mathbf{R}^{|P|}}{\text{Max}} \quad & \left(\frac{k(x) - < k(x) >}{stdev(k(x))}\right)_C \\ \text{Subject to} \quad & \\ & \sum_{p \in P} x_p \leq B \\ & x \succcurlyeq 0 \end{aligned}$$

where k(x) is the second largest eigenvector of $M_{CC'}$ after adding x to the original export vector, C is the country that we are interested in, P is the product space, B is the heuristic budget.

If we can solve this problem, then we can know what the largest ECI that a country can improve to. Accordingly, the optimal solution x * that we obtain here is exactly our optimal allocation. However, the biggest problem is that the objective function is not convex. Therefore, we cannot apply the classical tools for convex optimization on this problem. In order to solve this problem, our idea is to use greedy algorithms. The way that we apply greedy algorithm is that firstly we separate the total budget into k equal parts, and then for the first equal part we try to search for the product that can optimize our objective function by iterating through each $p \in P$. After we find the optimal product p for this equal part, we add the amount back to the export value of this product p and update the ECI for this country. If we observe that ECI does not change after iterating all the products, then we can add up one more equal part to invest. Until we find there is an ECI increment, we add the amount now to that product. The rest equal parts can be done in the same way.

However, as is known to all, greedy algorithm is a kind of local search algorithm, which is pretty possible to run into a local minimum. Therefore, for local search algorithms, one typical way is to keep it away from the local minimum is to enhance the vision of the algorithm by looking more steps forward. In our setting, whenever we obtain an increment of ECI, we mark down the required amount of export growth. Simultaneously, we continue searching for the next ECI increment point, compare the ratios of these two possibilities and pick the largest one. The ratio is defined as the following:

$$Ratio(p) = \frac{ECI_p - ECI_0}{||x_p - x_0||_1}$$

where ECI_p is just the ECI of the country after adding some amount of export increment to product p, which is exactly the amount that is able to make ECI change. Also, we can express it in the way of $||x_p - x_0||_1$.

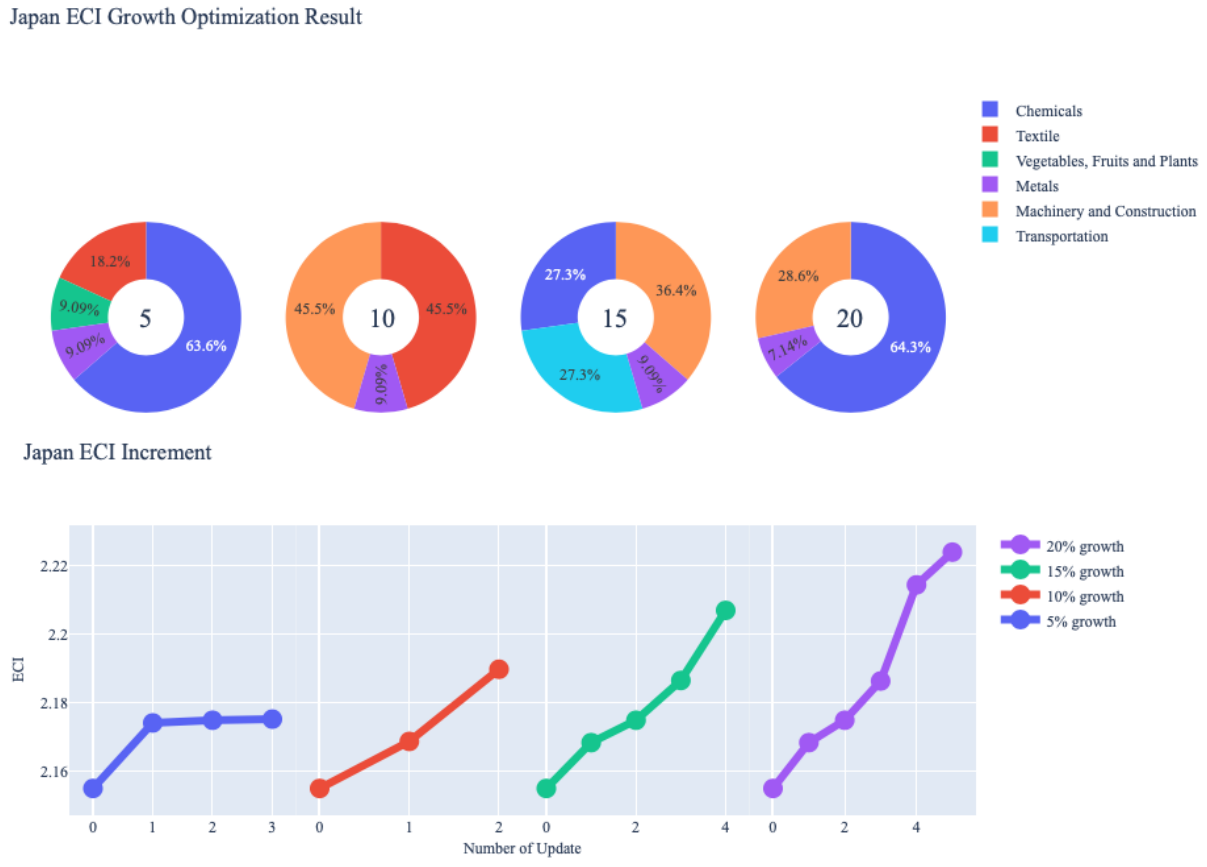
In this way, we can obtain a further sighted greedy algorithm. Also, the number of parts that we would like to separate the budget into also matters. In order to solve this problem, we added a stabilizer on top of the enhanced greedy algorithm, by running the algorithm for

different numbers of parts and selecting the portfolio with the largest ECI increment and most complex economic structure.

Besides, it is quite common that there is a surplus for the budget. To deal with the surplus, we just add it to the product which needs the least amount of dollar to make $M_{cp} = 1$, (i.e., the smallest amount of required export increase).

Economic Panel:

As stated above, the enhanced greedy algorithm is developed mainly for solving the optimal allocation strategy. In order to visualize this allocation, an economic panel is created, consisting of a pie chart, a line chart and a table. Firstly, a pie chart is used to show the percentage of each product in the optimal portfolio. The number located in the center of the circle denotes the heuristic growth of total export, which is also our budget. For example, for the first pie chart below, it shows we should allocate 25% for food and preparations, animals and by-products, and chemicals. In addition, we should allocate 12.5% for raw manufacturing and chemical manufacturing. The lines below the pie charts show how the ECI changes during the searching process of the greedy algorithm. For example, in the last pie chart, we can see there are three components, but there are four increments in the last line chart. That is just because many equalized amounts have been invested in high-complexity products. Even though sometimes people may feel 15% and 20% is nonsense to developed countries, yet it can also give a sense of how a country should develop in the long term. Eventually, the graph in the end is just for numerical explanation for the pie charts.

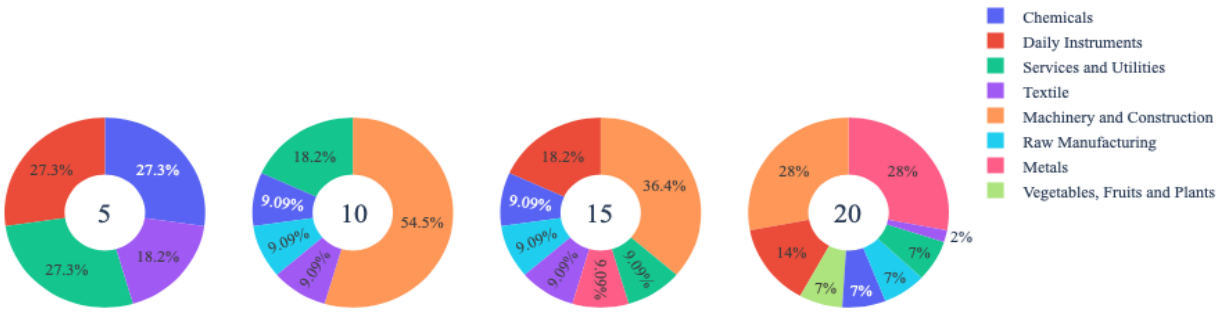


Japan (2013)				
Total Export in 2013 (US. $)	1.17E+12			
Original ECI	2.155			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. $)	5.86E+10	1.17E+11	1.76E+11	2.35E+11
Metals(US. $)	5.33E+09	1.07E+10	1.60E+10	1.68E+10
Transportation(US. $)	0.00E+00	0.00E+00	4.80E+10	0.00E+00
Chemicals(US. $)	3.73E+10	0.00E+00	4.80E+10	1.51E+11
Machinery and Construction(US. $)	0.00E+00	5.33E+10	6.40E+10	6.70E+10
Textile(US. $)	1.07E+10	5.33E+10	0.00E+00	0.00E+00
Vegetables, Fruits and Plants(US. $)	5.33E+09	0.00E+00	0.00E+00	0.00E+00
Increased ECI	2.175	2.190	2.207	2.224

Interpretation:

Below is the economic panel for Brazil in 2013. We can see that for different percentages of heuristic total export growth, the ECI of Brazil will have a different amount of increments. From all the four graphs, we see that Spain already obtains some great increment in terms of ECI, even if the budget is 5 percent growth of total export. When the budget is 5 percent, the increment of ECI seems to be explained by some basic industries, like Daily Instrument, Chemicals, and Textile plus services industry. With larger budgets, the ECI under the constraint of 10, 15, and 20 percent growth has achieved almost double of the ECI during 2013, which is an incredible increase. In these scenarios, increasing export in miscellaneous industries can make Spain have gains on economic complexity. Specifically, machinery and construction accounts for the largest component for the large amount of budget, and then daily instrument and metals.

Brazil ECI Growth Optimization Result

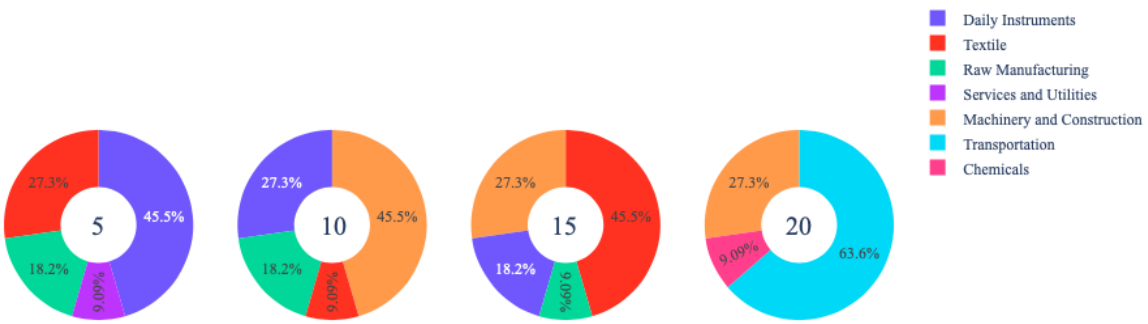


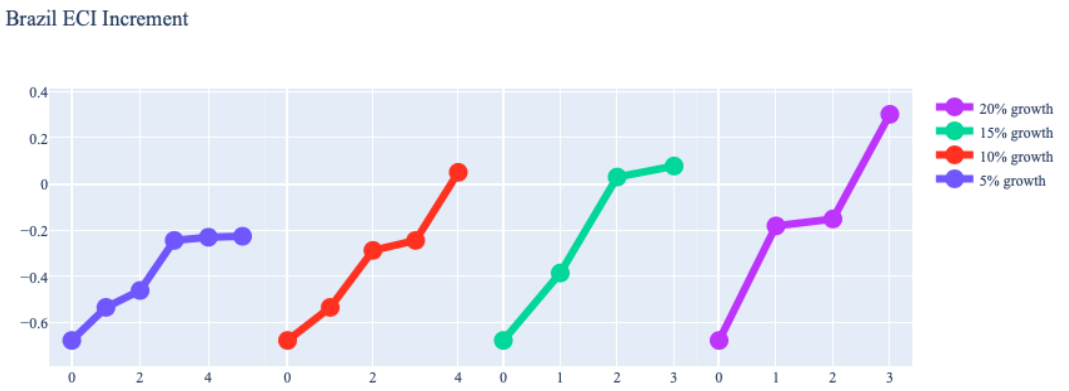
Brazil ECI Increment

Brazil (2013)				
Total Export in 2013 (US. $)	2.96E+11			
Original ECI	- 0.54			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. $)	1.48E+10	2.96E+10	4.44E+10	5.91E+10
Vegetables, Fruits and Plants (US. $)	0.00E+00	0.00E+00	0.00E+00	4.14E+09
Chemicals (US. $)	4.03E+09	2.69E+09	4.03E+09	4.14E+09
Raw Manufacturing (US. $)	0.00E+00	2.69E+09	4.03E+09	4.14E+09
Textile (US. $)	2.69E+09	2.69E+09	4.03E+09	1.18E+09
Metals (US. $)	0.00E+00	0.00E+00	4.03E+09	1.66E+10
Machinery and Construction (US. $)	0.00E+00	1.61E+10	1.61E+10	1.66E+10
Daily Instruments (US. $)	4.03E+09	0.00E+00	8.06E+09	8.28E+09
Services and Utilities (US. $)	4.03E+09	5.38E+09	4.03E+09	4.14E+09
Increased ECI	0.05	0.36	0.48	0.49

For further suggestions on Brazil's development in the future. We also offer the optimization result of Brazil based on export data in 2018. Below is the economic panel for Brazil in 2018. We can see that for different percentages of heuristic total export growth, the ECI of Brazil also deviates a lot. When the budget is 5 percent, the increment of ECI seems to be explained by some basic industries, like Daily Instrument, Chemicals, and Textile plus a little services industry. For the budget of 10, 15 percent growth, investment in machinery and construction offer a great increment in ECI. Furthermore, if the budget is abundant enough, we can also consider the increase in the export of transportation, which also accounts for a great part in last pie graph and causes a great increment in ECI for the last increment in the last line chart. Therefore, for the future strategy, Brazil should prioritize development of machinery and construction products. Afterwards, Daily instruments, textiles, and raw manufacturing are pretty good choices.

Brazil ECI Growth Optimization Result





Brazil (2018)				
Total Export in 2018 (US. $)	2.90E+11			
Original ECI	- 0.68			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. $)	1.45E+10	2.90E+10	4.36E+10	5.81E+10
Chemicals (US. $)	0.00E+00	0.00E+00	0.00E+00	5.28E+09
Raw Manufacturing (US. $)	2.64E+09	5.28E+09	3.96E+09	0.00E+00
Textile (US. $)	3.96E+09	2.64E+09	1.98E+10	0.00E+00
Machinery and Construction (US. $)	0.00E+00	1.32E+10	1.19E+10	1.58E+10
Transportation (US. $)	0.00E+00	0.00E+00	0.00E+00	3.70E+10
Daily Instruments (US. $)	6.60E+09	7.92E+09	7.92E+09	0.00E+00
Services and Utilities (US. $)	1.32E+09	0.00E+00	0.00E+00	0.00E+00
Increased ECI	-0.23	0.050	0.077	0.30

4.3 Sensitivity Analysis

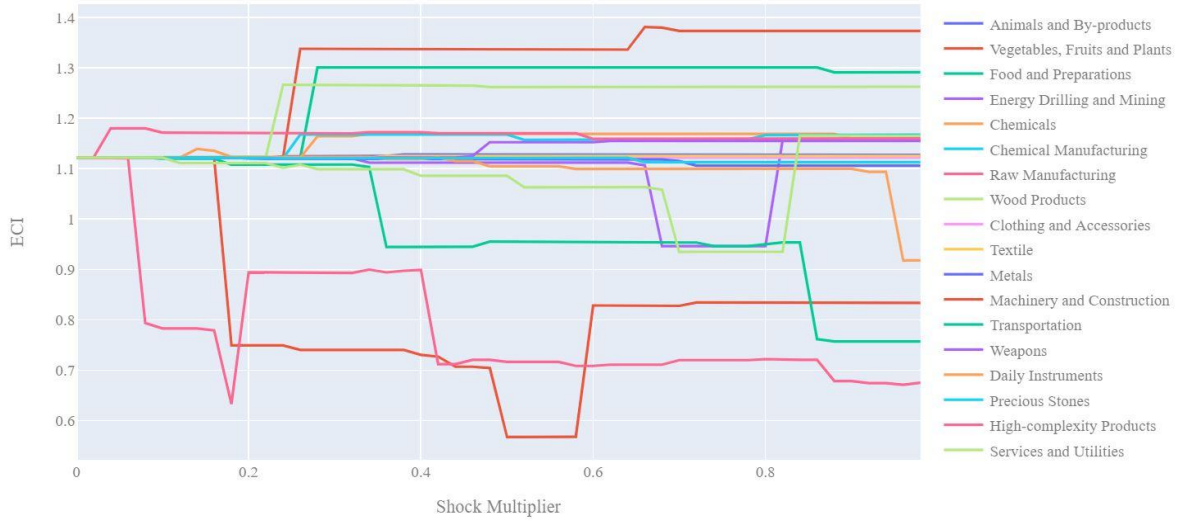
In the following section our broad aim is to understand how sensitive Brazil is to changes in export in various industries. While the Economic Complexity Index has been shown to contain valuable information about the economic strength/capacity of a country, little has been said as to the stability of the measure itself. We seek to uncover the main drivers of stability under a country's ECI score and better understand longer-term projections for ECI growth. Additionally, gaining an intuition on the industries that are bolstering an economy and the industries that offer the greatest return per unit of investment is best done through visualization of industry specific sensitivity.

ECI Sensitivity Graph

Firstly, in order to assess the effect particular industries have on each respective country, we developed ECI Sensitivity graphs. We use shocking methodology to increment or decrement an industry's export level by a certain percentage and recalculate the ECI all else being equal. While freezing the export dynamics of the rest of the world and enacting an instantaneous shock in export for a particular industry and country may not reflect real-life dynamics, what

it does offer us is an understanding of a country's level of dependency on an industry in the context of ECI. The shocking is done in small percentage increments in order to smooth out the resulting curve. Additionally, a recurring theme one will see is that for most industries, a breaking point occurs where the ECI either jumps upwards or downwards, creating a hockey stick shape rather than a linear trend. While the inflection point may not be accurate in the context of real life, comparing the various inflection points across industries can give us valuable insight.

The graphs are formulated as follows: There are four ECI Sensitivity graphs. The first two represent data from 2018. The first chart shows positive shocks in which export numbers are shocked upwards per industry. The X-axis is in terms of percentage shock per current dollar value of export. The Y-axis is the recalculated ECI level post-shocking. The second chart follows the same format except the X-axis represents negative shocking. In other words, exports for each industry are decremented and the ECI is accordingly recomputed. The final two sensitivity graphs show the same results using 2013 data. Below is an example of an ECI sensitivity graph.



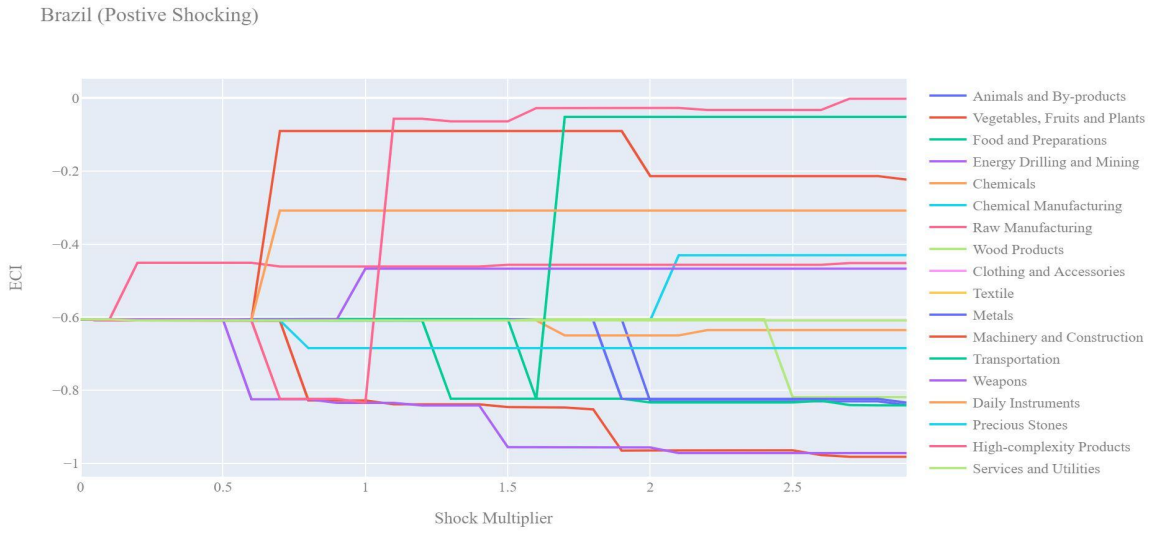
Example 2018 (Incremental ECI Sensitivity)

4.3 Sensitivity Analysis Results and Interpretation

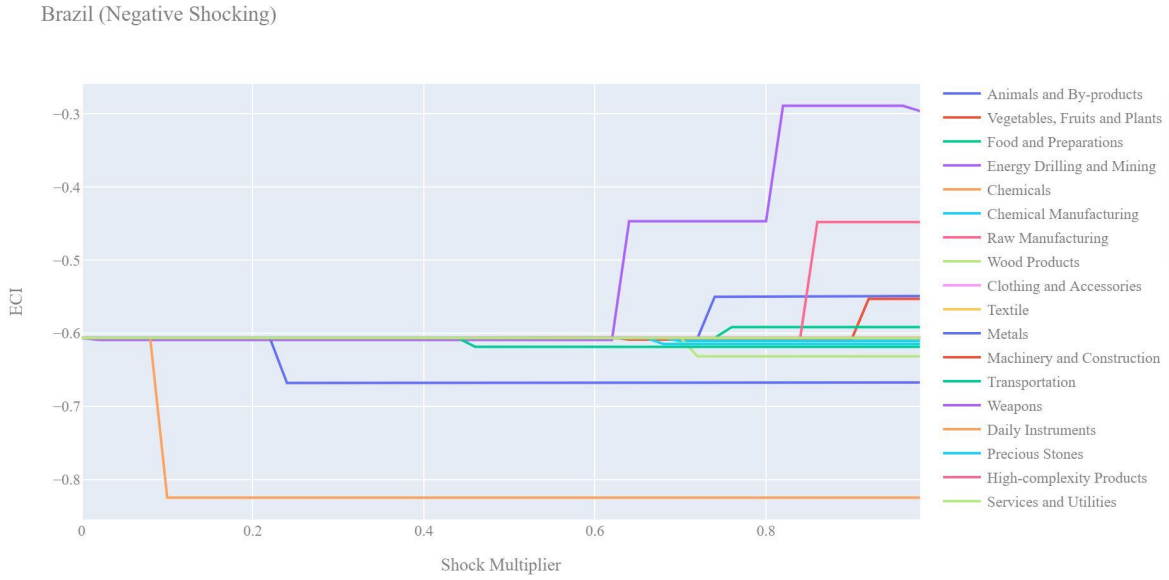
Below is Brazil's 2018 ECI Sensitivity Charts. Firstly in the positive chart, we notice immediately that quite a few industries give rise to large increases in ECI. Machinery, Daily Instrument, Raw Manufacturing all improve the ECI of Brazil significantly after 50% increases in export. High Complexity Products and Transportation offer the best increases in ECI however require over 100% increases in export.

Next we consider Brazil's 2018 Negative Shock chart. Similar to other developing countries, negative shocking has an effect on a very small number of instrues. We see that Energy and

Drilling increases ECI if production is cut by 60%. While Chemicals drastically decreases the ECI if production is cut by as little as 10%. Brazil is also fairly sensitive to drops in production of Metals.



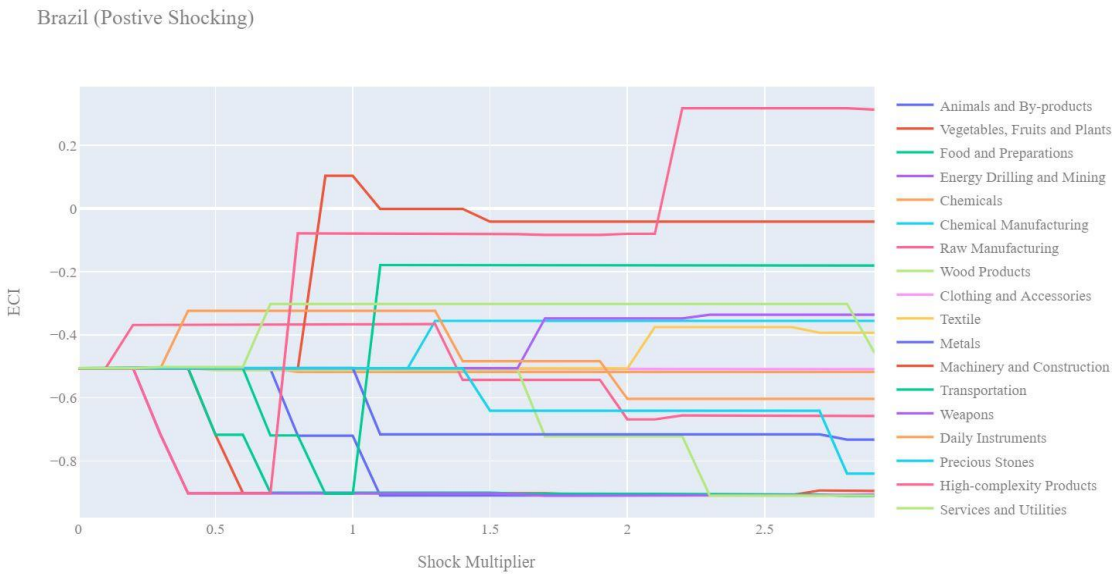
Brazil 2018 (Incremental ECI Sensitivity)



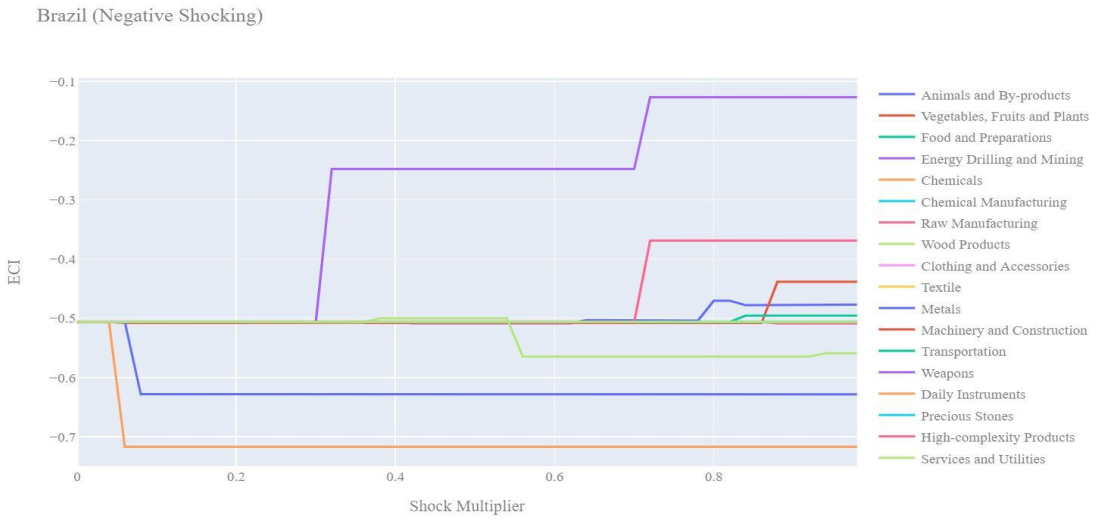
Brazil 2018 (Decremental ECI Sensitivity)

Next we consider the 2013 ECI Sensitivity graphs. We see that Brazil, unlike other developing countries, is highly sensitive to positive shocks in exports. This would suggest that the Brazilian economy has quite a few viable pathways to economic improvement. Machinery and High Complexity Products offer the best ECI increases into the positive territory, however require large increases of about 70% in export. Industries like Daily Instrument, Raw Manufacturing and Service & Utilities can improve ECI in smaller amounts and require much smaller changes in absolute export levels.

In the 2013 negative shocking case, we see that again decreasing the export in Energy Drilling drastically improves ECI. Similar to the 2018 case Brazil is sensitive to drops in Chemicals and Metals however we see that in the 2018 case there is a larger buffer period with Metals. This would suggest that Brazil has stopped relying on Metals as heavily to bolster their ECI.



Brazil 2013 (Incremental ECI Sensitivity)



Brazil 2013 (Decremental ECI Sensitivity)

5. Macro-level Predictions

5.1 Structural Optimality Index

Indeed, such choice of prioritization has proven to be a significant factor in deciding the economic outcomes of countries. In order to quantitatively evaluate how effective our development strategies are and how deviations from the suggested developmental path will lead to suboptimal growth results, we define the measure – Structural Optimality Index (SOI) – on a country level as the Adjusted R-Square obtained from regressing the country's realized

industry development over the suggested development strategy. Both strategies are quantified in nature, with the realized development represented by export increase in every major industry group and the suggested development strategy represented by the opportunity gains of developing the corresponding industry groups as calculated in previous sections. The adjusted R-square from the regression thus provides us with a quantified measure of how the development path adopted by the country has fitted with/differed from calculations on a complexity level.

After obtaining this measure for all countries in our database, we further regress countries' five-year economic growth, which is defined as the percent increase in GDP (USD), over their SOI. Figure 6 illustrates the regression output, which shows a strong positive correlation between countries' SOI and their five-year GDP growth, significant at the 2% level and achieving an adjusted R^2 of 4.5%. In other words, the more a country develops as suggested by calculations on a complexity level, the better economic outcomes it achieves.

Table 18: OLS Regression Results	
Dep. Variable: GDP	**F-Statistic:** 5.963
R^2: 0.054	**Prob (F-Stat):** 0.0163
Adj R^2: 0.045	**No. Observations:** 106

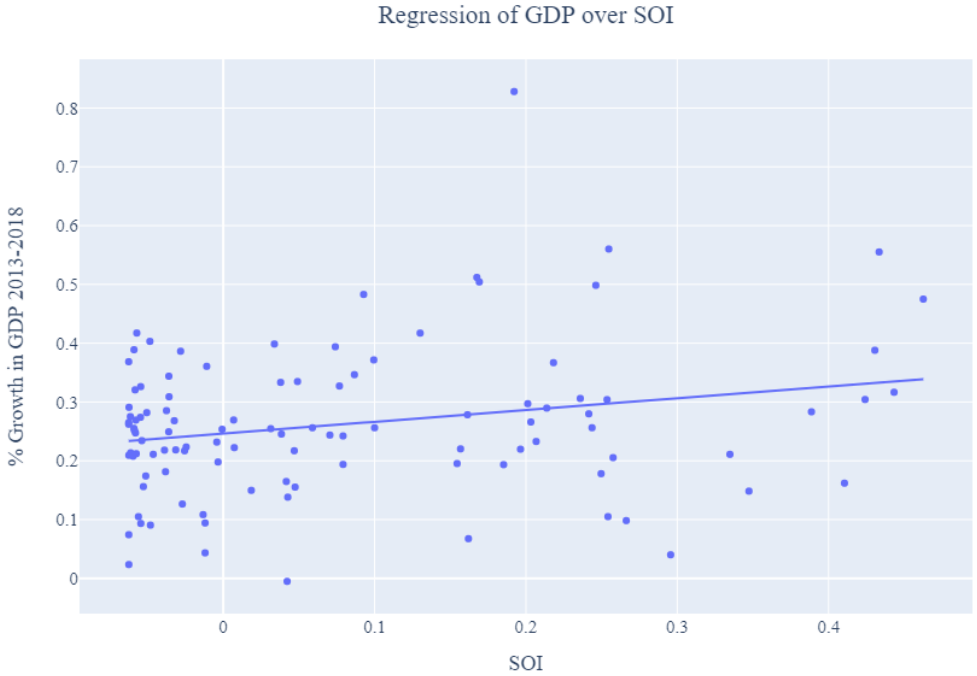


Figure 2: Regression of Five-year GDP Growth over SOI

5.2 SOI of Brazil and Its Implications

Brazil, for instance, has a high level of structural optimality as compared with its emerging peers. As the regression in Figure 7 suggests (the orange curve represents RID increase and the blue curve stands for opportunity gain of the corresponding industry), Brazil demonstrates

a high level of correlation with the suggested developmental path, having an adjusted R-square of merely around 29.6%. Brazil ranks 10th place among all countries in terms of SOI and has one of the slowest GDP growth rates (4.0%) among its emerging peers from 2013 to 2018. This is in direct contrast to emerging economies such as Turkey, where there is a high SOI and a corresponding GDP growth of 36.7%, making it one of the fastest developing economies during the period. In sum, Brazil's stagnant economic progress from 2013 to 2018 cannot be explained by a mismatched development strategy that demonstrates a considerable level of deviations from our suggested developmental path. In specific, various economic and political factors have led Brazil down a path of stagnation, and the Economic Complexity model does not seem as applicable here.

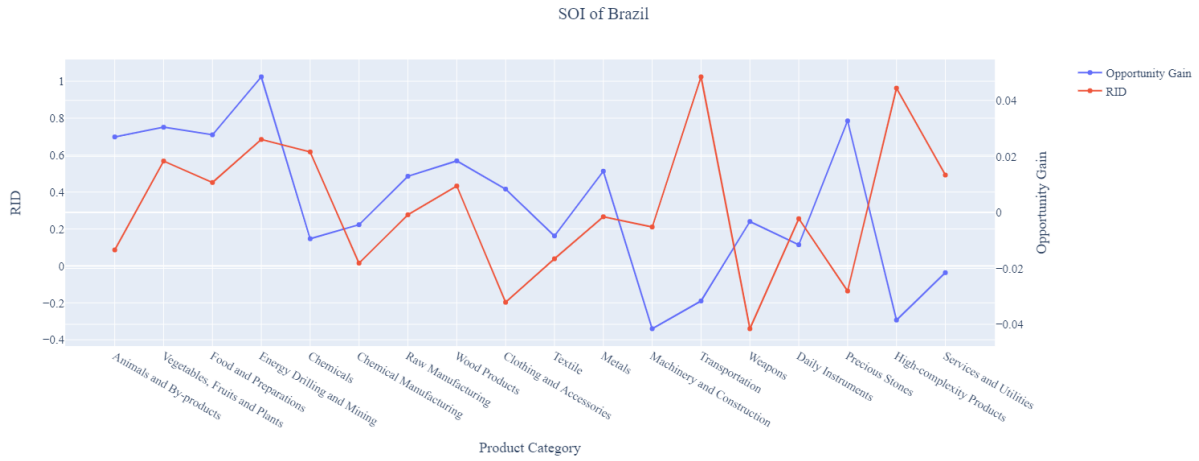


Figure 7: SOI of Brazil (2013-2018)

6. Concluding Remarks

In conclusion, Brazil demonstrated a moderate level of economic growth with an annual GDP growth rate of -3.7%, concurrent with a decrease in economic complexity as compared with other major emerging economies during the period from 2013 to 2018.

The level of economic progress during the period, we believe, can be partially explained through analysis of the economic and product complexity structure of Brazil on the industry group level. The product classification system we adopt allows us to measure the realized development for various industry groups and to observe that Brazil aggressively invested in developing Weapons, Clothing and Accessories, Precious Stones during the period, while its emerging peers and developed economies around the globe have adopted paths that were more well-suited to their current stances in the product space.

Based on our analysis of the opportunity gain and a sensitivity analysis of major industry groups, Brazil can further its gains by prioritizing stone, Services and Utilities, and clothing industry groups. We further note that Brazil has an ill-matched development strategy that indicates a particularly low level of structural optimality on the complexity level, having an adjusted R-square of 29.6%. Since a significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, Brazil indeed has a suboptimal growth experience as compared with fast-growing economies

both on a regional scale and on a global scale, and has the potential to further its economic gains through industrial structure optimization as suggested in the paper.

References

Hausmann, R., Hidalgo, C., Bustos, S., Coscia, M., Chung, S., Jimenez, J., Simoes, A. and Yıldırım, M. (2007). *The Atlas of Economic Complexity*. [online] Atlas.cid.harvard.edu. Available at: http://atlas.cid.harvard.edu/.

Balassa, B., "The Purchasing Power Parity Doctrine - A Reapprais- al," *Journal of Political Economy* **72**, 584-596 (1964).

Feenstra, R.; Lipsey, R.; Deng, H.; Ma, A. & Mo, H. "World Trade Flows: 1962-2000" NBER working paper 11040. National Bureau of Economic Research, Cambridge MA (2005).

United Nations Commodity Trade Statistics Database (http://comtrade.un.org/db/), accessed in August 2019.

The World Economic Forum, "The global competitiveness report," (various years).

Barro, R. & Lee, J-W. "A New Data Set of Educational Attainment in the World, 1950-2010," NBER Working Paper No. 1590 (2010).

Kaufmann, D. & Kraay, A. "Governance Indicators: Where Are We, Where Should We Be Going?" Policy Research Working Paper 4370. Washington, DC: World Bank (2008).

Hanushek, E.A. & Woessmann, L. "The Role of Cognitive Skills in Economic Development," Journal of Economic Literature 46(3), 607- 668 (2008).