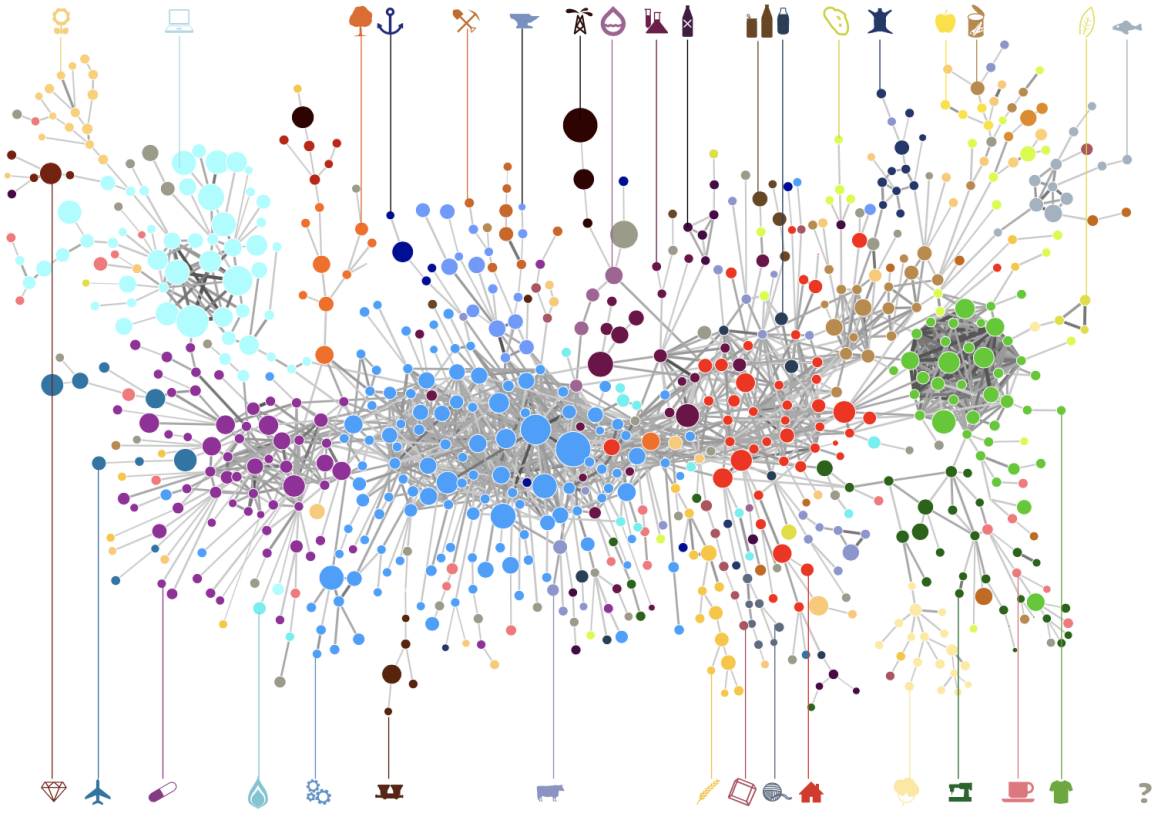

https://atlas.cid.harvard.edu/

Optimal Industry Development Strategy Using Economic and Product Complexity

Portugal

—

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Optimal Industry Development Strategy for Portugal

0. Executive Summary

In this report, we aim to uncover the economic path Portugal went through during the period from 2013 to 2018. Specifically, we dive into the topic through a macroeconomic overview of Portugal 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, Portugal demonstrated a low level of economic growth with an annual GDP growth rate of 2.1%, concurrent with a decrease in economic complexity as compared with other major economies in Europe.

The level of economic progress during the period, we believe, can be partially explained through analysis of the economic and product complexity structure of Portugal on the industry group level. The product classification system we adopt allows us to measure the realized industry development for various industry groups and to observe that Portugal invested heavily in developing High-complexity Products, Machinery and Construction, and Chemical Manufacturing during the period, while its emerging peers and developed economies around the globe have adopted more conservative developmental paths.

Based on our analysis of the opportunity gain and a sensitivity analysis of major industry groups, Portugal can further its gains by prioritizing Transportation, Daily Instruments. We further note that Portugal has a slightly mismatched development strategy that indicates a moderate level of structural optimality on the complexity level, having an adjusted R-square of around 25.0%. Since a significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, Portugal 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 47th largest economy in the world by GDP, Portugal has a GDP of 226 billion USD in 2013 and 240 billion USD in 2018, exhibiting an extraordinary level of economic output. Figure 1 illustrates the time-series GDP results for the world's major european economies from 1999-2018, and Portugal ranks among its counterparts as a stable player. Portugal exhibits an slightly increasing level of GDP during the 6 years from 2013 to 2018, with an average annual growth rate of 2.1%. This rate is clearly above the average annual growth rate of the other 4 major European economies in the world, which have a geometric average growth rate of 0.6% and an arithmetic average growth rate of 0.9%. The rapid economic growth in Portugal, we believe, can be reflected through consistent ECI and PCI, and can be further explained by an optimal set of production strategies Portugal adopted during the period, which we will expand at the later stage of the report.

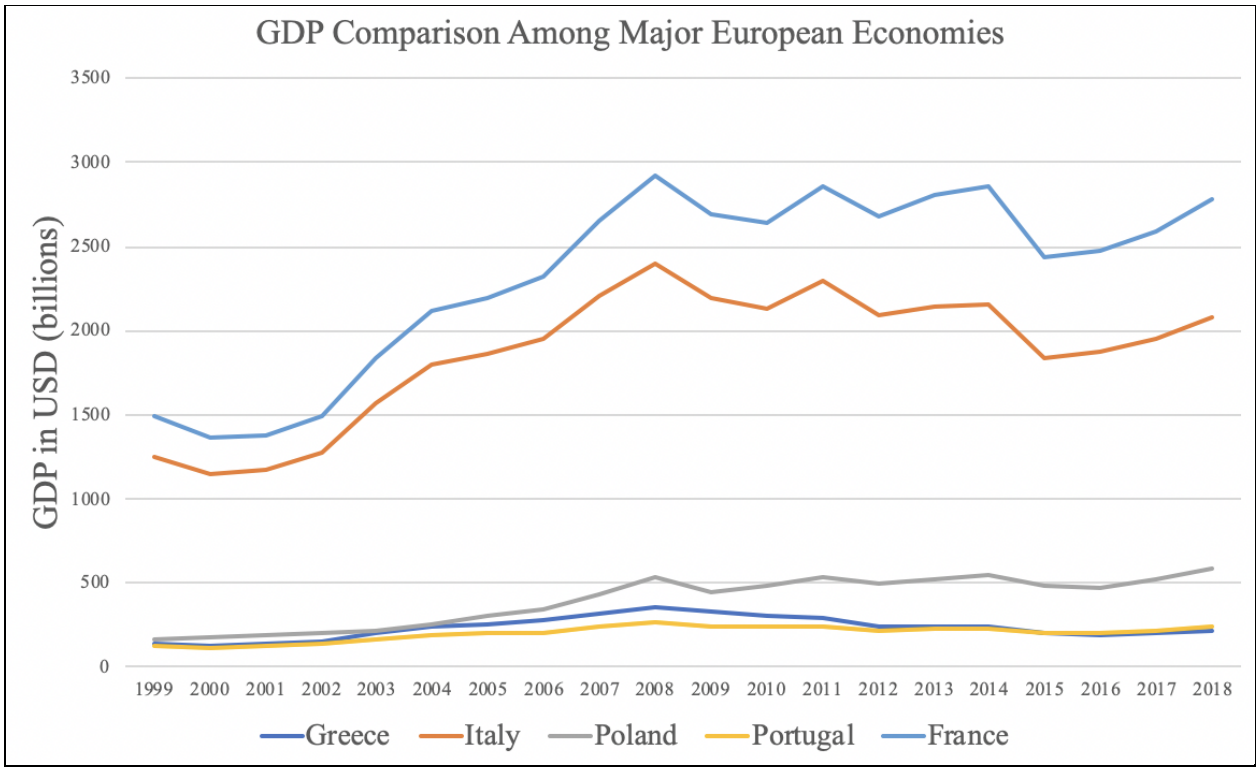


Figure 1: GDP Comparison Among Major European Economies

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 Portugal. As illustrated in Figure 2 below, Portugal exhibits a stably low level in terms of its production capability from 2013 to 2018. This is in direct contrast to countries such as France, which demonstrates overwhelming advantage over Portugal in terms of both ECI and GDP growth during the period.

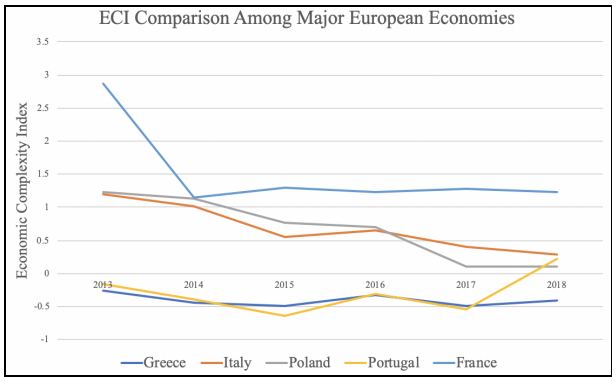


Figure 2: ECI Comparison

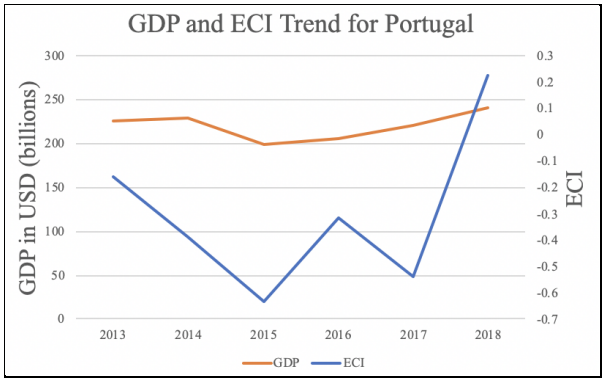


Figure 3: GDP and ECI (Portugal)

Figure 3 offers a further comparison of GDP and ECI over the time span from 2013 to 2018 for Portugal. The slight increase in GDP during this period is accompanied by a stably low ECI,

indicating that the mild economic growth experienced by Portugal during the period from 2013 to 2018 might not be attributed to its stagnant ECI, or the ineffectiveness of the country in developing a competitive product space that helps to accumulate complicated knowledge and technology. In order to provide a more concrete answer to why this has happened, we will dive into an analysis of Portugal'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 Portugal'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 Portugal 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, Portugal has focused on products with a moderate level of complexity and those requiring intermediate skills.

Rank	Category	RID	Rank	Category	RID
1	High-complexity Products	-0.177	10	Food and Preparations	-0.013
2	Machinery and Construction	-0.140	11	Animals and By-products	-0.011
3	Chemical Manufacturing	-0.070	12	Chemicals	-0.011
4	Clothing and Accessories	-0.049	13	Energy Drilling and Mining	-0.008
5	Raw Manufacturing	-0.047	14	Weapons	-0.007
6	Metals	-0.034	15	Vegetables, Fruits and Plants	-0.005
7	Precious Stones	-0.032	16	Wood Products	0.010
8	Transportation	-0.026	17	Services and Utilities	0.019
9	Textile	-0.020	18	Daily Instruments	0.032

Table 2: Realized Industry Development (RID) of Portugal

3.3 Regional and Global Comparison

Table 3 and 4 below summarize how the production strategy adopted by Portugal compares with leading economies and a selected group of emerging economies in the world, as measured in RID. It can be directly observed that Portugal 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 such as clothing, services and utilities, and chemical manufacturing.

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 Portugal'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 Portugal should have relied 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, Portugal is indeed adopting a moderate but slightly out-of-phase 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 decrement 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 structures are often in better shape.

Ranking	Spain	Portugal	Greece
1	Energy Drilling and Mining	Energy Drilling and Mining	Precious Stones
2	Precious Stones	Machinery and Construction	Weapons
3	Weapons	Precious Stones	Clothing and Accessories
4	Textile	High-complexity Products	Machinery and Construction
5	Chemicals	Services and Utilities	Services and Utilities
6	Daily Instruments	Weapons	High-complexity Products
7	Animals and By-products	Transportation	Daily Instruments
8	Vegetables, Fruits and Plants	Daily Instruments	Transportation
9	Food and Preparations	Chemical Manufacturing	Chemicals
10	Chemical Manufacturing	Chemicals	Animals and By-products
11	Raw Manufacturing	Animals and By-products	Vegetables, Fruits and Plants
12	Wood Products	Vegetables, Fruits and Plants	Food and Preparations
13	Clothing and Accessories	Food and Preparations	Energy Drilling and Mining
14	Metals	Raw Manufacturing	Chemical Manufacturing
15	Transportation	Wood Products	Raw Manufacturing
16	Services and Utilities	Clothing and Accessories	Wood Products
17	Machinery and Construction	Textile	Textile
18	High-complexity Products	Metals	Metals
ECI	0.45830144	-0.157783672	-0.232930358

Ranking	Spain	Portugal	Greece
1	Energy Drilling and Mining	Energy Drilling and Mining	Precious Stones
2	Precious Stones	Precious Stones	Clothing and Accessories
3	Weapons	Weapons	High-complexity Products
4	Textile	Services and Utilities	Transportation
5	Services and Utilities	Chemicals	Machinery and Construction
6	Chemicals	Chemical Manufacturing	Weapons
7	Daily Instruments	Animals and By-products	Chemicals
8	Machinery and Construction	Vegetables, Fruits and Plants	Services and Utilities
9	Animals and By-products	Food and Preparations	Daily Instruments
10	Vegetables, Fruits and Plants	Raw Manufacturing	Animals and By-products
11	Food and Preparations	Wood Products	Vegetables, Fruits and Plants
12	Chemical Manufacturing	Clothing and Accessories	Food and Preparations
13	Raw Manufacturing	Textile	Energy Drilling and Mining
14	Wood Products	Metals	Chemical Manufacturing
15	Clothing and Accessories	Transportation	Raw Manufacturing
16	Metals	Daily Instruments	Wood Products
17	Transportation	Machinery and Construction	Textile
18	High-complexity Products	High-complexity Products	Metals
ECI	0.168962035	0.272765537	-0.425579783

Table 5: Opportunity Gain Ranking on a Regional Scale for 2013(up), 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 Portugal compares with a selected group of regional economies 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 Portugal shares the characters of developing countries, with a premature economics structure that leans towards basic to intermediate level industries.

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

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:

$$\max_{x \in \mathbf{R}^{|P|}} \quad \left(\frac{k(x) - < k(x) >}{stdev(k(x))}\right)_C$$

Subject to

$$\sum_{p \in P} x_p \leq B$$

$$x \succcurlyeq 0$$

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 algorithm. 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 $||x_p - x_0||_1$.

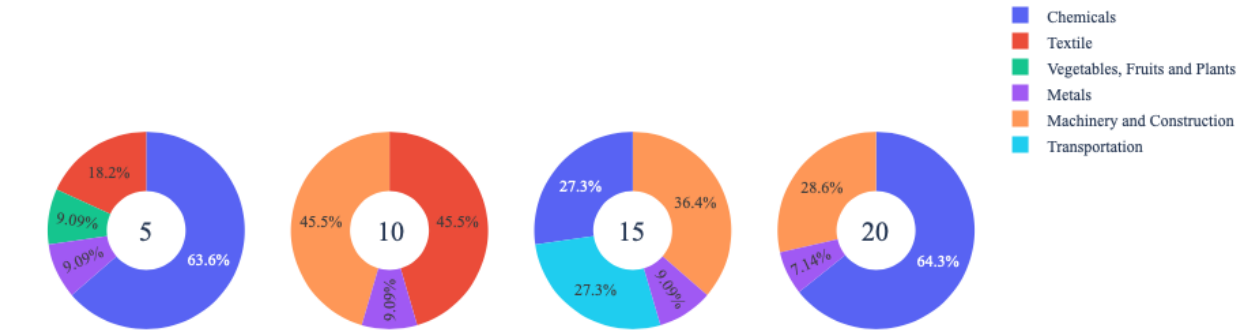
In this way, we can obtain a further sighted greedy algorithm. Also, the number of parts that we would like to separate the budget into also matters. In order to solve this problem, we added a stabilizer on top of the enhanced greedy algorithm, by running the algorithm for different number of parts and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

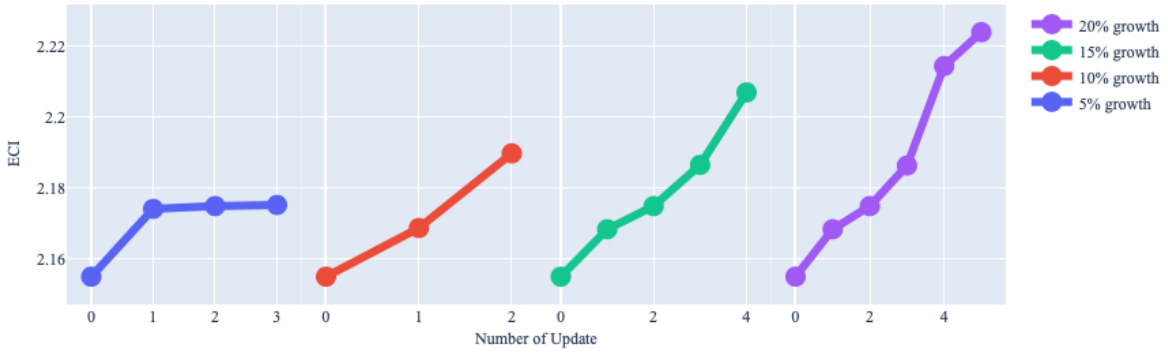
Economic Panel:

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 chart.

Japan ECI Growth Optimization Result



Japan ECI Increment

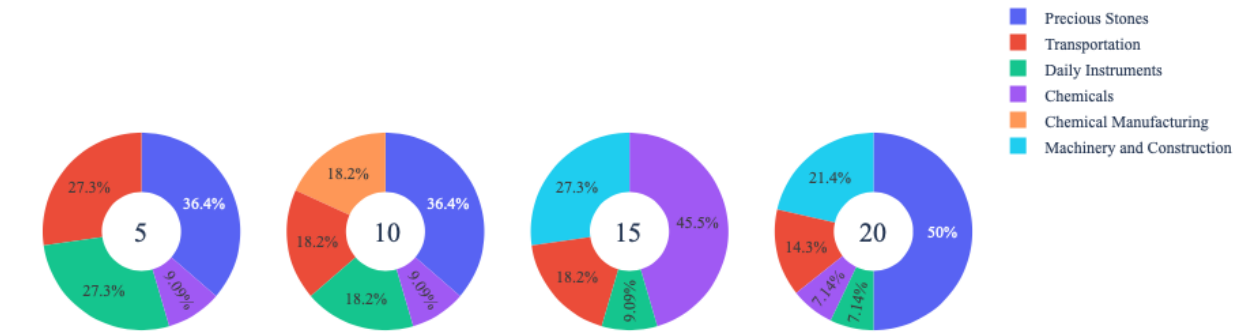


Japan (2013)				
Total Export in 2013 (US. $)	1.17E+12			
Original ECI	2.155			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. $)	5.86E+10	1.17E+11	1.76E+11	2.35E+11
Metals(US. $)	5.33E+09	1.07E+10	1.60E+10	1.68E+10
Transportation(US. $)	0.00E+00	0.00E+00	4.80E+10	0.00E+00
Chemicals(US. $)	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

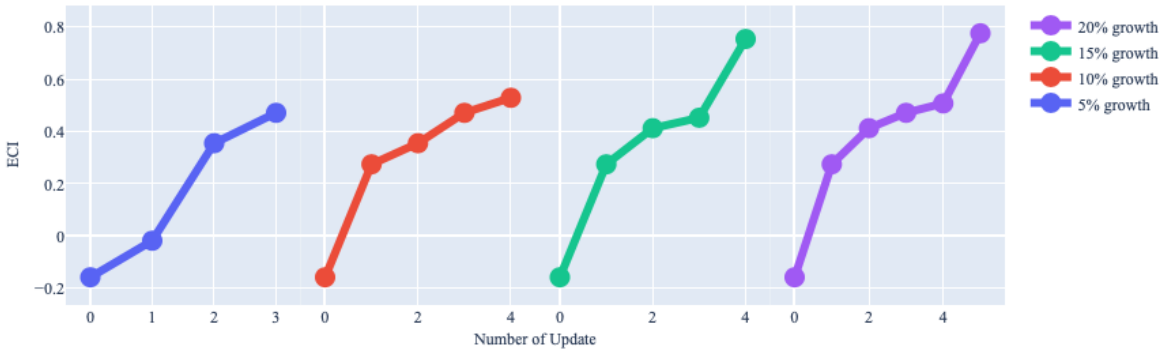
Interpretation:

Below is the economic panel for Portugal in 2013. We can see that for different percentages of heuristic total export growth, the ECI of Portugal has different performance. From all the four line graphs, we see that Portugal already obtains some great increment in terms of ECI. Most importantly, the higher the budget is, the greater the ECI will be. This means that in both short term and long term, Portugal still has great room to improve. For all cases, we see that the portfolio contains many products, meaning that opportunities of increasing ECI is much larger than other countries, whose portfolio typically dominates by one or more products.

Portugal ECI Growth Optimization Result



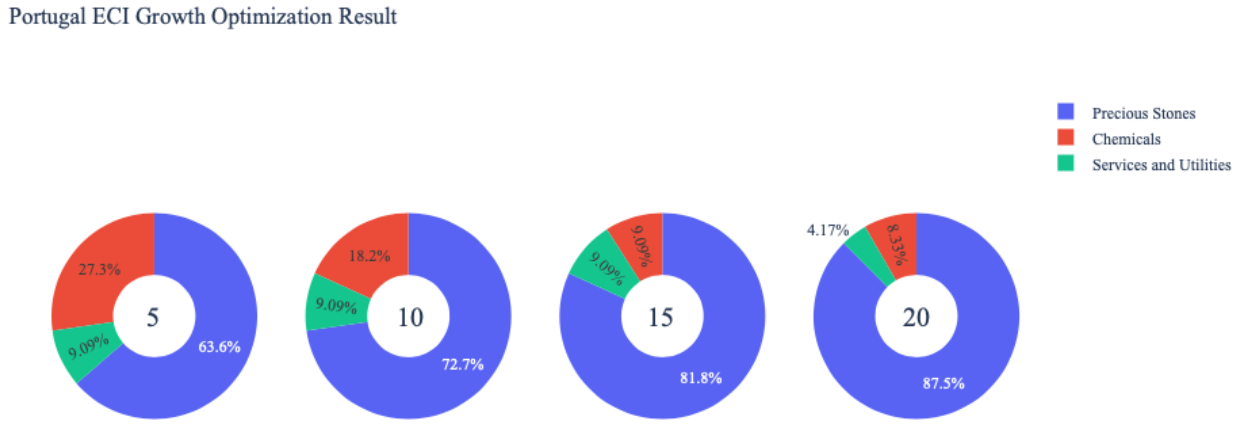
Portugal ECI Increment

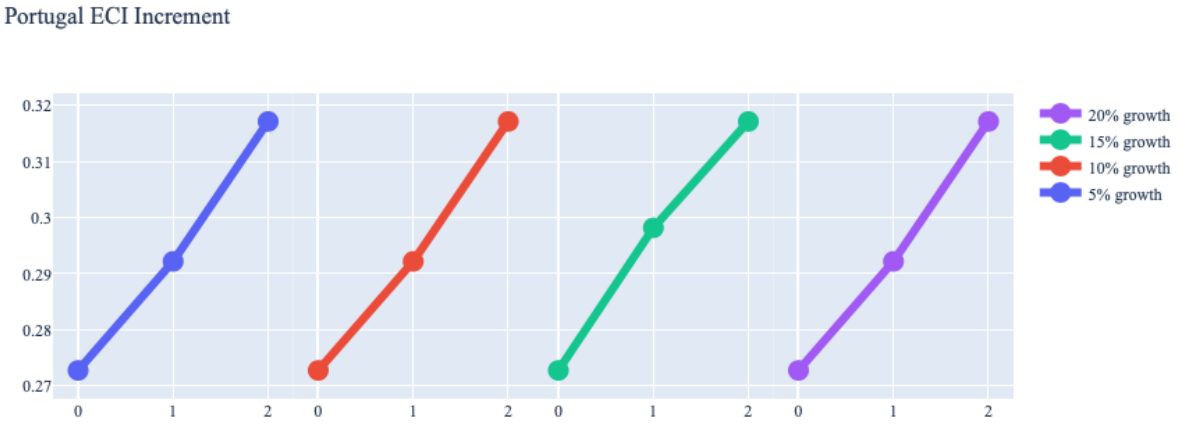


Portugal (2013)				
Total Export in 2013 (US. $)	8.16E+10			
Original ECI	-0.158			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. $)	4.08E+09	8.16E+09	1.22E+10	1.63E+10
Chemical Manufacturing(US. $)	0.00E+00	1.48E+09	0.00E+00	0.00E+00
Precious Stones(US. $)	1.48E+09	2.97E+09	0.00E+00	8.16E+09
Daily Instruments(US. $)	1.11E+09	1.48E+09	1.11E+09	1.17E+09
Chemicals(US. $)	3.71E+08	7.42E+08	5.56E+09	1.17E+09
Machinery and Construction(US. $)	0.00E+00	0.00E+00	3.34E+09	3.50E+09
Transportation(US. $)	1.11E+09	1.48E+09	2.23E+09	2.33E+09
Increased ECI	0.471	0.528	0.753	0.775

For further suggestions on Portugal's development in the future. We also offer the optimization result of Portugal based on export data in 2018. Below is the economic panel for Portugal in 2018. We can see that for different percentages of heuristic total export growth, the ECI growth pattern of Portugal is quite different from the one in 2013. From all the four line graphs, we see that Portugal already obtains some great increment in terms of ECI. However, the growth is pretty limited and have reached the same optimal ECI in each stage. For all cases, chemicals as well as services and utilities account for the increment of the ECI. Therefore, for future strategy,

Portugal should prioritize development of chemicals as well as services and utilities, in order to optimize ECI.





Portugal (2018)				
Total Export in 2018 (US. $)	9.85E+10			
Original ECI	0.27			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. $)	4.92E+09	9.85E+09	1.48E+10	1.97E+10
Chemicals (US. $)	1.34E+09	1.79E+09	1.34E+09	1.64E+09
Precious Stones (US. $)	3.13E+09	7.16E+09	1.21E+10	1.72E+10
Services and Utilities (US. $)	4.48E+08	8.95E+08	1.34E+09	8.20E+08
Increased ECI	0.32	0.32	0.32	0.32

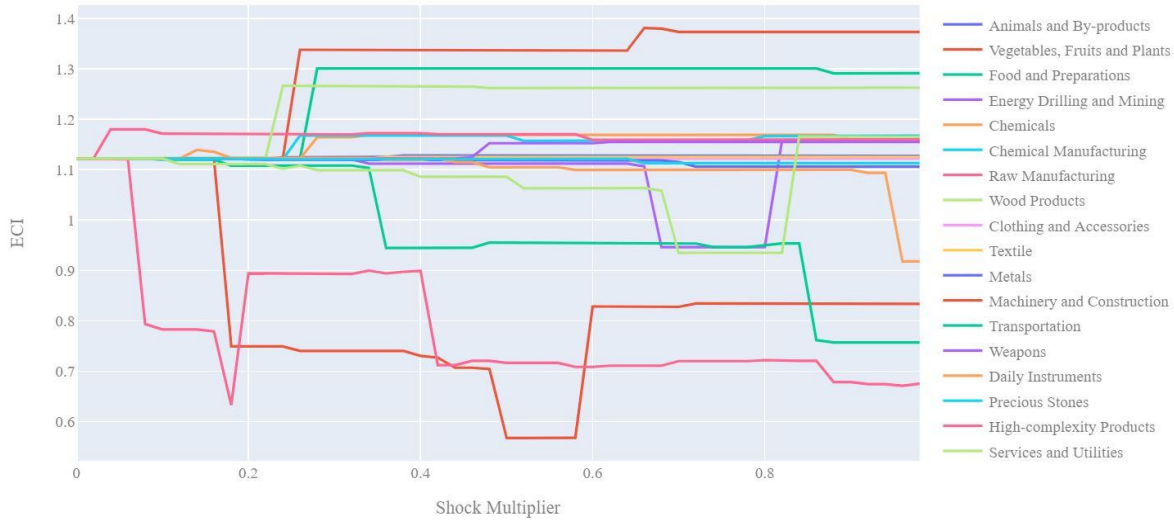
4.3 Sensitivity Analysis and Contingency Strategy

In the following section our broad aim is to understand how sensitive Portugal 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. To this end, we have developed two categories of sensitivity analysis.

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 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 shocking 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)

SDV sensitivity

Secondly, we analyze the sensitivity of the SDV to changes in export levels. The goal is to understand how export level changes for a particular industry can affect the marginal opportunity gain for other industries. We will be using specifically High Complexity Products and Food and Preparations as our base industries. We will be increasing or decreasing the absolute export level in both of these industries and observing the effects on the SDV.

When the opportunity gain of an industry is negative, the SDV sensitivity approximates how an over-development of the industry jeopardizes the economic structure of a country. When the opportunity gain of the industry is zero, the SDV sensitivity determines whether the further development of the industry shapes the country with a better economic structure and predicts how the SDV would change accordingly. Specifically, as we reduce the export of such an industry to 25%-50% of its original value, a few other industries originally with negative opportunity gain could likely become profitable.

Similar to the ECI sensitivity graphs above, we will be shocking export of High Complexity Products and Food and Preparations in small percentage increments. A new SDV, represented by a new column in the charts, is recorded only when a certain level of shock changes the structure of the SDV. In effect we are incrementing or decrementing export levels of two industries until the marginal opportunity gain of any industry changes in category (positive, negative, or neutral). Below is an example of a SDV Sensitivity chart with Positive Shocking. Industries with positive marginal opportunity gain are colored blue, neutral is colored white and negative is colored red.

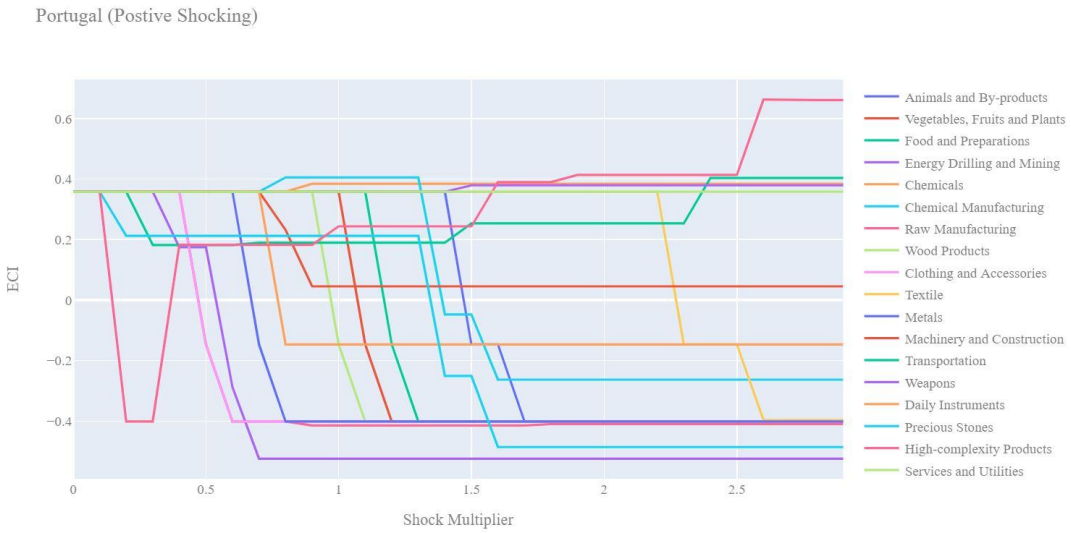
	0.0%	10.0%	30.0%	50.0%	80.0%	100.0%	120.0%
0	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants	Chemicals	Chemicals	Chemicals	Machinery and Construction
1	Daily Instruments	Daily Instruments	Daily Instruments	Services and Utilities	Services and Utilities	Daily Instruments	Chemicals
2	Weapons	Weapons	Weapons	Textile	Textile	Textile	Daily Instruments
3	Transportation	Transportation	Transportation	Weapons	Daily Instruments	Services and Utilities	Services and Utilities
4	Machinery and Construction	Machinery and Construction	Machinery and Construction	Transportation	High-complexity Products	Transportation	Transportation
5	Metals	Metals	High-complexity Products	Machinery and Construction	Transportation	Chemical Manufacturing	Textile
6	High-complexity Products	High-complexity Products	Chemicals	High-complexity Products	Machinery and Construction	Weapons	Chemical Manufacturing
7	Chemicals	Services and Utilities	Services and Utilities	Daily Instruments	Chemical Manufacturing	High-complexity Products	Weapons
8	Services and Utilities	Chemicals	Textile	Chemical Manufacturing	Weapons	Machinery and Construction	High-complexity Products
9	Textile	Textile	Chemical Manufacturing	Precious Stones	Clothing and Accessories	Clothing and Accessories	Clothing and Accessories
10	Chemical Manufacturing	Chemical Manufacturing	Precious Stones	Clothing and Accessories	Precious Stones	Precious Stones	Raw Manufacturing
11	Precious Stones	Precious Stones	Clothing and Accessories	Vegetables, Fruits and Plants	Raw Manufacturing	Raw Manufacturing	Precious Stones
12	Clothing and Accessories	Clothing and Accessories	Raw Manufacturing	Raw Manufacturing	Wood Products	Metals	Wood Products
13	Raw Manufacturing	Raw Manufacturing	Metals	Metals	Metals	Wood Products	Metals
14	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining	Wood Products	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining
15	Wood Products	Wood Products	Wood Products	Energy Drilling and Mining	Animals and By-products	Animals and By-products	Animals and By-products
16	Animals and By-products	Animals and By-products	Animals and By-products	Animals and By-products	Vegetables, Fruits and Plants	Food and Preparations	Food and Preparations
17	Food and Preparations	Food and Preparations	Food and Preparations	Food and Preparations	Food and Preparations	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants
ECI	2.261503667	2.520234671	3.08896214	3.452901685	4.299466299	4.439916975	5.069638102

Example High-complexity Products 2018 (Incremental SDV Sensitivity)

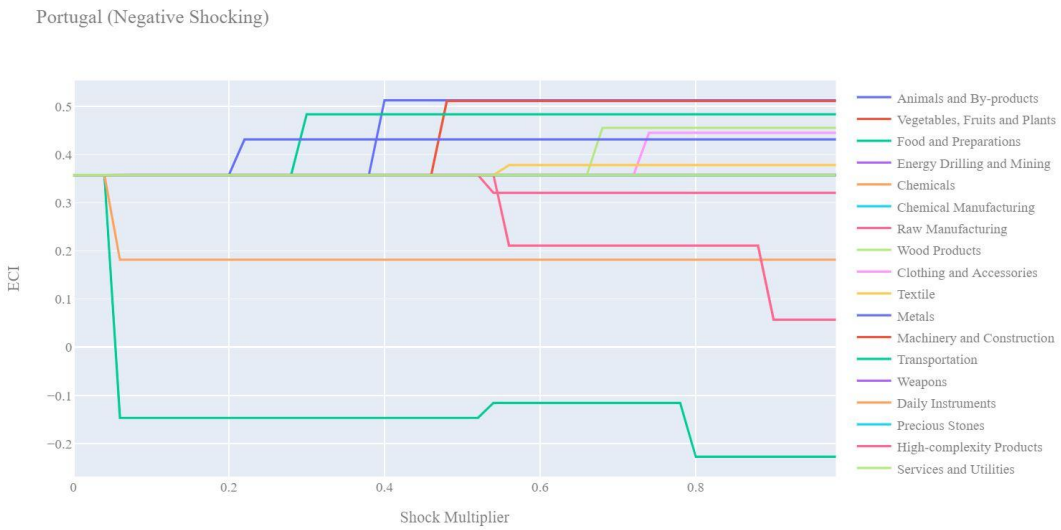
4.3 Sensitivity Analysis Results and Interpretation

Below is Portugal's 2018 ECI Sensitivity Charts. Firstly in the positive chart, we notice immediately that almost no industries allow for increases in ECI. The majority of industries drastically decrease ECI when exports are increased.

Next we consider Portugal's 2018 Negative Shock chart. We can see that Portugal is fairly sensitive to decreases in export in Transportation and Daily Instrument. Portugal is also sensitive to decreases in High Complexity Products however more than 50% drops in export are needed to experience any detriment in ECI.



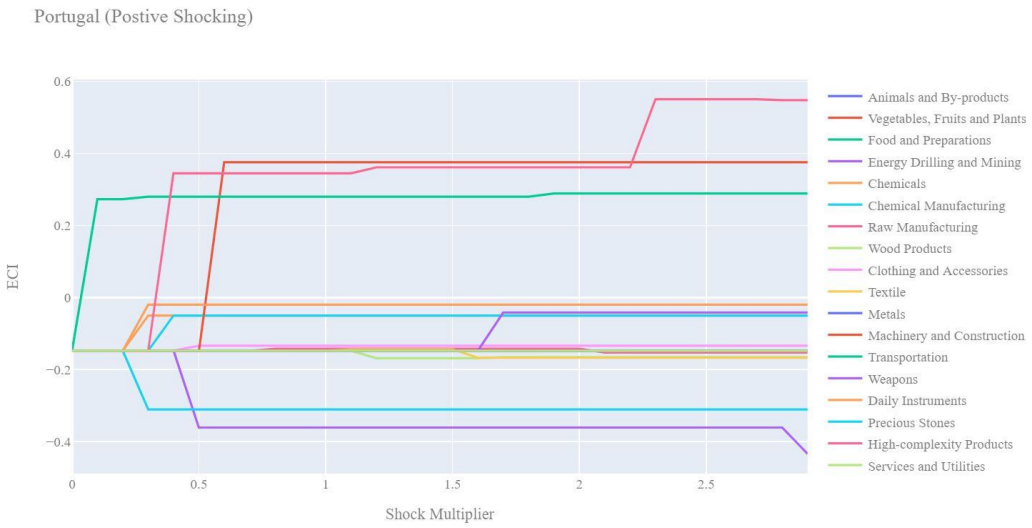
Portugal 2018 (Incremental ECI Sensitivity)



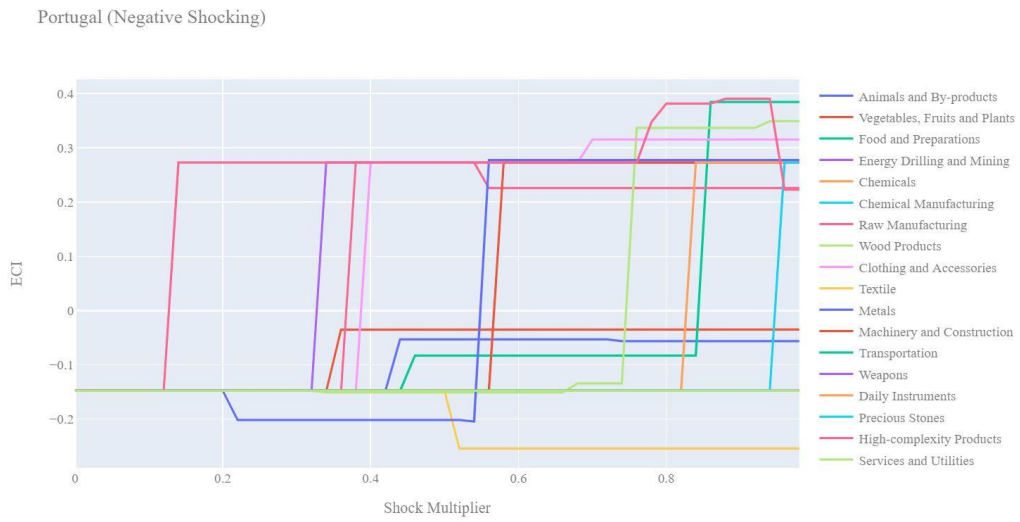
Portugal 2018 (Decremental ECI Sensitivity)

Next we consider the 2013 ECI Sensitivity graphs. We see that in the positive shocking case there are quite a few industries that can greatly improve ECI with only 10% to 50% increase in export. For example, increases in export of Transportation, Machinery, and High Complexity products all lead to the boosting of ECI from below zero to oer 0.4.

In the 2013 negative shocking case, we see that decreases in exports in quite a few industries leads to major increases in ECI. This may suggest that Portugal had a suboptimal blend of exporting industries in 2013 and improved the balance of exporting industries by 2018.



Portugal 2013 (Incremental ECI Sensitivity)



Portugal 2013 (Decremental ECI Sensitivity)

Below we see the SDV sensitivity charts for High Complexity Products. We see that fairly small increases in export of High Complexity Products makes room for other industries to shift into positive opportunity gain territory. A 20% increase in High Complexity product exports leads to four additional industries with positive opportunity gains: Chemicals.. Weapons, Chemical Manufacturing, Precious Stones.

Considering the Negative SDV sensitivity chart we observe that as export of High Complexity products decrease, industries that were worth investing begin to shift to the neutral opportunity gain region. Intuitively, may of the industries that are available to Portugal are dependent on the Portugal's strength in High Complexity Products.

	0.0%	20.0%	40.0%	100.0%	160.0%
0	Services and Utilities	High-complexity Products	Services and Utilities	Machinery and Construction	Machinery and Construction
1	Machinery and Construction	Machinery and Construction	Machinery and Construction	Services and Utilities	Services and Utilities
2	Chemicals	Transportation	Daily Instruments	Daily Instruments	Daily Instruments
3	High-complexity Products	Daily Instruments	Chemicals	Chemicals	Chemicals
4	Weapons	Services and Utilities	Transportation	Weapons	Weapons
5	Vegetables, Fruits and Plants	Chemicals	Weapons	Transportation	Chemical Manufacturing
6	Food and Preparations	Weapons	Chemical Manufacturing	Chemical Manufacturing	Energy Drilling and Mining
7	Raw Manufacturing	Chemical Manufacturing	Raw Manufacturing	Precious Stones	Metals
8	Wood Products	Precious Stones	Vegetables, Fruits and Plants	Energy Drilling and Mining	Precious Stones
9	Clothing and Accessories	Vegetables, Fruits and Plants	Food and Preparations	Metals	Transportation
10	Textile	Food and Preparations	Clothing and Accessories	Vegetables, Fruits and Plants	Food and Preparations
11	Metals	Clothing and Accessories	Wood Products	Food and Preparations	Vegetables, Fruits and Plants
12	Transportation	Raw Manufacturing	High-complexity Products	Clothing and Accessories	Clothing and Accessories
13	Daily Instruments	Wood Products	Textile	Raw Manufacturing	Raw Manufacturing
14	Animals and By-products	Textile	Metals	Wood Products	Wood Products
15	Precious Stones	Metals	Animals and By-products	High-complexity Products	High-complexity Products
16	Chemical Manufacturing	Animals and By-products	Precious Stones	Textile	Textile
17	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining	Animals and By-products	Animals and By-products
ECI	0.357742087	-0.400966598	0.182593472	0.243630283	0.389783411

Portugal High-complexity Products 2018 (Incremental SDV Sensitivity)

	-0.0%	-56.0%	-90.0%
0	Services and Utilities	Machinery and Construction	Machinery and Construction
1	Machinery and Construction	Services and Utilities	Services and Utilities
2	Chemicals	Chemicals	High-complexity Products
3	High-complexity Products	High-complexity Products	Vegetables, Fruits and Plants
4	Weapons	Vegetables, Fruits and Plants	Food and Preparations
5	Vegetables, Fruits and Plants	Food and Preparations	Energy Drilling and Mining
6	Food and Preparations	Raw Manufacturing	Raw Manufacturing
7	Raw Manufacturing	Wood Products	Wood Products
8	Wood Products	Clothing and Accessories	Clothing and Accessories
9	Clothing and Accessories	Textile	Textile
10	Textile	Metals	Metals
11	Metals	Transportation	Transportation
12	Transportation	Daily Instruments	Daily Instruments
13	Daily Instruments	Precious Stones	Precious Stones
14	Animals and By-products	Animals and By-products	Animals and By-products
15	Precious Stones	Weapons	Chemicals
16	Chemical Manufacturing	Chemical Manufacturing	Weapons
17	Energy Drilling and Mining	Energy Drilling and Mining	Chemical Manufacturing
ECI	0.357742087	0.211044767	0.057301488

Portugal High-complexity Products 2018 (Decremental SDV Sensitivity)

Below we see the SDV sensitivity charts for Food and Preparations. In the negative shocking case we see that decrease in exports of Food and Preparation make other industries attractive with positive opportunity gains. The same can be said about the positive shocking case.

	-0.0%	-30.0%
0	Services and Utilities	Services and Utilities
1	Machinery and Construction	Machinery and Construction
2	Chemicals	Chemicals
3	High-complexity Products	High-complexity Products
4	Weapons	Weapons
5	Vegetables, Fruits and Plants	Precious Stones
6	Food and Preparations	Chemical Manufacturing
7	Raw Manufacturing	Energy Drilling and Mining
8	Wood Products	Raw Manufacturing
9	Clothing and Accessories	Vegetables, Fruits and Plants
10	Textile	Clothing and Accessories
11	Metals	Wood Products
12	Transportation	Textile
13	Daily Instruments	Metals
14	Animals and By-products	Transportation
15	Precious Stones	Daily Instruments
16	Chemical Manufacturing	Animals and By-products
17	Energy Drilling and Mining	Food and Preparations
ECI	0.357742087	0.483932742

Portugal Food and Preparations 2018 (Decremental SDV Sensitivity)

	0.0%	120.0%	130.0%
0	Services and Utilities	High-complexity Products	High-complexity Products
1	Machinery and Construction	Machinery and Construction	Machinery and Construction
2	Chemicals	Transportation	Transportation
3	High-complexity Products	Services and Utilities	Daily Instruments
4	Weapons	Chemicals	Services and Utilities
5	Vegetables, Fruits and Plants	Weapons	Chemicals
6	Food and Preparations	Chemical Manufacturing	Weapons
7	Raw Manufacturing	Raw Manufacturing	Chemical Manufacturing
8	Wood Products	Vegetables, Fruits and Plants	Precious Stones
9	Clothing and Accessories	Food and Preparations	Vegetables, Fruits and Plants
10	Textile	Clothing and Accessories	Food and Preparations
11	Metals	Wood Products	Clothing and Accessories
12	Transportation	Textile	Raw Manufacturing
13	Daily Instruments	Metals	Wood Products
14	Animals and By-products	Daily Instruments	Textile
15	Precious Stones	Animals and By-products	Metals
16	Chemical Manufacturing	Precious Stones	Animals and By-products
17	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining
ECI	0.357742087	-0.146523263	-0.400966598

Portugal Food and Preparations 2018 (Incremental SDV 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 groups 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 1% 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

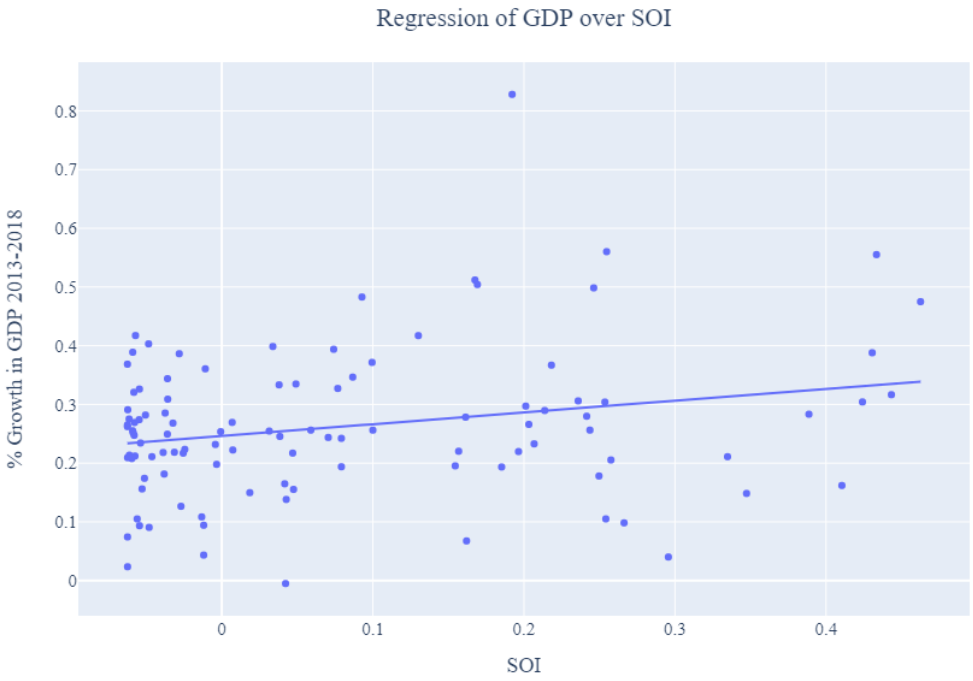


Figure 6: Regression of Five-year GDP Growth over SOI

5.2 SOI of Portugal and Its Implications

Portugal, for instance, has a relatively high level of structural optimality as compared with its developed peers. As the regression in Figure 7 suggests (the orange curve represents export increase and the blue curve stands for opportunity gain of the corresponding industry), Portugal demonstrates a high level of correlation with the suggested developmental path, having an adjusted R-square of around 25.0%. Portugal ranks 16th place among all countries in terms of SOI and has a 5-year growth rate of 17.8% from 2013 to 2018, which is somewhat consistent with the regression result in Figure 6. SOI predicts a much higher growth rate than reality. This is in direct contrast to emerging economies such as Turkey, where there is high SOI of around 21.8% and a corresponding GDP growth of 36.7% from 2013 to 2018, making it one of the fastest developing economies during the period. In sum, Portugal's slower economic progress from 2013 to 2018 can be at least partially explained by a mismatched development strategy that demonstrates a considerable level of deviations from our suggested developmental path. In specific, Portugal invested heavily in high complexity products, while it should have focused more on industry groups such as Services and Utilities.

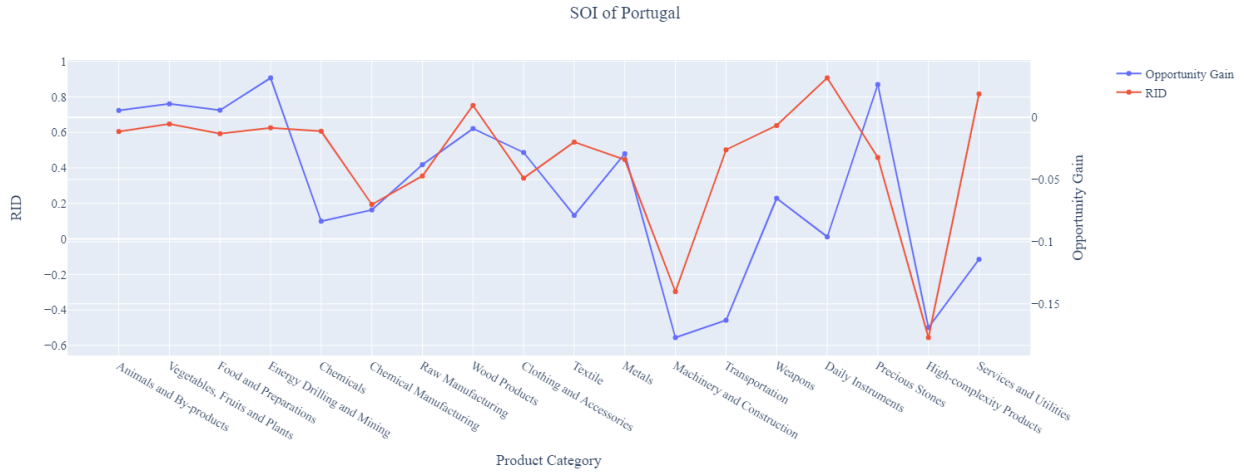


Figure 7: SOI of Portugal (2013-2018)

6. Concluding Remarks

In conclusion, Portugal has demonstrated a low level of economic growth in terms of GDP during the period from 2013 to 2018, concurrent with a stagnation in economic complexity as compared with other major African 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 Portugal on the industry group level. The product classification system we adopt allows us to measure the realized industry development for various industry groups and to observe that Portugal invested heavily in developing High-complexity Products, Machinery and Construction, and Chemical Manufacturing during the period, while its emerging peers and developed economies around the globe have adopted more conservative developmental paths.

Based on our analysis of the opportunity gain and a sensitivity analysis of major industry groups, Portugal can further its gains by prioritizing Transportation, Daily Instruments. We further note that Portugal has a slightly mismatched development strategy that indicates a moderate level of structural optimality on the complexity level, having an adjusted R-square of around 25.0%. Since a significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, Portugal 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.

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