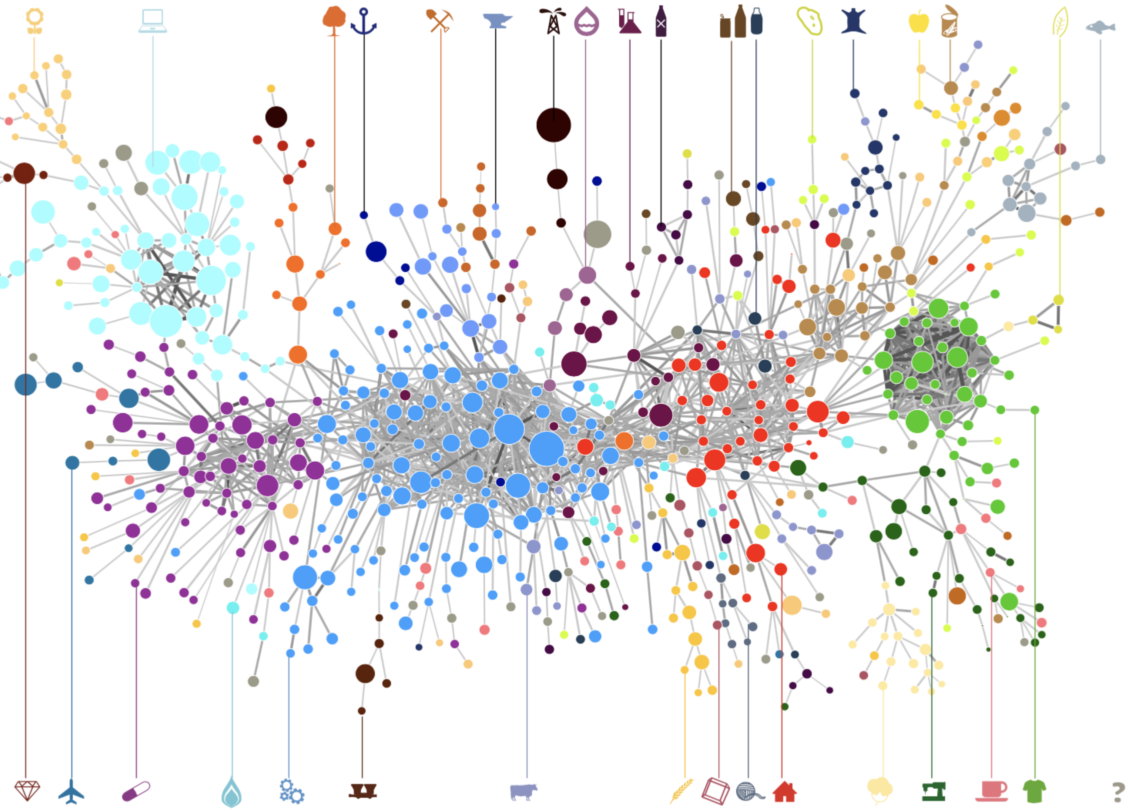

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Optimal Industry Development Strategy Using Economic and Product Complexity

Guatemala

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Optimal Industry Development Strategy for Guatemala

0. Executive Summary

In this report, we uncover the economic path Guatemala went through during the period from 2013 to 2018. Specifically, we dive into the topic through a macroeconomic overview of Guatemala 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, Guatemala demonstrated a moderate level of economic growth with an average annual GDP growth rate of 4.38%, concurrent with a decrease in economic complexity as compared with other emerging economies.

The lack of progress during the period can be partially explained through analysis of the economic and product complexity structure of Guatemala 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 Guatemala consistently relied on developing the Animals and By-products industry during the period, while its emerging counterparts and developed economies around the globe have adopted much more complex and progressive paths.

Based on our analysis of the opportunity gain and a sensitivity analysis of major industry groups, Guatemala can further its gains by prioritizing Machinery & Construction and Daily Instruments. We further note that Guatemala has a strongly mismatched development strategy that indicates a low (compared to other developed countries) level of structural optimality on the complexity level, having an adjusted R-square of around 0.69%. A significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, and Guatemala has an average growth experience as compared with emerging economies both on a regional scale and on a global scale. However, the country has the potential to further its economic gains through industrial structure optimization as suggested in the paper.

1. Report Overview

We aim to uncover the economic path Guatemala went through during the period from 2013 to 2018. Specifically, we dive into the topic through a macroeconomic overview of Guatemala 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 of Guatemala 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 changes to this framework 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 Guatemala, 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

Figure 1 illustrates the time-series GDP results for Guatemala and three of its peer countries (El Salvador, Costa Rica, Honduras) from 2013-2018. All countries displayed constant upwards growth over all years. Guatemala's average annual growth rate of 4.38% over the five-year period is average relative to its peers, which are 3.34%, 4.35%, and 4.67% for El Salvador, Costa Rica, and Honduras respectively.

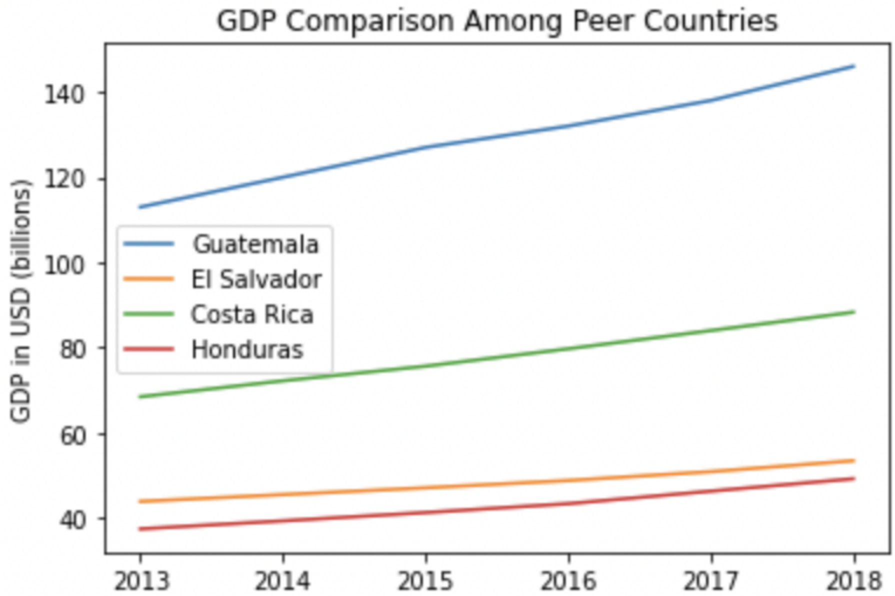


Figure 1: GDP Comparison Among Peer Countries

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 negative growth pattern for Guatemala. As illustrated in Figure 2 below, Guatemala (-229.99% ECI change) exhibited a decrease in terms of its production capability from 2013 to 2018, at a much greater magnitude than El Salvador (-19.52%), Costa Rica (-67.33%), and Honduras (-33.69%). Ultimately, Guatemala performs suboptimally amongst its peer country set, displaying an average GDP growth rate and a highly negative ECI change across the period.

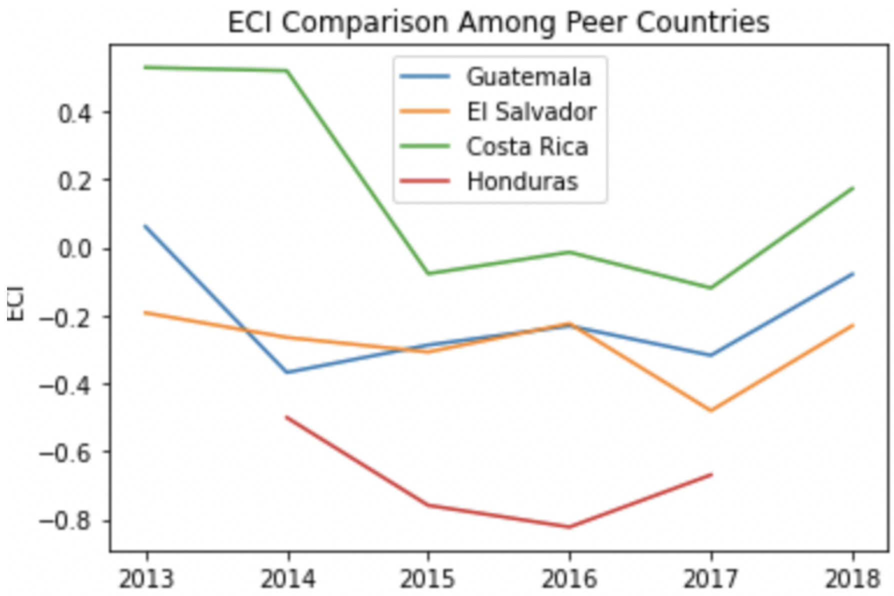


Figure 2: ECI Comparison

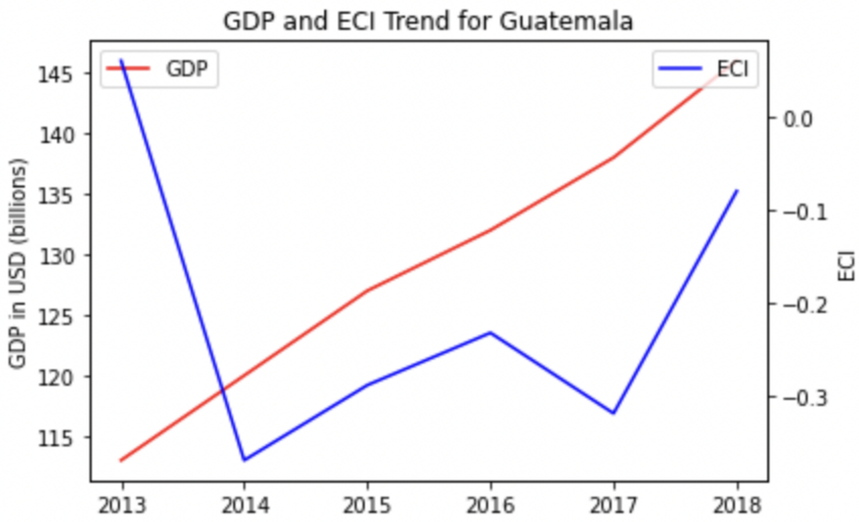


Figure 3: GDP Growth and ECI (Guatemala)

Figure 3 offers a further comparison of GDP Growth and ECI over the time span from 2013 to 2018 for Guatemala. The increase in GDP during the period from 2013 to 2018 is accompanied by a sharp decline in ECI. The results show that the economic growth experienced by Guatemala during the period from 2013 to 2018 is not consistent with the predictions by ECI and Guatemala did not effectively make strides to develop 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 Guatemala'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 Guatemala'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 US 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.

Category	RID
High-complexity Products	0.196138
Vegetables, Fruits and Plants	0.221954
Machinery and Construction	0.227552
Food and Preparations	0.229990
Raw Manufacturing	0.240161
Transportation	0.252271
Textile	0.269330
Services and Utilities	0.272129
Daily Instruments	0.284691
Chemical Manufacturing	0.297687
Weapons	0.317797
Chemicals	0.322119
Metals	0.328131
Precious Stones	0.346909
Wood Products	0.348599
Clothing and Accessories	0.351316
Energy Drilling and Mining	0.354993
Animals and By-products	0.368614

Table 2: Realized Industry Development (RID) of Guatemala

3.3 Regional and Global Comparison

Table 3 and 4 below summarize how the production strategy adopted by Guatemala compares with leading economies and a selected group of emerging economies in the world, as measured in RID.

Ranking	France	US	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 Guatemala'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.

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	Finland	Sweden	Norway	Denmark
1	Transportation	Energy Drilling and Mining	High-complexity Products	Vegetables, Fruits and Plants
2	High-complexity Products	Animals and By-products	Transportation	Energy Drilling and Mining
3	Daily Instruments	Chemical Manufacturing	Machinery and Construction	Precious Stones
4	Textile	Raw Manufacturing	Daily Instruments	Textile
5	Services and Utilities	Wood Products	Weapons	Weapons
6	Weapons	Metals	Chemicals	Chemicals
7	Chemicals	Machinery and Construction	Textile	Animals and By-products
8	Raw Manufacturing	High-complexity Products	Chemical Manufacturing	Food and Preparations
9	Wood Products	Services and Utilities	Raw Manufacturing	Chemical Manufacturing
10	Metals	Vegetables, Fruits and Plants	Animals and By-products	Raw Manufacturing
11	Machinery and Construction	Textile	Energy Drilling and Mining	Clothing and Accessories
12	Chemical Manufacturing	Precious Stones	Metals	Machinery and Construction
13	Clothing and Accessories	Clothing and Accessories	Services and Utilities	Daily Instruments
14	Animals and By-products	Weapons	Wood Products	Services and Utilities
15	Energy Drilling and Mining	Food and Preparations	Vegetables, Fruits and Plants	Wood Products
16	Precious Stones	Daily Instruments	Food and Preparations	Transportation
17	Food and Preparations	Chemicals	Clothing and Accessories	Metals
18	Vegetables, Fruits and Plants	Transportation	Precious Stones	High-complexity Products
ECI	1.159	1.338	-0.247	0.904

Ranking	Finland	Sweden	Norway	Denmark
1	Transportation	Energy Drilling and Mining	High-complexity Products	Textile
2	High-complexity Products	Clothing and Accessories	Transportation	Transportation
3	Textile	Textile	Machinery and Construction	Weapons
4	Weapons	Animals and By-products	Daily Instruments	Chemicals
5	Chemicals	Chemical Manufacturing	Weapons	Energy Drilling and Mining
6	Raw Manufacturing	Raw Manufacturing	Chemicals	Precious Stones
7	Wood Products	Wood Products	Chemical Manufacturing	High-complexity Products
8	Metals	Metals	Textile	Vegetables, Fruits and Plants
9	Machinery and Construction	Machinery and Construction	Raw Manufacturing	Animals and By-products
10	Daily Instruments	Weapons	Clothing and Accessories	Food and Preparations
11	Services and Utilities	High-complexity Products	Animals and By-products	Chemical Manufacturing
12	Clothing and Accessories	Vegetables, Fruits and Plants	Energy Drilling and Mining	Clothing and Accessories
13	Chemical Manufacturing	Food and Preparations	Metals	Machinery and Construction
14	Precious Stones	Precious Stones	Wood Products	Daily Instruments
15	Energy Drilling and Mining	Chemicals	Food and Preparations	Services and Utilities
16	Animals and By-products	Services and Utilities	Vegetables, Fruits and Plants	Raw Manufacturing
17	Vegetables, Fruits and Plants	Daily Instruments	Precious Stones	Metals
18	Food and Preparations	Transportation	Services and Utilities	Wood Products
ECI	0.803	1.02	-0.928	0.541

Table 5: SDV of High E_fCI Countries 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 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 Guatemala shares the characters of developing countries, with a balanced economics structure that leans towards intermediate-level industries.

Ranking	Algeria	Italy	USA	United Arab Emirates
1	High-complexity Products	Energy Drilling and Mining	Energy Drilling and Mining	High-complexity Products
2	Machinery and Construction	Precious Stones	Precious Stones	Transportation
3	Transportation	Vegetables, Fruits and Plants	Animals and By-products	Machinery and Construction
4	Services and Utilities	Animals and By-products	Vegetables, Fruits and Plants	Daily Instruments
5	Daily Instruments	Food and Preparations	Food and Preparations	Chemicals
6	Chemicals	Chemical Manufacturing	Chemicals	Weapons
7	Chemical Manufacturing	Raw Manufacturing	Chemical Manufacturing	Textile
8	Weapons	Wood Products	Raw Manufacturing	Chemical Manufacturing
9	Textile	Clothing and Accessories	Wood Products	Raw Manufacturing
10	Raw Manufacturing	Textile	Machinery and Construction	Energy Drilling and Mining
11	Energy Drilling and Mining	Metals	Weapons	Precious Stones
12	Metals	Machinery and Construction	Daily Instruments	Services and Utilities
13	Wood Products	Daily Instruments	High-complexity Products	Metals
14	Clothing and Accessories	High-complexity Products	Services and Utilities	Clothing and Accessories
15	Animals and By-products	Weapons	Clothing and Accessories	Wood Products
16	Food and Preparations	Chemicals	Metals	Animals and By-products
17	Precious Stones	Services and Utilities	Textile	Vegetables, Fruits and Plants
18	Vegetables, Fruits and Plants	Transportation	Transportation	Food and Preparations
ECI	-2.190	1.180	1.220	-0.734

Table 6: SDV of Other Typical Countries 2013

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:

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

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 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).

Interpretation:

For the purpose of a clear explanation of the line charts, we try to label all the products in Table 7. Please refer to this table when trying to understand the investment trajectories in the line charts.

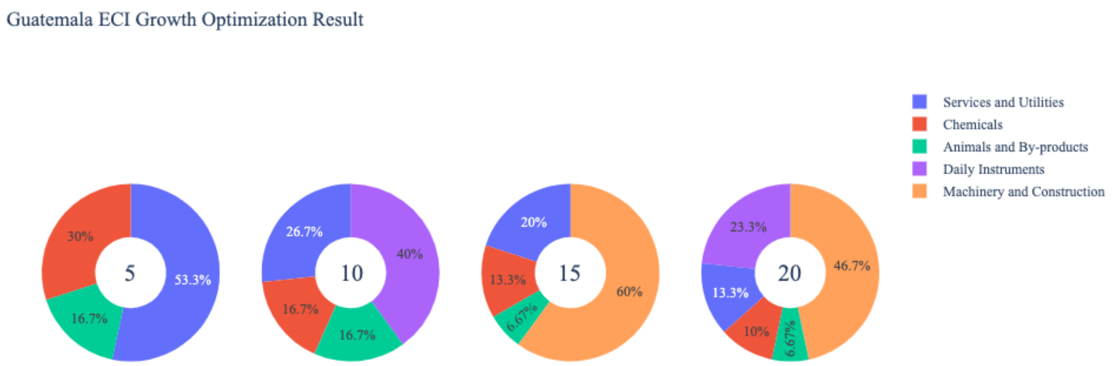
Label	Product Names
1	Animals and By-products
2	Vegetables, Fruits and Plants
3	Food and Preparations
4	Energy Drilling and Mining
5	Chemicals
6	Chemical Manufacturing

7	Raw Manufacturing
8	Wood Products
9	Clothing and Accessories
10	Textile
11	Metals
12	Machinery and Construction
13	Transportation
14	Weapons
15	Daily Instruments
16	Precious Stones
17	High-complexity Products
18	Services and Utilities

Table 7: Products Labeling

Below is the economic panel for Guatemala in 2013. We can see that for different percentages of heuristic total export growth, the ECIs of Guatemala have different amounts of increments. A 5% export growth results in an ECI improvement of pattern from 0.08 to 0.3. 10, 15, and 20 percent export growth result in even more significant ECI improvement trajectories, reaching an ECI of 0.4, 0.65, and 0.75, respectively.

For the case of 5 percent export growth, Services and Utilities and Chemicals account for most of the portfolio. For 10 percent export growth, more weight is awarded to Daily Instruments, suggesting that with a low economic improvement anticipation, Guatemala should focus more on developing this industry. For the case of 15 and 20 percent increment budgets, we realize that the development trajectories are in a similar pattern to a 5% increment budget except that there are a few additional steps when there are more budgets. Contrary to the first case, the solutions suggest that Guatemala should invest more on Machinery and Construction and Daily Instruments. This makes sense because with more budgets, a country should focus more on the development of high-end product spaces. A more detailed numerical representation of the portfolio is shown in Table 8.



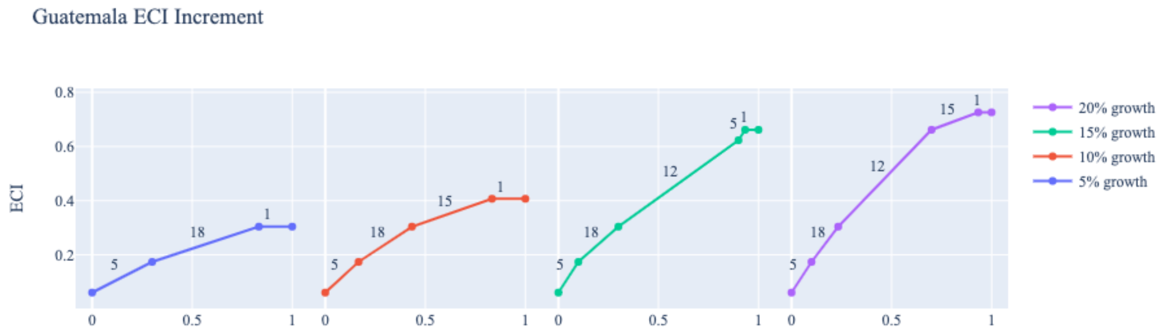


Figure 5: Greedy Based ECI Improvement Results of Guatemala in 2013 with Different Budgets

Guatemala (2013)				
Original ECI	0.0609			
Heuristic Export Growth	5%	10%	15%	20%
Animals and By-products	90294352.87	180588705.7	111964997.6	144470964.6
Chemicals	162529835.2	180588705.7	223929995.1	216706446.9
Machinery and Construction	0	0	1007684978	1011296752
Daily Instruments	0	433412893.8	0	505648376.1
Services and Utilities	288941929.2	288941929.2	335894992.7	288941929.2
Increased ECI	0.3042902281	0.4071735984	0.6617211434	0.7260884071

Table 8: Portfolio of Guatemala in 2013

For further suggestions on Guatemala's development in the future, we also offer the optimization result for Guatemala based on export data in 2018. Below is the economic panel for Guatemala in 2018. While 5%, 10%, and 15% export growth exhibit similar ECI improvements, 20% growth shows a significantly greater improvement up to 0.55. However, the maximum ECI reached is lower than in 2013. Another key difference is that the main components that result in ECI improvements are not quite similar. For a 5 percent export growth, the improvement is concentrated in Daily Instruments, while for 10, 15, and 20 percent growth, it decreases in importance, allowing Machinery & Construction to take the lead in 20 percent growth (just like in 2013). A more detailed numerical representation of the portfolio is shown in Table 9.

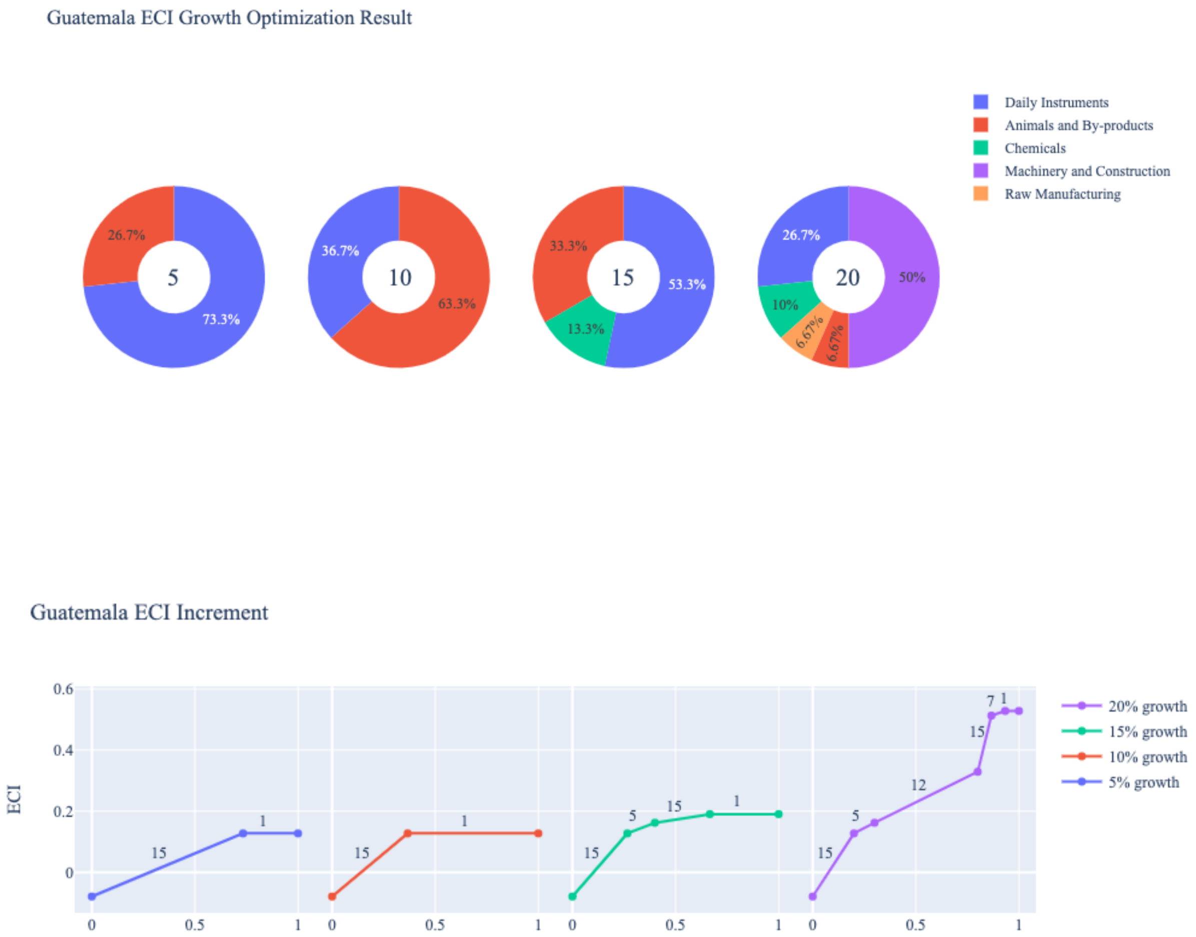


Figure 6: Greedy Based ECI Improvement Results of Guatemala in 2018 with Different Budgets

Guatemala (2018)				
Original ECI	-0.0792			
Heuristic Export Growth	5%	10%	15%	20%
Animals and By-products	182890487.1	868729813.7	685839326.6	195083186.2
Chemicals	0	0	274335730.6	292624779.3
Raw Manufacturing	0	0	0	195083186.2
Machinery and Construction	0	0	0	1463123897
Daily Instruments	502948839.5	502948839.5	1097342923	780332744.9
Increased ECI	0.1274193731	0.1274193731	0.1904167125	0.5279961922

Table 9: Portfolio of Guatemala in 2018

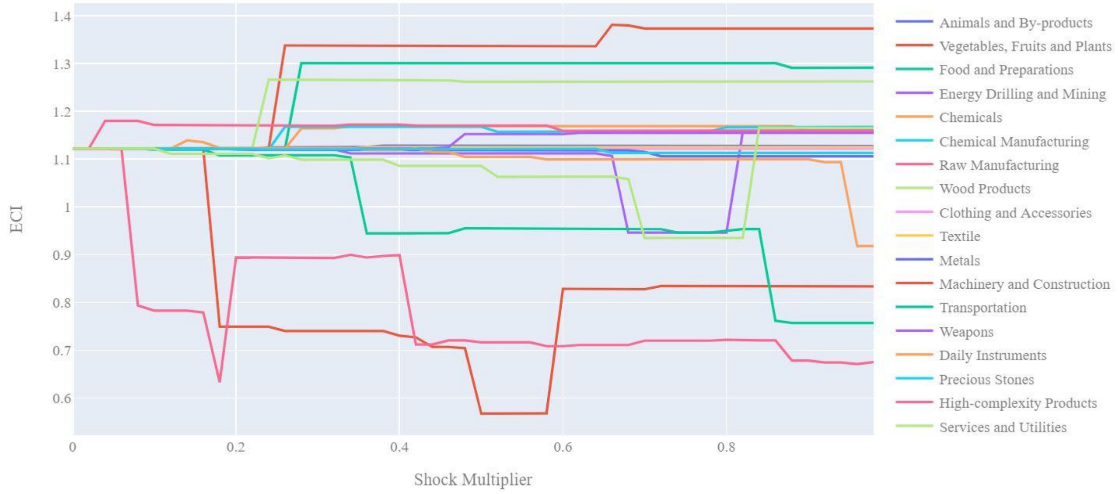
4.3 Sensitivity Analysis and Contingency Strategy

In the following section our broad aim is to understand how sensitive Guatemala 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 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 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)

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 the 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)

Contingency Plan

The Contingency Plan aims to present a set of solutions with respect to upheavals in different industries. Instead of compensating for the declining production directly, the best strategy is to develop those incipiently profitable industries. In this manner, we can derive the contingency strategy for countries to deal with possible abrupt declines of crucial industries. In some cases, the SDV remains unchanged even when a zero-opportunity-gain industry declines to its 20% in terms of export. We can then conclude the industry is not indispensable to the country. As a clarification, the three consecutive N/As means that the country doesn't even need to respond to a collapse in the industry. Countries tend to have distinct solutions to the up and down of the same industry. To create the contingency strategy table we decrease the export level for each industry in the country's current production space by 60% respectively. The three highest ranking industries in the new SDV are then returned.

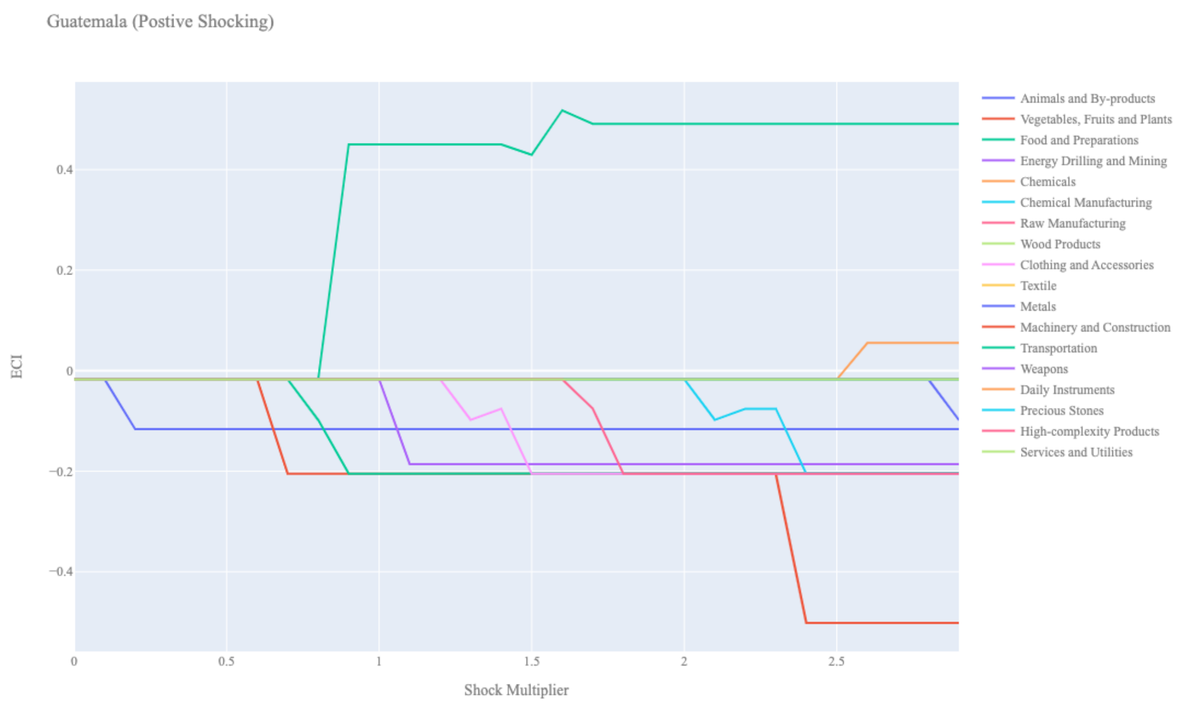
	0	1	2
Animals and By-products	Services and Utilities	Daily Instruments	Weapons
Vegetables, Fruits and Plants	Services and Utilities	Daily Instruments	Weapons
Food and Preparations	Services and Utilities	Daily Instruments	Weapons
Energy Drilling and Mining	Services and Utilities	Daily Instruments	Weapons
Chemicals	Services and Utilities	Daily Instruments	Weapons
Chemical Manufacturing	Services and Utilities	Daily Instruments	Weapons
Raw Manufacturing	Services and Utilities	Daily Instruments	Weapons
Wood Products	Services and Utilities	Daily Instruments	Weapons
Clothing and Accessories	Services and Utilities	Daily Instruments	Weapons
Textile	Services and Utilities	Daily Instruments	Weapons
Metals	Services and Utilities	Daily Instruments	Weapons
Machinery and Construction	Services and Utilities	Daily Instruments	Weapons
Transportation	Services and Utilities	Raw Manufacturing	Daily Instruments
Weapons	Services and Utilities	Daily Instruments	Transportation
Daily Instruments	Services and Utilities	Weapons	Transportation
Precious Stones	Services and Utilities	Daily Instruments	Weapons
High-complexity Products	Services and Utilities	Daily Instruments	Weapons
Services and Utilities	Daily Instruments	Weapons	Transportation

Example Contingency Strategy 2018

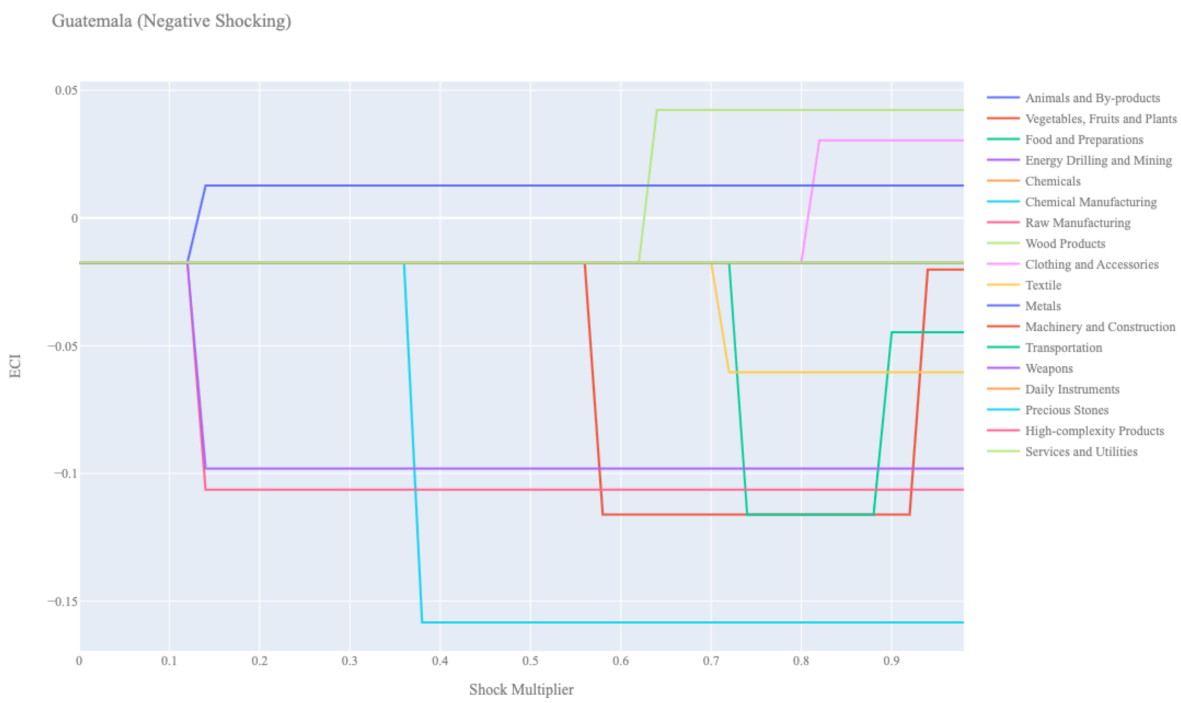
4.3 Sensitivity Analysis Results and Interpretation

Below is Guatemala's 2018 ECI Sensitivity Charts. Firstly in the positive chart, we notice immediately that increases in Transportation leads to an uptrend in ECI. Transportation offers the best ECI growth per unit of export increase. All other industries tend to not greatly affect the ECI level making it fairly clear which industries to pursue.

Next we consider Guatemala's 2018 Negative Shock chart. We see that Guatemala's ECI is highly sensitive to drawdowns in Chemical Manufacturing; Vegetables, Fruits, and Plants; and Raw Manufacturing. More interestingly, we see that large decreases in Wood Products, Clothing & Accessories, and Metals seem to greatly increase the ECI score. These industries are very important industries for Guatemala's economy and thus the results that are reflected in the chart may be suggesting that there is another industry that could be very beneficial for Guatemala that is far in proximity from the Wood Products, Clothing & Accessories, and Metals industries.



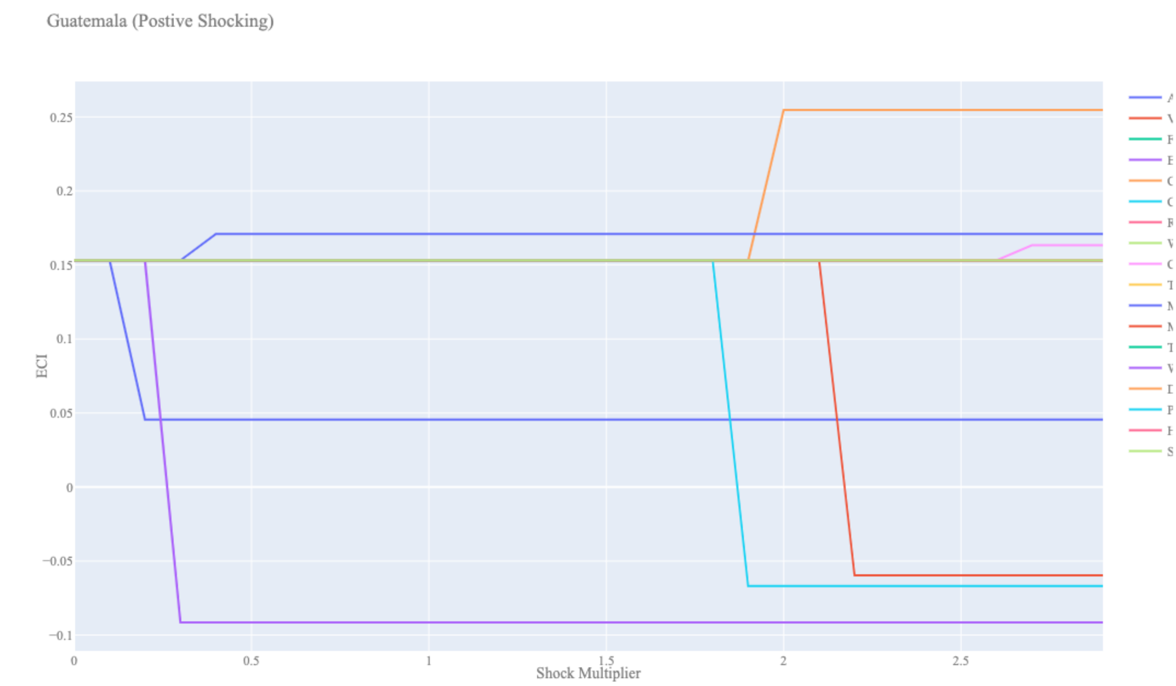
Guatemala 2018 (Incremental ECI Sensitivity)



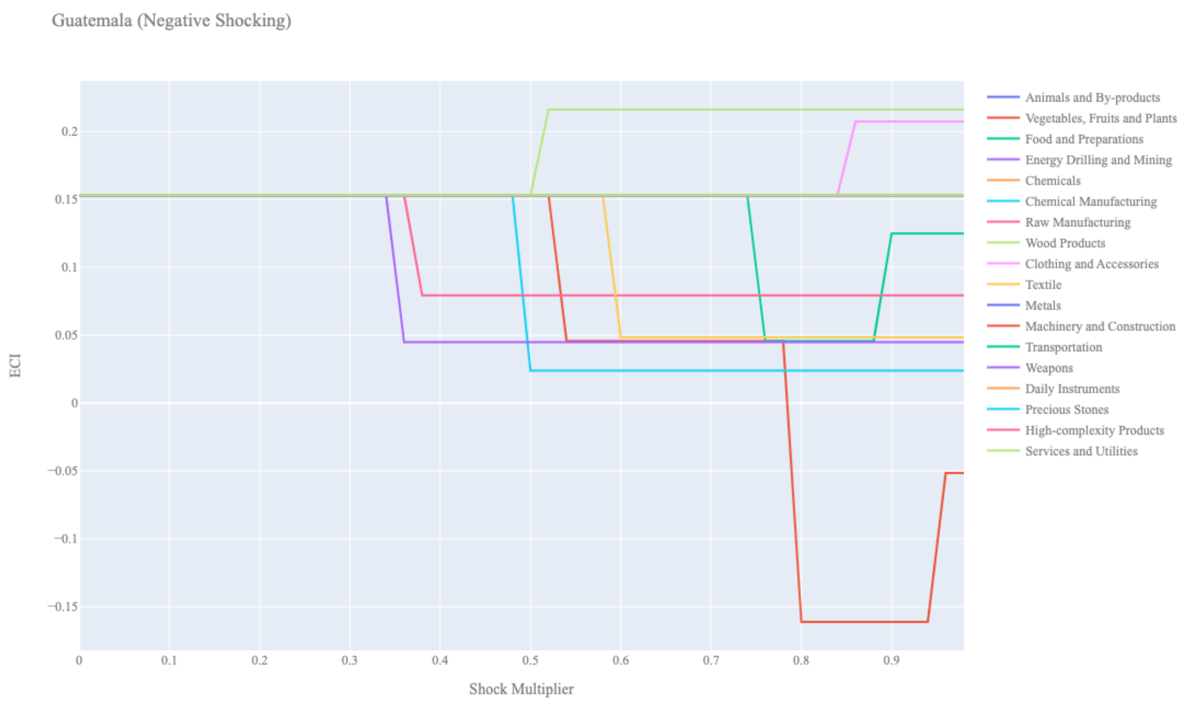
Guatemala 2018 (Decremental ECI Sensitivity)

Next we consider the 2013 ECI Sensitivity graphs. We see that in the positive shocking case, the landscape of ECI sensitivity has altered significantly over the five year period. Chemicals seemed to offer the best ECI growth prospects in 2013.

In the 2013 negative shocking case, we see that again Guatemala is very sensitive to drawdowns in Vegetables, Fruits, and Plants, Chemical Manufacturing, and Raw Manufacturing.



Guatemala 2013 (Incremental ECI Sensitivity)



Guatemala 2013 (Decremental ECI Sensitivity)

Below we see the SDV sensitivity charts for Transportation. We see that increasing the export of Transportation does not affect the number of positive opportunity gain industries for Guatemala to move into.

In the negative Transportation SDV chart, we see that as we decrease the export of Transportation, nothing happens. The number of industries with positive opportunity gain stays the same, suggesting that the opportunities available to Guatemala are independent of its Transportation footprint.

Concerning Vegetables, Fruits, and Plants, Guatemala seems to be highly sensitive to this industry in the case of decrement. Decreasing the export of Vegetables, Fruits, and Plants negatively affects many industries involved in Guatemala's economy. suggesting that Guatemala is highly dependent on this industry in terms of the stability of its SDV.

	0%
0	Energy Drilling and Mining
1	Machinery and Construction
2	Precious Stones
3	Animals and By-products
4	Services and Utilities
5	High-complexity Products
6	Daily Instruments
7	Transportation
8	Chemicals
9	Metals
10	Chemical Manufacturing
11	Raw Manufacturing
12	Wood Products
13	Clothing and Accessories
14	Vegetables, Fruits and Plants
15	Weapons
16	Food and Preparations
17	Textile
ECI	0.1531264556

Guatemala Transportation 2018 (Decremental SDV Sensitivity)

	0%
0	Energy Drilling and Mining
1	Machinery and Construction
2	Precious Stones
3	Animals and By-products
4	Services and Utilities
5	High-complexity Products
6	Daily Instruments
7	Transportation
8	Chemicals
9	Metals
10	Chemical Manufacturing
11	Raw Manufacturing
12	Wood Products
13	Clothing and Accessories
14	Vegetables, Fruits and Plants
15	Weapons
16	Food and Preparations
17	Textile
ECI	0.1531264556

Guatemala Transportation 2018 (Incremental SDV Sensitivity)

	-0%	-54%	-80%	-96%
0	Energy Drilling and Mining	Energy Drilling and Mining	Precious Stones	Vegetables, Fruits and Plants
1	Machinery and Construction	Precious Stones	Metals	Precious Stones
2	Precious Stones	Machinery and Construction	Services and Utilities	Services and Utilities
3	Animals and By-products	Services and Utilities	Daily Instruments	Machinery and Construction
4	Services and Utilities	Daily Instruments	Machinery and Construction	Metals
5	High-complexity Products	Metals	Chemicals	Daily Instruments
6	Daily Instruments	Chemicals	High-complexity Products	Chemicals
7	Transportation	High-complexity Products	Transportation	High-complexity Products
8	Chemicals	Transportation	Weapons	Transportation
9	Metals	Weapons	Animals and By-products	Weapons
10	Chemical Manufacturing	Animals and By-products	Vegetables, Fruits and Plants	Animals and By-products
11	Raw Manufacturing	Vegetables, Fruits and Plants	Clothing and Accessories	Clothing and Accessories
12	Wood Products	Clothing and Accessories	Wood Products	Wood Products
13	Clothing and Accessories	Wood Products	Raw Manufacturing	Raw Manufacturing
14	Vegetables, Fruits and Plants	Raw Manufacturing	Chemical Manufacturing	Chemical Manufacturing
15	Weapons	Chemical Manufacturing	Energy Drilling and Mining	Energy Drilling and Mining
16	Food and Preparations	Food and Preparations	Food and Preparations	Food and Preparations
17	Textile	Textile	Textile	Textile
ECI	0.1531264556	0.04563632926	-0.1611414301	-0.05155650069

Guatemala Vegetables, Fruits, and Plants 2018 (Decremental SDV Sensitivity)

	0%
0	Energy Drilling and Mining
1	Machinery and Construction
2	Precious Stones
3	Animals and By-products
4	Services and Utilities
5	High-complexity Products
6	Daily Instruments
7	Transportation
8	Chemicals
9	Metals
10	Chemical Manufacturing
11	Raw Manufacturing
12	Wood Products
13	Clothing and Accessories
14	Vegetables, Fruits and Plants
15	Weapons
16	Food and Preparations
17	Textile
ECI	0.1531264556

Guatemala Vegetables, Fruits, and Plants 2018 (Incremental SDV Sensitivity)

4.4 Contingency Strategy

Decreasing export of each industry in Guatemala's current production space by 60% respectively, we derive the contingency strategy shown below.

	0	1	2
Animals and By-products	Energy Drilling and Mining	Machinery and Construction	Precious Stones
Vegetables, Fruits and Plants	Energy Drilling and Mining	Precious Stones	Machinery and Construction
Food and Preparations	Energy Drilling and Mining	Machinery and Construction	Precious Stones
Energy Drilling and Mining	Energy Drilling and Mining	Machinery and Construction	Precious Stones
Chemicals	Energy Drilling and Mining	Machinery and Construction	Precious Stones
Chemical Manufacturing	Machinery and Construction	High-complexity Products	Services and Utilities
Raw Manufacturing	Machinery and Construction	High-complexity Products	Transportation
Wood Products	Machinery and Construction	High-complexity Products	Services and Utilities
Clothing and Accessories	Energy Drilling and Mining	Machinery and Construction	Precious Stones
Textile	Machinery and Construction	High-complexity Products	Transportation
Metals	Energy Drilling and Mining	Machinery and Construction	Precious Stones
Machinery and Construction	Energy Drilling and Mining	Machinery and Construction	Precious Stones
Transportation	Energy Drilling and Mining	Machinery and Construction	Precious Stones
Weapons	Machinery and Construction	High-complexity Products	Transportation
Daily Instruments	Energy Drilling and Mining	Machinery and Construction	Precious Stones
Precious Stones	Energy Drilling and Mining	Machinery and Construction	Precious Stones
High-complexity Products	Energy Drilling and Mining	Machinery and Construction	Precious Stones
Services and Utilities	Energy Drilling and Mining	Machinery and Construction	Precious Stones

Guatemala Contingency Strategy 2018

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 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

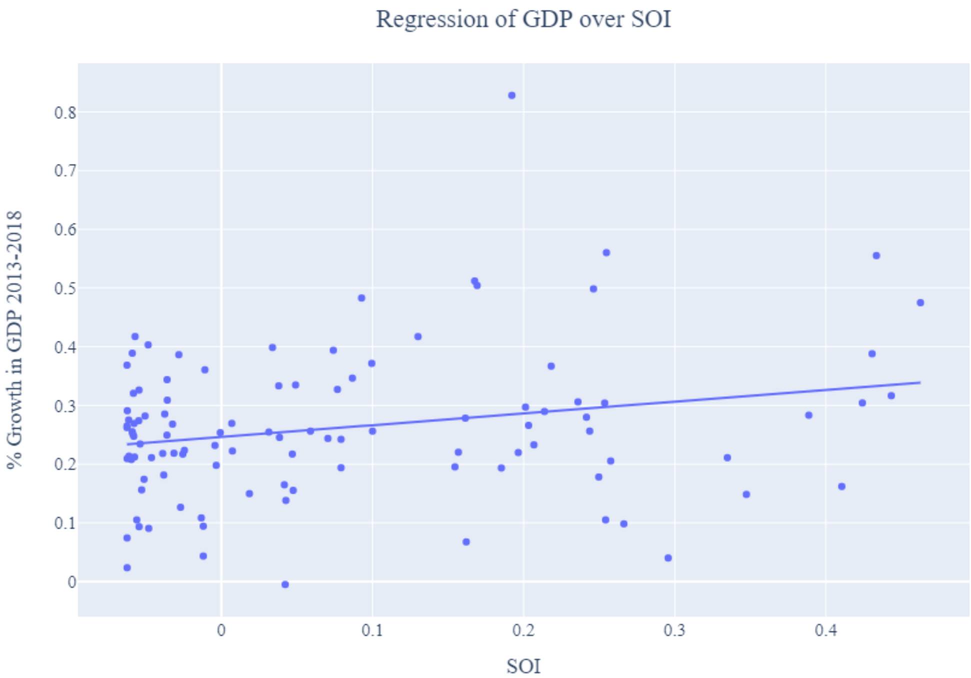


Figure 2: Regression of Five-year GDP Growth over SOI

5.2 SOI of Guatemala and Its Implications

Guatemala, for instance, has a low 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), Guatemala demonstrates a low level of correlation with the suggested developmental path, having an adjusted R-square of around 0.69%. Guatemala ranks in the lower quartile among all countries in terms of SOI and has made an average rate of economic progress below its developing peers from 2013 to 2018 with a 5-year GDP growth rate of 4.38%, which is consistent with the regression result in Figure 6. This is in direct contrast to leading developed economies such as Japan, where there is low SOI of around -5.7% and a corresponding GDP growth of 9.05% from 2013 to 2018, making Guatemala a much slower developing economy during the period. In sum, Guatemala's mixed economic progress from 2013 to 2018 can be at least partially explained by a development strategy that demonstrates a suboptimal level of matches with our suggested developmental path. In specific, Guatemala invested heavily in the Services and Utilities industry, while it should have focused more on more complex industry groups such as Energy Drilling and Mining and Precious Stones. That being said, it stayed fairly in line with our expectations in the Chemicals industry.

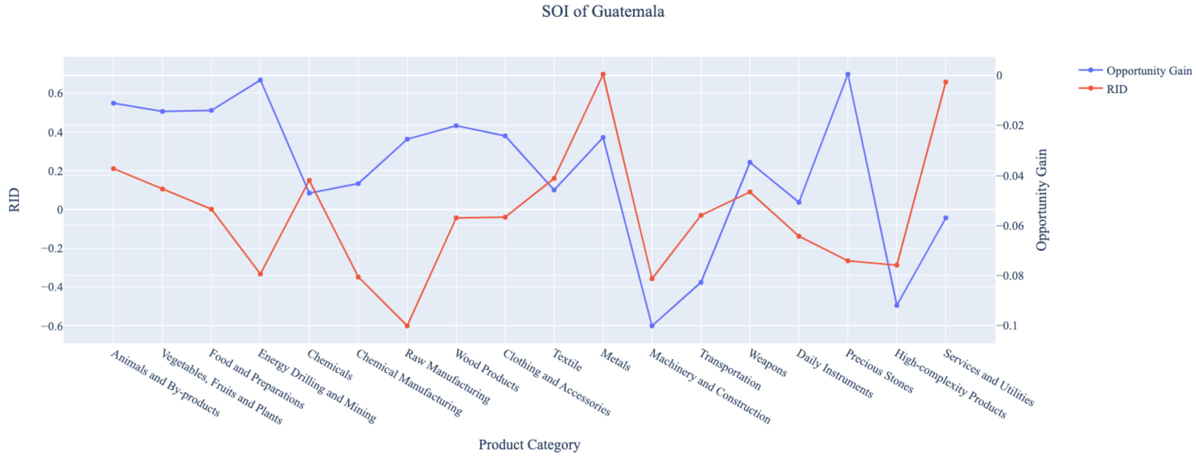


Figure 7: SOI of Guatemala (2009-2014)

6. Concluding Remarks

In conclusion, Guatemala has demonstrated a moderate level of economic growth in terms of annual GDP increase during the period from 2013 to 2018, concurrent with a decrease in economic complexity.

The lack of progress during the period, we believe, can be partially explained through analysis of the economic and product complexity structure of Guatemala 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 Guatemala consistently relied on developing the Services & Utilities industry during the period, while its developed counterparts and emerging economies around the globe have adopted much more complex and progressive paths.

Based on our analysis of the opportunity gain and a sensitivity analysis of major industry groups, Guatemala can further its gains by prioritizing Transportation and Daily Instruments. We further note that Guatemala has a slightly mismatched development strategy that indicates a moderately high (compared to other developing countries) level of structural optimality on the complexity level, having an adjusted R-square of around 0.69%. Since a significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, Guatemala, however, still 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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