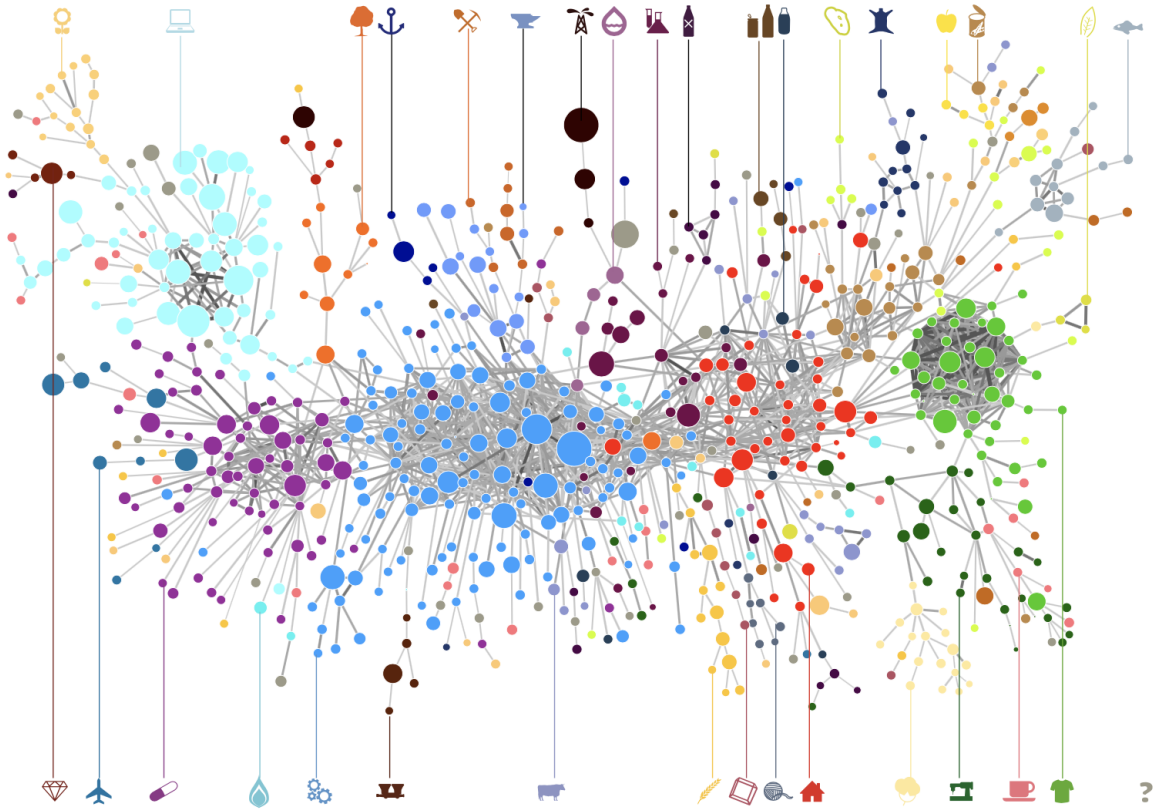

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Optimal Industry Development Strategy Using Economic and Product Complexity

United States

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The Economic Complexity Lab - Columbia University

Haoxian Chen, Davepriyan Gunaratnam, Rohan Macherla, Ajit Akole, Shomik Ghose, Alex Wei-Liang Ku, Sannidhya Modi, Xilin Wang, Alexandra Garcia

Optimal Industry Development Strategy for the United States

0. Executive Summary

In this report, we aim to uncover the economic path the United States went through during the period from 2013 to 2018. Specifically, we dive into the topic through a macroeconomic overview of the United States 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, the United States demonstrated a moderate level of economic growth with an annual GDP growth rate of 3.9%, concurrent with a decrease in economic complexity as compared with other major developed economies.

The lack of progress during the period, we believe, can be partially explained through analysis of the economic and product complexity structure of the United States 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 the United States consistently relied on developing Services and Utilities, Weapons and Raw Manufacturing industries 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, the United States can further its gains by prioritizing High-complexity Products and Chemicals. We further note that the United States 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 15.7%. Since a significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, the United States 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 the United States went through during the period from 2013 to 2018. Specifically, we dive into the topic through a macroeconomic overview of U.S. 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 the United States 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 the United States, 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 largest economy in the world by GDP, the United States has a GDP of 16.8 trillion USD in 2013 and 20 trillion USD in 2018, exhibiting an extraordinary level of economic output. Figure 1 illustrates the time-series GDP results for world's leading economies from 1999-2018, and the United States ranks among its counterparts as the absolute winner. Except for the period of financial crisis from 2008 to 2009, the United States has exhibited a rather consistent level of economic growth, with an annual GDP growth rate of 4% from 2013 to 2018. This rate is slightly above the annual growth rate of the group of leading economies in the world, which have a geometric average growth rate of 2.2% and an arithmetic average growth rates of 2.4%. However, the annual growth rate of 4% is in sharp contrast to an annual growth rate of 8.2% for China, one of the United States' major competitors in the market. The steady rate of growth in the United States, we believe, can be reflected through consistent ECI and PCI, and can be further explained by a moderate set of production strategies the United States adopted during the period, which we will expand at the later stage of the report.

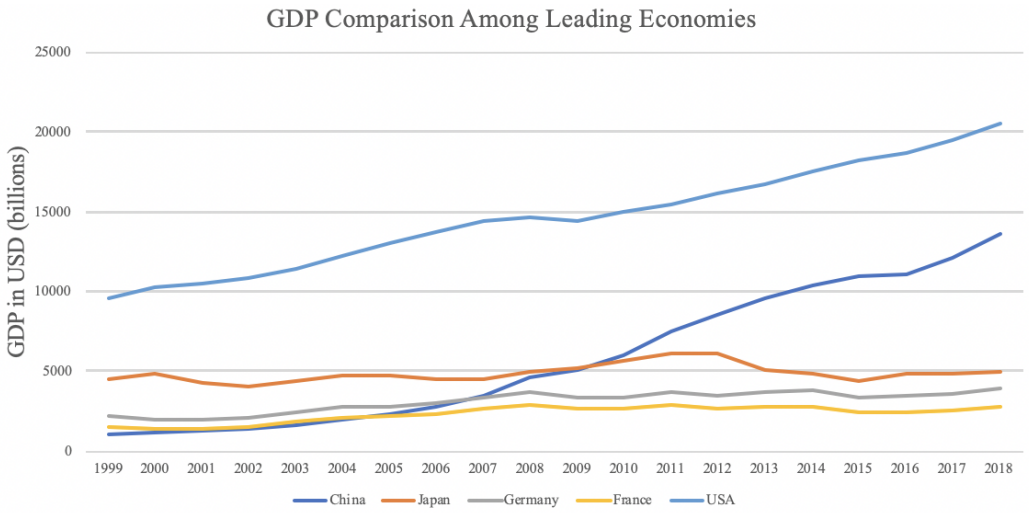


Figure 1: GDP Comparison Among Leading Economies

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 the United States. As illustrated in Figure 2 below, the United States exhibits a mild decrease in terms of its production capability from 2013 to 2018, which is true for most of the developed economies. This is in direct contrast to countries such as China, which demonstrates overwhelming advantage over the United States in terms of both ECI and GDP growth during the period.

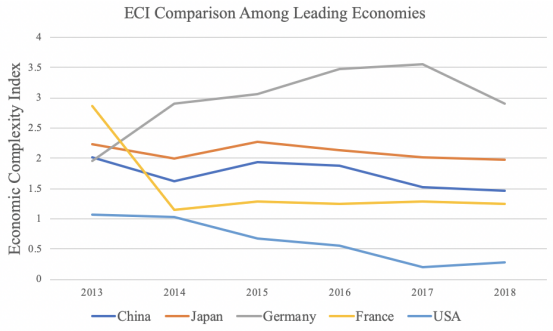


Figure 2: ECI Comparison

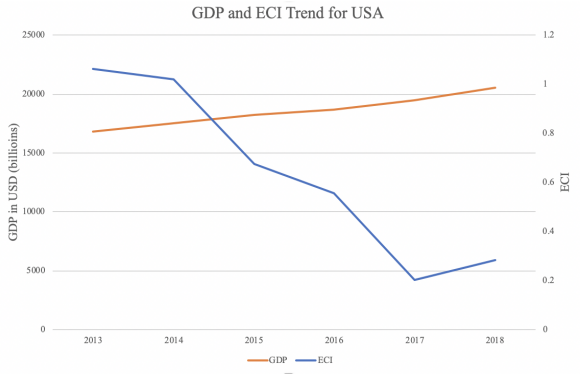


Figure 3: GDP Growth and ECI (U.S.)

Figure 3 offers a further comparison of GDP Growth and ECI over the time span from 2013 to 2018 for U.S.. The stagnancy in GDP growth during the period from 2013 to 2018 is accompanied by a significant decrease in ECI. The results show that the economic growth experienced by the U.S. during the period from 2013 to 2018, though stable, is not very consistent with the predictions by ECI and the U.S. had not yet effectively developed 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 U.S. '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 US'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. As ranked in Table 2, during the period from 2013 to 2018, US has focused on products with a moderate level of complexity and those requiring intermediate skills.

Rank	Category	RID	Rank	Category	RID
1	Services and Utilities	-0.074	10	Daily Instruments	0.008
2	Weapons	-0.041	11	Food and Preparations	0.010
3	Raw Manufacturing	-0.039	12	Chemicals	0.010
4	Precious Stones	-0.004	13	Textile	0.011
5	Animals and By-products	-0.004	14	Metals	0.021
6	Energy Drilling and Mining	-0.004	15	Chemical Manufacturing	0.049
7	Wood Products	-0.002	16	High-complexity Products	0.068
8	Vegetables, Fruits and Plants	-0.002	17	Machinery and Construction	0.108
9	Clothing and Accessories	0.001	18	Transportation	0.121

Table 2: Realized Industry Development (RID) of US

3.3 Regional and Global Comparison

Table 3 and 4 below summarize how the production strategy adopted by US compares with leading economies and a selected group of emerging economies in the world, as measured in RID. It can be directly observed that US 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 US'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 US 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, US 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	Singapore	Japan	USA	Germany
1	Chemicals	Chemicals	Energy Drilling and Mining	Chemical Manufacturing
2	Transportation	Metals	Precious Stones	Wood Products
3	High-complexity Products	Machinery and Construction	Animals and By-products	Metals
4	Services and Utilities	Transportation	Vegetables, Fruits and Plants	Machinery and Construction
5	Machinery and Construction	Weapons	Food and Preparations	Transportation
6	Daily Instruments	Daily Instruments	Chemicals	Weapons
7	Weapons	High-complexity Products	Chemical Manufacturing	High-complexity Products
8	Textile	Services and Utilities	Raw Manufacturing	Services and Utilities
9	Chemical Manufacturing	Precious Stones	Wood Products	Energy Drilling and Mining
10	Raw Manufacturing	Energy Drilling and Mining	Machinery and Construction	Precious Stones
11	Clothing and Accessories	Textile	Weapons	Textile
12	Metals	Clothing and Accessories	Daily Instruments	Clothing and Accessories
13	Wood Products	Chemical Manufacturing	High-complexity Products	Chemicals
14	Precious Stones	Animals and By-products	Services and Utilities	Animals and By-products
15	Animals and By-products	Wood Products	Clothing and Accessories	Vegetables, Fruits and Plants
16	Food and Preparations	Vegetables, Fruits and Plants	Metals	Food and Preparations
17	Energy Drilling and Mining	Food and Preparations	Textile	Daily Instruments
18	Vegetables, Fruits and Plants	Raw Manufacturing	Transportation	Raw Manufacturing
ECI	2.751108815	2.154947	1.220401303	1.937171566

Ranking	Singapore	Japan	USA	Germany
1	Energy Drilling and Mining	Chemicals	Animals and By-products	Chemical Manufacturing
2	Chemicals	Metals	Clothing and Accessories	Machinery and Construction
3	Machinery and Construction	Machinery and Construction	Metals	Transportation
4	Transportation	Transportation	Textile	Daily Instruments
5	High-complexity Products	Weapons	Raw Manufacturing	High-complexity Products
6	Services and Utilities	Daily Instruments	Vegetables, Fruits and Plants	Services and Utilities
7	Weapons	High-complexity Products	Food and Preparations	Chemicals
8	Textile	Services and Utilities	Energy Drilling and Mining	Textile
9	Precious Stones	Textile	Chemicals	Weapons
10	Chemical Manufacturing	Precious Stones	Chemical Manufacturing	Clothing and Accessories
11	Clothing and Accessories	Clothing and Accessories	Wood Products	Precious Stones
12	Daily Instruments	Energy Drilling and Mining	Machinery and Construction	Raw Manufacturing
13	Animals and By-products	Animals and By-products	Weapons	Wood Products
14	Metals	Wood Products	Daily Instruments	Energy Drilling and Mining
15	Raw Manufacturing	Chemical Manufacturing	Precious Stones	Animals and By-products
16	Wood Products	Food and Preparations	Services and Utilities	Metals
17	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants	Transportation	Food and Preparations
18	Food and Preparations	Raw Manufacturing	High-complexity Products	Vegetables, Fruits and Plants
ECI	2.112887919	1.979430054	0.261724796	2.959929484

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 shows the SDV of a selected group of leading economies with outstanding economic complexity, 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, countries listed in Table 6 have nearly half of industries with positive opportunity gain. While the economies with absolute negative E_fCI, for example, United Arab Emirates and Algeria, need to develop High-complexity Products, Transportation, Machinery and Construction, those with median E_fCI are facing a more complicated and diverse situation, such as Italy, Spain and U.S..

It can be concluded that the U.S. is categorized to be a highly complexed country as compared with the world's leading economies and other major economies in Europe.

Ranking	Thailand	Italy	Spain	United Arab Emirates
1	Animals and By-products	Energy Drilling and Mining	Energy Drilling and Mining	High-complexity Products
2	Food and Preparations	Precious Stones	Precious Stones	Transportation
3	Chemicals	Vegetables, Fruits and Plants	Weapons	Machinery and Construction
4	Raw Manufacturing	Animals and By-products	Textile	Daily Instruments
5	Textile	Food and Preparations	Chemicals	Chemicals
6	Machinery and Construction	Chemical Manufacturing	Daily Instruments	Weapons
7	Transportation	Raw Manufacturing	Animals and By-products	Textile
8	High-complexity Products	Wood Products	Vegetables, Fruits and Plants	Chemical Manufacturing
9	Energy Drilling and Mining	Clothing and Accessories	Food and Preparations	Raw Manufacturing
10	Vegetables, Fruits and Plants	Textile	Chemical Manufacturing	Energy Drilling and Mining
11	Precious Stones	Metals	Raw Manufacturing	Precious Stones
12	Weapons	Machinery and Construction	Wood Products	Services and Utilities
13	Clothing and Accessories	Daily Instruments	Clothing and Accessories	Metals
14	Services and Utilities	High-complexity Products	Metals	Clothing and Accessories
15	Wood Products	Weapons	Transportation	Wood Products
16	Metals	Chemicals	Services and Utilities	Animals and By-products
17	Chemical Manufacturing	Services and Utilities	Machinery and Construction	Vegetables, Fruits and Plants
18	Daily Instruments	Transportation	High-complexity Products	Food and Preparations
ECI	1.68914409	1.179705915	0.45830144	-0.734459148

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:

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

$$\text{Subject to}$$

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

$$x \succcurlyeq 0$$

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 $||x_p - x_0||_1$.

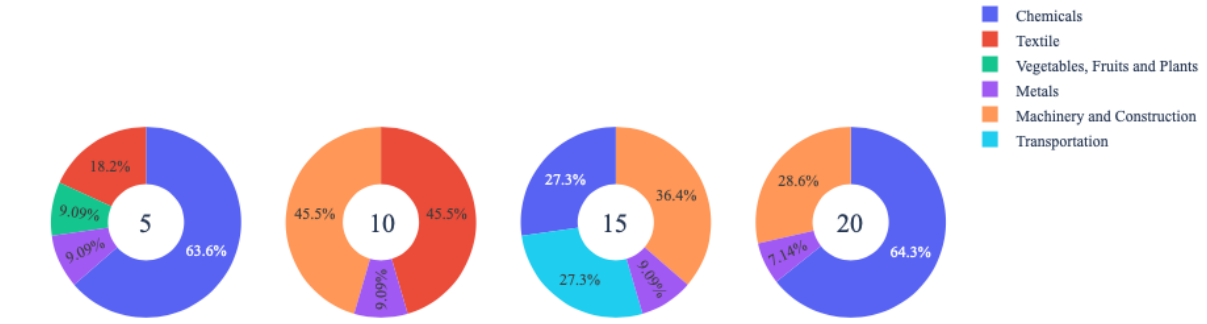
In this way, we can obtain a further sighted greedy algorithm. Also, the number of parts that we would like to separate the budget into also matters. In order to solve this problem, we added a stabilizer on top of the enhanced greedy algorithm, by running the algorithm for different number of parts and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

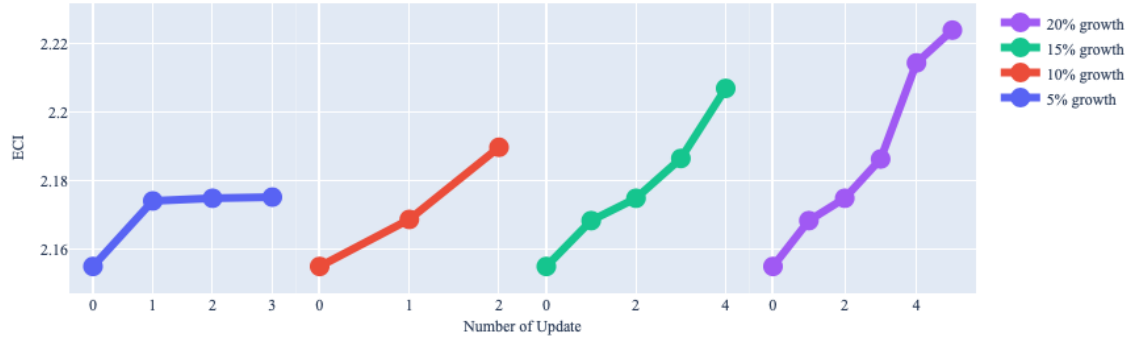
Economic Panel:

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 charts.

Japan ECI Growth Optimization Result



Japan ECI Increment

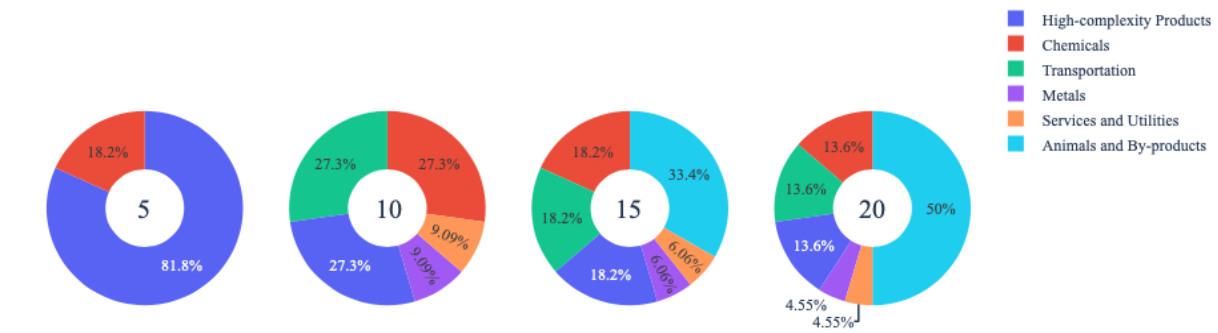


Japan (2013)				
Total Export in 2013 (US. $)	1.17E+12			
Original ECI	2.155			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. $)	5.86E+10	1.17E+11	1.76E+11	2.35E+11
Metals(US. $)	5.33E+09	1.07E+10	1.60E+10	1.68E+10
Transportation(US. $)	0.00E+00	0.00E+00	4.80E+10	0.00E+00
Chemicals(US.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

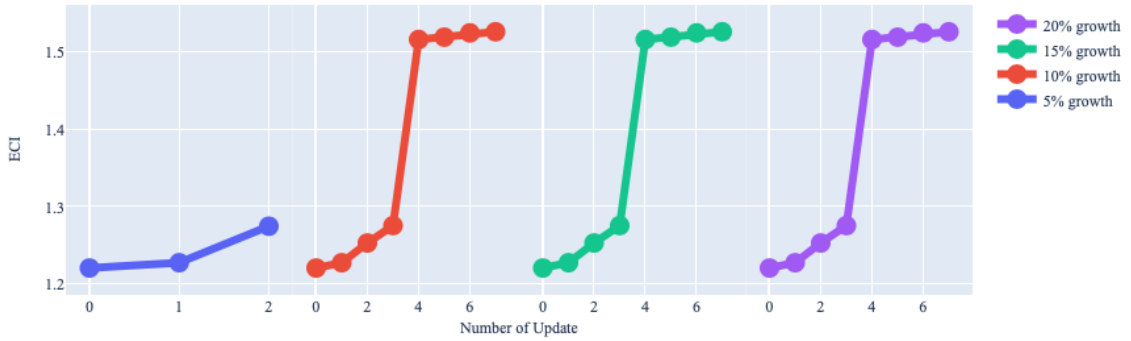
Interpretation:

Below is the economic panel for America in 2013. We can see that for different percentages of heuristic total export growth, the ECI of America will have a different amount of increments. For the case of 5 percent export growth, both high complexity products and chemicals account for the only small amount of increment in the first line graph. For the case of 10, 15, and 20 percent increments, it is obvious that involvement of machinery and construction products can boost the ECI a lot. Increases in other industries, including chemicals, animals and by-product, and metals, can slightly increase the ECI as well. Therefore, under the budgeted constraint, America should prioritize the machinery and construction and chemicals products to optimize the ECI increment.

USA ECI Growth Optimization Result



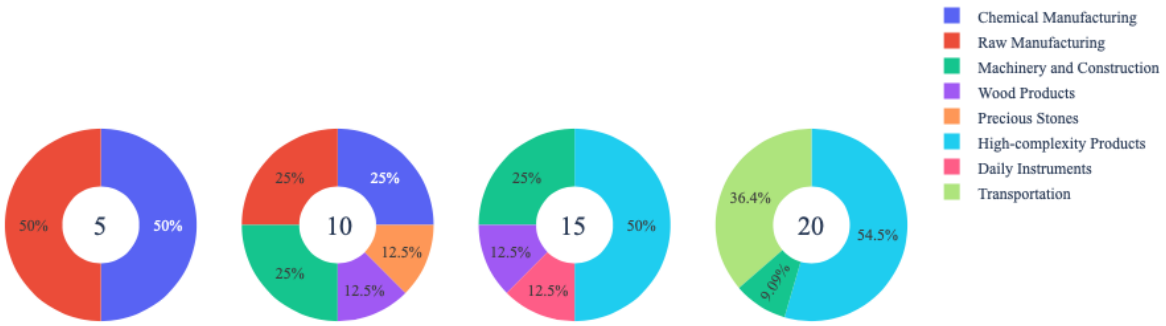
USA ECI Increment



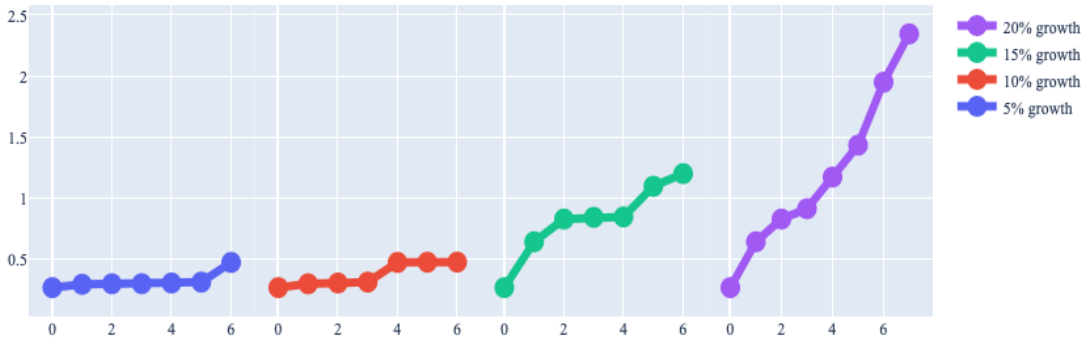
USA (2013)				
Total Export in 2013 (US. $)	2.24E+12			
Original ECI	1.220			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. $)	1.12E+11	2.24E+11	3.36E+11	4.48E+11
Metals(US. $)	0.00E+00	2.03E+10	2.03E+10	2.03E+10
Chemicals(US. $)	2.03E+10	6.10E+10	6.10E+10	6.10E+10
High-complexity Products(US. $)	9.15E+10	6.10E+10	6.10E+10	6.10E+10
Animals and By-products(US. $)	0.00E+00	0.00E+00	1.12E+11	2.24E+11
Services and Utilities (US. $)	0.00E+00	2.03E+10	2.03E+10	2.03E+10
Transportation(US. $)	0.00E+00	6.10E+10	6.10E+10	6.10E+10
Increased ECI	1.275	1.526	1.526	1.526

For further suggestions on America's development in the future. We also offer the optimization result of America based on export data in 2018. Below is the economic panel for America in 2018. We can see that for different percentages of heuristic total export growth, the ECI growth deviates a lot. For the case of 5 and10 percent export growth, some basic products stimulate a small amount of ECI increment, including raw manufacturing, precious stones, wood products etc. For the case of 15 and 20 percent growth, a large portion of allocation to high complexity products causes multiple increments in ECI. Therefore, for short-term strategy, America should focus on the development of raw manufacturing, chemical manufacturing, and machinery to optimize the growth of ECI. For long-term strategy, the gain from high complexity is huge as well.

USA ECI Growth Optimization Result



USA ECI Increment



USA (2018)				
Total Export in 2018 (US. $)	2.34E+12			
Original ECI	0.26			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. $)	1.17E+11	2.34E+11	3.51E+11	4.67E+11
Chemical Manufacturing (US. $)	5.84E+10	5.84E+10	0.00E+00	0.00E+00
Raw Manufacturing (US. $)	5.84E+10	5.84E+10	0.00E+00	0.00E+00
Wood Products (US. $)	0.00E+00	2.92E+10	4.38E+10	0.00E+00
Machinery and Construction (US. $)	0.00E+00	5.84E+10	8.76E+10	4.25E+10
Transportation (US. $)	0.00E+00	0.00E+00	0.00E+00	1.70E+11
Daily Instruments (US. $)	0.00E+00	0.00E+00	4.38E+10	0.00E+00
Precious Stones (US. $)	0.00E+00	4.38E+10	0.00E+00	0.00E+00
High-complexity Products (US. $)	0.00E+00	0.00E+00	1.75E+11	2.55E+11
Increased ECI	0.47	0.47	1.20	2.34

4.3 Sensitivity Analysis and Contingency Strategy

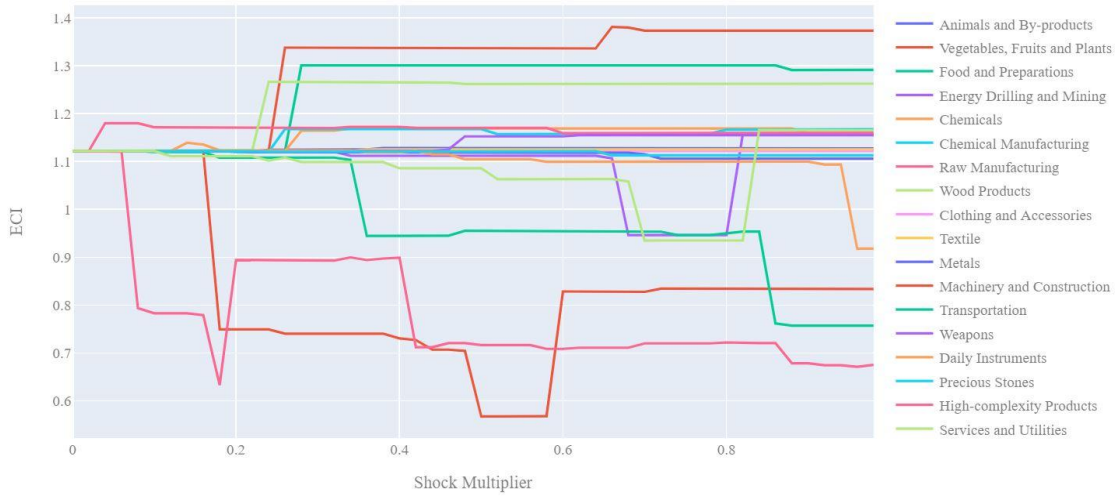
In the following section our broad aim is to understand how sensitive the United States is to changes in export in various industries. While the Economic Complexity Index has been shown to contain valuable information about the economic strength/capacity of a country, little has been said as to the stability 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)

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.

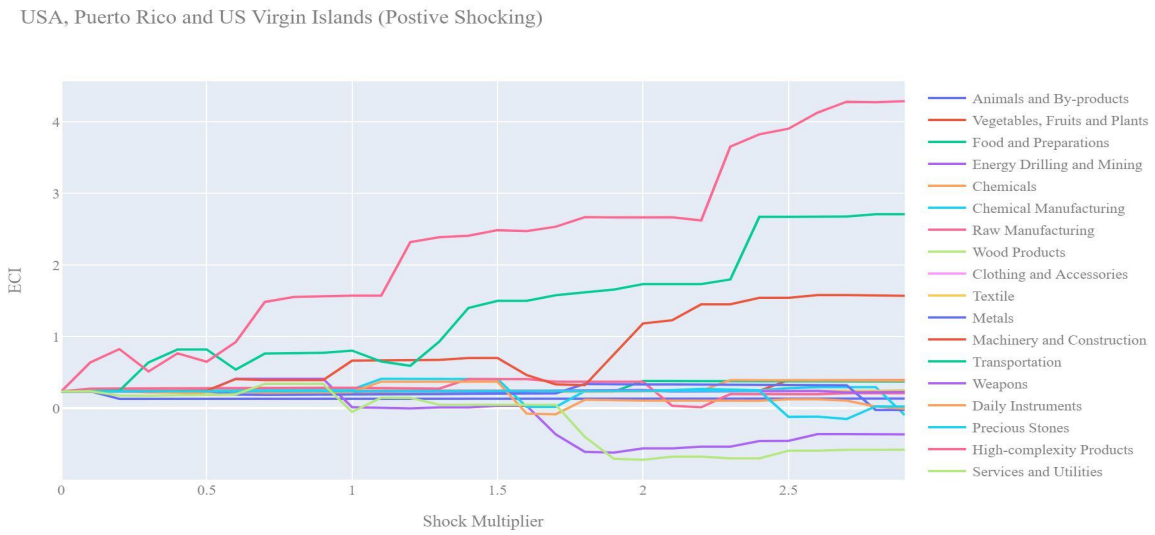
	0	1	2
Animals and By-products	Services and Utilities	Daily Instruments	Weapons
Vegetables, Fruits and Plants	Services and Utilities	Daily Instruments	Weapons
Food and Preparations	Services and Utilities	Daily Instruments	Weapons
Energy Drilling and Mining	Services and Utilities	Daily Instruments	Weapons
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

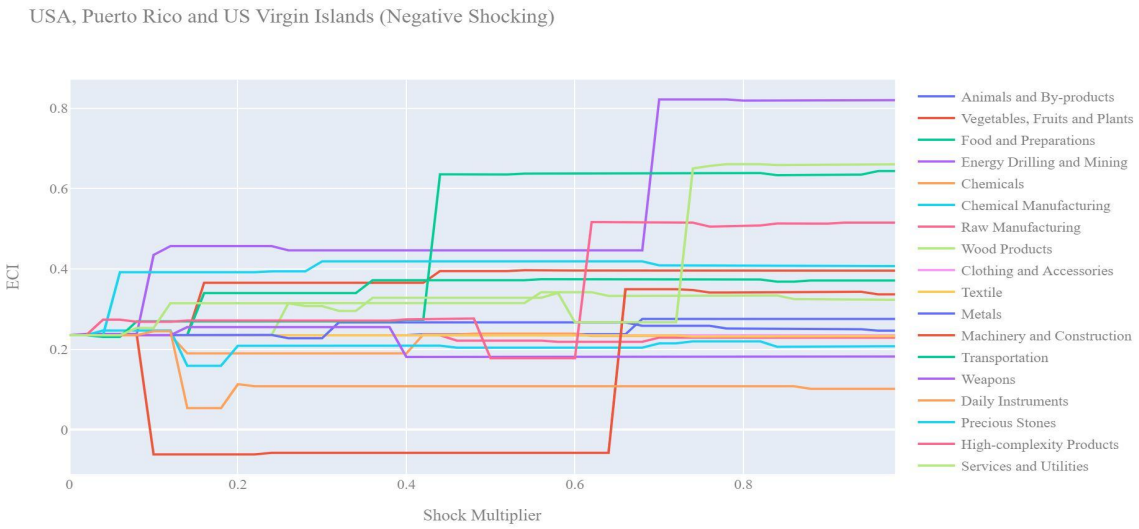
4.3 Sensitivity Analysis Results and Interpretation

Below is USA's 2018 ECI Sensitivity Charts. Firstly in the positive chart, we notice immediately that increases in High Complexity Product, Transportation, and Machinery lead to linear uptrend of ECI. High Complexity Products offer 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 USA's 2018 Negative Shock chart. We see that the US is highly sensitive to changes in export level in most of its industries. This is characteristic of a highly developed nation that has large export numbers in various industries. Interestingly, Energy and Drilling seems to improve the ECI level when exports are decreased. The US is most sensitive to drawdowns in Machinery which can push the ECI into the negative territory.



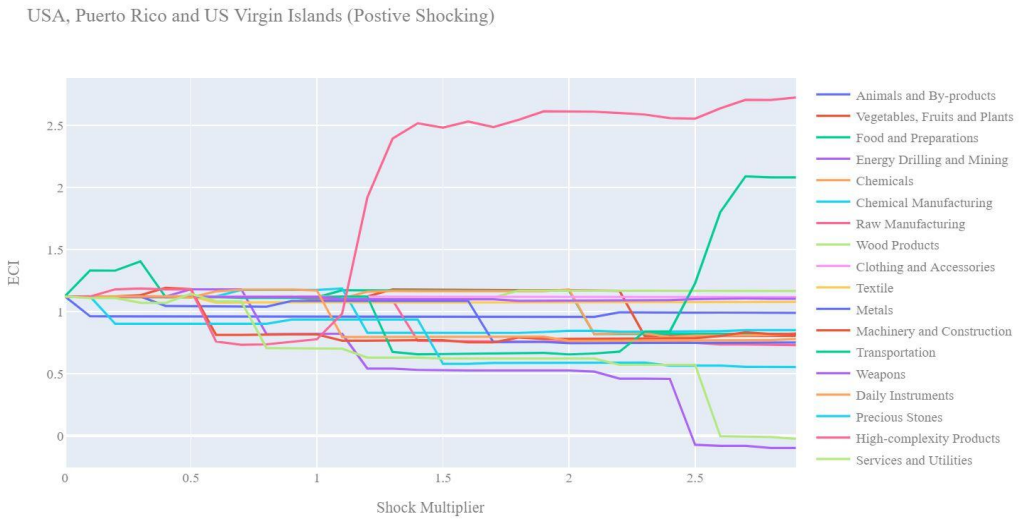
USA, Puerto Rico and US Virgin Islands 2018 (Incremental ECI Sensitivity)



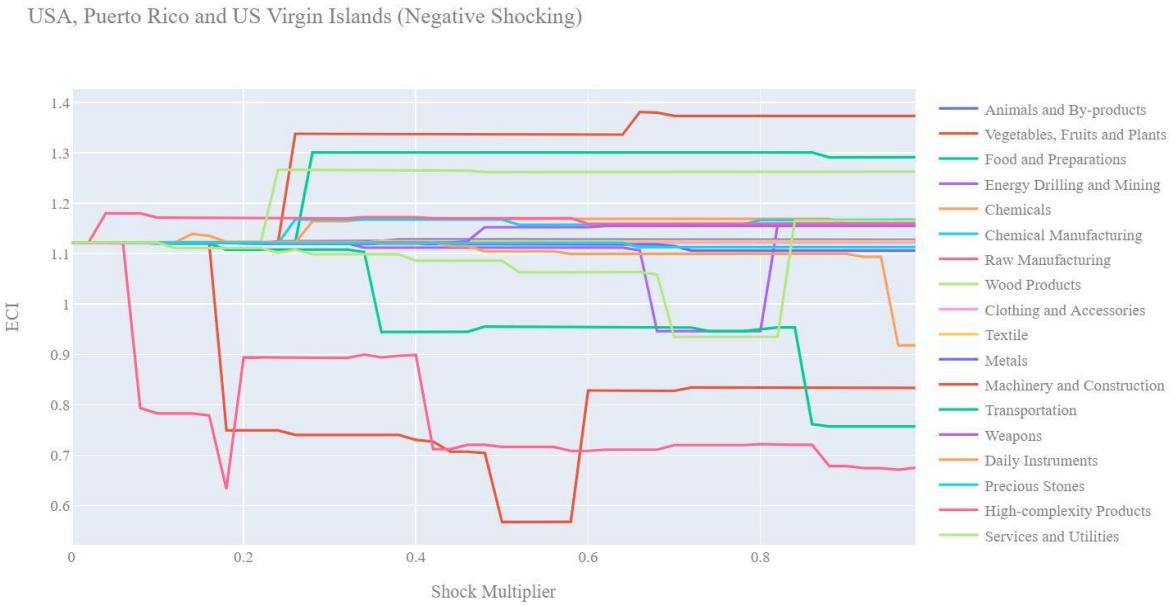
USA, Puerto Rico and US Virgin Islands 2018 (Decremental ECI Sensitivity)

Next we consider the 2013 ECI Sensitivity graphs. We see that in the positive shocking case, the landscape of ECI sensitivity has not altered significantly over the five year period. High complexity products seem to offer the best ECI growth prospects. Transportation and Machinery do not affect ECI levels as positively as in 2018 but see that the overall ECI of the US is approximately 0.2 in 2018 and approximately 1 in 2013.

In the 2013 negative shocking case, we see that again the US is very sensitive to drawbacks in Machinery. However unlike the 2018 case, we see quite a bit of sensitivity to High Complexity Products as well. In general the US is fairly sensitive to the majority of its industries.



USA, Puerto Rico and US Virgin Islands 2013 (Incremental ECI Sensitivity)



USA, Puerto Rico and US Virgin Islands 2013 (Decremental ECI Sensitivity)

Below we see the SDV sensitivity charts for High Complexity Products. USA's SDV is quite sensitive to changes in High Complexity products since the US economy is highly dependent on the export of products that are produced from this industry. As exports in High COmplexity Products is positively shocked, more industries become attractive, showing positive opportunity gains. However after about a 60% increase in export we start to see quite a few industries shift from neutral opportunity gain to negative opportunity gain signifying that an increase in export of above 60% would make quite a few industries not worth pursuing because of the dominance of High Complexity Products.

Considering the Negative SDV sensitivity chart we observe that as the export of High Complexity Products decreases the number of industries with positive opportunity gain go to

zero. This is characteristic of a well-developed economy with a large reliance on High Complexity Products and not many other avenues for large ECI improvement.

	0.0%	10.0%	20.0%	30.0%	40.0%	50.0%	60.0%	70.0%
0	Transportation	Services and Utilities	Clothing and Accessories	Textile	Metals	Metals	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants
1	High-complexity Products	Energy Drilling and Mining	Textile	Raw Manufacturing	Raw Manufacturing	Raw Manufacturing	Machinery and Construction	Machinery and Construction
2	Raw Manufacturing	Precious Stones	Raw Manufacturing	Clothing and Accessories	Clothing and Accessories	Textile	Chemicals	Chemicals
3	Textile	Daily Instruments	Wood Products	Metals	Textile	Clothing and Accessories	Transportation	Transportation
4	Services and Utilities	Weapons	Vegetables, Fruits and Plants	Transportation	Precious Stones	Daily Instruments	Services and Utilities	Daily Instruments
5	Food and Preparations	Vegetables, Fruits and Plants	Food and Preparations	Vegetables, Fruits and Plants	Animals and By-products	Chemicals	Weapons	Textile
6	Precious Stones	Machinery and Construction	Energy Drilling and Mining	Food and Preparations	Energy Drilling and Mining	Transportation	Food and Preparations	Services and Utilities
7	Daily Instruments	Food and Preparations	Chemicals	Energy Drilling and Mining	Transportation	Animals and By-products	High-complexity Products	Weapons
8	Weapons	High-complexity Products	Chemical Manufacturing	Chemicals	Weapons	Energy Drilling and Mining	Wood Products	High-complexity Products
9	Machinery and Construction	Wood Products	Services and Utilities	Chemical Manufacturing	High-complexity Products	Precious Stones	Daily Instruments	Wood Products
10	Vegetables, Fruits and Plants	Chemical Manufacturing	High-complexity Products	Services and Utilities	Wood Products	Machinery and Construction	Textile	Chemical Manufacturing
11	Wood Products	Chemicals	Machinery and Construction	Wood Products	Daily Instruments	High-complexity Products	Chemical Manufacturing	Clothing and Accessories
12	Chemical Manufacturing	Textile	Weapons	High-complexity Products	Chemical Manufacturing	Wood Products	Clothing and Accessories	Raw Manufacturing
13	Chemicals	Raw Manufacturing	Daily Instruments	Weapons	Chemicals	Weapons	Precious Stones	Precious Stones
14	Energy Drilling and Mining	Clothing and Accessories	Metals	Daily Instruments	Food and Preparations	Chemical Manufacturing	Raw Manufacturing	Metals
15	Clothing and Accessories	Metals	Precious Stones	Machinery and Construction	Vegetables, Fruits and Plants	Food and Preparations	Metals	Energy Drilling and Mining
16	Metals	Animals and By-products	Animals and By-products	Precious Stones	Services and Utilities	Vegetables, Fruits and Plants	Energy Drilling and Mining	Animals and By-products
17	Animals and By-products	Transportation	Transportation	Animals and By-products	Machinery and Construction	Services and Utilities	Animals and By-products	Food and Preparations
ECI	0.235220232	0.640484066	0.827101479	0.514712824	0.767731191	0.650728806	0.925355816	1.485268804

USA, Puerto Rico and US Virgin Islands High-complexity Products 2018 (Incremental SDV Sensitivity)

	-0.0%	-4.0%	-50.0%	-62.0%
0	Transportation	Transportation	Services and Utilities	Services and Utilities
1	High-complexity Products	Services and Utilities	Wood Products	Wood Products
2	Raw Manufacturing	Food and Preparations	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants
3	Textile	Precious Stones	Food and Preparations	Food and Preparations
4	Services and Utilities	Daily Instruments	Energy Drilling and Mining	Energy Drilling and Mining
5	Food and Preparations	Weapons	Chemicals	Chemicals
6	Precious Stones	Machinery and Construction	Chemical Manufacturing	Chemical Manufacturing
7	Daily Instruments	Vegetables, Fruits and Plants	Raw Manufacturing	Raw Manufacturing
8	Weapons	Wood Products	Animals and By-products	Animals and By-products
9	Machinery and Construction	Raw Manufacturing	Machinery and Construction	Machinery and Construction
10	Vegetables, Fruits and Plants	Chemical Manufacturing	Weapons	Transportation
11	Wood Products	Chemicals	Daily Instruments	Weapons
12	Chemical Manufacturing	Energy Drilling and Mining	Precious Stones	Daily Instruments
13	Chemicals	High-complexity Products	Transportation	Precious Stones
14	Energy Drilling and Mining	Textile	High-complexity Products	Textile
15	Clothing and Accessories	Clothing and Accessories	Textile	Clothing and Accessories
16	Metals	Metals	Clothing and Accessories	High-complexity Products
17	Animals and By-products	Animals and By-products	Metals	Metals
ECI	0.235220232	0.274042895	0.178127323	0.516784741

USA, Puerto Rico and US Virgin Islands High-complexity Products 2018 (Decremental SDV Sensitivity)

4.4 Contingency Strategy

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

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

USA Contingency Strategy 2018

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

USA Contingency Strategy 2013

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

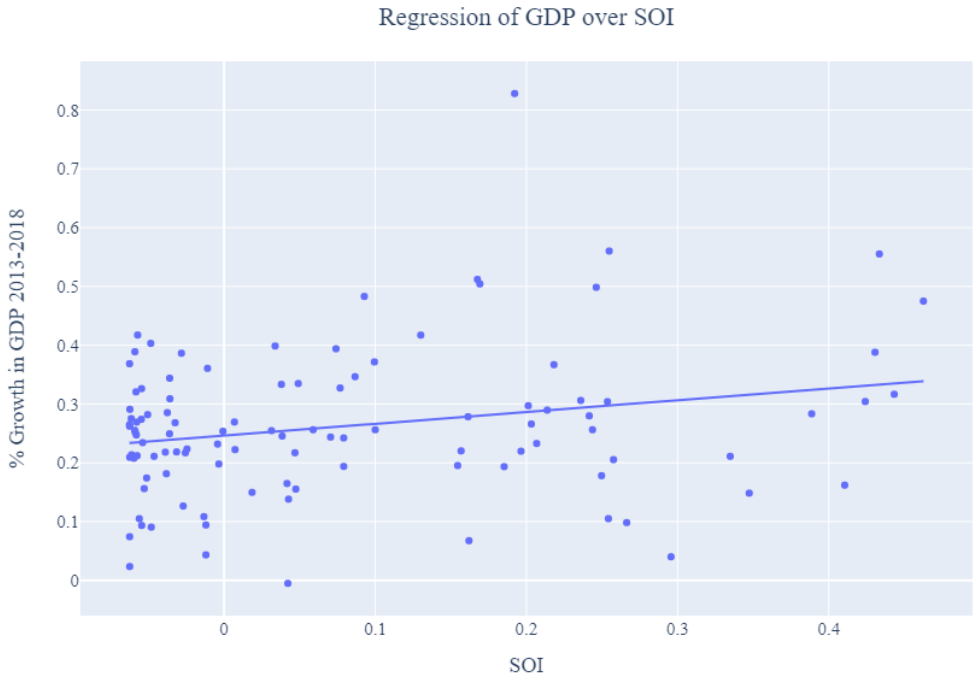


Figure 2: Regression of Five-year GDP Growth over SOI

5.2 SOI of U.S. and Its Implications

U.S., for instance, has a higher level of structural optimality as compared with its emerging 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), U.S. demonstrates an average level of correlation with the suggested developmental path, having an adjusted R-square of around 15.7%. The U.S. ranks in 34th place among all countries in terms of SOI and has made an average rate of economic progress among its emerging peers from 2013 to

2018 with a 5-year GDP growth rate of 22.0%, which is consistent with the regression result in Figure 6. 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, U.S.'s stable economic progress from 2013 to 2018 can be at least partially explained by a development strategy that demonstrates a considerable but not perfect level of matches with our suggested developmental path. In specific, U.S. invested heavily in the Services and Utilities industry, while it should have focused more on moderately complex industry groups such as chemical manufacturing.

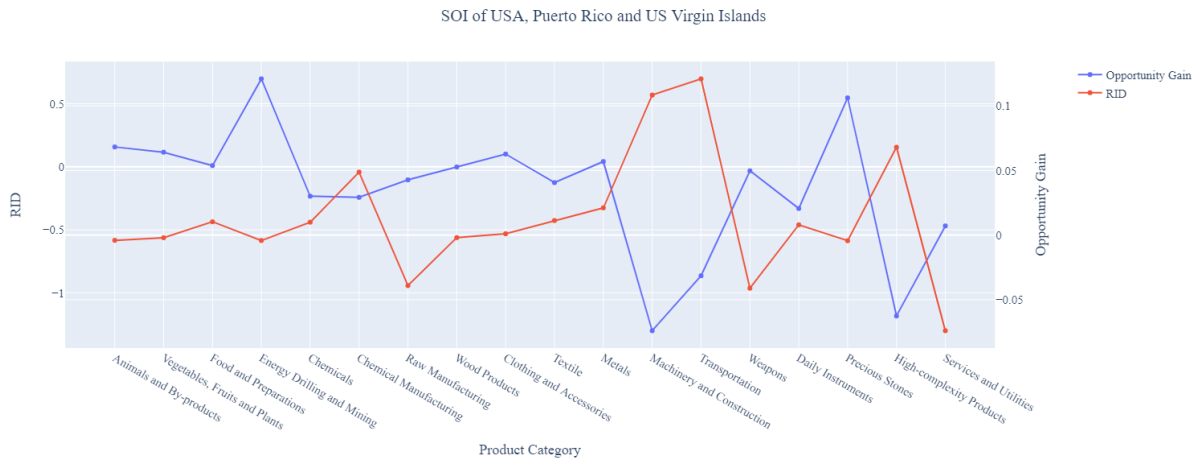


Figure 7: SOI of U.S. (2009-2014)

6. Concluding Remarks

In conclusion, the U.S. 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 as compared with other major developed economies.

The lack of progress during the period, we believe, can be partially explained through analysis of the economic and product complexity structure of the United States 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 the United States consistently relied on developing Services and Utilities, Weapons and Raw Manufacturing industries 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, the United States can further its gains by prioritizing High-complexity Products and Chemicals. We further note that the United States 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 15.7%. Since a significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, the United States 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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