

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

Optimal Industry Development Strategy Using Economic and Product Complexity

South Korea

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 South Korea

0. Executive Summary

In this report, we aim to uncover the economic path South Korea went through during the period from 2013 to 2018. Specifically, we dive into the topic through a macroeconomic overview of South Korea 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, South Korea demonstrated a promising level of economic growth with an annual GDP growth rate of 5.0%, concurrent with an increase in economic complexity as compared with other major Asian or developed economies in the world.

The outstanding progress made during the period, we believe, can be largely explained through analysis of the economic and product complexity structure of South Korea 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 South Korea strategically invested in developing Transportation, Textile and High-complexity Products industries during the period, while its Asian counterparts and developed economies around the globe have adopted much more conservative growth paths.

Based on our analysis of the opportunity gain and a sensitivity analysis of major industry groups, South Korea can further its gains by investing in Services and Utilities, and Raw Manufacturing. We further note that South Korea already has a well-matched development strategy that indicates a moderate level of fitness with the strategy calculated on a complexity level, having an adjusted R-square of around -6.2%. Since a significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, South Korea indeed adopted an outstanding development plan as compared with other emerging economies both on a regional scale and on a global scale, and has fully leveraged the potential to further its economic gains through industrial structure balancing as suggested in the paper.

1. Report Overview

In this report, we aim to uncover the economic path South Korea went through during the period from 2013 to 2018. Specifically, we dive into the topic through a macroeconomic overview of South Korea 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 South Korea 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 South Korea, 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 12th largest economy in the world by GDP in 2018, South Korea has a GDP of 1.3 trillion USD in 2013 and 1.6 trillion USD in 2018, exhibiting an extraordinary level of economic output. Figure 1 illustrates the time-series GDP results for world's emerging economies from 1999-2018, and South Korea ranks among its counterparts as a stable player. South Korea exhibits a consistent level of GDP growth during the 6 years from 2013 to 2018, with an annual growth rate of about 5%. This number is staggering compared to the annual growth rate of the other five leading emerging economies, which have a geometric average growth rates of 2.4% and an arithmetic average growth rate of 2.3%. Such an annual GDP growth rate is comparable with that of more developed economies on a global scale, such as the United States, which has an annual GDP increase of merely around 4% during the period. The rapid economic growth, we believe, can be reflected through changes in ECI and PCI, and can be further explained by a well-chosen set of production strategies adopted by South Korea from 2013 to 2018, which we will expand at the later stage of the report.

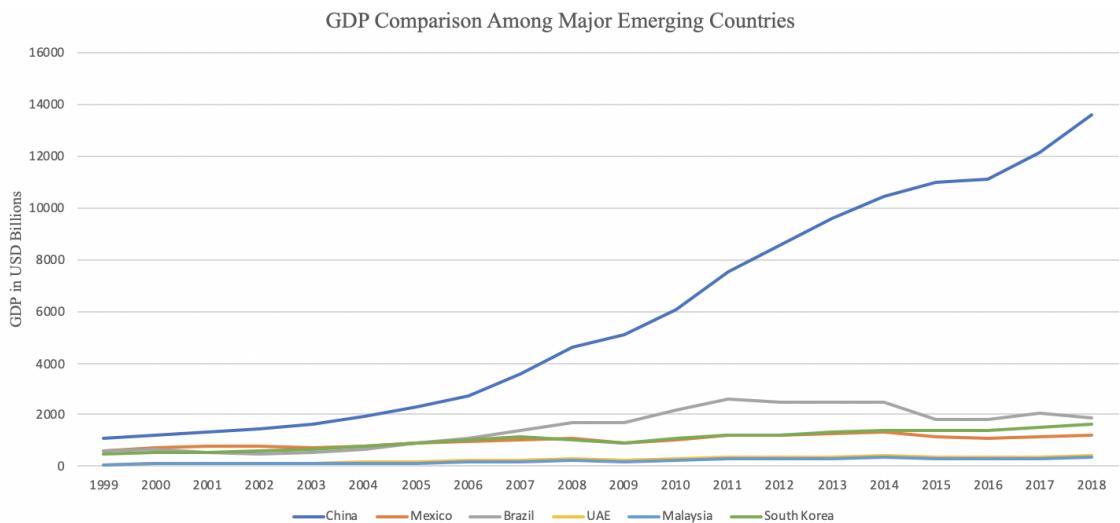


Figure 1: GDP Comparison Among Major Emerging Economies

2.2 ECI Ranking and Changes

The Economic Complexity Index (ECI), as defined by Ricardo Hausmann and Cesar Hidalgo in 2009 to explain the knowledge accumulated in a country's population, exhibits a similar pattern for South Korea. As illustrated in Figure 2 below, South Korea exhibits a significant increase in terms of its production capability from 2013 to 2015, as measured by ECI. This is in direct contrast to countries such as Brazil and UAE, which demonstrate both low ECI and a stagnant/decreasing ECI growth rate.

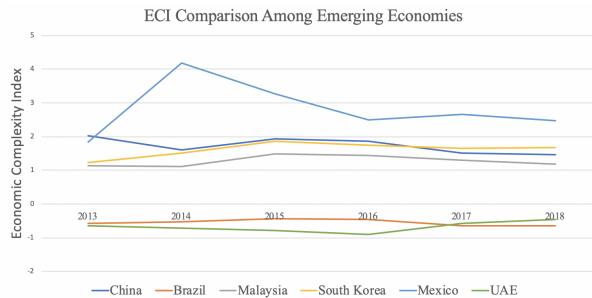


Figure 2: ECI Comparison

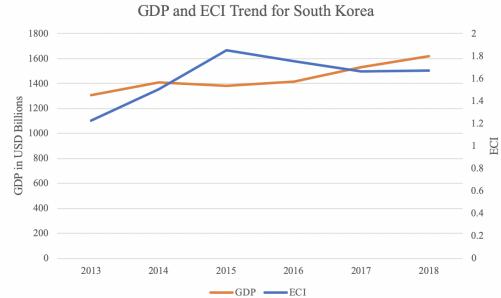


Figure 3: GDP and ECI (South Korea)

Figure 3 offers a further comparison of GDP and ECI over the entire time span from 2013 to 2018 for South Korea. Based on statistical analysis, ECI is a significant covariate for GDP with an adjusted R-square of 94.0%. Moreover, we observe a particularly strong correlation between GDP and ECI from this period, indicating the potential that the GDP increase experienced by South Korea during the period from 2013 to 2018 can be largely attributed to its high ECI, or the effectiveness of the country in developing a competitive product space that helps to accumulate complicated knowledge and technology. In order to provide a more concrete answer to why this has happened, we will dive into an analysis of South Korea'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 economies, 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 France's realized industry production strategy between 2013 and 2018 on a complexity level. In Hausmann and Hidalgo (2009), distance is defined to be a measure of how far a country is from a certain product not in its product space. We extend this concept to all product groups and quantify how technically equipped a country is to develop the corresponding product groups. In other words, the shorter the distance between a country and a product group, the more capable a country is in developing products within that group. Defining this net distance change as the Realized Industry Development (RID), our export data allow us to calculate and compare RID of France and the 18 product groups in 2013 and 2018 through subtraction, where a positive RID indicates a shortening of the distance (i.e., advancement of the industry), and a negative RID indicates the reverse. As ranked in Table 2, during the period from 2013 to 2018, France has focused on products with a moderate level of complexity and those requiring intermediate skills, including raw manufacturing, Energy Drilling and Mining, which is unusual among developed economies.

Category	RID	Category	RID
1. Raw Manufacturing	-0.080	2. Energy Drilling and Mining	-0.082
3. Refined and Processed Stones	-0.086	4. Chemical Manufacturing	-0.095
5. Chemicals	-0.102	6. Wood Products	-0.111
7. Clothing and Accessories	-0.113	8. Services and Utilities	-0.114
9. Weapons	-0.114	10. Animals and By-products	-0.118
11. Vegetables, Fruits and Plants	-0.120	12. High-complexity Products	-0.129
13. Food and Preparations	-0.134	14. Metals	-0.136
15. Textiles	-0.147	16. Transportation	-0.178
17. Daily Instruments	-0.241	18. Machinery and Construction	-0.324

Table 2: Realized Industry Development (RID) of France

3.3 Regional and Global Comparison

Table 3 and 4 below summarize how the production strategy adopted by France compares with other leading economies and a selected group of emerging economies in the world, as measured in RID. It can be directly observed that France focused on products with a lower complexity level, when compared against its leading counterparts 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 France's development strategy against those of emerging economies on a global scale. Reasonably, emerging economies such as China, South Korea, Singapore and India have devoted the majority of their efforts into intermediate industry groups while developed economies such as France should have rely more on advanced industry groups. This trend holds true in general, regardless of the continent or the time period, and serves as an indicator for which phase of development a country is currently in as evaluated from its production strategy. Based on this standard, the United States 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	Mexico	Singapore	Japan	China	Germany	Republic of Korea
1	Vegetables, Fruits and Plants	Chemicals	Chemicals	Raw Manufacturing	Chemical Manufacturing	Services and Utilities
2	Machinery and Construction	Transportation	Metals	Clothing and Accessories	Wood Products	Chemicals
3	Transportation	High-complexity Products	Machinery and Construction	Textile	Metals	Raw Manufacturing
4	High-complexity Products	Services and Utilities	Transportation	Machinery and Construction	Machinery and Construction	Textile
5	Services and Utilities	Machinery and Construction	Weapons	Transportation	Transportation	Metals
6	Chemicals	Daily Instruments	Daily Instruments	Weapons	Weapons	Transportation
7	Textile	Weapons	High-complexity Products	Daily Instruments	High-complexity Products	Daily Instruments
8	Weapons	Textile	Services and Utilities	High-complexity Products	Services and Utilities	High-complexity Products
9	Daily Instruments	Chemical Manufacturing	Precious Stones	Precious Stones	Weapons	Weapons
10	Chemical Manufacturing	Raw Manufacturing	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining
11	Clothing and Accessories	Clothing and Accessories	Textile	Services and Utilities	Precious Stones	Chemical Manufacturing
12	Raw Manufacturing	Metals	Clothing and Accessories	Chemicals	Textile	Precious Stones
13	Food and Preparations	Wood Products	Chemical Manufacturing	Energy Drilling and Mining	Clothing and Accessories	Machinery and Construction
14	Animals and By-products	Precious Stones	Chemical Manufacturing	Chemical Manufacturing	Chemicals	Clothing and Accessories
15	Metals	Animals and By-products	Animals and By-products	Wood Products	Animals and By-products	Wood Products
16	Wood Products	Food and Preparations	Wood Products	Animals and By-products	Vegetables, Fruits and Plants	Animals and By-products
17	Precious Stones	Energy Drilling and Mining	Vegetables, Fruits and Plants	Food and Preparations	Food and Preparations	Food and Preparations
18	Energy Drilling and Mining	Vegetables, Fruits and Plants	Food and Preparations	Metals	Daily Instruments	Vegetables, Fruits and Plants
ECI	2.753793255	2.751108815	2.154947	1.96086598	1.937171566	1.7759805

Ranking	Germany	Mexico	Singapore	Japan	China	Republic of Korea
1	Chemical Manufacturing	Vegetables, Fruits and Plants	Energy Drilling and Mining	Chemicals	Chemicals	Services and Utilities
2	Machinery and Construction	Machinery and Construction	Chemicals	Metals	Raw Manufacturing	Chemicals
3	Transportation	Transportation	Machinery and Construction	Machinery and Construction	Clothing and Accessories	Raw Manufacturing
4	Daily Instruments	High-complexity Products	Transportation	Transportation	Textile	Textile
5	High-complexity Products	Services and Utilities	High-complexity Products	Weapons	Machinery and Construction	Metals
6	Services and Utilities	Chemicals	Services and Utilities	Daily Instruments	Transportation	Transportation
7	Chemicals	Weapons	Weapons	High-complexity Products	Weapons	Daily Instruments
8	Textile	Textile	Textile	Services and Utilities	Daily Instruments	High-complexity Products
9	Weapons	Daily Instruments	Precious Stones	Textile	High-complexity Products	Weapons
10	Clothing and Accessories	Clothing and Accessories	Chemical Manufacturing	Precious Stones	Precious Stones	Clothing and Accessories
11	Precious Stones	Chemical Manufacturing	Clothing and Accessories	Clothing and Accessories	Services and Utilities	Precious Stones
12	Raw Manufacturing	Precious Stones	Daily Instruments	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining
13	Wood Products	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining	Chemical Manufacturing	Chemical Manufacturing
14	Energy Drilling and Mining	Animals and By-products	Animals and By-products	Animals and By-products	Wood Products	Wood Products
15	Animals and By-products	Raw Manufacturing	Raw Manufacturing	Raw Manufacturing	Chemical Manufacturing	Animals and By-products
16	Metals	Food and Preparations	Wood Products	Food and Preparations	Metals	Food and Preparations
17	Food and Preparations	Wood Products	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants	Chemical Manufacturing	Vegetables, Fruits and Plants
18	Vegetables, Fruits and Plants	Metals	Food and Preparations	Raw Manufacturing	Food and Preparations	Machinery and Construction
ECI	2.959929484	2.527893051	2.112887919	1.979430054	1.700687855	1.648971597

Table 5: SDV of High ECI 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 , such as South Africa and Colombia, all need to develop High-complexity Products, Machinery and Construction and daily instruments, those with median E_fCI are facing a more complicated and diverse situation, such as Italy, Spain and the United States.

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

Ranking	Italy	Tunisia	South Africa	Colombia
1	Energy Drilling and Mining	Machinery and Construction	High-complexity Products	High-complexity Products
2	Precious Stones	Services and Utilities	Machinery and Construction	Machinery and Construction
3	Vegetables, Fruits and Plants	Daily Instruments	Animals and By-products	Transportation
4	Animals and By-products	High-complexity Products	Transportation	Services and Utilities
5	Food and Preparations	Weapons	Services and Utilities	Daily Instruments
6	Chemical Manufacturing	Chemical Manufacturing	Daily Instruments	Chemicals
7	Raw Manufacturing	Precious Stones	Clothing and Accessories	Weapons
8	Wood Products	Textile	Chemicals	Chemical Manufacturing
9	Clothing and Accessories	Raw Manufacturing	Chemical Manufacturing	Textile
10	Textile	Animals and By-products	Raw Manufacturing	Raw Manufacturing
11	Metals	Food and Preparations	Textile	Metals
12	Machinery and Construction	Metals	Vegetables, Fruits and Plants	Food and Preparations
13	Daily Instruments	Vegetables, Fruits and Plants	Food and Preparations	Animals and By-products
14	High-complexity Products	Energy Drilling and Mining	Energy Drilling and Mining	Wood Products
15	Weapons	Chemicals	Wood Products	Clothing and Accessories
16	Chemicals	Clothing and Accessories	Metals	Vegetables, Fruits and Plants
17	Services and Utilities	Transportation	Weapons	Energy Drilling and Mining
18	Transportation	Wood Products	Precious Stones	Precious Stones
ECI	1.179705915	0.239091536	-0.80405844	-1.752771623

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:

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

Subject to

$$\begin{aligned} \sum_{p \in P} x_p &\leq B \\ x &\geq 0 \end{aligned}$$

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

If we can solve this problem, then we can know what the largest ECI that a country can improve to. Accordingly, the optimal solution x^* that we obtain here is exactly our optimal allocation. However, the biggest problem is that the objective function is not convex. Therefore, we cannot apply the classical tools for convex optimization on this problem. In order to solve this problem, our idea is to use greedy 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 $\|x_p - x_0\|_1$.

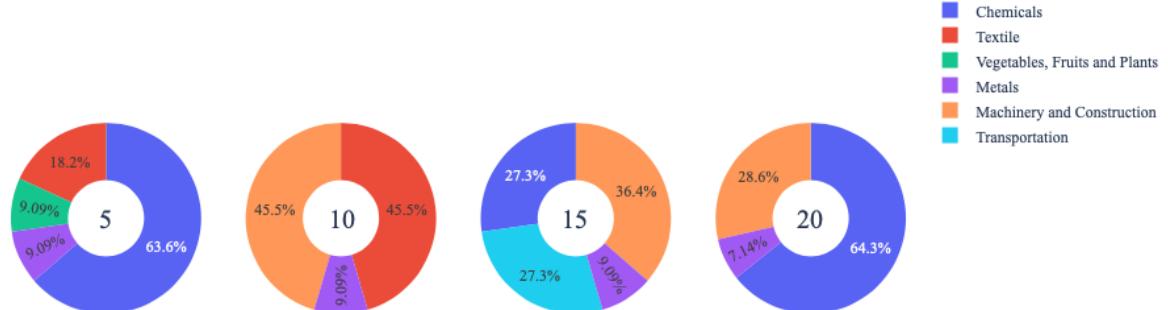
In this way, we can obtain a further sighted greedy algorithm. Also, the number of parts that we would like to separate the budget into also matters. In order to solve this problem, we added a stabilizer on top of the enhanced greedy algorithm, by running the algorithm for different number of parts and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

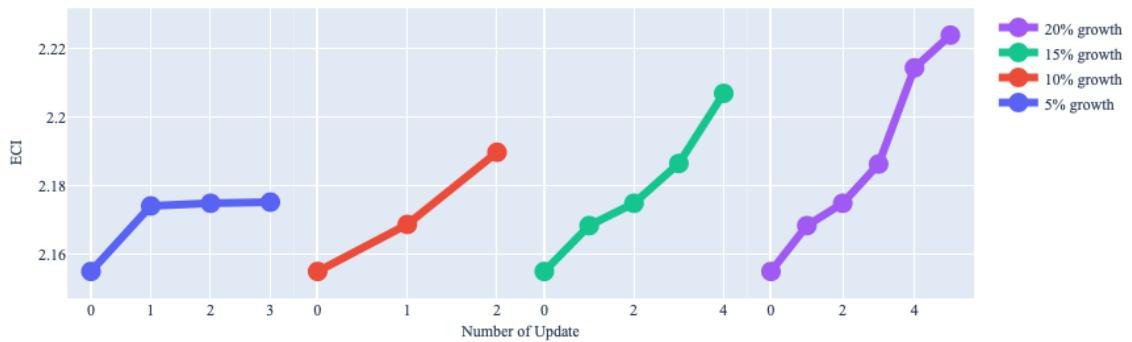
Economic Panel:

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

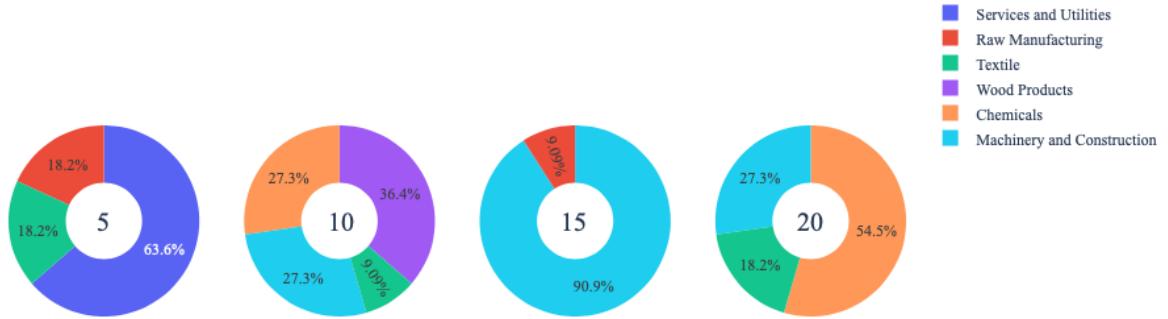


Japan (2013)				
Total Export in 2013 (US. \$)	1.17E+12			
Original ECI	2.155			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. \$)	5.86E+10	1.17E+11	1.76E+11	2.35E+11
Metals(US. \$)	5.33E+09	1.07E+10	1.60E+10	1.68E+10
Transportation(US. \$)	0.00E+00	0.00E+00	4.80E+10	0.00E+00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

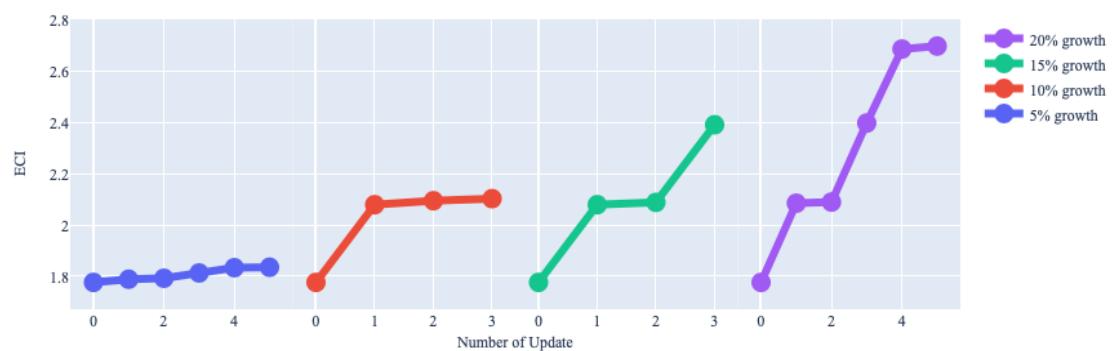
Interpretation:

Below is the economic panel for South Korea in 2013. We can see that for different percentages of heuristic total export growth, the ECI of South Korea has different performance. From all the four line graphs, we see that South Korea already obtains some great increment in terms of ECI. Most importantly, the higher the budget is, the greater the ECI will be. This means that in both short term and long term, South Korea still has great room to improve. For the case of 5 percent growth, the ECI does not increase so much. For 10 percent growth, the ECI increases is mainly because of increase in machinery products. Similarly, for 15 and 20 percent, ECI increments are also due to the increase in both machinery products and chemicals.

Republic of Korea ECI Growth Optimization Result



Republic of Korea ECI Increment

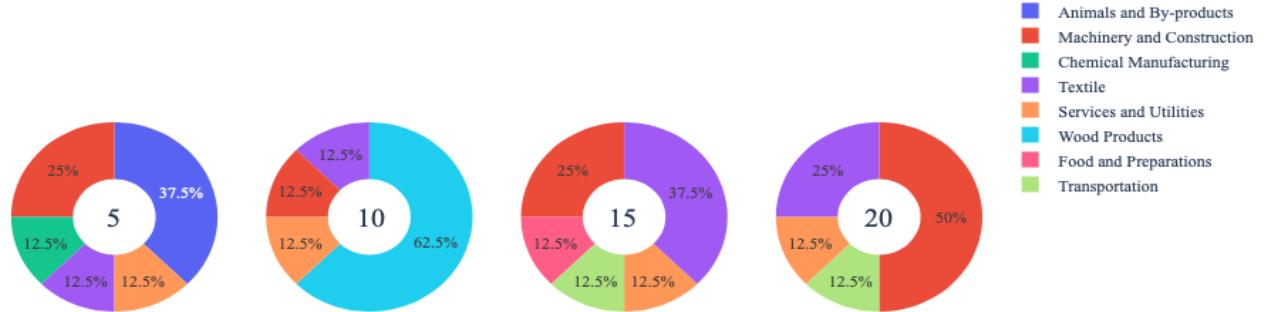


Republic of Korea (2013)				
Total Export in 2013 (US. \$)	8.99E+11			
Original ECI	1.776			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. \$)	4.50E+10	8.99E+10	1.35E+11	1.80E+11
Chemicals(US. \$)	0.00E+00	2.45E+10	0.00E+00	9.81E+10
Machinery and Construction(US. \$)	0.00E+00	2.45E+10	1.23E+11	4.91E+10
Raw Manufacturing(US. \$)	8.18E+09	0.00E+00	1.23E+10	0.00E+00
Textile(US. \$)	8.18E+09	8.18E+09	0.00E+00	3.27E+10
Services and Utilities (US. \$)	2.86E+10	0.00E+00	0.00E+00	0.00E+00
Wood Products(US. \$)	0.00E+00	3.27E+10	0.00E+00	0.00E+00
Increased ECI	1.835	2.103	2.391	2.698

For further suggestions on South Korea's development in the future. We also offer the optimization result of South Korea based on export data in 2018. Below is the economic panel for South Korea in 2018. We can see that for different percentages of heuristic total export growth, the ECI growth pattern of South Korea is similar from the one in 2013. From all the four line graphs, we see that South Korea already obtains some great increment in terms of ECI. Most importantly, the higher the budget is, the greater the ECI will be. This means that in both short term and long term, South Korea still has great room to improve. For the case of 5 percent export growth budget, the ECI does not increase so much. The greatest increment in the first line graph is actually caused by machinery and construction. For the case of 15 and 20 percent, the result shows that adding machinery and chemical manufacturing as a growth component can bring lots of gains in ECI. Therefore, for future strategy, South Korea should prioritize development of machinery and construction, which

causes the greatest jump in each stage. And then services industry and transportations, in order to optimize ECI.

Republic of Korea ECI Growth Optimization Result



Republic of Korea ECI Increment



Republic of Korea (2018)				
Total Export in 2018 (US. \$)	9.92E+11			
Original ECI	1.65			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. \$)	4.96E+10	9.92E+10	1.49E+11	1.98E+11
Animals and Byproducts (US. \$)	1.86E+10	0.00E+00	0.00E+00	0.00E+00
Food and Preparations (US. \$)	0.00E+00	0.00E+00	1.86E+10	0.00E+00
Chemical Manufacturing (US. \$)	6.20E+09	0.00E+00	0.00E+00	0.00E+00
Wood Products (US. \$)	0.00E+00	6.20E+10	0.00E+00	0.00E+00
Textile (US. \$)	6.20E+09	1.24E+10	5.58E+10	4.96E+10
Machinery and Construction (US. \$)	1.24E+10	1.24E+10	3.72E+10	9.92E+10
Transportation (US. \$)	0.00E+00	0.00E+00	1.86E+10	2.48E+10
Services and Utilities (US. \$)	6.20E+09	1.24E+10	1.86E+10	2.48E+10
Increased ECI	1.90	1.88	2.52	2.69

4.3 Sensitivity Analysis and Contingency Strategy

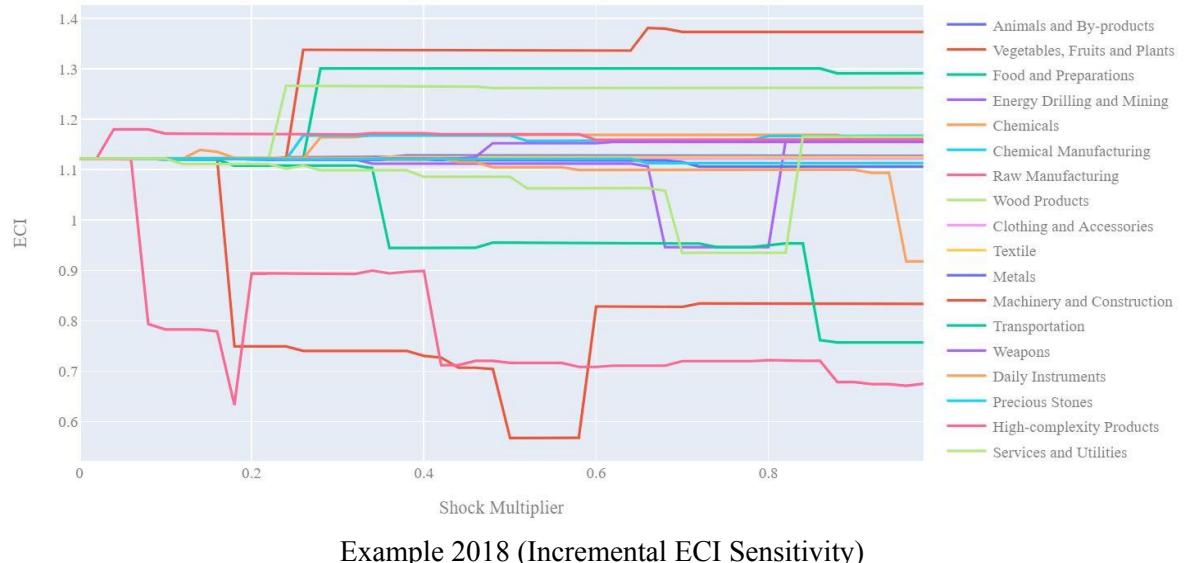
In the following section our broad aim is to understand how sensitive South Korea is to changes in export in various industries. While the Economic Complexity Index has been

shown to contain valuable information about the economic strength/capacity of a country, little has been said as to the stability of the measure itself. We seek to uncover the main drivers of stability under a country's ECI score and better understand longer-term projections for ECI growth. Additionally, gaining an intuition on the industries that are bolstering an economy and the industries that offer the greatest return per unit of investment is best done through visualization of industry specific sensitivity.

ECI Sensitivity Graph

Firstly, in order to assess the effect particular industries have on each respective country, we developed ECI Sensitivity graphs. We use shocking methodology to increment or decrement an industry's export level by a certain percentage and recalculate the ECI all else being equal. While freezing the export dynamics of the rest of the world and enacting an instantaneous shock in export for a particular industry and country may not reflect real-life dynamics, what it does offer us is an understanding of a country's level of dependency on an industry in the context of ECI. The shocking is done in small percentage increments in order to smooth out the resulting curve. Additionally, a recurring theme one will see is that for most industries, a breaking point occurs where the ECI either jumps upwards or downwards, creating a hockey stick shape rather than a linear trend. While the inflection point may not be accurate in 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.



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

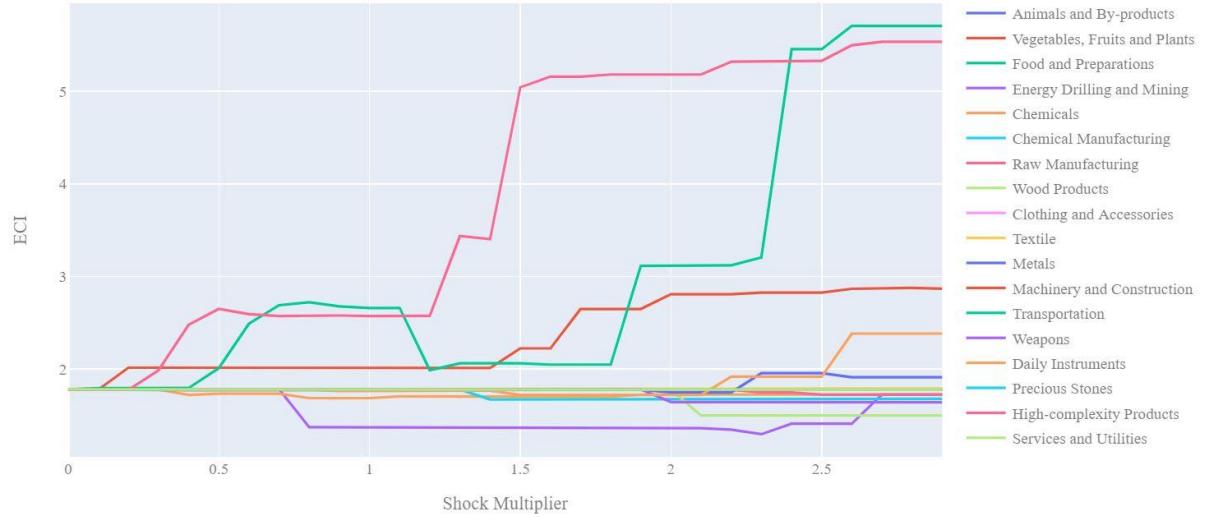
4.3 Sensitivity Analysis Results and Interpretation

Below is South Korea's 2018 ECI Sensitivity Charts. Firstly in the positive chart, we notice immediately that High Complexity Products, Transportation give fairly significant increases in ECI with only a 25-50% increase in net export value. Export increases of more than 100% in both these industries begin to show massive gains in ECI, suggesting that South Korea is an important participant in both of these industries within the global landscape. All other industries tend to not greatly affect the ECI level making it fairly clear which industries to pursue.

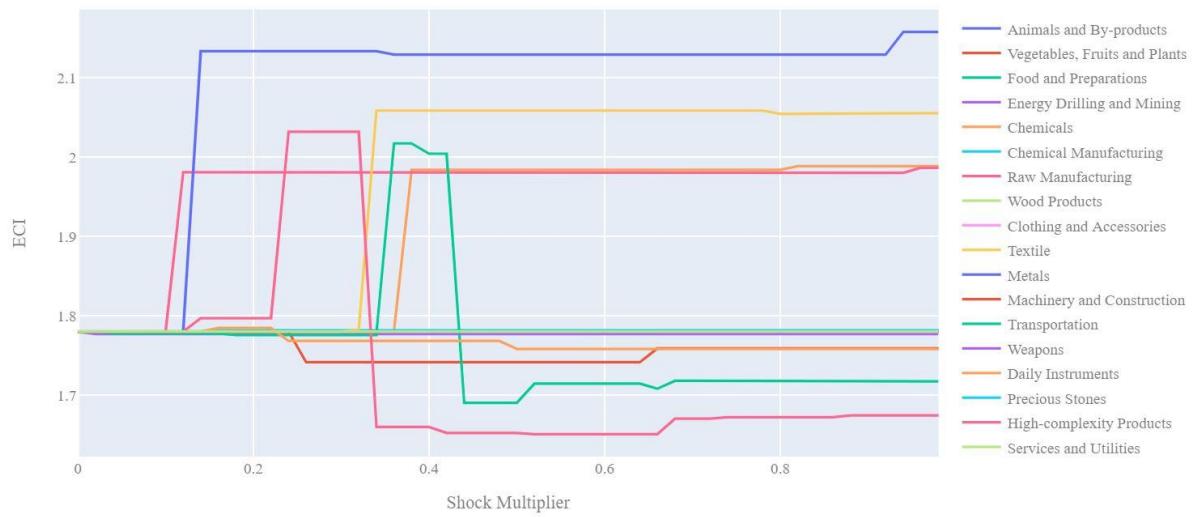
Next we consider South Korea's 2018 Negative Shock chart. We can see that decreases in export of industries such as Metals, Textile, Raw Manufacturing, and Chemicals actually increase the ECI level greatly. This may suggest that it may be optimal to reduce exports from these specific industries and allocate those resources to industries such as

Transportation or High Complexity Products.

Republic of Korea (Positive Shocking)



Republic of Korea (Negative Shocking)

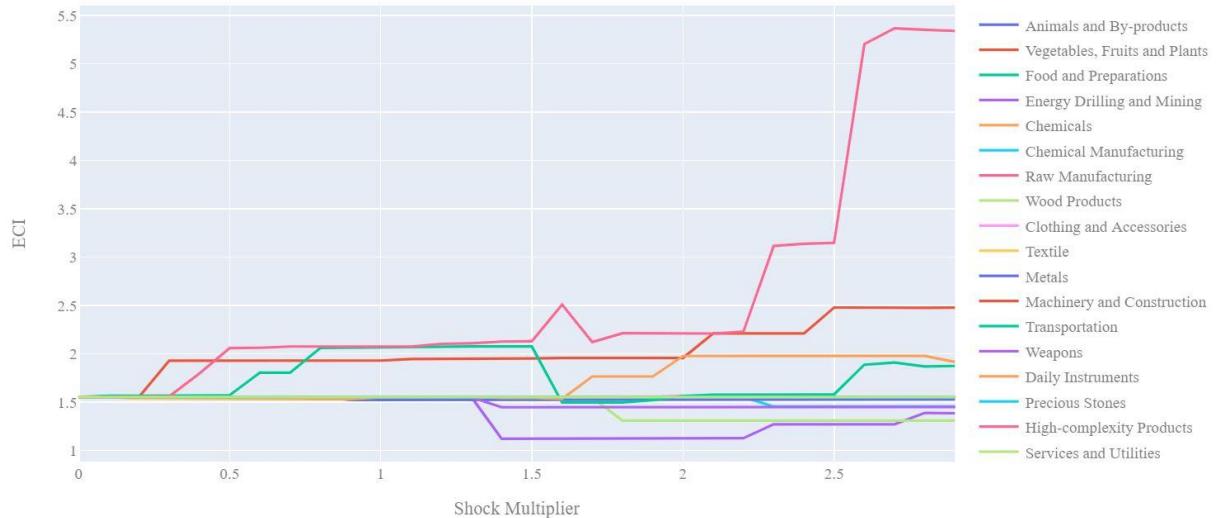


Next we consider the 2013 ECI Sensitivity graphs. We see that in the positive shocking case we have a very similar profile as the 2018 graph. Most industries give either little or no benefit to ECI. However High Complexity Products offer significant increases to ECI after large increases to export levels.

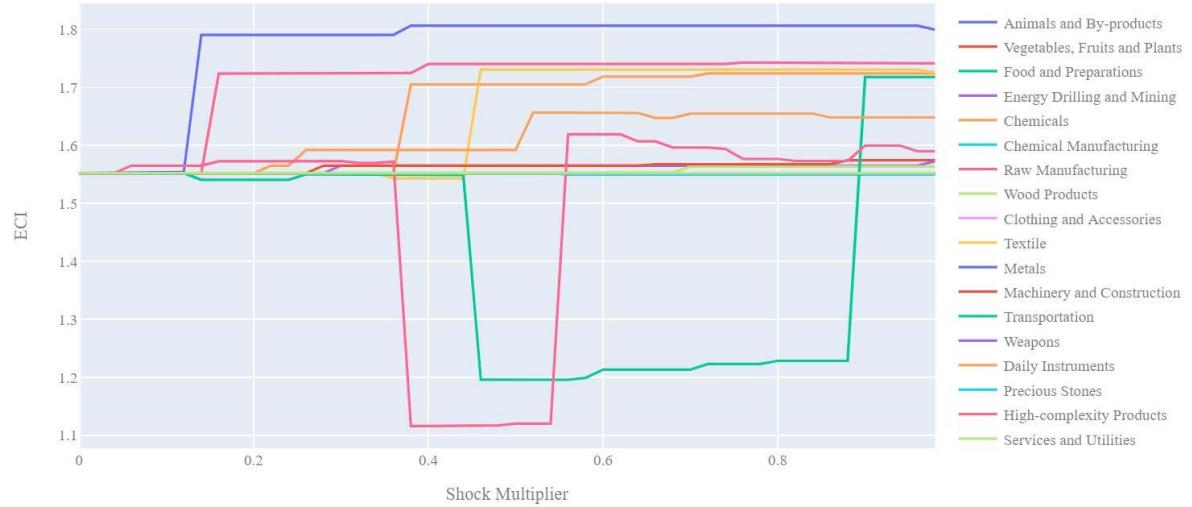
In the 2013 negative shocking case, we see that again South Korea is far more sensitive to downturns in Transportation and High Complexity Products as compared to the 2018 case.

This would suggest that South Korea has expanded into other industries that bolster its ECI in addition to Transportation and High Complexity Products,

Republic of Korea (Positive Shocking)



Republic of Korea (Negative Shocking)



4.4 Contingency Strategy

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

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

South Korea Contingency Strategy 2018

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

South Korea 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
R²: 0.054	Prob (F-Stat): 0.0163
Adj R²: 0.045	No. Observations: 106



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

5.2 SOI of South Korea and Its Implications

South Korea, for instance, has a low level of structural optimality as compared with even its developed peers. In fact, South Korea has the lowest SOI of all countries observed. South Korea demonstrates a disappointing level of correlation with the suggested developmental path, having an adjusted R-square of around -6.2%. South Korea has made an above average rate of economic progress among its developed peers, around 26.2% growth in GDP from 2013 to 2018, which is inconsistent 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. As mentioned, there are many factors that affect Economic Growth, and the SOI measure does not take into account many of those factors. It can be said with relative confidence that if Korea had invested more optimally, it would have grown at a faster pace.

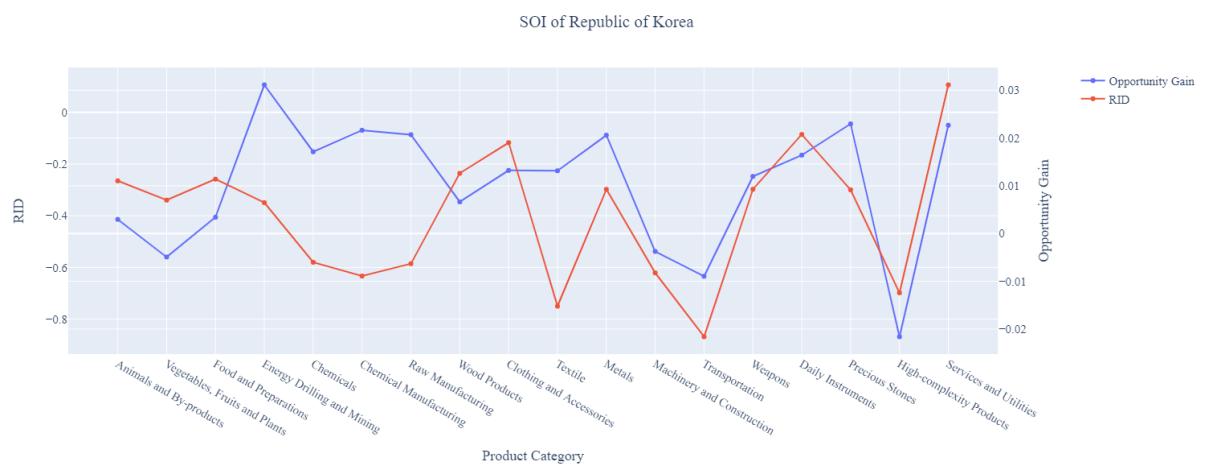


Figure 7: SOI of South Korea (2013-2018)

6. Concluding Remarks

In conclusion, South Korea has demonstrated a promising level of economic growth in terms of GDP during the period from 2013 to 2018, concurrent with an increase in economic complexity as compared with other major Asian or developed economies in the world.

The outstanding progress made during the period, we believe, can be largely explained through analysis of the economic and product complexity structure of South Korea 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 South Korea strategically invested in developing Transportation, Textile and High-complexity Products industries during the period, while its Asian counterparts and developed economies around the globe have adopted much more conservative growth paths.

Based on our analysis of the opportunity gain and a sensitivity analysis of major industry groups, South Korea can further its gains by investing in Services and Utilities, and Raw Manufacturing. We further note that South Korea already has a well-matched development

strategy that indicates a moderate level of fitness with the strategy calculated on a complexity level, having an adjusted R-square of around -6.2%. Since a significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, South Korea indeed adopted an outstanding development plan as compared with other emerging economies both on a regional scale and on a global scale, and has fully leveraged the potential to further its economic gains through industrial structure balancing as suggested in the paper.

References

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

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

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

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

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

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

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

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