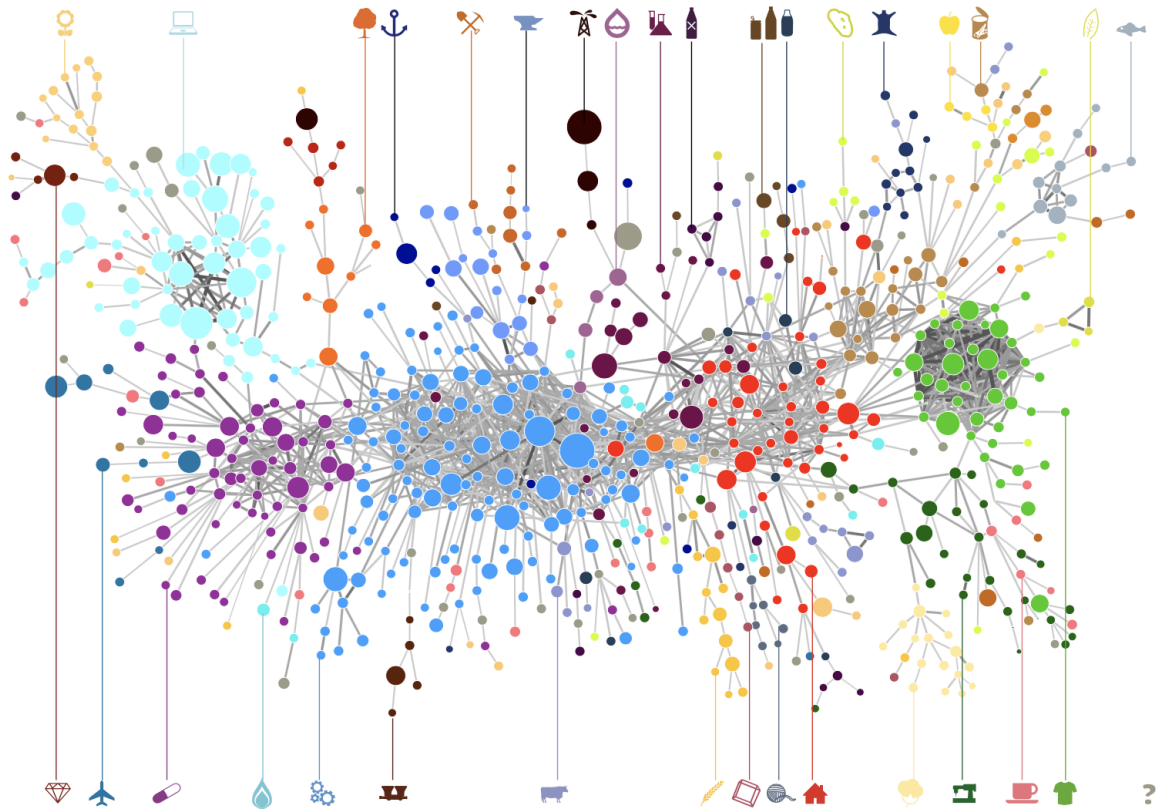




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Optimal Industry Development Strategy Using Economic and Product Complexity

Saudi Arabia

The Economic Complexity Lab - Columbia University

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Optimal Industry Development Strategy for Saudi Arabia

0. Executive Summary

In this report, we aim to uncover the economic path Saudi Arabia went through during the period from 2013 to 2021. Specifically, we dive into the topic through a macroeconomic overview of Saudi Arabia 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, Saudi Arabia demonstrated a low level of economic growth with an average annual GDP growth rate of 1.5% between 2013 and 2018 and 2.0% between 2019 and 2021, with a decreased economic complexity compared to other major emerging economies.

The lack of progress during the period, we believe, can be partially explained through the analysis of the economic and product complexity structure of Saudi Arabia on the industry group level, as well as the stagnant macro and microeconomic strategies. The product classification system we adopt allows us to measure the realized industry development for various industry groups and to observe that Saudi Arabia regressed in developing most of its industries during the period while its emerging counterparts and economies around the globe also adopted complex and progressive paths with variable degrees of success.

Based on our analysis of the opportunity gain and sensitivity analysis of major industry groups, Saudi Arabia could have furthered its gains by prioritizing Services and Utilities and Raw Manufacturing in 2018. Three years later, in 2021, its focus should have shifted to the Precious Stones and Vegetables, Fruits, and Plants industries, which were also underdeveloped industries at the time. We further note that Saudi Arabia has a slightly mismatched development strategy that indicates a moderate level (compared to other emerging countries) of structural optimality on the complexity level, having an adjusted R-square of around -5.9% in 2018 and a much higher score of 21.4% in 2021, demonstrating improvement in development. Since a significant positive correlation exists between five-year GDP growth between 2013 and 2018 and the structural optimality index of an economy as we define and calculate, Saudi Arabia 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.

The three years following showed a significant improvement in Saudi Arabia's economic growth, boosting its position on the global scale. Its GDP recovered to above the pre-pandemic levels, and it saw a significant boost in the ECI, particularly compared to its peer countries. Its current strategy still has the viable potential upside to increase its performance and optimize its structure further.

1. Report Overview

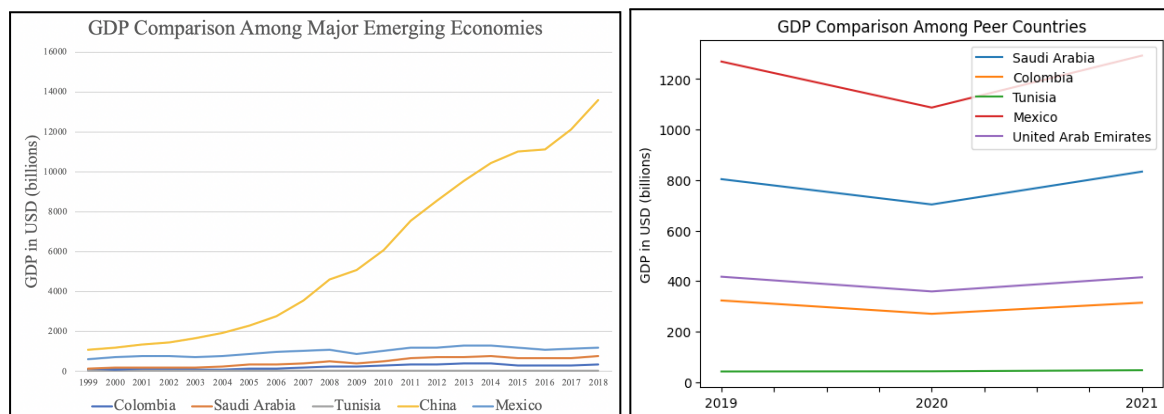
In this report, we aim to uncover the economic path Saudi Arabia went through during the period from 2019 to 2021, before and after the COVID pandemic, compared to its performance from 2013 to 2018, before and after the Vision 2030 economic diversification plan was announced. Specifically, we dive into the topic through a macroeconomic overview of Saudi Arabia 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 Saudi Arabia during the period based on quantitative measures such as the 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 Saudi Arabia, as deduced from regression models we have established on a global scale, which take into account countries' stances in their product space.

2. Macroeconomic Results

2.1 GDP Ranking and Changes

Figure 1a illustrates the time-series GDP results for Saudi Arabia and four of its peer countries (Colombia, Tunisia, China, and Mexico) from 2013 to 2018. Similar to the other countries, Saudi Arabia displayed an eventual upward trend over the period; however, its growth was less consistent than China's growth. Saudi Arabia's AAGR of 1.5% is similar to the AAGR of the other four leading emerging economies (1.8%) but significantly less than China's AAGR (8.2%).

Figure 1b shows the GDP levels for Saudi Arabia and its peer countries (Colombia, Tunisia, Mexico, and the United Arab Emirates) from 2019 to 2021. Similar to the other countries, Saudi Arabia displayed a drop in GDP from 2019 to 2020 because of the pandemic, with all GDPs rebounding in 2021. Over these three years, Saudi Arabia's average annual GDP growth rate (2.01%) is greater than the UAE's rate (0.55%) and Mexico's rate (1.53%) but less than Tunisia's (3.98%).



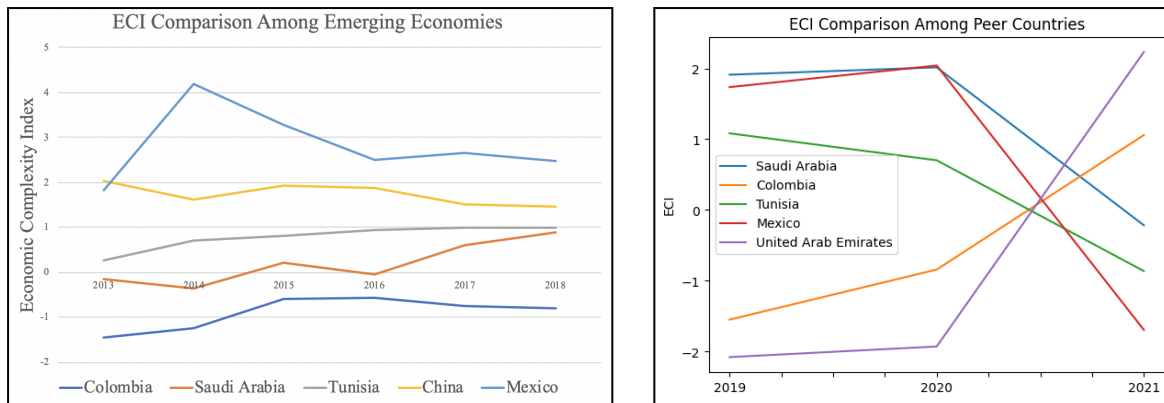
Figures 1a and 1b. GDP Comparison Among Peer Countries (left: 2013-2018; right: 2019-2021)

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, is illustrated in Figures 2a and 2b.

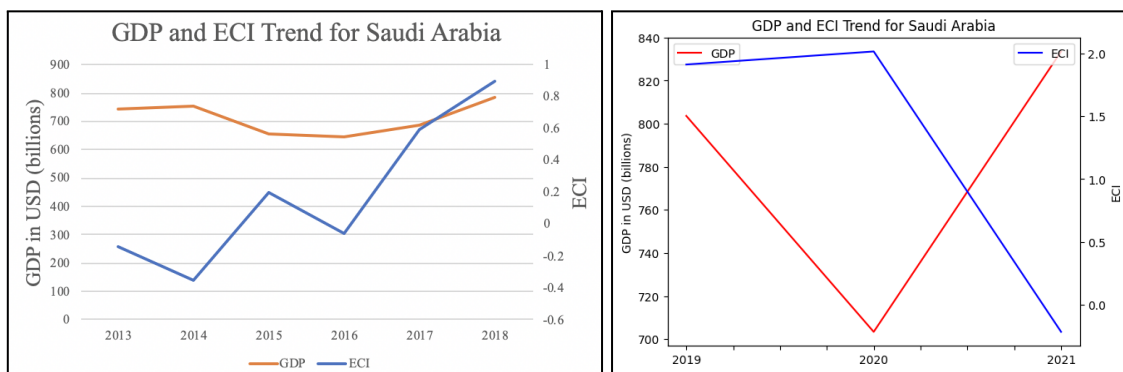
As shown, Saudi Arabia exhibits a steady increase in production capability from 2013 to 2018, as measured by ECI. This is in direct contrast to countries such as Mexico, which demonstrates more variable performance in terms of the ECI index.

The comparable countries maintain a small change in ECI level between 2019 and 2020, with a sharp change between 2020 and 2021. Saudi Arabia exhibits a large decrease in production capability in 2021 to levels not seen prior, with disruptions due to the pandemic being one of the primary reasons. Saudi Arabia has seen a 111% decrease in its ECI, which is more negative than Colombia's increase (180%) and the UAE's increase (207%), but milder than Tunisia's decrease (180%).



Figures 2a and 2b. ECI Comparison Among Peer Countries (left: 2013-2018; right: 2019-2021)

Figures 3a and 3b offer a further comparison of GDP Growth and ECI over the time span from 2013 to 2021 for Saudi Arabia. In contrast to the GDP slump and recovery from 2013 to 2018 during which the ECI increased, the slump and recovery in GDP from 2019 to 2021 was accompanied by a decrease in ECI. The results show that the economic growth experienced by Saudi Arabia during the period from 2013 to 2018 is only partially consistent with the predictions by ECI and that Saudi Arabia made weak progress towards effectively developing a competitive product space that helps to accumulate complicated knowledge and technology. For the period 2019 to 2021, the ECI did not follow GDP trends, which may potentially be attributed to Saudi Arabia's exports being not closely aligned with its domestic production. In order to provide a more concrete answer to why this has happened, we will dive into an analysis of Saudi Arabia's production structure and its product space designs in the next few sections.



Figures 3a and 3b. GDP Growth and ECI for Saudi Arabia (left: 2013-2018; right: 2019-2021)

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 labeled from 010000-999999, with the first two digits representing a general category to which the product belongs. Based on the 99 categories extracted from the label, we further group the products into the 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 technological 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. Tables 2a and 2b 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

Table 2a. 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

Table 2b. OLS Regression Results of GDP against Volume of Percentage Exports

3.2 Realized Industry Development

Based on the aforementioned product categorization, we aim to capture Saudi Arabia's realized industry production strategy between 2013 and 2021 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 of 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 the RID of Saudi Arabia and the 18 product groups in 2021 and 2018 through the difference, where a positive RID indicates a shortening of the distance (i.e., advancement of the industry), and a negative RID indicates the reverse. Notably, the number of industries with positive RID has decreased from 11 to 7 from 2018 to 2021.

Category	RID (2021)	RID (2018)
Daily Instruments	-0.001	-0.008
Chemicals	-0.009	0.012
Weapons	0.013	-0.003
Wood Products	-0.015	0.005
Transportation	-0.041	-0.001
Machinery and Construction	-0.012	-0.019
Metals	0.026	0.023
Raw Manufacturing	0.011	0.016
Services and Utilities	0.001	0.051
Clothing and Accessories	-0.006	0.013
Chemical Manufacturing	0.000	0.018
Food and Preparations	0.006	0.018
Textile	0.017	-0.013
High-complexity Products	-0.070	0.005
Vegetables, Fruits and Plants	-0.002	0.020
Animals and By-products	-0.008	0.010
Energy Drilling and Mining	-0.020	-0.007
Precious Stones	0.018	0.000

Table 3. Realized Industry Development (RID) of Saudi Arabia

3.3 Regional and Global Comparison

Tables 4a-4b below summarize how the production strategy adopted by Saudi Arabia compares with selected leading economies in the world across different years, as measured in RID. Leading economies such as France, the United States and Germany gave a considerable level of attention to more advanced product groups such as Weapons and High-Complexity Products in 2018 and Services and Utilities, Precious Stones, and High-Complexity Products in 2021.

Ranking	France	the UK	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 4a. RID Comparison across Leading Economies (2018)

Ranking	France	the UK	Germany
1	Services and Utilities	Precious Stones	Daily Instruments
2	Precious Stones	High-complexity Products	Transportation
3	High-complexity Products	Services and Utilities	Chemicals
4	Energy Drilling and Mining	Energy Drilling and Mining	Chemical Manufacturing
5	Machinery and Construction	Wood Products	Clothing and Accessories

Table 4b. RID Comparison across Leading Economies (2021)

Tables 4c-4d further examine Saudi Arabia's development strategy against those of emerging economies on a global scale. Reasonably, emerging economies such as China, South Korea, and Singapore, have devoted the majority of their efforts to intermediate industry groups, showing drastic shifts in strategies over the course of three years.

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 4c. RID Comparison across Emerging Economies (2018)

Ranking	China	South Korea	Singapore
1	Chemicals	Chemicals	Weapons
2	Daily Instruments	Daily Instruments	Energy Drilling and Mining
3	Transportation	Transportation	Transportation
4	Raw Manufacturing	Textile	Machinery and Construction
5	Weapons	Raw Manufacturing	High-complexity Products

Table 4d. RID Comparison across Emerging Economies (2021)

4. Product Space Design

4.1 Suggested Development Vector

As outlined above, 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 of the product as compared to the 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. An unreasonable investment in a certain product p would lead to a relative decrement in the 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 economic strength, those having higher ECI, or in other words, more reasonable economic structures are often in better shape.

Ranking	Saudi Arabia	Turkey	United Arab Emirates
1	Machinery and Construction	Energy Drilling and Mining	High-complexity Products
2	High-complexity Products	Machinery and Construction	Transportation
3	Transportation	High-complexity Products	Machinery and Construction
4	Services and Utilities	Animals and By-products	Daily Instruments
5	Daily Instruments	Services and Utilities	Chemicals
6	Weapons	Weapons	Weapons
7	Chemical Manufacturing	Daily Instruments	Textile
8	Textile	Transportation	Chemical Manufacturing
9	Energy Drilling and Mining	Chemical Manufacturing	Raw Manufacturing
10	Chemicals	Chemicals	Energy Drilling and Mining
11	Raw Manufacturing	Vegetables, Fruits and Plants	Precious Stones
12	Metals	Food and Preparations	Services and Utilities
13	Wood Products	Raw Manufacturing	Metals
14	Animals and By-products	Wood Products	Clothing and Accessories
15	Clothing and Accessories	Clothing and Accessories	Wood Products
16	Precious Stones	Textile	Animals and By-products
17	Vegetables, Fruits and Plants	Metals	Vegetables, Fruits and Plants
18	Food and Preparations	Precious Stones	Food and Preparations
ECI	-0.114986575	-0.314199878	-0.734459148

Table 5a. Opportunity Gain Ranking on a Comparable Scale (2013)

Ranking	Saudi Arabia	Turkey	United Arab Emirates
1	High-complexity Products	High-complexity Products	High-complexity Products
2	Transportation	Energy Drilling and Mining	Transportation
3	Machinery and Construction	Transportation	Machinery and Construction
4	Daily Instruments	Machinery and Construction	Daily Instruments
5	Weapons	Animals and By-products	Chemicals
6	Textile	Weapons	Weapons
7	Chemicals	Services and Utilities	Textile
8	Raw Manufacturing	Daily Instruments	Chemical Manufacturing
9	Services and Utilities	Chemicals	Raw Manufacturing
10	Chemical Manufacturing	Chemical Manufacturing	Energy Drilling and Mining
11	Clothing and Accessories	Vegetables, Fruits and Plants	Precious Stones
12	Metals	Food and Preparations	Services and Utilities
13	Precious Stones	Raw Manufacturing	Clothing and Accessories
14	Wood Products	Wood Products	Metals
15	Animals and By-products	Clothing and Accessories	Wood Products
16	Energy Drilling and Mining	Textile	Animals and By-products
17	Food and Preparations	Metals	Food and Preparations
18	Vegetables, Fruits and Plants	Precious Stones	Vegetables, Fruits and Plants
ECI	0.785777571	-0.468281415	-0.490703037

Table 5b. Opportunity Gain Ranking on a Comparable Scale (2018)

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

Table 5c. Opportunity Gain Ranking on a Comparable Scale (2021)

We define the ranking of opportunity gain for a country c , as the Suggested Development Vector (SDV) of c . Tables 5a-5c summarize how the SDV of Saudi Arabia compares with a selected group of comparable economies in the world, with the industry groups ranked in decreasing order of significance. We focus on SDV results for 2018 because they give the most accurate snapshot of complexity for global comparison in the absence of the irregular effects of the COVID-19 pandemic observed in 2021.

Dark blue indicates positive opportunity gains, light blue indicates zero opportunity gains, and white indicates negative opportunity gains. The result shows that comparable countries

have moderate numbers of industries with positive opportunity gain. In other words, those countries are already in the most stable and efficient economic structure. Without the necessity of economic transition, those countries merely need to maintain a steady and balanced economic development. In contrast, developing countries have nearly half of industries with positive opportunity gain and share common interests in daily instruments and chemical manufacturing industries. It can be concluded that Saudi Arabia shares the characteristics of developing countries, with a balanced economic structure that leans towards intermediate-level industries.

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:

$$\begin{aligned}
 & \text{Max}_{x \in \mathbf{R}^{|P|}} \left(\frac{k(x) - \langle k(x) \rangle}{stdev(k(x))} \right) C \\
 & \text{Subject to} \\
 & \sum_{p \in P} x_p \leq B \\
 & x \succcurlyeq 0
 \end{aligned}$$

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

If we can solve this problem, then we can know what the largest ECI to which a country can improve. 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 to this problem. In

order to solve this problem, our idea is to use a greedy algorithm. The way that we apply the 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 equal rest parts can be done in the same way.

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

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

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

In this way, we can obtain a further sighted greedy algorithm. Also, the number of parts that we would like to separate the budget into also matters. In order to solve this problem, we added a stabilizer on top of the enhanced greedy algorithm by running the algorithm for different numbers of parts and selecting the portfolio with the largest ECI increment and most complex economic structure.

Besides, it is quite common that there is a surplus in the budget. To deal with the surplus, we just add it to the product which needs the least amount of dollars 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. First, 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. Each category in the chart has a determined percentage of the allocated budget. The lines below the pie charts show how the ECI changes during the searching process of the greedy algorithm. Even though sometimes an increase of the export by 15% or 20% does not seem reasonable 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.

Interpretation

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

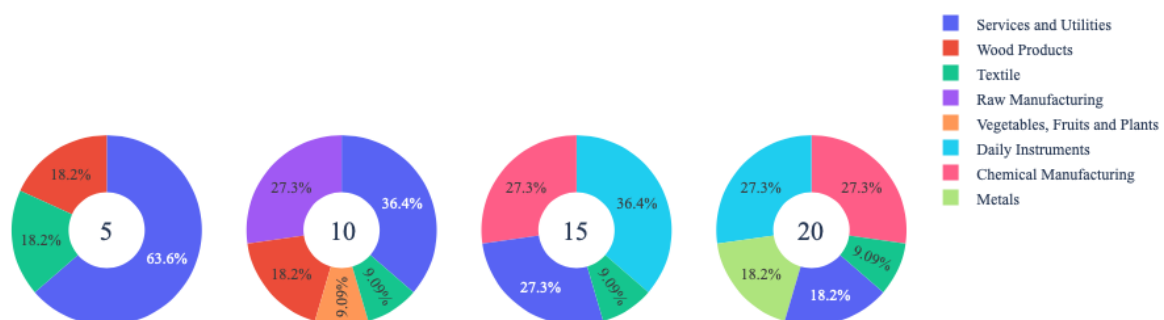
Label	Product Names
1	Animal and By-products
2	Vegetables, Fruits and Plants
3	Food and Preparations
4	Energy Drilling and Mining
5	Chemicals
6	Chemical Manufacturing
7	Raw Manufacturing
8	Wood Products
9	Clothing and Accessories
10	Textile
11	Metals
12	Machinery and Construction
13	Transportation
14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

Table 7. Products Labeling

Figures 4a-4c show an economic panel for Saudi Arabia in 2013, 2018, and 2021. We can see that for different percentages of heuristic total export growth, the ECIs of Saudi Arabia actually have different increments.

For 2013, in the case of 5 percent export growth, Services and Utilities is one of the main components. With a budget of 10 percent export growth, Services and Utilities and Raw Manufacturing account for most of the portfolio. Overall, development trajectories follow a similar pattern, mainly consisting of manufacturing and services and utilities. Similar to other countries with emerging economies, Saudi Arabia has a moderately dense solution, which can be attributed to its developing economic structure that has room for further growth and expansion. A more detailed numerical representation of the portfolio is shown in Table 8a.

Saudi Arabia ECI Growth Optimization Result



Saudi Arabia ECI Increment

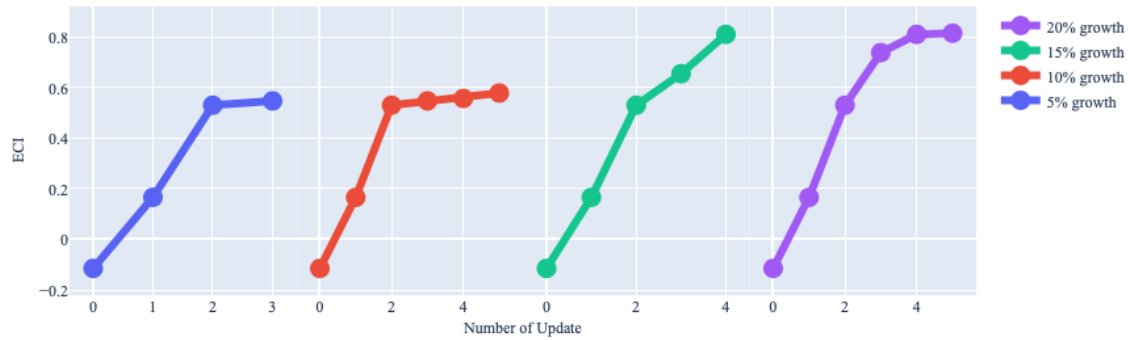


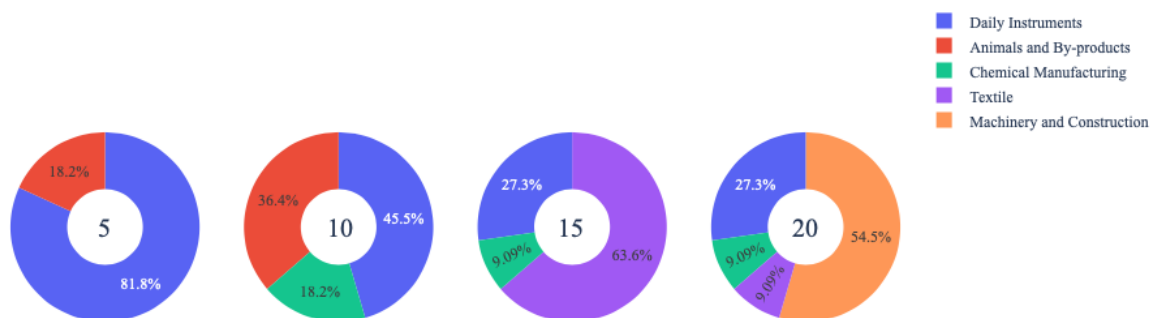
Figure 4a. Greedy-Based ECI Improvement Results of Saudi Arabia with Different Budgets (2013)

Saudi Arabia (2013)				
Total Export in 2013 (US. \$)	3.99E+11			
Original ECI	- 0.115			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. \$)	1.99E+10	3.99E+10	5.98E+10	7.98E+10
Metals(US. \$)	0.00E+00	0.00E+00	0.00E+00	1.45E+10
Chemical Manufacturing(US. \$)	0.00E+00	0.00E+00	1.63E+10	2.18E+10
Daily Instruments(US. \$)	0.00E+00	0.00E+00	2.18E+10	2.18E+10
Raw Manufacturing(US. \$)	0.00E+00	1.09E+10	0.00E+00	0.00E+00
Textile(US. \$)	3.63E+09	3.63E+09	5.44E+09	7.25E+09
Services and Utilities (US. \$)	1.27E+10	1.45E+10	1.63E+10	1.45E+10
Wood Products(US. \$)	3.63E+09	7.25E+09	0.00E+00	0.00E+00
Vegetables, Fruits and Plants(US. \$)	0.00E+00	3.63E+09	0.00E+00	0.00E+00
Increased ECI	0.547	0.579	0.811	0.815

Table 8a. Portfolio of Saudi Arabia (2013)

For further suggestions on Saudi Arabia's development in the future, we also offer the optimization result based on its export data in 2018. Below is the economic panel for Saudi Arabia in 2018. It is evident that Saudi Arabia's ECI follows a similar growth pattern to 2013 for various heuristic percentages of total export growth insofar as higher budgets result in greater ECIs. In the case of all export growth levels, Daily Instruments are a main component; therefore, for future strategy, Saudi Arabia should prioritize Daily Instruments first. A more detailed numerical representation of the portfolio is shown in Table 8b.

Saudi Arabia ECI Growth Optimization Result



Saudi Arabia ECI Increment

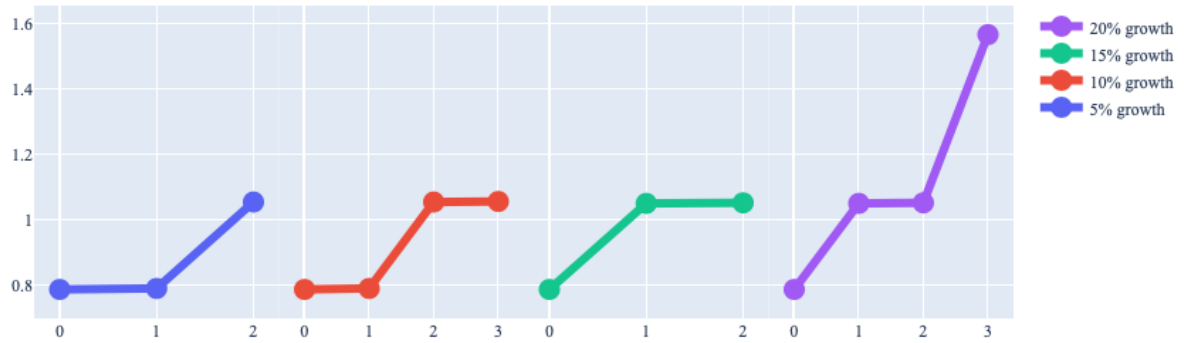
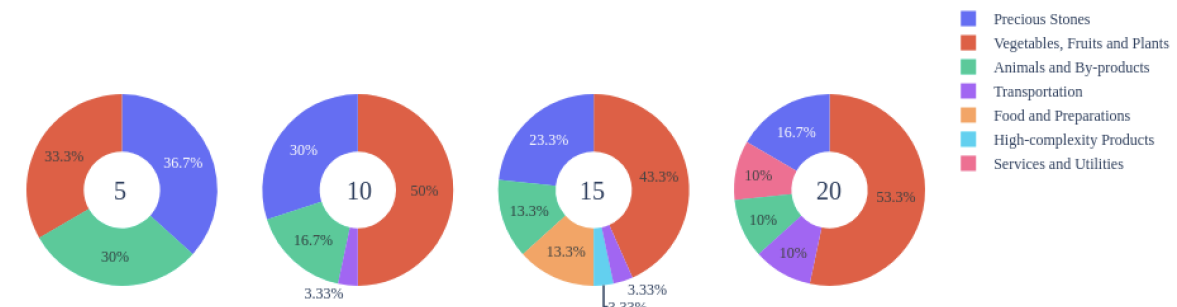


Figure 4b. Greedy-Based ECI Improvement Results of Saudi Arabia with Different Budgets (2018)

Saudi Arabia (2018)				
Total Export in 2018 (US. \$)	3.20E+11			
Original ECI	0.79			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. \$)	1.60E+10	3.20E+10	4.80E+10	6.40E+10
Animals and Byproducts (US. \$)	2.91E+09	1.16E+10	0.00E+00	0.00E+00
Chemical Manufacturing (US. \$)	0.00E+00	5.82E+09	4.37E+09	5.82E+09
Textile (US. \$)	0.00E+00	0.00E+00	3.06E+10	5.82E+09
Machinery and Construction (US. \$)	0.00E+00	0.00E+00	0.00E+00	3.49E+10
Daily Instruments (US. \$)	1.31E+10	1.46E+10	1.31E+10	1.75E+10
Increased ECI	1.05	1.06	1.05	1.57

Table 8b. Portfolio of Saudi Arabia (2018)

To compare with the performance in 2013 and 2018, we also re-examine suggested strategies for 2021. For 2021, a 5 percent increase in export would emphasize Precious Stones, followed by Vegetables, Fruits, and Plants, Animals and By-products, and Services and Utilities for 10, 15, and 20 percent export growth respectively. These strategies are consistent with the suggested trajectories based on ECI. It is noteworthy that the proposed economic reaction after the pandemic involves significant investment in sectors with lower complexity. This can be construed as a requirement to strengthen the basic industries due to the disturbances in the global trade and supply chain. Furthermore, these indicators reflect the efforts to diversify Saudi Arabia's economy and move away from reliance on oil exports. By focusing on other sectors such as agriculture and services, Saudi Arabia can create a more sustainable and diverse economy for the future. A more detailed numerical representation of the portfolio for Saudi Arabia is shown in Table 8c.



Saudi Arabia ECI Increment

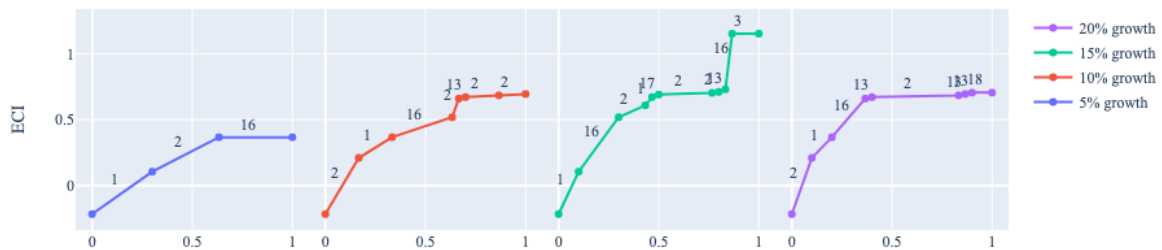


Figure 4c. Greedy-Based ECI Improvement Results of Saudi Arabia with Different Budgets (2021)

Saudi Arabia (2021)				
Original ECI	0.89			
Heuristic Export Growth	5%	10%	15%	20%
Animals and By-products	4.60E+09	1.38E+10	1.23E+10	1.33E+10
Vegetables, Fruits and Plants	5.11E+09	4.14E+10	3.98E+10	7.08E+10
Food and Preparations	0.00E+00	0.00E+00	1.23E+10	0.00E+00
Transportation	0.00E+00	2.76E+09	3.06E+09	1.33E+10
Precious Stones	5.62E+09	2.48E+10	2.15E+10	2.21E+10
High-complexity Products	0.00E+00	0.00E+00	3.06E+09	0.00E+00
Services and Utilities	0.00E+00	0.00E+00	0.00E+00	1.33E+10
Increased ECI	0.367	0.694	1.15	0.704

Table 8c. Portfolio of Saudi Arabia (2021)

4.3 Sensitivity Analysis and Contingency Strategy

In the following section, our broad aim is to understand how sensitive Saudi Arabia 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

First, in order to assess the effect particular industries have on each respective country, we developed ECI Sensitivity graphs (Figure 5). We use the shocking methodology to increment or decrement an industry's export level by a certain percentage and recalculate the ECI, all else being equal. While freezing the export dynamics of the rest of the world and enacting an instantaneous shock in export for a particular industry and country may not reflect real-life dynamics, what it does offer us is an understanding of a country's level of dependency on an industry in the context of ECI. The shocking is done in small percentage increments in order to smooth out the resulting curve. Additionally, a recurring theme one will see is that for most industries, a breaking point occurs where the ECI either jumps upwards or downwards, creating a hockey stick shape rather than a linear trend. While the inflection point may not be accurate in the context of real life, comparing the various inflection points across industries can give us valuable insight.

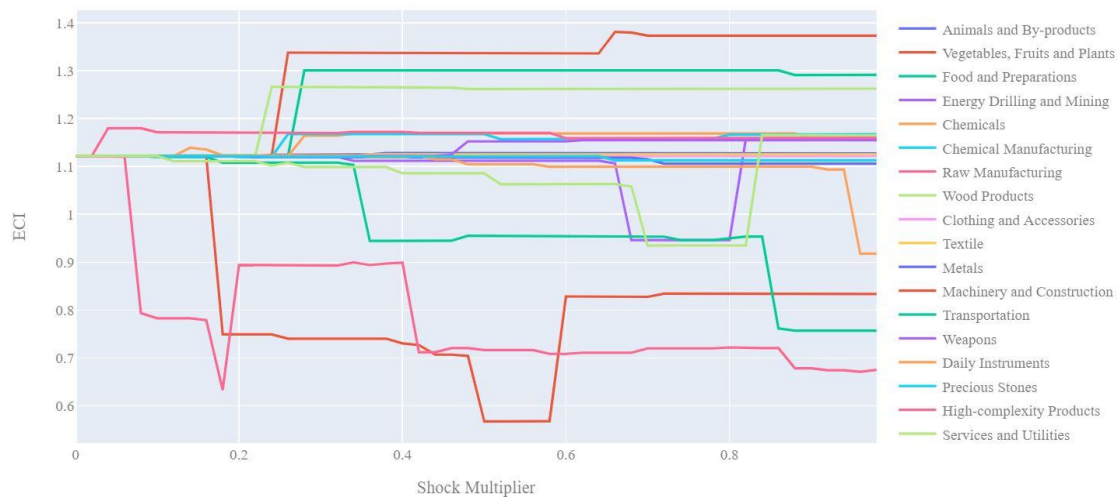


Figure 5. Sample ECI Sensitivity Graph (2018)

The graphs are formulated as follows. There are six ECI Sensitivity graphs, two for each of the following years: 2021, 2018, and 2013. The first chart, Incremental ECI Sensitivity, 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, Decremental ECI Sensitivity, follows the same format except the X-axis represents negative shock. In other words, exports for each industry are decremented, and the ECI is accordingly recomputed.

Contingency Plan

The Contingency Plan aims to present a set of solutions concerning 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 a 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 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 mean that the country doesn't even need to respond to a collapse in the industry. Countries tend to have distinct solutions to the ups and downs 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.

Product Names	0	1	2
Animal 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 Constructions	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
Daily Instruments	Services and Utilities	Daily Instruments	Weapons
Services and Utilities	Daily Instruments	Weapons	Transportation

Table 10. Sample Contingency Strategy (2019)

SDV Sensitivity

4.3 Sensitivity Analysis Results and Interpretation

We examine Saudi Arabia's ECI Decremental and Incremental Sensitivity Charts for 2021. An increase in Energy Drilling and Mining will lead to the highest change in ECI, followed by Chemical Manufacturing and Daily Instruments. The strong sensitivity effect of manipulating the Daily Instruments category remains consistent with previous years. For the negative shock cases, Chemicals becomes most impactful, a new trend across the data emerging from the previous years. The rest of the industries do not appear to have the same level of sensitivity.

Saudi Arabia (Positive Shocking)

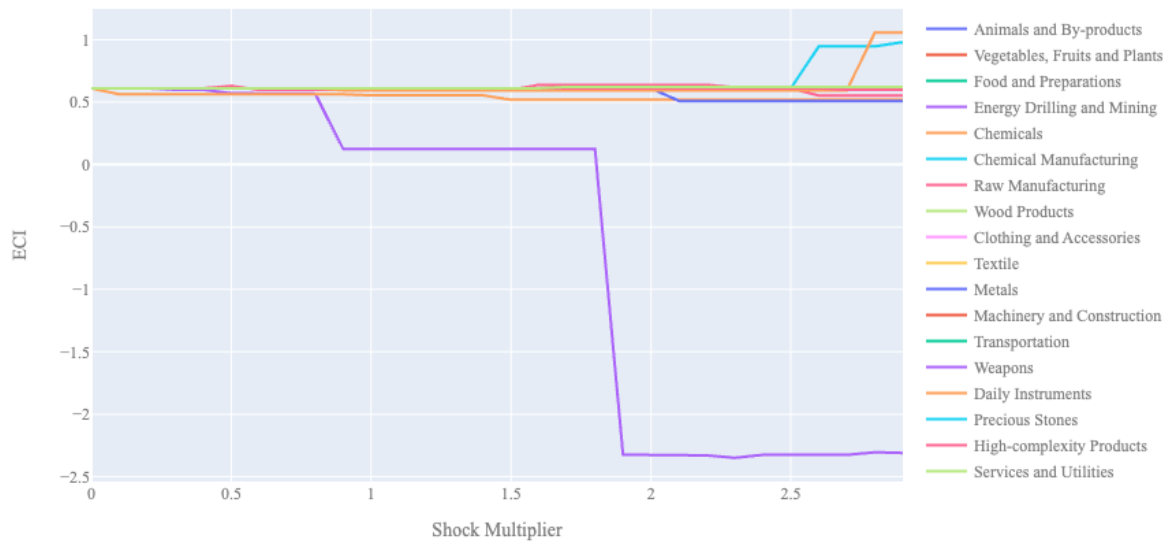


Figure 6a. Incremental ECI Sensitivity for Saudi Arabia (2021)

Saudi Arabia (Negative Shocking)

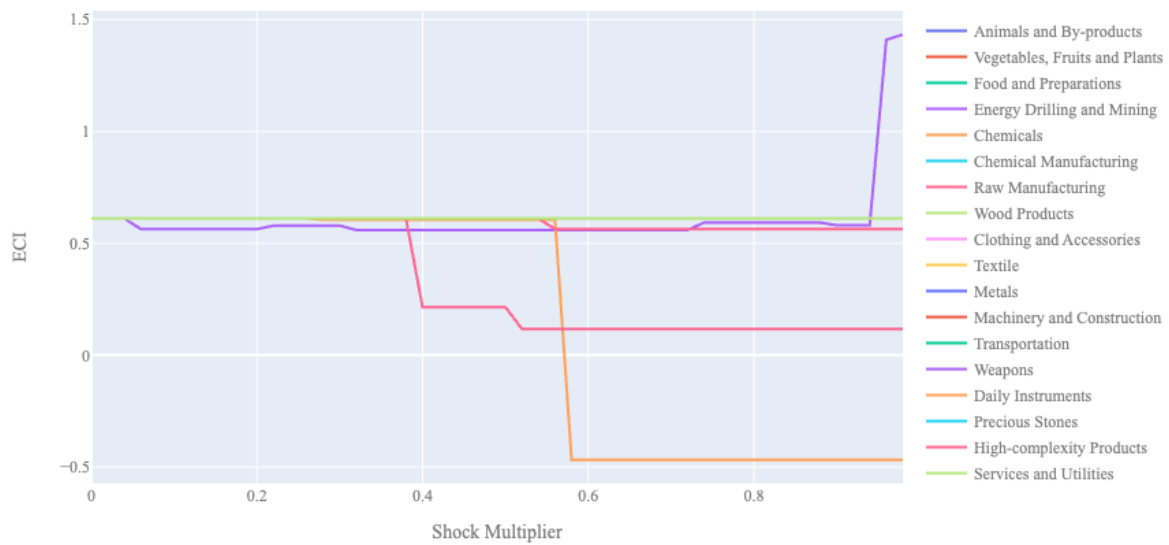


Figure 6b. Decremental ECI Sensitivity for Saudi Arabia (2021)

The ECI Sensitivity Charts for Saudi Arabia in 2018 are presented below. Notably, the positive chart indicates that increasing exports in any industry does not necessarily lead to gains in ECI. Moreover, we observe that an increase in the export of Services and Utilities is associated with a significant decrease in ECI. Therefore, in the best-case scenario, Saudi Arabia would not aim to expand this industry.

Next, we consider Saudi Arabia's 2018 Negative Shock chart. We can see that decreasing exports in Services and Utilities seem to result in large ECI gains, while drawbacks in High-complexity Products lead to significant ECI losses. Saudi Arabia is fairly insensitive to the majority of the other industries.

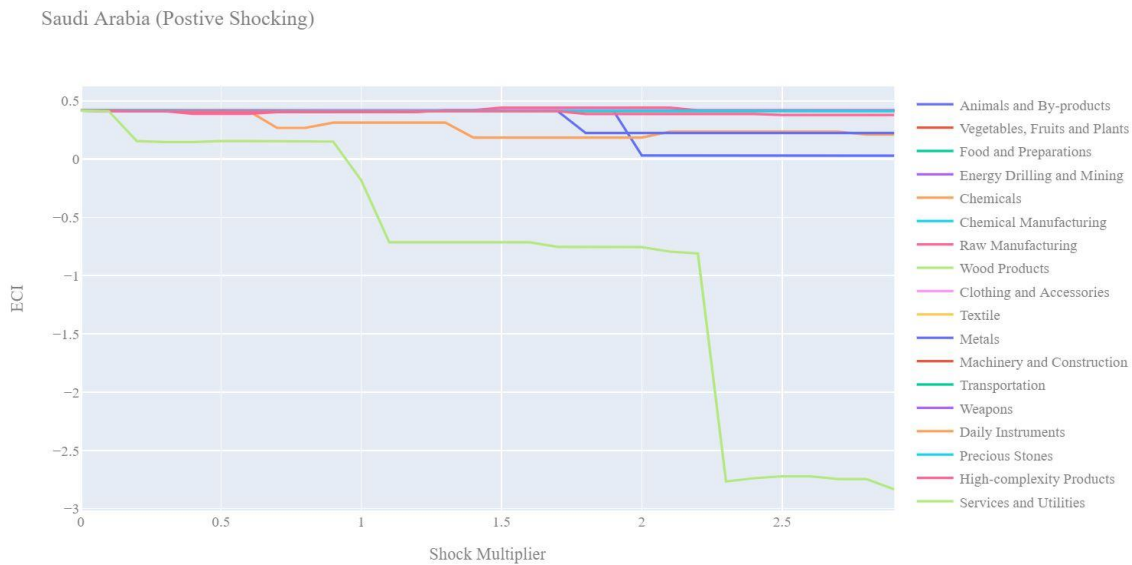


Figure 7a. Incremental ECI Sensitivity for Saudi Arabia (2018)

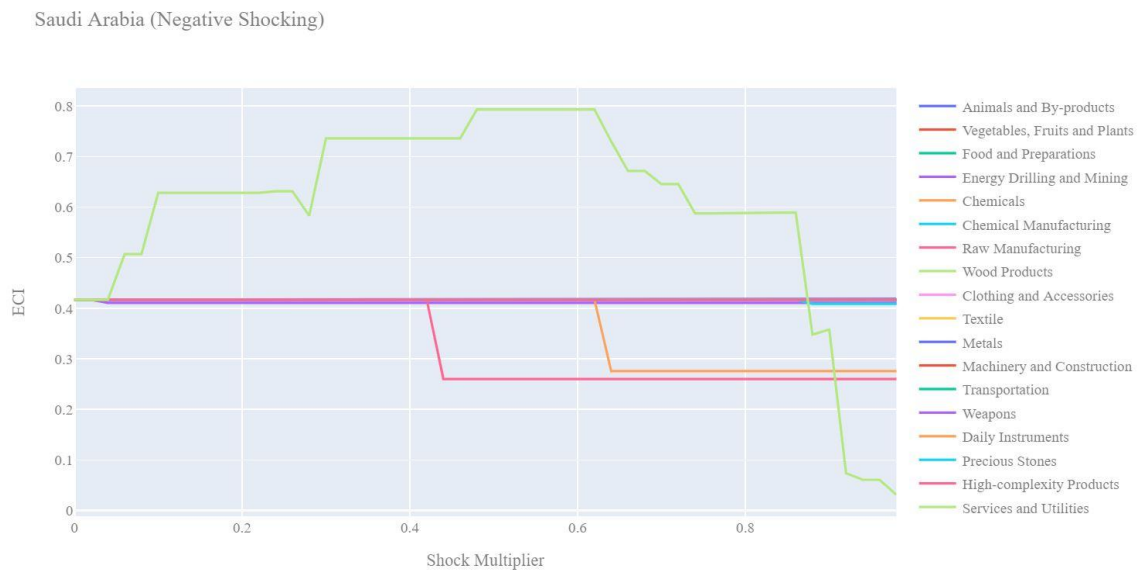


Figure 7b. Decremental ECI Sensitivity for Saudi Arabia (2018)

Moving on to the 2013 ECI Sensitivity charts, we can observe that a positive shock to the export of any industry did not lead to an increase in ECI gains, similar to the 2018 case. However, in contrast to 2018, Saudi Arabia showed high sensitivity to the Energy and Drilling Industry, rather than Services and Utilities.

In the 2013 negative shocking case, Saudi Arabia was less sensitive to Services and Utilities but highly sensitive to drawdowns in Raw Manufacturing and Chemicals. Even a small 10% drawdown in Raw Manufacturing could cause a significant decline in ECI, while Chemicals

would need around a 50% drawdown to see the same effect.

Saudi Arabia (Postive Shocking)

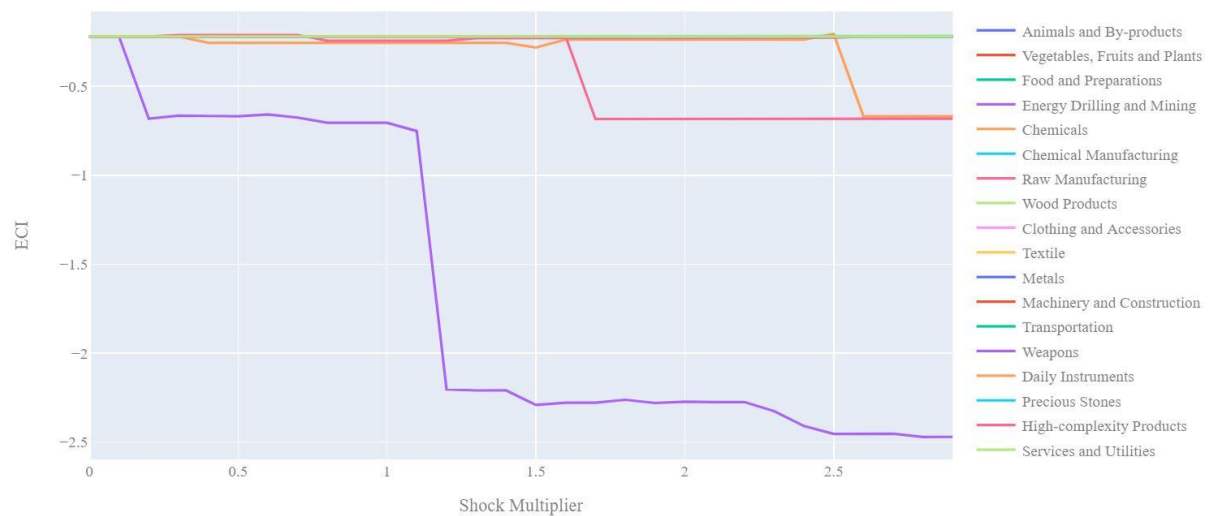


Figure 8a. Incremental ECI Sensitivity for Saudi Arabia (2013)

Saudi Arabia (Negative Shocking)

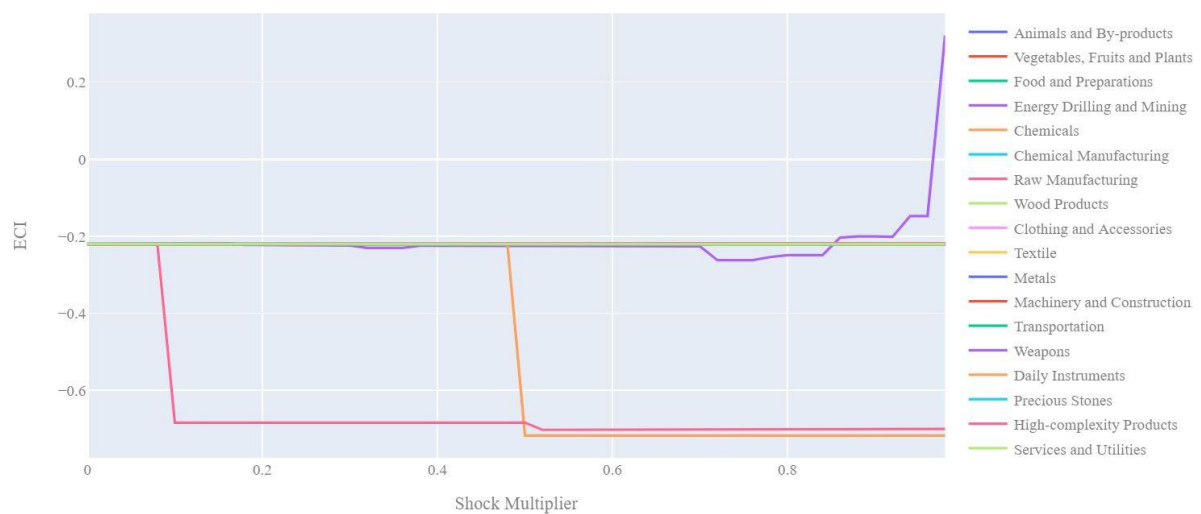


Figure 8b. Decremental ECI Sensitivity for Saudi Arabia (2013)

4.4 Contingency Strategy

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

Product Names	0	1	2
Animal and By-products	High-complexity Products	Transportation	Services and Utilities
Vegetables, Fruits and Plants	High-complexity Products	Transportation	Services and Utilities
Food and Preparations	High-complexity Products	Transportation	Services and Utilities

Energy Drilling and Mining	High-complexity Products	Transportation	Services and Utilities
Chemicals	High-complexity Products	Transportation	Chemicals
Chemical Manufacturing	High-complexity Products	Transportation	Services and Utilities
Raw Manufacturing	High-complexity Products	Transportation	Services and Utilities
Wood Products	High-complexity Products	Transportation	Services and Utilities
Clothing and Accessories	High-complexity Products	Transportation	Services and Utilities
Textile	High-complexity Products	Transportation	Services and Utilities
Metals	High-complexity Products	Transportation	Services and Utilities
Machinery and Construction	High-complexity Products	Transportation	Services and Utilities
Transportation	High-complexity Products	Transportation	Services and Utilities
Weapons	High-complexity Products	Transportation	Services and Utilities
Daily Instruments	High-complexity Products	Transportation	Services and Utilities
Precious Stones	High-complexity Products	Transportation	Services and Utilities
High-complexity Products	High-complexity Products	Services and Utilities	Transportation
Services and Utilities	High-complexity Products	Transportation	Services and Utilities

Table 11. Saudi Arabia's Contingency Strategy (2018)

5. Macro-level Predictions

5.1 Structural Optimality Index

ECI sensitivity described in the section before 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 increasing export 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 9 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 14: 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

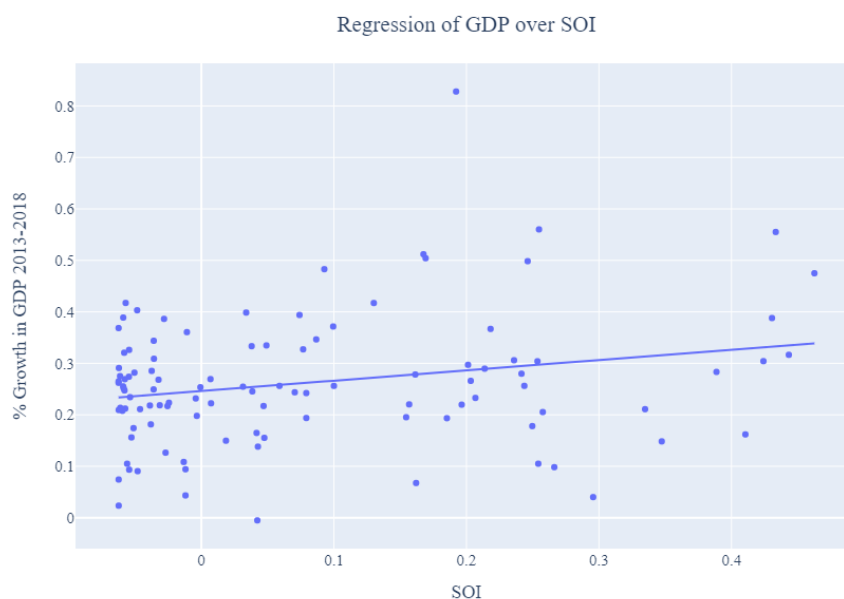


Figure 9. Regression of Five-Year GDP Growth over SOI (2013-2018)

5.2 SOI of Saudi Arabia and Its Implications

Saudi Arabia, for instance, has a low level of structural optimality as compared with its developed peers. As the regression in Figure 10a suggests (the red curve represents export increase and the blue curve stands for opportunity gain of the corresponding industry), Saudi Arabia demonstrates a low level of correlation with the suggested developmental path, having an adjusted R-square of around -5.9%. Saudi Arabia ranks in the 102th place among all countries in terms of SOI and has a 5-year GDP growth rate of 7.5% from 2013 to 2018, which is faster than the prediction by regression result in Figure 6 and thus may not be sustainable in the long run. This is in direct contrast to emerging economies such as Turkey, where there is high SOI of around 21.8% and corresponding GDP growth of 36.7% from 2013 to 2018, making it one of the fastest-developing economies during the period. In sum, Saudi Arabia's slow 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, Saudi Arabia invested heavily in the Services and Utilities industry, while it invested little in most other industries.

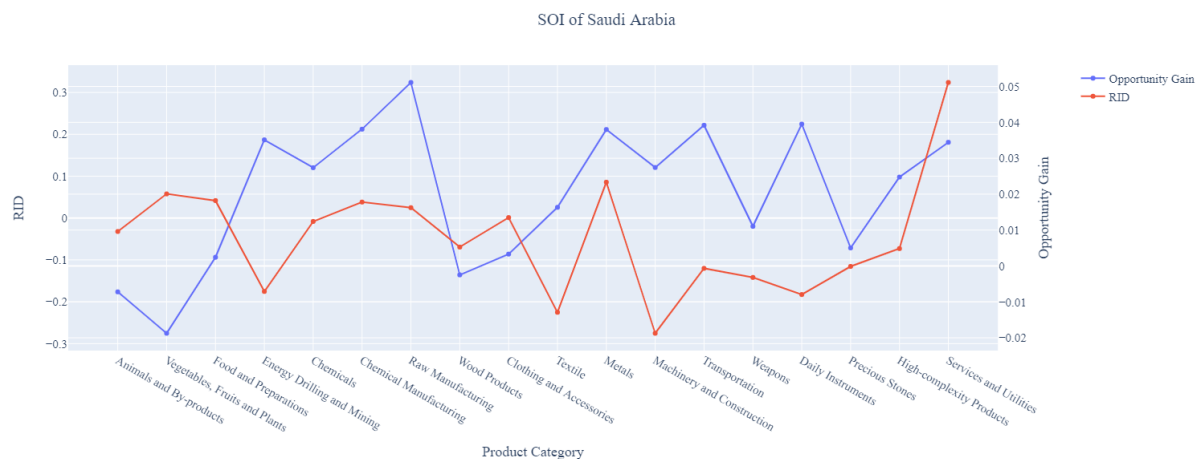


Figure 10a. SOI of Saudi Arabia (2013-2018)

For the 2019-2021 years, Saudi Arabia has a strong presence in the Metals and Precious Stones industries, which seem to be overdeveloped when considering their lower opportunity gain relative to RID. It also could consider Energy Drilling and Mining to improve its growth. Saudi Arabia has seen a growth in GDP over those three years of 3.7%, compared to 7.5% for the five years prior.

Higher than before, its adjusted R-squared value of 21.4% now indicates a higher correlation between the GDP growth and the implemented development path. Progress is slow on a global scale during this period, but Saudi Arabia demonstrates a moderately improved ability to adjust to negative economic shocks by improving SOI and increasing GDP growth than it did between 2013 and 2018.

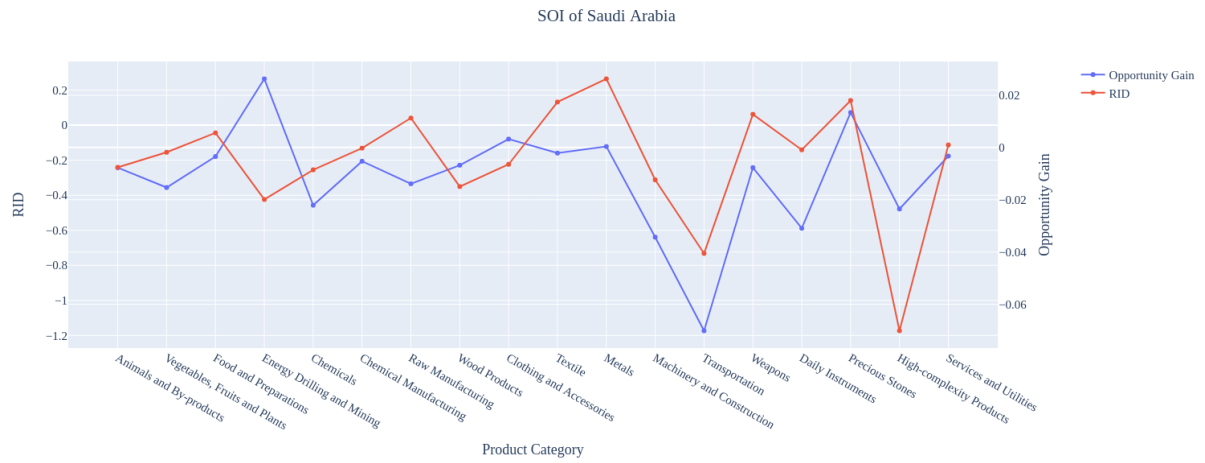


Figure 10b. SOI of Saudi Arabia (2019-2021)

6. Concluding Remarks

In conclusion, Saudi Arabia has demonstrated a low level of economic growth in terms of annual GDP increase during the period from 2013 to 2018, concurrent with an increase in economic complexity as compared with other major developed economies. For 2019-2021, the growth in GDP has slowed alongside a decrease in ECI, contrasting with some of its comparable countries.

We believe that the lack of progress during the first period can be partially explained through the analysis of the economic and product complexity structure of Saudi Arabia 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 Saudi Arabia regressed in developing most of its industries during the period, while its developed counterparts and emerging economies around the globe adopted much more complex and progressive paths.

Based on our analysis of the opportunity gain and sensitivity analysis of major industry groups for 2013-2018, Saudi Arabia can further its gains by prioritizing Services and Utilities and Raw Manufacturing. We further note that Saudi Arabia has a mismatched development strategy that indicates a low level (compared to other emerging countries) of structural optimality on the complexity level, having an adjusted R-square of around -5.9%. Since a negative correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, Saudi Arabia 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.

During the second examined period from 2019 to 2021, Saudi Arabia performed much similarly to before and compared to other countries, particularly Mexico. We infer that during the COVID-19 period, Saudi Arabia focused on developing higher complexity industries despite a lower demand for these industries given the global economic downturn/lower complexity industries, in line with lower demand for these industries given the global economic downturn. We also note that Saudi Arabia has increased its investment in the sectors identified earlier, leading to a strong boost from Metals and Precious Stones industries, leaving some room for strategic improvement. The ECI suggests that greater growth could have been achieved through Services and Utilities. The surprising growth also increased the adjusted R-squared value to 21.4% in 2021 from -5.9% in 2018, demonstrating the pursued strategies contributed to the GDP. With the revised focus, Saudi Arabia has further potential to advance its economic growth to maintain its position among other countries to continue its ongoing economic expansion.

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