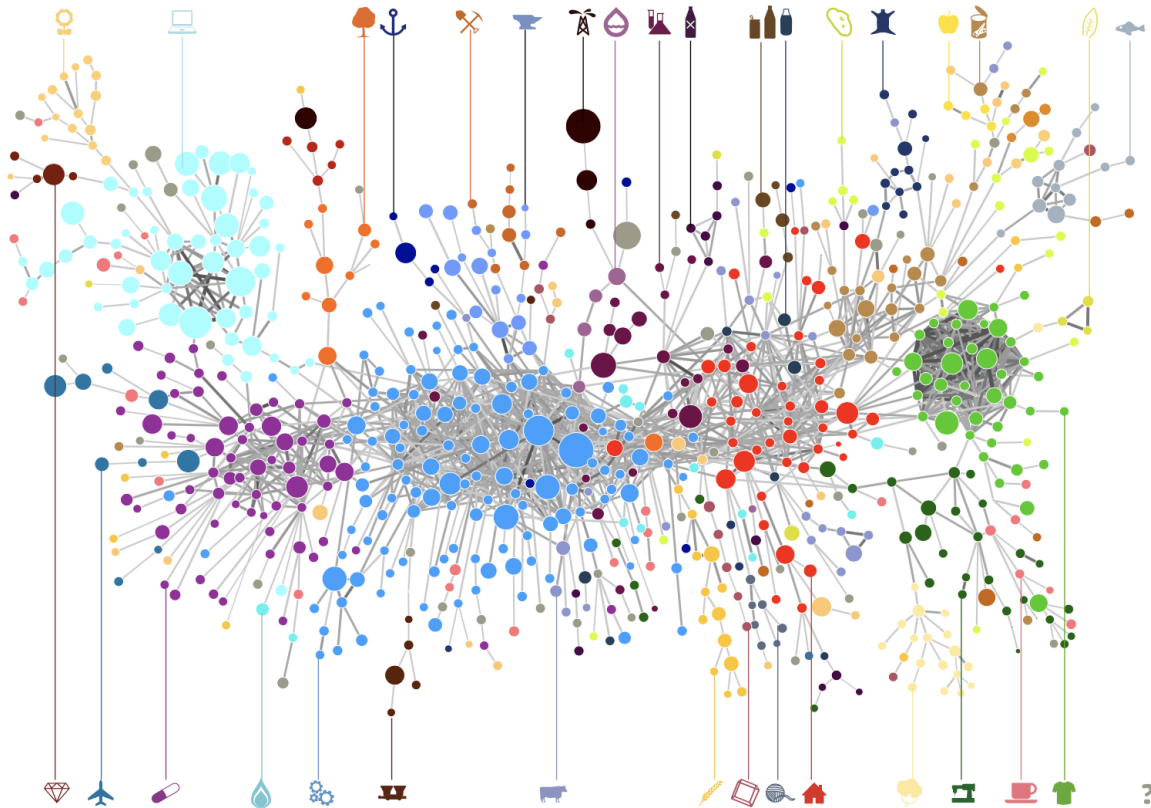




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Optimal Industry Development Strategy Using Economic and Product Complexity

Poland

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Optimal Industry Development Strategy for Poland

0. Executive Summary

In this report, we aim to uncover the economic path Poland went through during the period from 2013 to 2018. Specifically, we dive into the topic through a macroeconomic overview of Poland 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, Poland demonstrated a low level of economic growth with an annual GDP growth rate of 3%, concurrent with a decrease in economic complexity as compared with other major economies in Europe.

The level of economic progress during the period, we believe, can be partially explained through analysis of the economic and product complexity structure of Poland 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 Poland invested heavily in developing Animals and By-products, Chemical Manufacturing and Textiles during the period, while its emerging peers and developed economies around the globe have adopted much more complex and progressive paths.

Based on our analysis of the opportunity gain and a sensitivity analysis of major industry groups, Poland can further its gains by prioritizing Services and Utilities, and Chemicals. We further note that Poland has a slightly mismatched development strategy that indicates a moderate level of structural optimality on the complexity level, having an adjusted R-square of around 20.3%. Since a significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, Poland indeed has a suboptimal growth experience as compared with fast-growing economies both on a regional scale and on a global scale, and has the potential to further its economic gains through industrial structure optimization as suggested in the paper.

1. Report Overview

In this report, we aim to uncover the economic path Brazil went through during the period from 2013 to 2018. Specifically, we dive into the topic through a macroeconomic overview of Brazil from the perspective of Gross Domestic Product (GDP) and Economic Complexity Index (ECI), which reflect countries' production capability and production structure, respectively. We then analyze the industrial framework and changes of Brazil during the period based on quantitative measures such as Product Complexity Index (PCI) and Product Family Complexity Index (PfCI), followed by a detailed analysis of how such changes have matched with development strategies as quantitatively measured by opportunity gains on an industry-level. We conclude our report with macro-level results and predictions of Brazil, as deduced from regression models we have established on a global scale, which take into account countries' stances in their product space.

2. Macroeconomic Results

2.1 GDP Ranking and Changes

As the 21st largest economy in the world by GDP, Poland has a GDP of 524 billion USD in 2013 and 585 billion USD in 2018, exhibiting an extraordinary level of economic output. Figure 1 illustrates the time-series GDP results for world's major European economies from 1999-2018, and Poland ranks among its counterparts as a stable player. Poland exhibits a consistent level of GDP during the 6 years from 2013 to 2018, with an average annual growth rate of about 3%. This rate is clearly above the average annual growth rate of the other 4 major European economies in the world, which have a geometric average growth rate of 0.6% and an arithmetic average growth rate of 0.9%. The rapid economic growth in Poland, we believe, can be reflected through consistent ECI and PCI, and can be further explained by an optimal set of production strategies Poland adopted during the period, which we will expand at the later stage of the report.

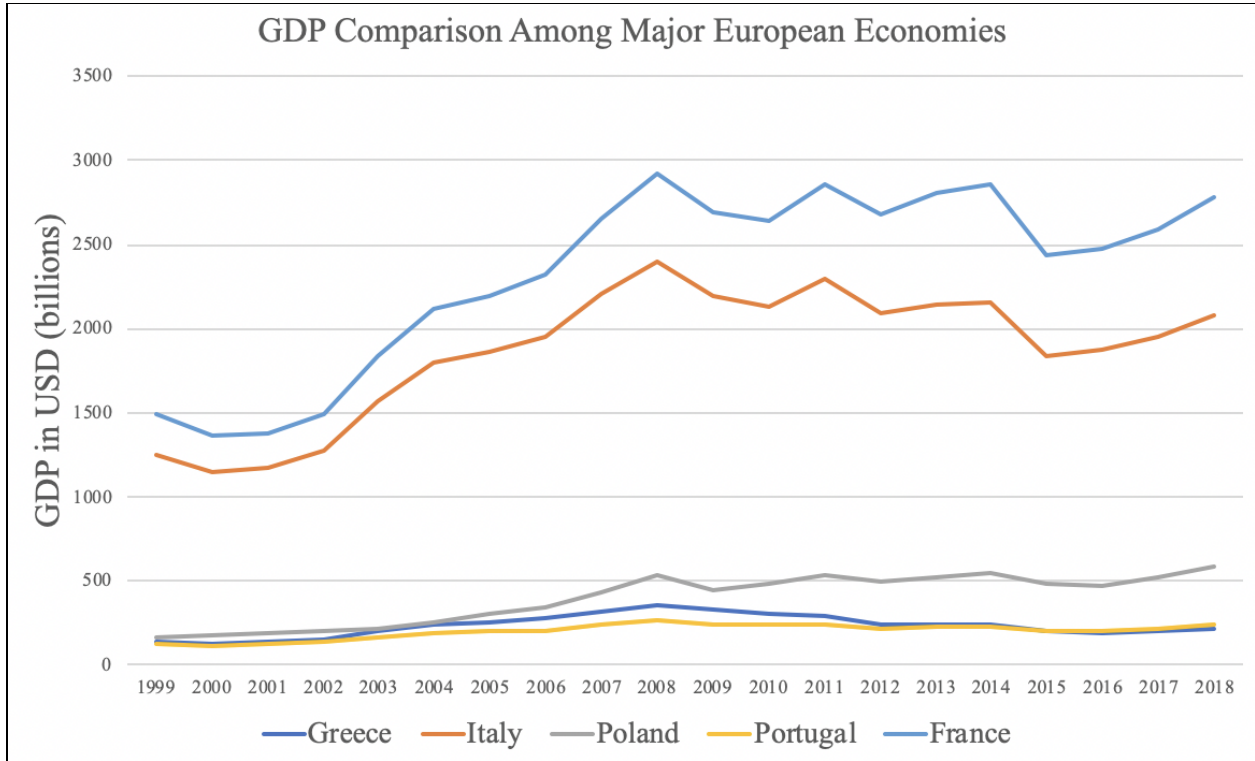


Figure 1: GDP Comparison Among Major European Economies

2.2 ECI Ranking and Changes

The Economic Complexity Index (ECI), as defined by Ricardo Hausmann and Cesar Hidalgo in 2009 to explain the knowledge accumulated in a country's population, exhibits a similar pattern for Poland. As illustrated in Figure 2 below, Poland exhibits a stably low level in terms of its production capability from 2013 to 2018. This is in direct contrast to countries such as France, which demonstrates overwhelming advantage over Poland in terms of both ECI and GDP growth during the period.

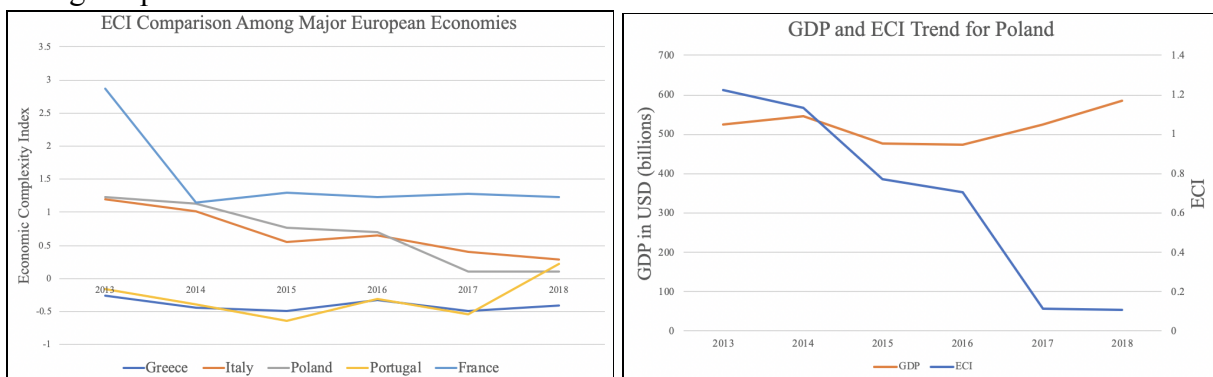


Figure 2: ECI Comparison

Figure 3: GDP and ECI (Poland)

Figure 3 offers a further comparison of GDP and ECI over the time span from 2013 to 2018 for Poland. The slight increase in GDP during this period is accompanied by a huge drop in ECI, indicating that the mild economic growth experienced by Poland during the period from 2013 to 2018 might not be attributed to its stagnant ECI, or the ineffectiveness of the country in

developing a competitive product space that helps to accumulate complicated knowledge and technology. In order to provide a more concrete answer to why this has happened, we will dive into an analysis of Poland's production structure and its product space designs in the next few chapters.

3. Production Analysis

3.1 Product Categorization

Our main data source in this research is the UN Comtrade Website (<https://comtrade.un.org>), which provides us with valuable information on countries' export values on an annual basis, including highly specific export data for more than 5000 categories of products. In order to have a holistic vision of the product space of a country, however, a level of categorization is required. Products in our data source are labelled from 010000-999999, with the first two-digits representing a general category to which the product belongs. Based on the 99 categories as extracted from the label, we further group the products into 18 most widely-accepted industries, as summarized in Table 1.

Note that the High-complexity Products industry group is not a distinct industry but rather an aggregated industry that encompasses the most complicated products from the most technologically-advanced industries (as measured by PCI). This industry serves as an indicator for us to quantitatively evaluate how well a country has performed in developing cutting-edge technologies and closing its technical gap with advanced economies, which has become a topic of wide concern today. Indeed, when we rank the 18 categories based on PfCI (an equivalent concept of PCI as calculated based on the 18 categorized product groups), the High-complexity Products industry has the highest PfCI among all industry groups.

Category	Description
Animals and By-products	All kinds of meat, livestock and related by-products
Vegetables, Fruits and Plants	All kinds of plants, edible vegetables and fruits
Food and Preparations	Edible preparations, raw cooking materials and appliances
Clothing and Accessories	All kinds of fabrics, filament, clothing and accessories
Textiles	All kinds of textile articles and related products
Wood Products	Book, paper and other elementary products related to wood
Metals	Mining of all sorts of raw Metals
Refined and Processed Stones	Refined or processed stone products such as pearl and ceramics
Energy Drilling and Mining	Mining industry for energy, minerals, stone materials, etc.
Daily Instruments	Basic daily instruments such as sport requisites, timing and measuring tools
Raw Manufacturing	Basic products made from plastic, rubber, leather, etc.
Chemical Manufacturing	Advanced chemical products and pharmaceutical products
Chemicals	Raw chemical materials and by-products
Machinery and Construction	Machinery and mechanical appliances, including electrical equipment
Transportation	Vehicles and locomotives including aircraft, ship, railway, etc.
Weapons	Explosives, arms and ammunition
Services and Utilities	Financial, business, legal, communication, travel Services and Utilities, etc.
High-complexity Products	Agglomeration of advanced products with highest PCIs

Table 1: Categorization of Products

We further observe a positive correlation between the GDP and the export of High-complexity Products. A higher adjusted R-square exists between GDP and High-complexity Products exports, indicating that more successful economics, as measured by GDP, tend to be those that are capable of producing and exporting High-complexity Products as we define them. The Figure 3 and 4 show the OLS results in a universe of 107 and 21 typical countries respectively.

	High-complexity Products	Food and Preparations	Animals and By-products
Adj.R-squared	0.075	0.006	0.002
F-statistic	9.556	1.638	1.175
No. Observations	107	107	107

Figure 3: OLS Regression Results of GDP against Percentage Volume of Exports

	High-complexity Products	Food and Preparations	Animals and By-products
Adj.R-squared	0.149	0.003	-0.012
F-statistic	4.510	1.059	0.7542
No. Observations	21	21	21

Figure 4: OLS Regression Results of GDP against Volume of Percentage Exports

3.2 Realized Industry Development

Based on the product categorization aforementioned, we aim to capture Poland'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 Poland 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, Poland has focused on products with a moderate level of complexity and those requiring intermediate skills.

Rank	Category	RID	Rank	Category	RID
1	Chemical Manufacturing	-0.094	10	High-complexity Products	-0.058
2	Textile	-0.093	11	Daily Instruments	-0.058
3	Animals and By-products	-0.081	12	Metals	-0.057
4	Weapons	-0.074	13	Energy Drilling and Mining	-0.020
5	Food and Preparations	-0.073	14	Chemicals	-0.020
6	Precious Stones	-0.073	15	Clothing and Accessories	-0.018
7	Raw Manufacturing	-0.069	16	Machinery and Construction	-0.016
8	Vegetables, Fruits and Plants	-0.066	17	Services and Utilities	-0.015
9	Wood Products	-0.062	18	Transportation	-0.009

Table 2: Realized Industry Development (RID) of Poland

3.3 Regional and Global Comparison

Table 3 and 4 below summarize how the production strategy adopted by Poland compares with leading economies and a selected group of emerging economies in the world, as measured in RID. It can be directly observed that Poland focused on products with a lower complexity level, when compared against leading economies such as the United States and Germany, which gave a considerable level of attention to more advanced product groups such as clothing, services and utilities, and chemical manufacturing.

Ranking	France	The United States	Germany
1	High-complexity Products	Services and Utilities	High-complexity Products
2	Chemical Manufacturing	Weapons	Transportation
3	Daily Instruments	Raw Manufacturing	Wood Products
4	Animals and By-products	Precious Stones	Metals
5	Food and Preparations	Animals and By-products	Food and Preparations

Table 3: RID Comparison across Leading Economies

Ranking	China	South Korea	Singapore
1	High-complexity Products	Transportation	Transportation
2	Transportation	Textile	High-complexity Products
3	Machinery and Construction	High-complexity Products	Precious Stones
4	Energy Drilling and Mining	Chemical Manufacturing	Daily Instruments
5	Daily Instruments	Machinery and Construction	Services and Utilities

Table 4: RID Comparison across Emerging Economies

Table 4 further examines Poland'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 Poland should have relied more on advanced industry groups. This trend holds true in general, regardless of the continent or the time period, and serves as an indicator for which phase of development a country is currently in as evaluated from its production strategy. Based on this standard, Poland 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 structure are often in better shape.

Ranking	Singapore	Japan	France	USA	Italy	Poland
1	Chemicals	Chemicals	Services and Utilities	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining
2	Transportation	Metals	Energy Drilling and Mining	Precious Stones	Precious Stones	Precious Stones
3	High-complexity Products	Machinery and Construction	Animals and By-products	Animals and By-products	Vegetables, Fruits and Plants	Clothing and Accessories
4	Services and Utilities	Transportation	Food and Preparations	Vegetables, Fruits and Plants	Animals and By-products	Animals and By-products
5	Machinery and Construction	Weapons	Chemical Manufacturing	Food and Preparations	Food and Preparations	Vegetables, Fruits and Plants
6	Daily Instruments	Raw Manufacturing	Raw Manufacturing	Chemicals	Chemical Manufacturing	Food and Preparations
7	Weapons	High-complexity Products	Transportation	Chemical Manufacturing	Raw Manufacturing	Raw Manufacturing
8	Textile	Services and Utilities	Weapons	Raw Manufacturing	Wood Products	Wood Products
9	Chemical Manufacturing	Precious Stones	High-complexity Products	Wood Products	Clothing and Accessories	Metals
10	Raw Manufacturing	Energy Drilling and Mining	Vegetables, Fruits and Plants	Machinery and Construction	Textile	Machinery and Construction
11	Clothing and Accessories	Textile	Precious Stones	Weapons	Metals	Transportation
12	Metals	Clothing and Accessories	Wood Products	Daily Instruments	Machinery and Construction	Daily Instruments
13	Wood Products	Chemical Manufacturing	Chemicals	High-complexity Products	Daily Instruments	High-complexity Products
14	Precious Stones	Animals and By-products	Textile	Services and Utilities	High-complexity Products	Weapons
15	Animals and By-products	Wood Products	Clothing and Accessories	Clothing and Accessories	Weapons	Textile
16	Food and Preparations	Vegetables, Fruits and Plants	Daily Instruments	Metals	Chemicals	Chemicals
17	Energy Drilling and Mining	Food and Preparations	Metals	Textile	Services and Utilities	Chemical Manufacturing
18	Vegetables, Fruits and Plants	Raw Manufacturing	Machinery and Construction	Transportation	Transportation	Services and Utilities
ECI	2.751108815	2.154947	1.294691459	1.220401303	1.179705915	1.142926

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	Clothing and Accessories	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	Animals and By-products	Animals and By-products	Wood Products	Chemical Manufacturing
14	Energy Drilling and Mining	Animals and By-products	Metals	Wood Products	Animals and By-products	Wood Products
15	Animals and By-products	Raw Manufacturing	Raw Manufacturing	Chemical Manufacturing	Metals	Animals and By-products
16	Metals	Food and Preparations	Wood Products	Food and Preparations	Chemical Manufacturing	Food and Preparations
17	Food and Preparations	Wood Products	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants	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 ECI, such as South Africa and Poland, all need to develop High-complexity Products, Machinery and Construction and Daily Instruments, those with median ECI are facing a more complicated and diverse situation, such as Italy and Spain.

It can be concluded that Poland 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:

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

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:

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

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

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

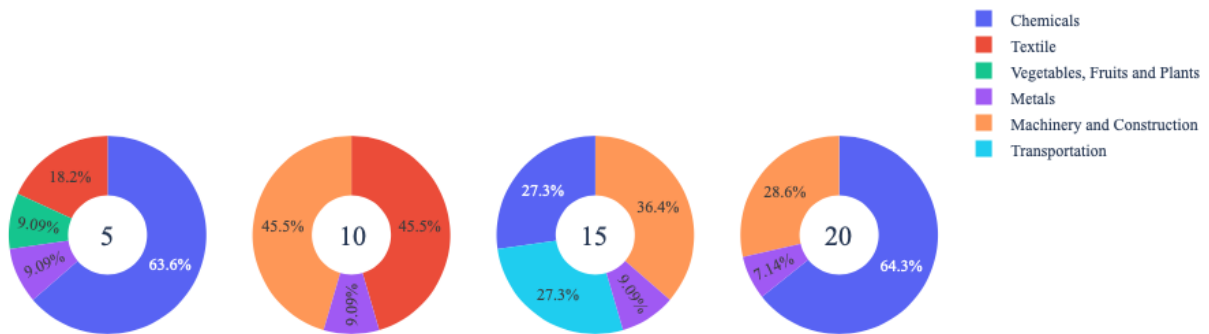
of parts and selecting the portfolio with the largest ECI increment and most complex economic structure.

Besides, it is quite common that there is a surplus for the budget. To deal with the surplus, we just add it to the product which needs the least amount of dollar to make $M_{cp} = 1$, (i.e., the smallest amount of required export increase).

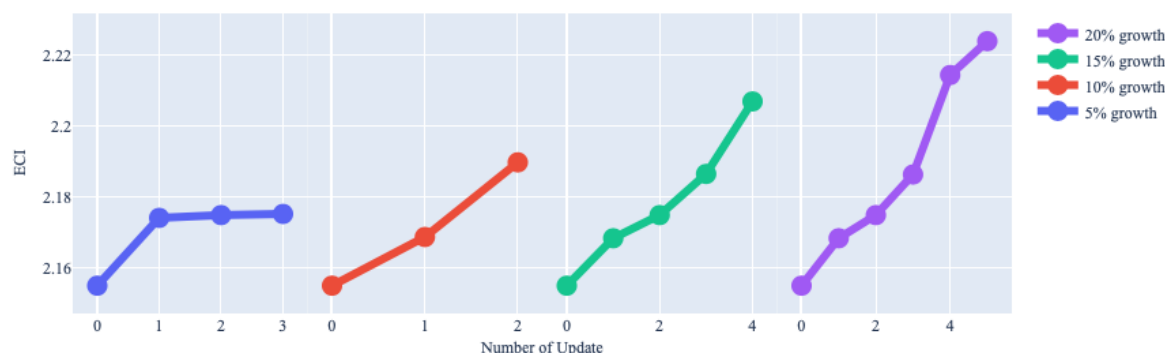
Economic Panel:

As stated above, the enhanced greedy algorithm is developed mainly for solving the optimal allocation strategy. In order to visualize this allocation, an economic panel is created, consisting of a pie chart, a line chart and a table. Firstly, a pie chart is used to show the percentage of each product in the optimal portfolio. The number located in the center of the circle denotes the heuristic growth of total export, which is also our budget. For example, for the first pie chart below, it shows we should allocate 25% for food and preparations, animals and by-products, and chemicals. In addition, we should allocate 12.5% for raw manufacturing and chemical manufacturing. The lines below the pie charts show how the ECI changes during the searching process of the greedy algorithm. For example, in the last pie chart, we can see there are three components, but there are four increments in the last line chart. That is just because many equalized amounts have been invested in high-complexity products. Even though sometimes people may feel 15% and 20% is nonsense to developed countries, yet it can also give a sense of how a country should develop in the long term. Eventually, the graph in the end is just for numerical explanation for the pie chart.

Japan ECI Growth Optimization Result



Japan ECI Increment

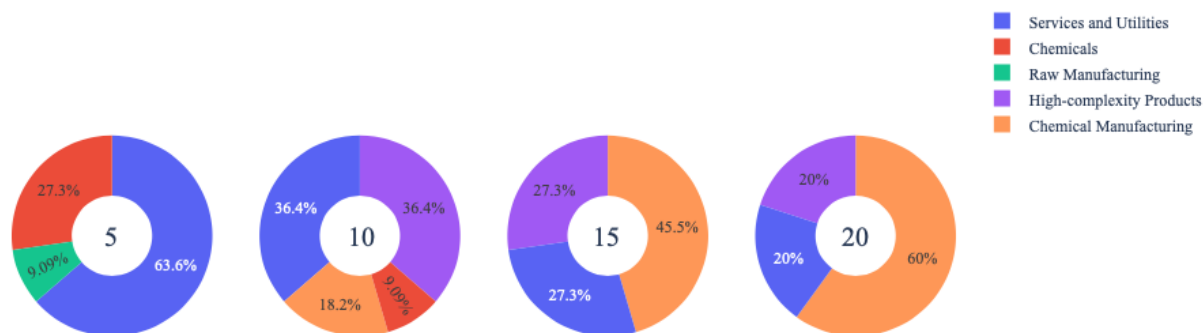


Japan (2013)				
Total Export in 2013 (US. \$)	1.17E+12			
Original ECI	2.155			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. \$)	5.86E+10	1.17E+11	1.76E+11	2.35E+11
Metals(US. \$)	5.33E+09	1.07E+10	1.60E+10	1.68E+10
Transportation(US. \$)	0.00E+00	0.00E+00	4.80E+10	0.00E+00
Chemicals(US. \$)	3.73E+10	0.00E+00	4.80E+10	1.51E+11
Machinery and Construction(US. \$)	0.00E+00	5.33E+10	6.40E+10	6.70E+10
Textile(US. \$)	1.07E+10	5.33E+10	0.00E+00	0.00E+00
Vegetables, Fruits and Plants(US. \$)	5.33E+09	0.00E+00	0.00E+00	0.00E+00
Increased ECI	2.175	2.190	2.207	2.224

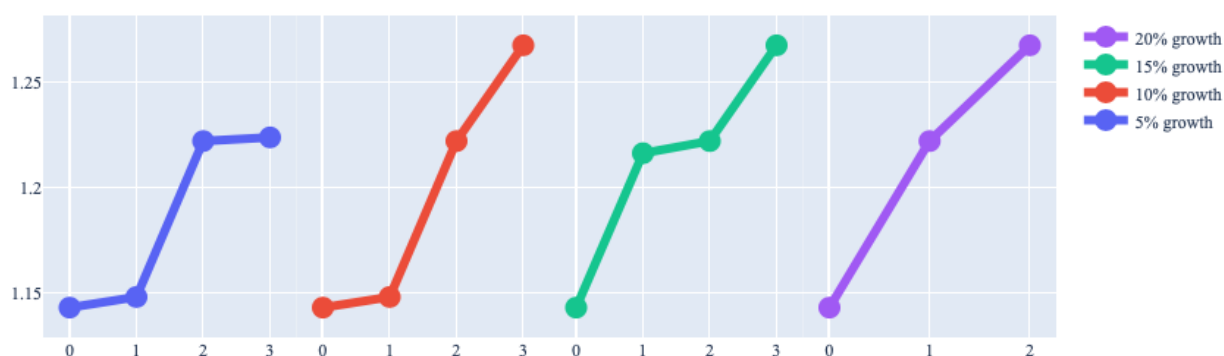
Interpretation:

Below is the economic panel for Poland in 2013. We can see that for different percentages of heuristic total export growth, the ECI of Poland has relatively similar performance. From all the four line graphs, we see that Poland already obtains some great increment in terms of ECI. However, increasing the budget for too large an amount would not produce a higher and higher ECI. Also the optimal ECI that we can achieve in all stages is not a great gain from the original one. This means that in long terms, Poland does not have a lot of room to improve. For the four export growth budget, the increment of ECI depends on services and utilities first and then shift to chemical manufacturing. Therefore, Poland should focus on developing services industry first, and then chemical manufacturing.

Poland ECI Growth Optimization Result



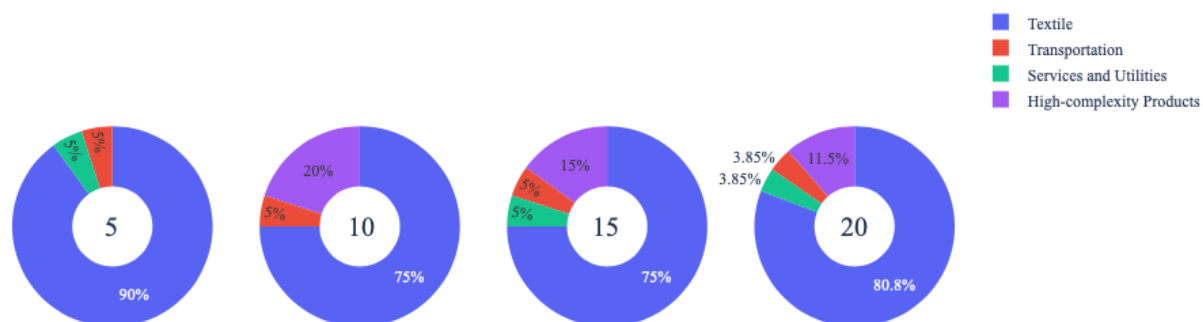
Poland ECI Increment



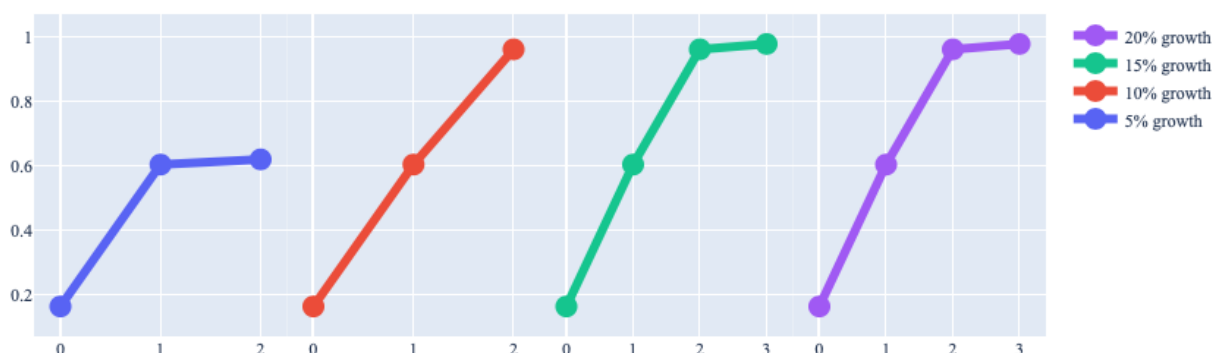
Poland (2013)				
Total Export in 2013 (US. \$)	2.91E+11			
Original ECI	1.14			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. \$)	1.45E+10	2.91E+10	4.36E+10	5.81E+10
Chemicals (US. \$)	3.96E+09	2.64E+09	0.00E+00	0.00E+00
Chemical Manufacturing (US. \$)	0.00E+00	5.28E+09	1.98E+10	3.49E+10
Raw Manufacturing (US. \$)	1.32E+09	0.00E+00	0.00E+00	0.00E+00
High-complexity Products (US. \$)	0.00E+00	1.06E+10	1.19E+10	1.16E+10
Services and Utilities (US. \$)	9.25E+09	1.06E+10	1.19E+10	1.16E+10
Increased ECI	1.22	1.27	1.27	1.27

For further suggestions on Poland's development in the future. We also offer the optimization result of Poland based on export data in 2018. Below is the economic panel for Poland in 2018. We can see that for different percentages of heuristic total export growth, the ECI growth pattern of Poland is similar to the one in 2013. From all the four line graphs, we cannot see Poland has a great increase in ECI. This means that Poland does not have a lot of room to improve. However, our optimization method shows Poland still can have gains by investing in transportation, services industry and high complexity products. Therefore, for future strategy, Poland should prioritize development of these three products in order to optimize the ECI.

Poland ECI Growth Optimization Result



Poland ECI Increment



Poland (2018)				
Total Export in 2018 (US. \$)	3.72E+11			
Original ECI	0.16			
Heuristic Export Growth (%)	5%	10%	15%	20%
Heuristic Export Growth (US. \$)	1.86E+10	3.72E+10	5.58E+10	7.44E+10
Textile (US. \$)	1.67E+10	2.79E+10	4.19E+10	6.01E+10
Transportation (US. \$)	9.30E+08	1.86E+09	2.79E+09	2.86E+09
High-complexity Products (US. \$)	0.00E+00	7.44E+09	8.37E+09	8.59E+09
Services and Utilities (US. \$)	9.30E+08	0.00E+00	2.79E+09	2.86E+09
Increased ECI	0.62	0.96	0.98	0.98

4.3 Sensitivity Analysis and Contingency Strategy

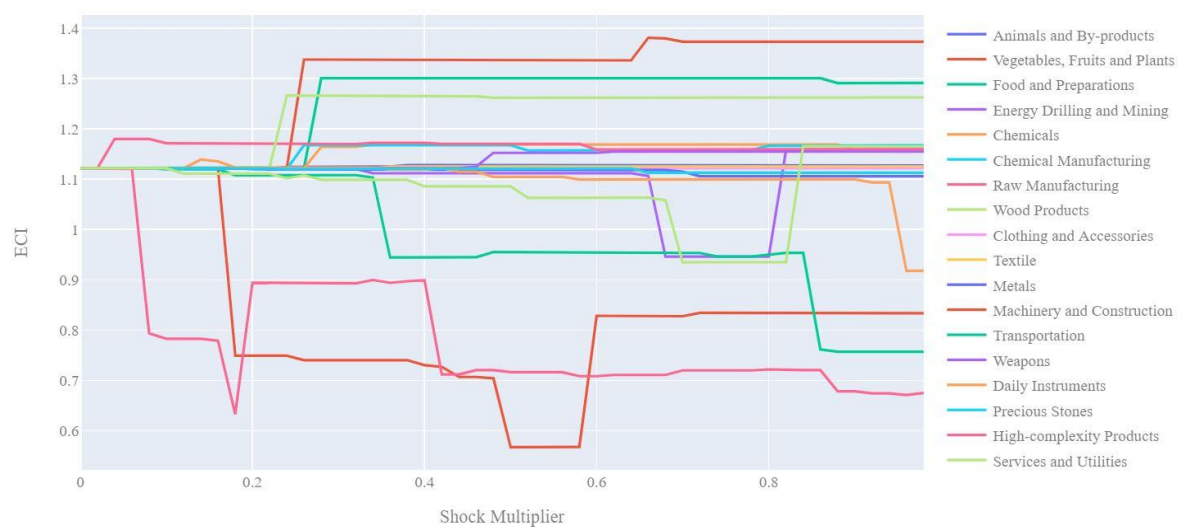
In the following section our broad aim is to understand how sensitive Poland is to changes in export in various industries. While the Economic Complexity Index has been shown to contain valuable information about the economic strength/capacity of a country, little has been said as to the stability of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



Example 2018 (Incremental ECI Sensitivity)

SDV sensitivity

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

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

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

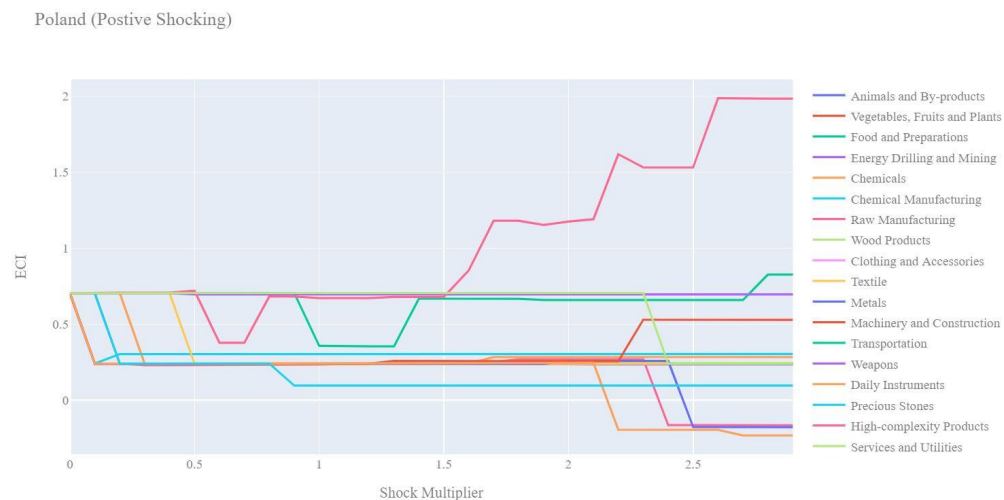
	0.0%	10.0%	30.0%	50.0%	80.0%	100.0%	120.0%
0	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants	Chemicals	Chemicals	Chemicals	Machinery and Construction
1	Daily Instruments	Daily Instruments	Daily Instruments	Services and Utilities	Services and Utilities	Daily Instruments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

Example High-complexity Products 2018 (Incremental SDV Sensitivity)

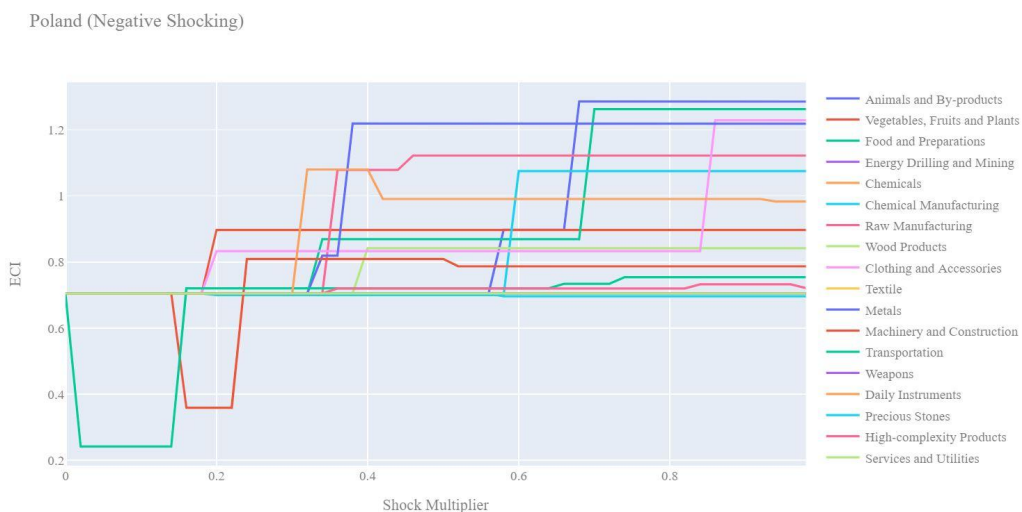
4.3 Sensitivity Analysis Results and Interpretation

Below is Poland's 2018 ECI Sensitivity Charts. Firstly in the positive chart, we notice that only High Complexity products lead to any positive gain in ECI. However over 150% expansion in High Complexity Product export is needed to experience this gain. Italy is mildly insensitive to the majority of the other industries .

Next we consider Poland's 2018 Negative Shock chart. We can see that Poland is highly sensitive to decreases in export of Transportation and mildly sensitive to decreases in export of Machinery. Decreases in export from the majority of industries actually improves the ECI, most drastically within the Metals and Animals and By-products industries.



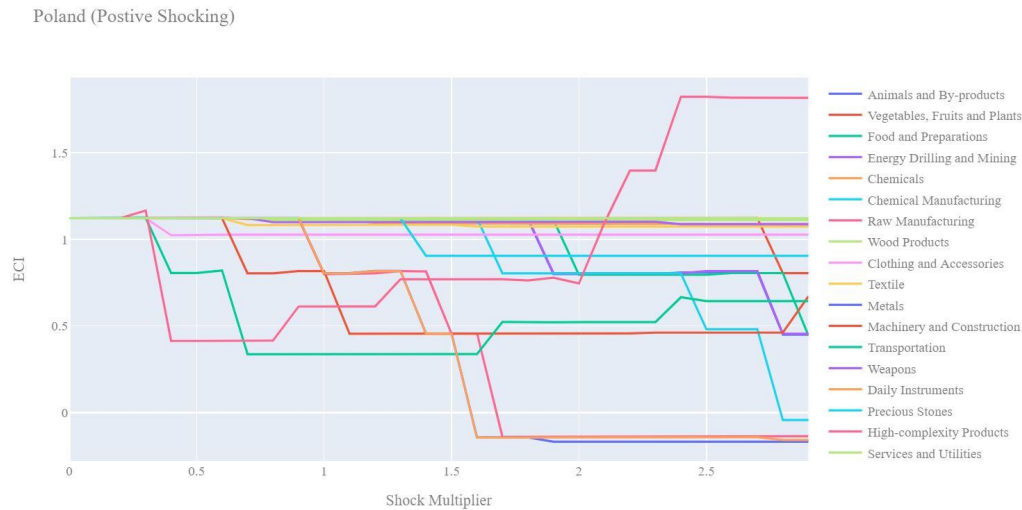
Poland 2018 (Incremental ECI Sensitivity)



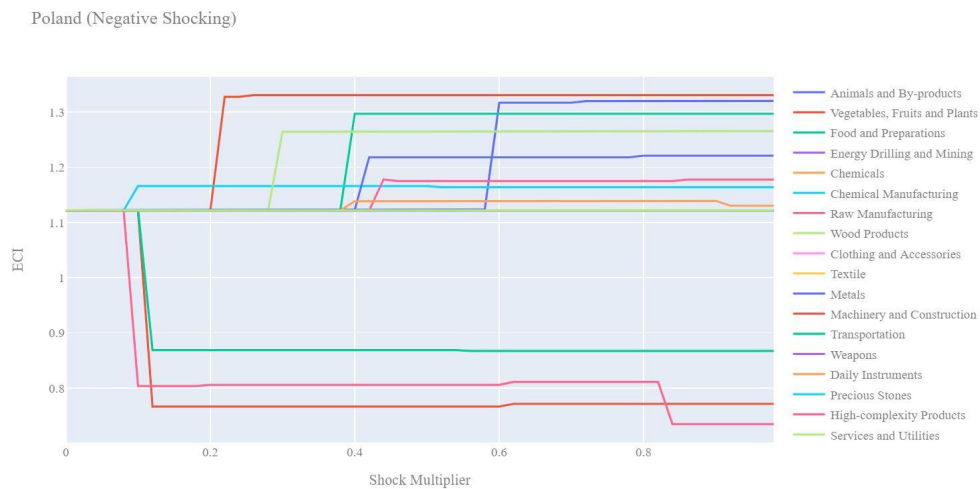
Poland 2018 (Decremental ECI Sensitivity)

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

In the 2013 negative shocking case, we see that again Poland is even more sensitive to downturns than in the 2018 case. Poland is highly sensitive to drawdown in Transportation, Machinery and High Complexity Products. Regarding the remaining industries, decreases in export seem to increase ECI levels marginally.



Poland 2013 (Incremental ECI Sensitivity)



Poland 2013 (Decremental ECI Sensitivity)

Below we see the SDV sensitivity charts for High Complexity Products. We see that moderate increases in export of High Complexity Products makes room for other industries to shift into positive opportunity gain territory. An increase of 60% seems to be optimal in that this shocked SDV contains 8 industries that offer attractive positive opportunity gains.

Considering the Negative SDV sensitivity chart we observe that as export of High Complexity products decrease, the number of industries with positive opportunity gains begins to twindle. Intuitively as High complexity products begin to recede other industries that are “close” to this industry become less attractive options to pursue.

	0.0%	10.0%	60.0%	80.0%	160.0%	170.0%	220.0%	230.0%
0	Chemicals	Chemicals	Services and Utilities	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants
1	Services and Utilities	Services and Utilities	Machinery and Construction	Machinery and Construction	Machinery and Construction	Machinery and Construction	Machinery and Construction	Machinery and Construction
2	Precious Stones	High-complexity Products	Chemicals	Services and Utilities	Services and Utilities	Services and Utilities	Services and Utilities	Chemicals
3	Wood Products	Vegetables, Fruits and Plants	Transportation	High-complexity Products	High-complexity Products	Chemicals	Chemicals	Services and Utilities
4	Vegetables, Fruits and Plants	Food and Preparations	Weapons	Food and Preparations	Food and Preparations	Transportation	Transportation	Daily Instruments
5	Food and Preparations	Raw Manufacturing	Textile	Raw Manufacturing	Raw Manufacturing	High-complexity Products	High-complexity Products	Transportation
6	Raw Manufacturing	Wood Products	Chemical Manufacturing	Wood Products	Wood Products	Raw Manufacturing	Raw Manufacturing	Textile
7	Clothing and Accessories	Clothing and Accessories	Precious Stones	Animals and By-products	Animals and By-products	Wood Products	Animals and By-products	High-complexity Products
8	Metals	Metals	Raw Manufacturing	Metals	Daily Instruments	Animals and By-products	Daily Instruments	Raw Manufacturing
9	Machinery and Construction	Machinery and Construction	Vegetables, Fruits and Plants	Daily Instruments	Chemicals	Daily Instruments	Textile	Animals and By-products
10	Transportation	Daily Instruments	Food and Preparations	Transportation	Transportation	Textile	Weapons	Weapons
11	Daily Instruments	Animals and By-products	Clothing and Accessories	Chemicals	Textile	Weapons	Chemical Manufacturing	Chemical Manufacturing
12	Animals and By-products	Precious Stones	Wood Products	Textile	Weapons	Chemical Manufacturing	Precious Stones	Clothing and Accessories
13	Textile	Textile	High-complexity Products	Weapons	Chemical Manufacturing	Precious Stones	Clothing and Accessories	Precious Stones
14	Weapons	Weapons	Metals	Chemical Manufacturing	Precious Stones	Clothing and Accessories	Wood Products	Wood Products
15	Chemical Manufacturing	Energy Drilling and Mining	Daily Instruments	Precious Stones	Clothing and Accessories	Metals	Metals	Metals
16	High-complexity Products	Transportation	Animals and By-products	Clothing and Accessories	Metals	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining
17	Energy Drilling and Mining	Chemical Manufacturing	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining	Food and Preparations	Food and Preparations	Food and Preparations
ECI	0.704833983	0.707699566	0.378814651	0.683090188	0.853551388	1.180810986	1.617450973	1.530271427

Poland High-complexity Products 2018 (Incremental SDV Sensitivity)

	-0.0%	-36.0%	-98.0%
0	Chemicals	Services and Utilities	Services and Utilities
1	Services and Utilities	Chemicals	Metals
2	Precious Stones	Wood Products	Vegetables, Fruits and Plants
3	Wood Products	Vegetables, Fruits and Plants	Food and Preparations
4	Vegetables, Fruits and Plants	Food and Preparations	Chemical Manufacturing
5	Food and Preparations	Chemical Manufacturing	Raw Manufacturing
6	Raw Manufacturing	Raw Manufacturing	Wood Products
7	Clothing and Accessories	Clothing and Accessories	Clothing and Accessories
8	Metals	Metals	Machinery and Construction
9	Machinery and Construction	Machinery and Construction	Transportation
10	Transportation	Transportation	Weapons
11	Daily Instruments	Daily Instruments	Daily Instruments
12	Animals and By-products	Animals and By-products	Animals and By-products
13	Textile	Precious Stones	Chemicals
14	Weapons	Weapons	Precious Stones
15	Chemical Manufacturing	Textile	Textile
16	High-complexity Products	High-complexity Products	High-complexity Products
17	Energy Drilling and Mining	Energy Drilling and Mining	Energy Drilling and Mining
ECI	0.704833983	0.71990162	0.721255073

Poland High-complexity Products 2018 (Decremental SDV Sensitivity)

Below we see the SDV sensitivity charts for Food and Preparations. Interestingly, in the positive shocking case we see that a small increase in this industry leads to quite a few industries switching from the negative and neutral categories to the positive opportunity gain category.

In the negative shocking case we see that again small drawdowns of the Food and Preparations Industry can cause drastic shifts in the suggested development vector.

	0.0%	10.0%
0	Chemicals	High-complexity Products
1	Services and Utilities	Chemicals
2	Precious Stones	Transportation
3	Wood Products	Services and Utilities
4	Vegetables, Fruits and Plants	Weapons
5	Food and Preparations	Textile
6	Raw Manufacturing	Precious Stones
7	Clothing and Accessories	Chemical Manufacturing
8	Metals	Raw Manufacturing
9	Machinery and Construction	Vegetables, Fruits and Plants
10	Transportation	Food and Preparations
11	Daily Instruments	Clothing and Accessories
12	Animals and By-products	Wood Products
13	Textile	Metals
14	Weapons	Machinery and Construction
15	Chemical Manufacturing	Daily Instruments
16	High-complexity Products	Animals and By-products
17	Energy Drilling and Mining	Energy Drilling and Mining
ECI	0.704833983	0.241919087

Poland Food and Preparations 2018 (Incremental SDV Sensitivity)

	-0.0%	-34.0%	-70.0%
0	Chemicals	Chemicals	Services and Utilities
1	Services and Utilities	Services and Utilities	Chemicals
2	Precious Stones	Precious Stones	Precious Stones
3	Wood Products	Energy Drilling and Mining	Energy Drilling and Mining
4	Vegetables, Fruits and Plants	Chemical Manufacturing	High-complexity Products
5	Food and Preparations	Textile	Vegetables, Fruits and Plants
6	Raw Manufacturing	Weapons	Raw Manufacturing
7	Clothing and Accessories	Food and Preparations	Wood Products
8	Metals	Raw Manufacturing	Clothing and Accessories
9	Machinery and Construction	Vegetables, Fruits and Plants	Metals
10	Transportation	Clothing and Accessories	Machinery and Construction
11	Daily Instruments	Wood Products	Transportation
12	Animals and By-products	Metals	Daily Instruments
13	Textile	Machinery and Construction	Animals and By-products
14	Weapons	Transportation	Food and Preparations
15	Chemical Manufacturing	Daily Instruments	Chemical Manufacturing
16	High-complexity Products	Animals and By-products	Textile
17	Energy Drilling and Mining	High-complexity Products	Weapons
ECI	0.704833983	0.86919121	1.262472189

Poland Food and Preparations 2018 (Decremental SDV Sensitivity)

5. Macro-level Predictions

5.1 Structural Optimality Index

Indeed, such choice of prioritization has proven to be a significant factor in deciding the economic outcomes of countries. In order to quantitatively evaluate how effective our development strategies are and how deviations from the suggested developmental path will lead to suboptimal growth results, we define the measure – Structural Optimality Index (SOI) – on a

country level as the Adjusted R-Square obtained from regressing the country's realized industry development over the suggested development strategy. Both strategies are quantified in nature, with the realized development represented by export increase in every major industry groups and the suggested development strategy represented by the opportunity gains of developing the corresponding industry groups as calculated in previous sections. The adjusted R-square from the regression thus provides us with a quantified measure of how the development path adopted by the country has fitted with/differed from calculations on a complexity level.

After obtaining this measure for all countries in our database, we further regress countries' five-year economic growth, which is defined as the percent increase in GDP (USD), over their SOI. Figure 6 illustrates the regression output, which shows a strong positive correlation between countries' SOI and their five-year GDP growth, significant at the 1% level and achieving an adjusted R^2 of 4.5%. In other words, the more a country develops as suggested by calculations on a complexity level, the better economic outcomes it achieves.

Table 18: OLS Regression Results	
Dep. Variable: GDP	F-Statistic: 5.963
R²: 0.054	Prob (F-Stat): 0.0163
Adj R²: 0.045	No. Observations: 106

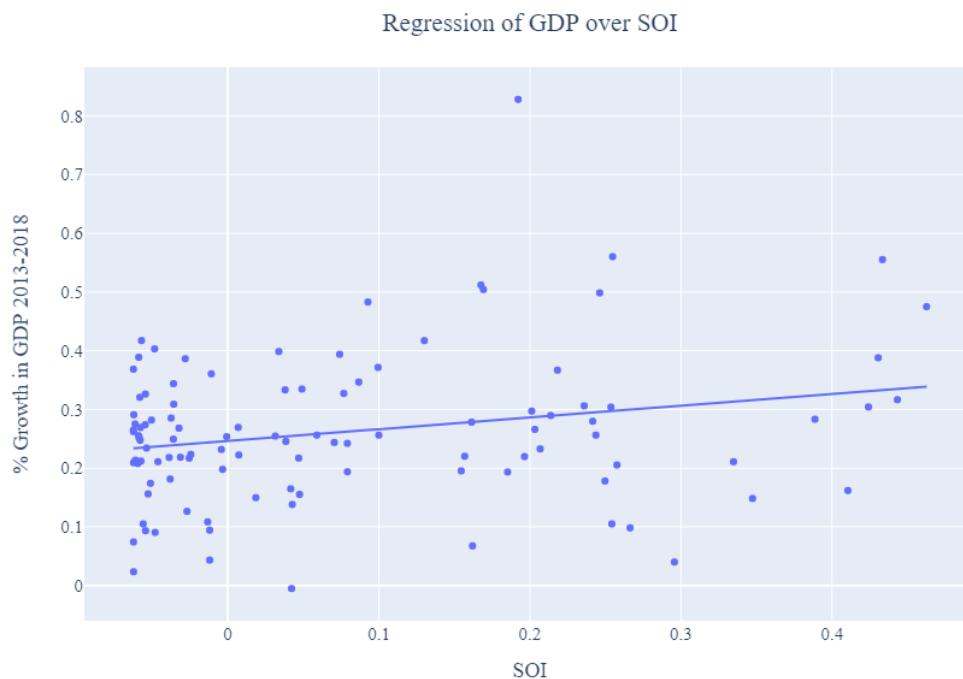
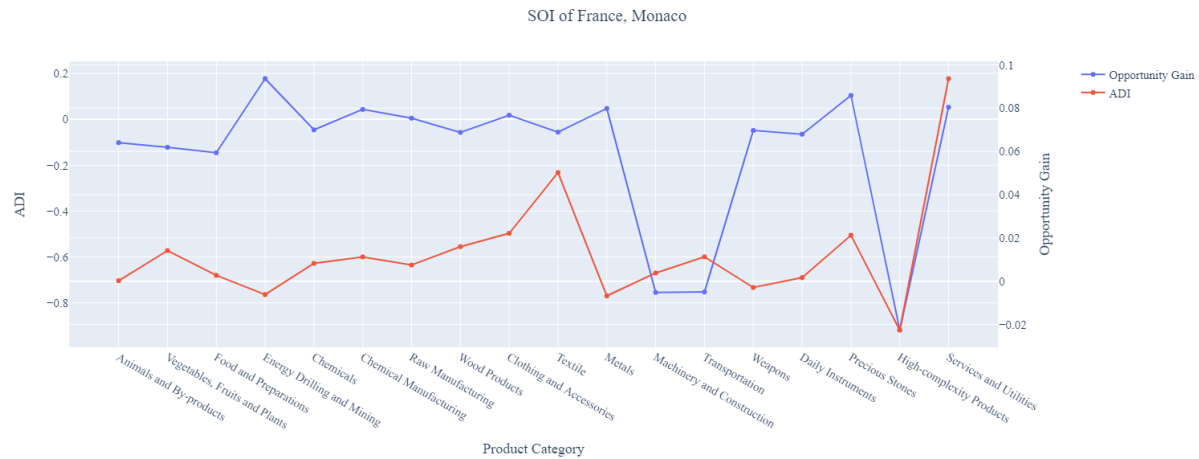


Figure 6: Regression of Five-year GDP Growth over SOI

5.2 SOI of Poland and Its Implications



Poland, for instance, has a relatively high level of structural optimality as compared with its developed peers. As the regression in Figure 7 suggests (the orange curve represents export increase and the blue curve stands for opportunity gain of the corresponding industry), Poland demonstrates a high level of correlation with the suggested developmental path, having an adjusted R-square of around 20.3%. Poland ranks 25th place among all countries in terms of SOI and has a 5-year growth rate of 26.5% from 2013 to 2018, which is consistent with the regression result in Figure 6. This is similar to some emerging economies such as Turkey, where there is high SOI of around 21.8% and a corresponding GDP growth of 36.7% from 2013 to 2018, making it one of the fastest developing economies during the period. In sum, Poland's relative economic progress from 2013 to 2018 can be at least partially explained by a matching development strategy that demonstrates a correlation to our suggested developmental path.

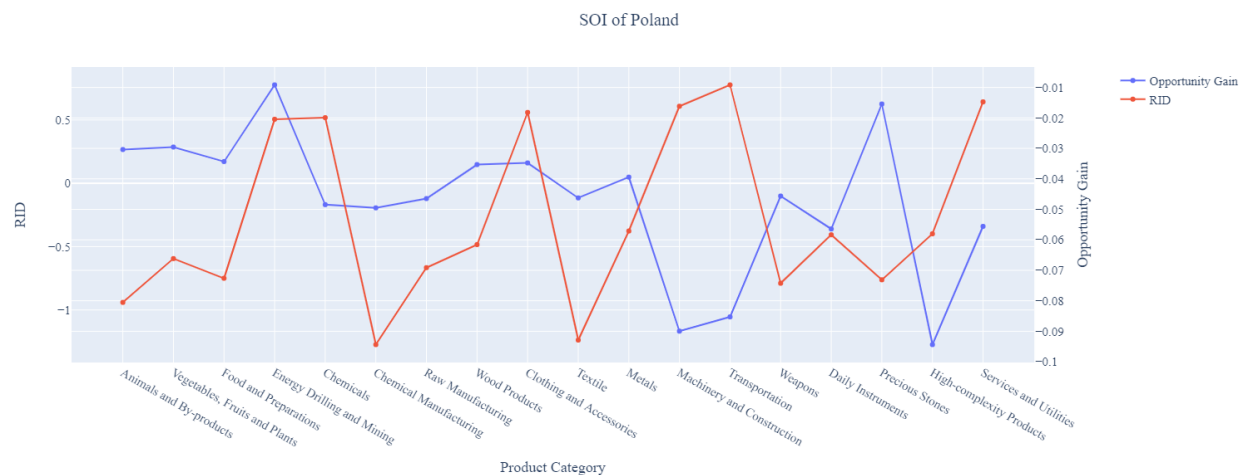


Figure 7: SOI of Poland(2013-2018)

6. Concluding Remarks

In conclusion, Poland has demonstrated a low level of economic growth in terms of GDP during the period from 2013 to 2018, concurrent with a stagnation in economic complexity as compared with other major European economies.

The level of economic progress during the period, we believe, can be partially explained through analysis of the economic and product complexity structure of Poland 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 Poland invested heavily in developing Animals and By-products, Chemical Manufacturing and Textiles during the period, while its emerging peers and developed economies around the globe have adopted much more complex and progressive paths.

Based on our analysis of the opportunity gain and a sensitivity analysis of major industry groups, Poland can further its gains by prioritizing Services and Utilities, and Chemicals. We further note that Poland has a slightly mismatched development strategy that indicates a moderate level of structural optimality on the complexity level, having an adjusted R-square of around 20.3%. Since a significant positive correlation exists between five-year GDP growth and the structural optimality index of an economy as we define and calculate, Poland 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.

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 Reappraisal," *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).