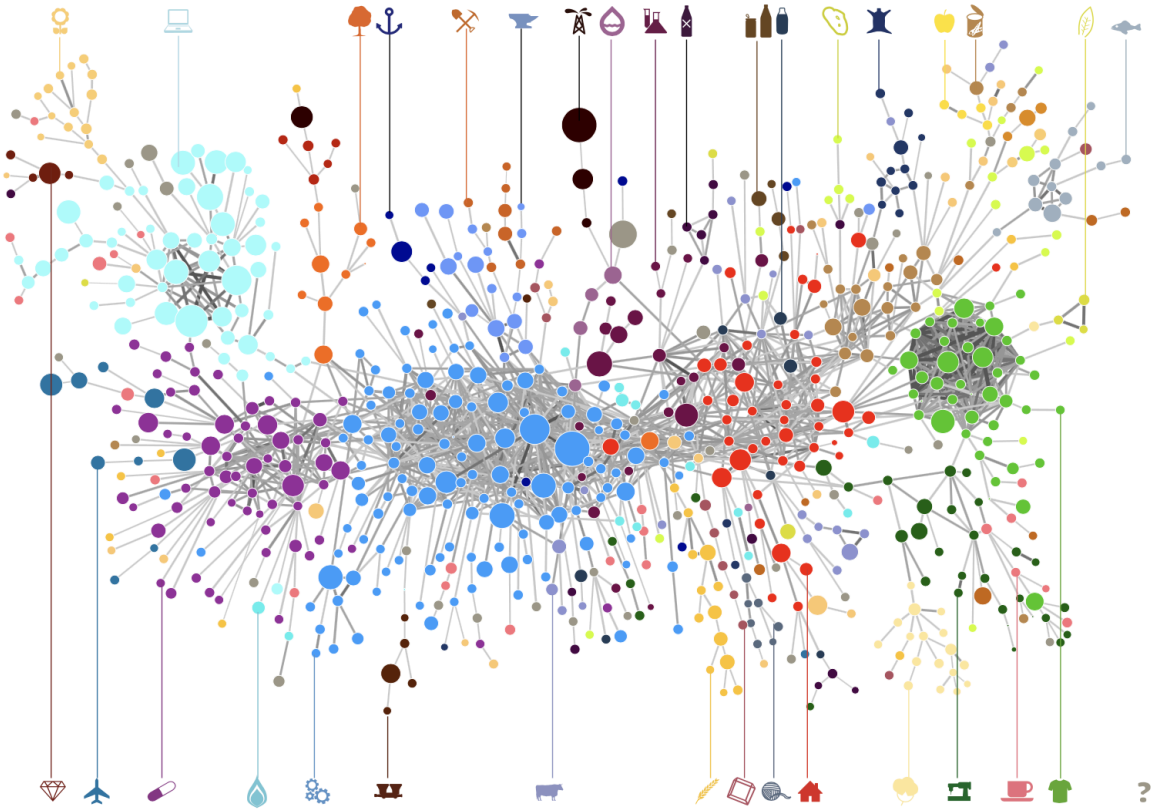

https://atlas.cid.harvard.edu/

Optimal Industry Development Strategy Using Economic and Product Complexity

Germany

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The Economic Complexity Lab - Columbia University

Alexandra Garcia, Kelly Mi, Margarita Demkina, Allison Lin, Helena Yang, Jane Zhang, Daniel Xu, Ryo Shibata, Navia Zhang, Haoxian Chen, Davepriyan Gunaratnam, Rohan Macherla, Ajit Akole, Shomik Ghose, Alex Wei-Liang Ku,

Sannidhya Modi, Xilin Wang

Optimal Industry Development Strategy for Germany

0. Executive Summary

In this report, we aim to uncover the economic path Germany went through during the period from 2019 to 2022. Specifically, we dive into the topic through a macroeconomic overview of Germany 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, Germany demonstrated a low level of economic growth with an average annual GDP growth rate of 1.26% between 2019 and 2022, with an increased economic complexity compared to other major developed economies.

The mixed progress during the period, we believe, can be partially explained through the analysis of the economic and product complexity structure of Germany 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 Germany regressed in developing most of its industries during the period while its developed 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, Germany could further its gains by prioritizing Weapons, Food and Preparations, Animals and By-products, and Precious Stones in 2022. We further note that Germany has a heavily mismatched development strategy that indicates a low level (compared to other developed countries) of structural optimality on the complexity level, having an adjusted R-square of around 25.4% in 2022. Since a significant positive correlation exists between GDP growth and the structural optimality index of an economy as we define and calculate, Germany 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 between 2019 and 2022 showed a significant improvement in Germany'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 Germany went through during the period from 2019 to 2022, including the COVID pandemic. Specifically, we dive into the topic through a macroeconomic overview of Germany 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 Germany 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 Germany, as deduced from regression models we have established on a global scale, which take into account countries' stances in their product space.

2. Macroeconomic Results

2.1 GDP Ranking and Changes

Figure 1 illustrates the time-series GDP results for Germany and four of its peer countries China, Japan, France, and USA from 2019 to 2022. Similar to the other countries, Germany displayed an eventual upward trend over the period; however, its growth was less consistent than both China and USA's growth. Germany's average annual GDP growth rate was 1.26%, which puts it lower than China's 6.25%, USA's 4.62% but higher than France's 0.69% and Japan's -4.43%.

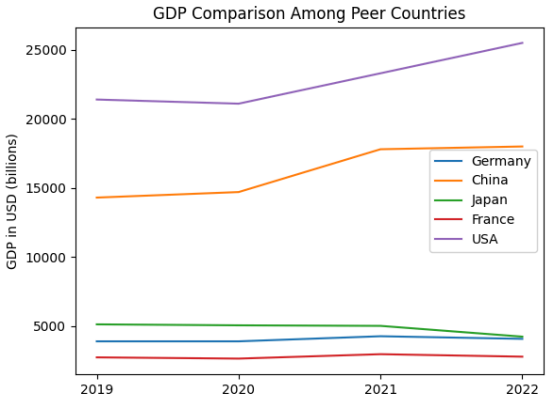


Figure 1. GDP Comparison Among Peer Countries (2019-2022)

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 Figure 2.

As shown, Germany exhibits a decrease in production capability from 2019 to 2022. Germany is in a moderate position in ECI terms, as its ECI change of -180.12% is greater than Japan's -203.32% and USA's -193.0% but less than China's -174.98% and France's -157.77%. Germany, China, Japan, and Germany all experience a drastic decrease between 2020-2021. This decrease in Germany may be explained by budgetary constraints placed on the country during the COVID-19 pandemic.

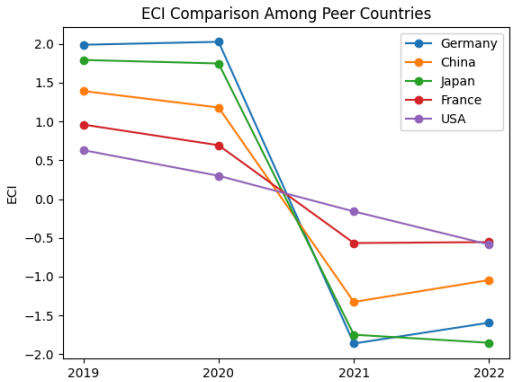


Figure 2. ECI Comparison Among Peer Countries (2019-2022)

Figure 3 offers a further comparison of GDP Growth and ECI over the time span from 2019 to 2022 for Germany. The GDP growth during the period from 2019 to 2021 is accompanied by a similarly volatile decrease in ECI. The results show that the economic growth experienced by Germany during the period from 2019 to 2022 is only partially consistent with the predictions by ECI and that Germany made weak progress towards effectively 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 Germany's production structure and its product space designs in the next few sections.

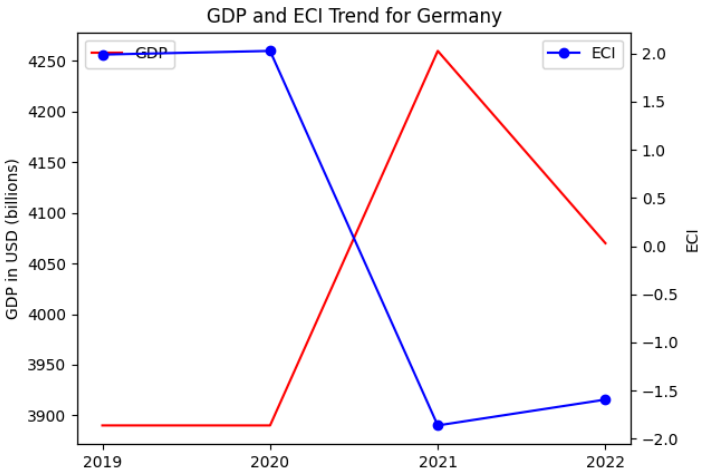


Figure 3. GDP Growth and ECI for Germany (2019-2022)

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 economics, 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 Germany's realized industry production strategy between 2019 and 2022 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 Germany and the 18 product groups in 2022 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.

Category	RID (2022)
Wood Products	0.02390
Precious Stones	0.03822
Animals and By-products	0.04059
Vegetables, Fruits and Plants	0.04351
Raw Manufacturing	0.05124
Energy Drilling and Mining	0.05509
Food and Preparations	0.06139
Chemicals	0.06415
Services and Utilities	0.06880
Textile	0.07197
Chemical Manufacturing	0.07859
Metals	0.08518
Weapons	0.08865
Clothing and Accessories	0.09328
High-complexity Products	0.09329
Machinery and Construction	0.11991
Daily Instruments	0.12742
Transportation	0.14740

Table 3. Realized Industry Development (RID) of Germany

3.3 Regional and Global Comparison

Table 4a below summarizes how the production strategy adopted by Germany compares with selected leading economies in the world across different years, as measured in RID. Leading economies such as France, Greece, and Portugal gave a considerable level of attention to more advanced product groups such as Services and Utilities, Energy Drilling, and Textiles in 2022.

Ranking	France	Greece	Portugal
1	Services and Utilities	Energy Drilling	Textile
2	Precious Stones	Wood Products	Fruit and Plants
3	High-complexity Products	Services and Utilities	Daily Instruments
4	Machinery & Construction	Clothing & Accessories	Clothing & Accessories
5	Animals & By-products	Wood Products	Transportation

Table 4. RID Comparison across Leading Economies (2022)

Table 4b further examines Germany's development strategy against those of emerging economies on a global scale. Reasonably, emerging economies such as China and Singapore have devoted the majority of their efforts to intermediate industry groups, showing moderate shifts in strategies over the course of three years.

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

Table 4b. RID Comparison across Emerging Economies (2022)

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	Germany	China	Japan	France	USA
1	Chemical Manufacturing	Textile	Chemicals	Energy Drilling and Mining	Animals and By-products
2	Raw Manufacturing	Chemicals	Raw Manufacturing	Textile	Textile
3	Wood Products	Food and Preparations	Metals	Precious Stones	Clothing and Accessories
4	Metals	Raw Manufacturing	Transportation	Animals and By-products	Wood Products
5	Machinery and Construction	Clothing and Accessories	Weapons	Vegetables, Fruits and Plants	Vegetables, Fruits and Plants
6	Transportation	Transportation	Daily Instruments	Food and Preparations	Food and Preparations
7	Weapons	Daily Instruments	High-complexity Products	Chemicals	Energy Drilling and Mining
8	Daily Instruments	Precious Stones	Services and Utilities	Chemical Manufacturing	Chemicals
9	High-complexity Products	Services and Utilities	Textile	Raw Manufacturing	Chemical Manufacturing
10	Textile	Weapons	Clothing and Accessories	Wood Products	Weapons
11	Energy Drilling and Mining	Energy Drilling and Mining	Wood Products	Clothing and Accessories	Daily Instruments
12	Clothing and Accessories	Vegetables, Fruits and Plants	Energy Drilling and Mining	Metals	Precious Stones
13	Precious Stones	Chemical Manufacturing	Precious Stones	Weapons	High-complexity Products
14	Chemicals	Machinery and Construction	Machinery and Construction	High-complexity Products	Services and Utilities
15	Animals and By-products	Wood Products	Animals and By-products	Machinery and Construction	Metals
16	Vegetables, Fruits and Plants	Animals and By-products	Vegetables, Fruits and Plants	Transportation	Raw Manufacturing
17	Food and Preparations	Metals	Food and Preparations	Daily Instruments	Machinery and Construction
18	Services and Utilities	High-complexity Products	Chemical Manufacturing	Services and Utilities	Transportation
ECI	**-1.593**	**-1.044**	**-1.852**	**-0.555**	**-0.586**

Table 5. Opportunity Gain Ranking on a Comparable Scale (2022)

We define the ranking of opportunity gain for a country c, as the Suggested Development Vector (SDV) of c. Table 5 summarizes how the SDV of Germany compares with a selected group of comparable and leading economies in the world, with the industry groups ranked in decreasing order of significance.

Dark blue indicates positive opportunity gains, light blue indicates zero opportunity gains, and white indicates negative opportunity gains. The result shows that leading countries barely have any industries with positive opportunity gain. In other words, those countries are already in the most stable and efficient economic structure. Without the necessity of economic transition, those countries merely need to maintain a steady and balanced economic development. In contrast, developing countries have nearly half of industries with positive opportunity gain and share common interests in Raw Manufacturing and Transportation industries. It can be concluded that Germany shares the characteristics of developing countries, with a balanced economic structure that leans towards moderate complex-level industries. However, its ECI has decreased over the past four years, and thus there remains significant room for improvement.

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 Sample Countries (2019)

4.2 Budgeted Industry Development Strategy and Interpretation

The optimal budgeted industry development strategy aims to solve the most efficient allocations under the budgeted constraint of different situations of heuristic total export growth. In order to obtain such an allocation portfolio, we formulate an optimization problem as the following:

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

Subject to

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

$$x \succcurlyeq 0$$

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

If we can solve this problem, then we can know what the largest ECI 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.

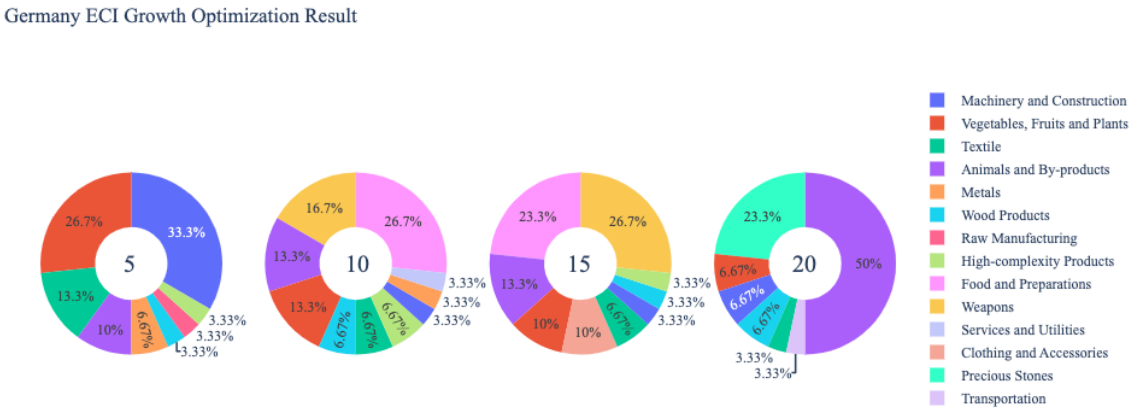
Label	Product Names
1	Animal and By-products
2	Vegetables, Fruits and Plants

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

Figure 4 shows an economic panel for Germany in 2022. We can see that for different percentages of heuristic total export growth, the ECIs of Germany actually have different increments.

For 2022, in the case of 5 percent export growth, Machinery and Construction is the primary industry with Vegetables, Fruits and Plants as the secondary industry. With a budget of 10 percent export growth, Food and Preparations, Weapons, and Animals and By-products account for most of the portfolio. For 15%, Weapons occupy more of the portfolio as the leading industry with Food and Preparations as a secondary industry. For 20%, Animals and By-products is the leading industry while Precious Stones is a secondary industry. This suggests that with increases in investment, resources should be directed to Animals and By-products, Weapons, and Food and Preparations. A more detailed numerical representation of the portfolio is shown in Table 8. The increased ECI row of the table suggests that Germany should focus on increases of 15% and 20% as it contributes the most to the overall increase in ECI. Thus, for optimal development, it should invest in Weapons, Food and Preparations, Animals and By-products, and Precious Stones.



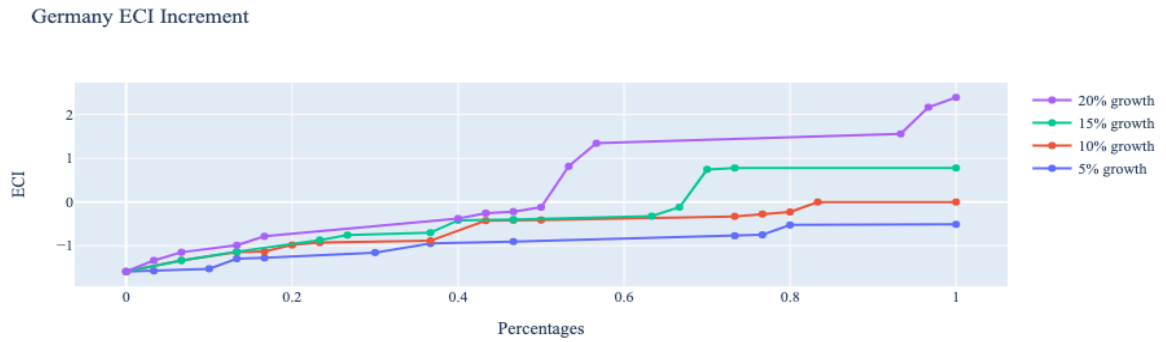


Figure 4. Greedy-Based ECI Improvement Results of Germany with Different Budgets (2022)

Germany (2022)				
Original ECI			**-1.593**	
Heuristic Export Growth	**5%**	**10%**	**15%**	**20%**
Animals and By-products	1.67E+10	4.45E+10	8.90E+10	6.45E+11
Vegetables, Fruits and Plants	4.45E+10	4.45E+10	6.67E+10	8.60E+10
Food and Preparations	0.00E+00	8.90E+10	1.56E+11	0.00E+00
Raw Manufacturing	5.56E+09	0.00E+00	0.00E+00	0.00E+00
Wood Products	5.56E+09	2.22E+10	2.22E+10	8.60E+10
Clothing and Accessories	0.00E+00	0.00E+00	6.67E+10	0.00E+00
Textile	2.22E+10	2.22E+10	4.45E+10	4.30E+10
Metals	1.11E+10	1.11E+10	0.00E+00	0.00E+00
Machinery and Construction	5.56E+10	1.11E+10	2.22E+10	8.60E+10
Transportation	0.00E+00	0.00E+00	0.00E+00	4.30E+10
Weapons	0.00E+00	5.56E+10	2.22E+10	0.00E+00
Precious Stones	0.00E+00	0.00E+00	0.00E+00	3.01E+11
High-complexity Products	5.56E+09	2.22E+10	2.22E+10	0.00E+00
Services and Utilities	0.00E+00	1.11E+10	0.00E+00	0.00E+00
Increased ECI	**-5.12E-01**	**-1.59E-01**	**7.79E-01**	**2.39E+00**

Table 8. Portfolio of Germany (2022)

4.3 Sensitivity Analysis and Contingency Strategy

In the following section, our broad aim is to understand how sensitive Germany 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.

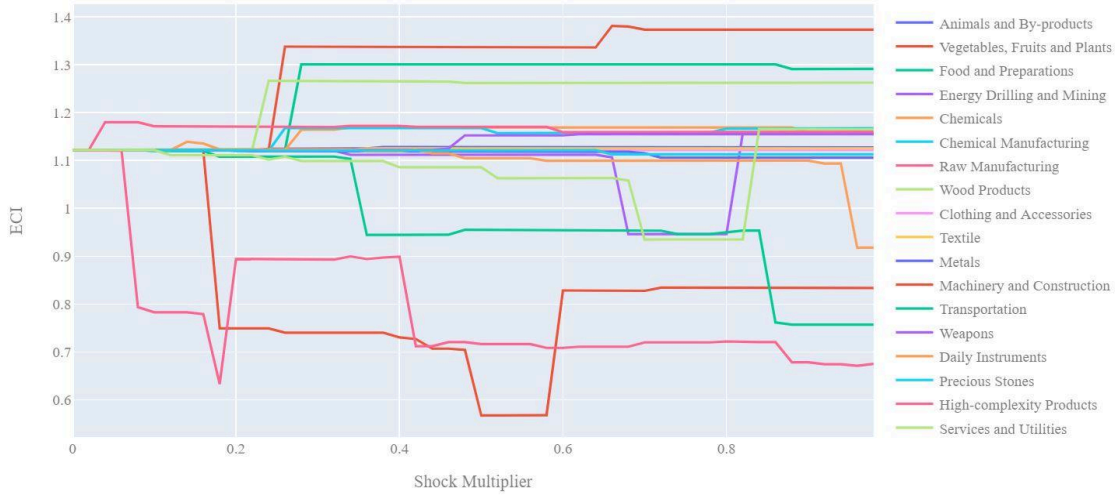


Figure 5. Sample ECI Sensitivity Graph (2018)

The graphs are formulated as follows. 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.

4.3 Sensitivity Analysis Results and Interpretation

We examine Germany's ECI Decremental and Incremental Sensitivity Charts for 2022. An increase in Textile will lead to the highest change in ECI, followed by Vegetables, Fruits and Plants. For the negative shock cases, Wood Products becomes most impactful. The rest of the industries do not appear to have the same level of sensitivity. This suggests that in economic downturns, Germany should continue to invest in Wood Products to avoid additional decreases in ECI.

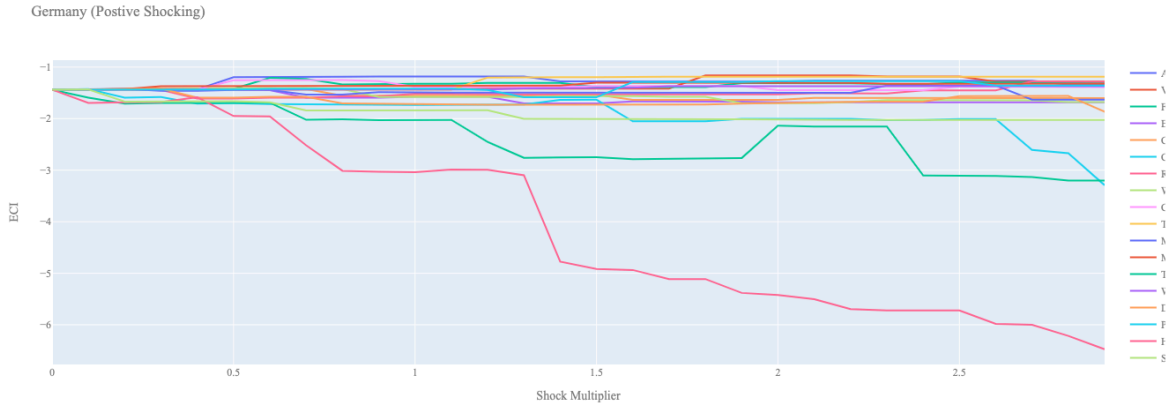


Figure 6a. Incremental ECI Sensitivity for Germany (2022)

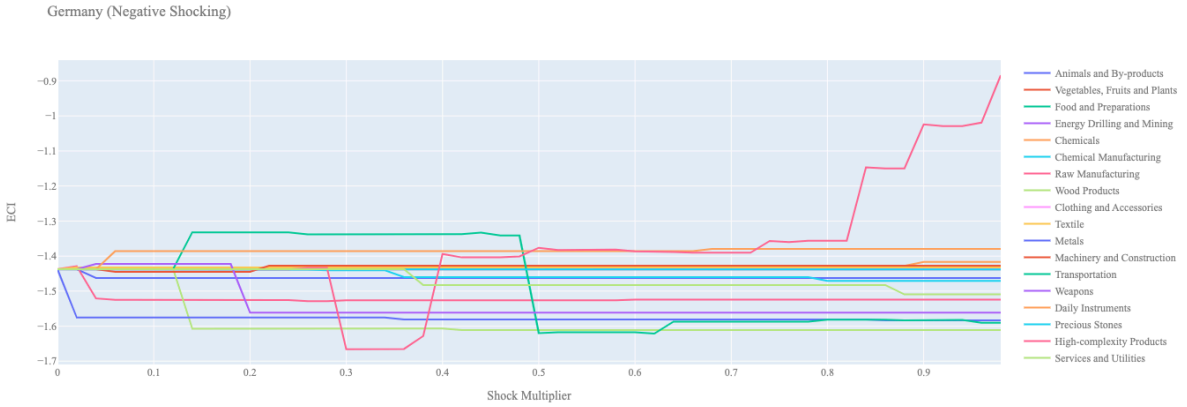


Figure 6b. Decremental ECI Sensitivity for Germany (2022)

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 [Percentage]%

level and achieving an adjusted R^2 of [Percentage]%. 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:** [F-Stat]
R^2: [R^2]	**Prob (F-Stat):** [Prob]
Adj R^2: [R^2 adj]	**No. Observations:** [nobs]

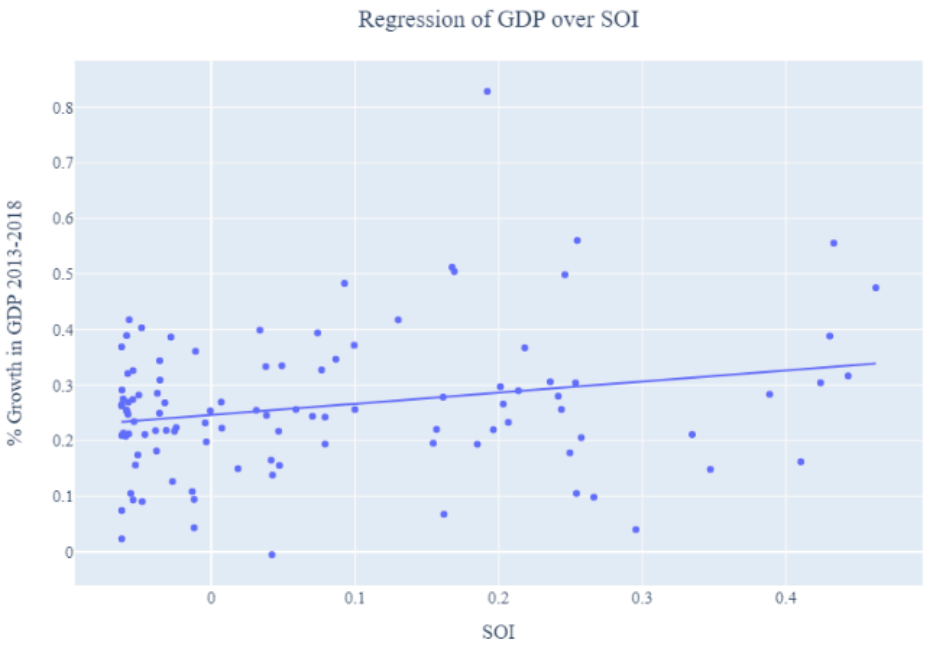


Figure 9. Regression of Five-Year GDP Growth over SOI (2013-2018)

5.2 SOI of Germany and Its Implications

During the first examined period, Germany, for instance, has a low level of structural optimality as compared with its developed peers. As the regression in Figure 10 suggests (the red curve represents export increase and the blue curve stands for opportunity gain of the corresponding industry), Germany demonstrates a low level of correlation with the suggested developmental path, having an adjusted R-square of around 25.4%.

Germany ranks in the middle quartile among all countries in terms of SOI and has made a moderate rate of economic progress among its emerging peers from 2019 to 2022 with a 3-year GDP growth rate of 1.26%, which is consistent with the regression result in Figure 4. Specifically, Germany's slow economic progress from 2019 to 2022 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, Germany invested heavily in the Transportation industry, while it should have focused more on industry groups such as Energy Drilling and Mining.

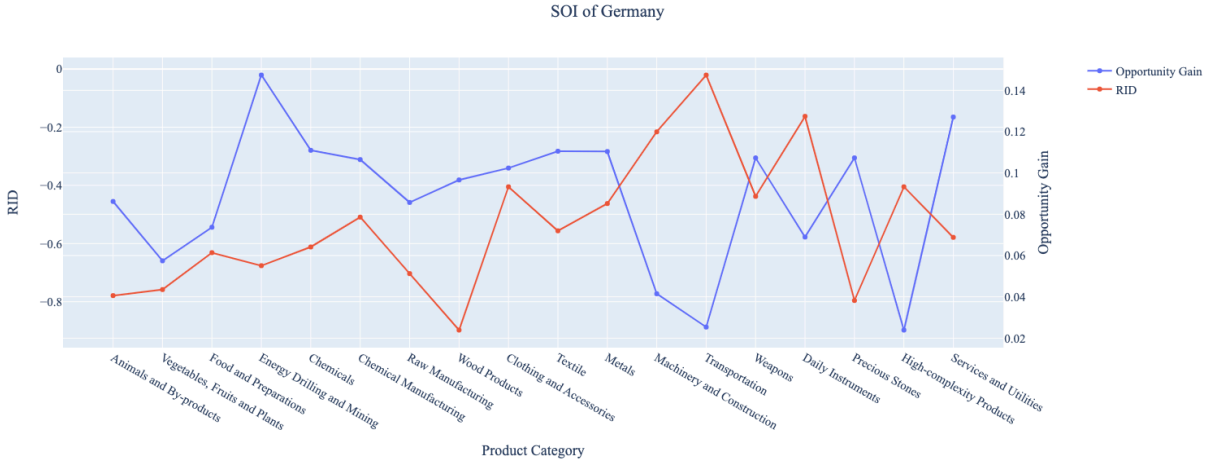


Figure 10. SOI of Germany (2019-2022)

6. Concluding Remarks

In conclusion, Germany has demonstrated a low level of economic growth in terms of annual GDP increase during the period from 2019 to 2022, concurrent with a decrease in economic complexity as compared with major developed economies.

We believe that the mixed progress during this period can be partially explained through the analysis of the economic and product complexity structure of Germany 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 Germany regressed in developing most of its industries during the period. Despite a relatively less intense ECI decrease compared to its peers, Germany did not undergo similar GDP growth, which indicates that there is further potential to target specific industries.

Based on our analysis of the opportunity gain and sensitivity analysis of major industry groups for 2019-2022, Germany can further its gains by prioritizing Weapons, Food and Preparations, Animals and By-products, and Precious Stones. We further note that Germany has a heavily mismatched development strategy that indicates a low level (compared to other developed countries) of structural optimality on the complexity level, having an adjusted R-square of around 25.4%. Since a positive correlation exists between three-year GDP growth and the structural optimality index of an economy as we define and calculate, Germany 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.

We infer that during the COVID-19 period, Germany focused on developing lower complexity industries, in line with lower demand for these industries given the global economic downturn. With the revised focus, Germany has further potential to advance its economic growth to maintain its position among other countries to continue its post-pandemic recovery.

References

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

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

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

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

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

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

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

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