ECONOMIC COMPLEXITY TO ADDRESS CURRENT CHALLENGES IN INNOVATION SYSTEMS

A NOVEL EMPIRICAL STRATEGY LINKED TO THE TERRITORIAL DIMENSION

Economic Complexity is a data driven empirical approach developed to **inform the territorial development debate with quantitative metrics**.

In this framework, techniques **inspired by complex systems analysis and network theory** allow to measure the intangible capabilities necessary for a country or region to be competitive, both in absolute terms and in specific markets.

This document addresses **how different clogs of the innovation system co-evolve under complexity**: both in terms of the different aspects (innovation, production, scientific activities) and geographical scales (countries, regions, cities).

By using a number of techniques from the Economic Complexity toolbox, this document **showcases examples of policy messages**.

1. Current Policy Challenges

EU manufacturing has lost ground due to the low growth of the EU domestic economy and its diminished participation in global manufacturing value chains.[1] EU industry is facing different transitions at the same time, including the digital transformation and the transition towards a net zero emission and circular economy. Developing technologies, products and solutions for this while having access to finance, resources and human capital equipped with the right skills are amongst the huge challenges to be overcome in the next decade. This implies the need for new business models and actors to ensure future competitiveness and employment. These competitive pressures challenge the EU as leading innovator in the world, which in turn is crucial for future industrial competitiveness.[2] From the policy side, a more integrated approach to industrial, innovation and regional policies is necessary to trigger successful industrial transformation.[3]

In this environment, conventional economic analyses have shown limited usefulness. Indeed, Complex System analysis has highlighted since the '80s the limitation of conventional economic analyses to identify hidden trends in complex environments (Anderson, Arrow and Pines 1987). Economic Complexity is an alternative, non-conventional bottom-up and data-driven approach inspired by statistical physics and complex systems science. By producing quantitative, falsifiable results and relationships, it has great potential in the analysis of the current challenges in Innovation Systems.

2. What is Economic Complexity?

Economic Complexity is a framework building on earlier evolutionary and institutional literature (Hirschman 1958, Cimoli and Dosi 1995, Teece, et al. 1994) to tackle the complexity of Economic systems by describing economics as an evolutionary process of globally interconnected ecosystems. The main advance with respect to the previous literature is using recent development in *network science* and *complex and dynamical systems* (Hausmann and Klinger 2006, Hidalgo and Hausmann 2009, Tacchella, Cristelli, et al. 2012) to separate the random noise from the underlying signal. The Economic Complexity framework shifts the focus of economic analysis from aggregate quantities (*What is the GDP of the country? How many patents are published?*) to their disaggregation (*In which industrial sectors the country specializes? Which patents are published?*) with the aim to provide information that is complementary to more traditional analysis. The shift in focus gives the opportunity of impacting several cross-cutting themes and answer quantitatively to several policy relevant questions that could be otherwise answered only qualitatively, or in specific case studies, or by ad hoc metrics.

[1] See "EU losing share in global manufacturing value chains", JRC Science for Policy Brief, June 2018

[2] See "Innovation and Industry: Policy for the next decade", JRC Policy Insights – Industrial R&I, December 2017, Innovation and Industry

[3] See "For a Transformative Industry & Innovation Strategy", JRC Policy Insights – Industrial R&I, February 2018, Innovation and Industry

This policy brief highlights the potential of the methodology to tackle different policy questions with a series of structured examples. Far from covering all possible uses of the Complexity techniques, these examples showcase to potential of these techniques to inform the relevant stakeholders and encourage dialogue.

3. The Geographical Dimension

The first dimension of analysis that Economic Complexity can tackle is to quantitatively measure the intangible capabilities of countries and regions, the complexity of their economies or innovation systems, by looking at the different activities they specializes into. Indeed, for a country to be able to perform complex activities, it requires advanced capabilities. The Economic Complexity framework is able to use this to extract information on countries capabilities by looking at the activities that the country specializes into.

Most of the early literature in Economic Complexity focused on exporting activities to measure the complexity of the economy. This brief will focus in particular on the Economic Fitness metrics (Tacchella, Cristelli, et al. 2012). Quantitative testing of such metric shows how the complexity of the economy gives information on future GDP trajectory (Pugliese, Chiarotti, et al. 2017), allowing to disentangle countries with similar GDP but very different growth prospects. A recent study in Nature Physics (Tacchella, Mazzilli and Pietronero 2018) showed how with this framework it is possible to forecast countries GDP better than the state of the art.

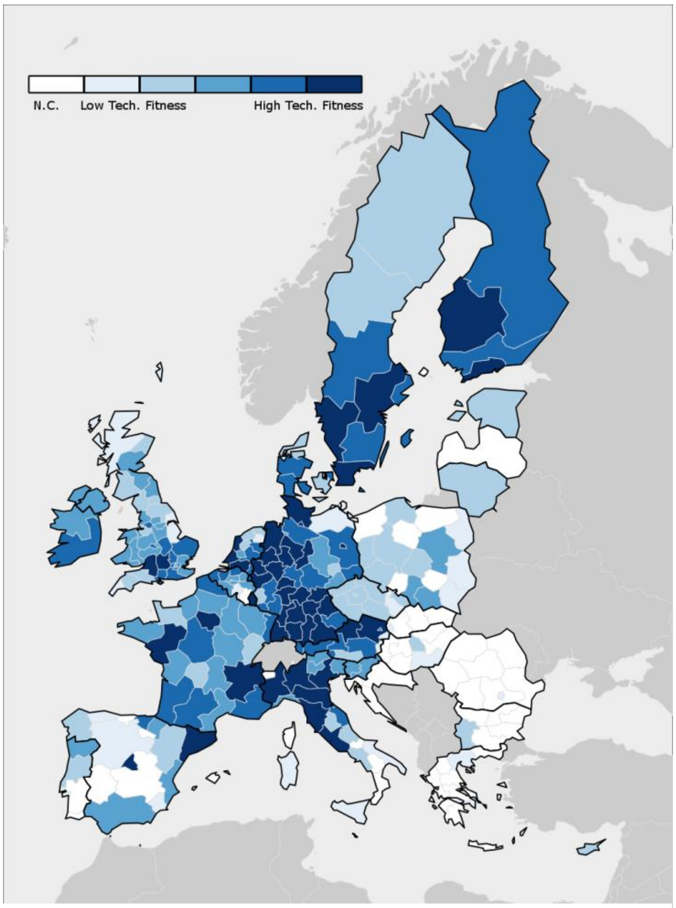


Figure 1 Technological Fitness of European NUTS 2 regions in 2015. Technological Fitness is a measure of technological diversification weighted for the complexity of the fields in which the region is specialized into. N.C. regions are regions for which there are not enough patents in the database. The rest of the regions are split in equally populated quintiles.

A similar technical framework can be used to extract information on the regional or national innovation system by looking at the different innovation activities – in terms of the different technological fields with relevant industrial innovation – present in the region or country. For many relevant technological fields this information is well measured by looking at patent data. Many studies looked in the past at patent data through the lenses of Economic Complexity techniques to characterizes firms (Breschi, Lissoni and Malerba 2003, Nesta and Saviotti 2005) and more recently regions and cities (Boschma, Balland and Kogler 2015, Balland, et al. 2018)

This brief introduces the Technological Fitness of a region. It is a measure of technological diversification, where each field is weighted with its relative complexity. This relative complexity is a measure of the technological capabilities required for a region to have a comparative advantage in that field: the higher the complexity of a field, the more ahead in the capability ladder that field is. Practically, the technological complexity of a field is computed using the Fitness algorithm applied at the country level (see the methods section for more details). It is therefore computed endogenously to the network approach, without any external source of data: from the complex systems point of view, it is an emerging property of the system.

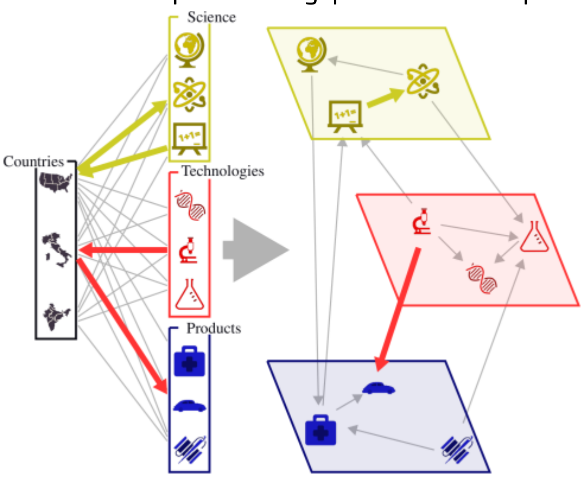
Interestingly, this methodology allows us to perform analysis at different aggregations. In figure 1, some preliminary results measuring the Technological Fitness of all EU NUTS2 regions are shown. It is important to notice that, although this figure agrees with the common understanding of the innovation potential of different European regions, it is built without the help of any extensive variable: to compute the Technological Fitness it was not used directly any information on *how many* patent applications were deposited by companies based in the region, but only information on the technological fields of these patents, *which* technologies were represented.

This information is readily exploitable by policy makers, as it allows quantifying in one single number the innovation potential of regions and their capabilities. More relevant however is the identification of which capabilities are present in each region, for example in relation to specific industrial and policy goals like the creation and support of industrial clusters. This will be the focus of the next exercises.

4. Innovation as one part in a complex system

The Economic Complexity framework is particularly well suited to understand complex systems like the innovation system, i.e. systems where different domains (institutions, science, industrial innovation, industrial production, trade, jobs, demand…) interact in a non-trivial way at each geographical scale. In particular it is possible to look at how the presence of activities in different domains in the same area interacts with each other. For example, if a region reveals a scientific focus in condensed matter physics this could be a signal of the presence in the region of capabilities allowing industrial innovation in material science. In the Economic Complexity framework it is possible to extract such information in a unified quantitative way, by looking at co-occurrences between activities (Pugliese, Cimini, et al. 2017). This can help informing policies. A competitive advantage in specific markets and export of specific products can be driven by specific scientific and technological capabilities (Bozeman 2000). It is therefore possible to look if the presence in one country of scientific or technological activities in one year correlates with the successful export of specific products in a future year to understand which technological and scientific fields are relevant to the export of specific products. Comparing this correlation with the probability of random events it is possible to extract the signal from the noise. In this way, knowing the innovation and scientific capabilities of countries can inform on which related products the country could be able to export.

As an example, the brief will showcase the technique for a crucial export market in which Europe traditionally lags: Lithium-ion batteries. Batteries are indeed at the centre of several important high technology value chains, from electric car to portable electronics. The technological fields significantly related to the export of Lithium-ion batteries are highlighted in Figure 2: sections G (Physics) and H (Electricity) are predominant, while in the other sections there are specific sub-sections that are relevant. Notice again that this technique did not use any previous knowledge of what Lithium-ion batteries are, but identified relevant technologies simply by exploiting the fact that countries that were to export



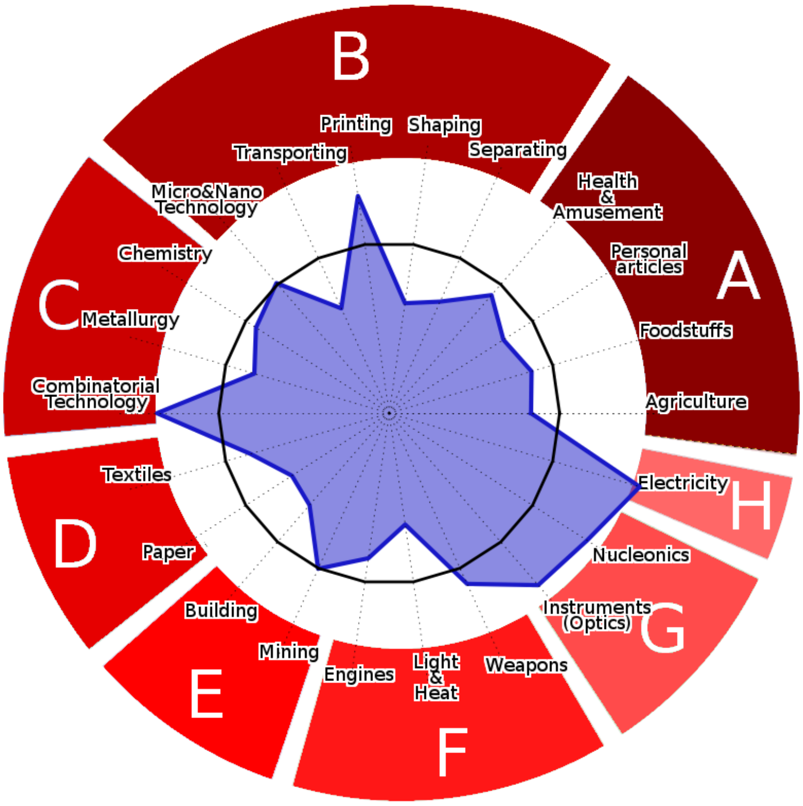


Figure 2 (above) Scheme of the process. (right) Technological fields representing early signals (3 years delay) for a competitive advantage in the export of a specific product (in this case, Lithium-ion batteries). The blue area represents the strength of the signal, the black line represents the 95% significance level. Source: Pugliese et al. 2017 and author's computations that product in a year were focused on those technologies three years earlier more than randomly. This allows for example to move the analysis to a finer disaggregation, by looking not at sub-sections but at classes and subclasses (not "Instruments", but "Measuring Electric and Magnetic Variables") or even finer disaggregations ("Arrangements for measuring time integral of electric power or current, e.g. electricity meters").

5. The identification of specialization opportunities

The results of section 2 and 3 can be combined to provide insights, for example, on which countries or regions have a technological advantage in specific exporting activities by looking at their innovation profile. This is clearly extremely policy relevant in the design of possible Smart Specialization Strategies for different regions. Economic Complexity has been proven a valuable asset for the S3 platform (Balland, et al. 2018), that used the Economic Complexity framework to prove that regions should focus on technologies related to their previous baskets. With this novel technique however it is possible to link the technological capabilities of regions directly to specific export markets.

A **first example**, relative to the technological capabilities related to the export of Lithium-Ion batteries can be seen in Figure 3. Through the map developed in the previous section, we compute the regional technological fitness by looking only at the technologies that are linked to future performances in the export market for Lithium-ion batteries. By combining this information with the presence of actual regional capacity related to Lithium Ion batteries, the analyst can immediately provide relevant advices to policy makers interested in regional specialization.

While the map in figure 3 is not radically dissimilar from the map in figure 1, the differences show qualitatively the potential of this approach: the measure was able to select, out of the various regions with an excellent innovation system, those with a well-known focus on electronics. By looking at the top 10 in table 1, it is possi a better understanding of it. Indeed, together with regions that are always among the top (Île-de-France, Lombardy, London, Oberbayern), there are well known regions specialized in electronics like North Brabant (headquarter of Philips) and Stockholm (headquarter of Erikson) and Lombardy itself (seat of the Italian half of STMicroelectronics). Other cases, like Espoo, are just outside the top 10 but still, as visible in the map, among the top regions in Europe.

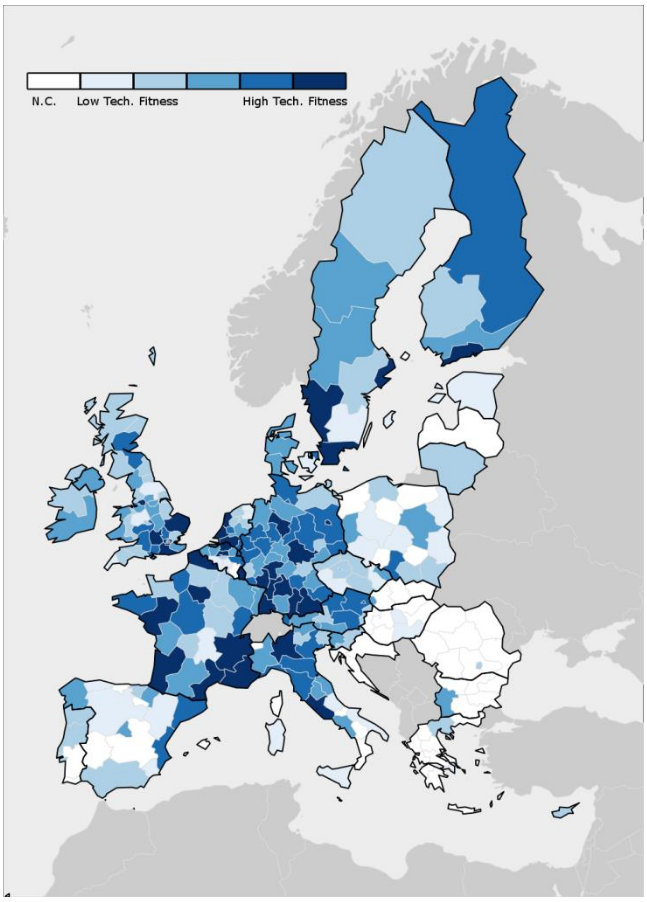


Figure 3 Technological Fitness by NUTS 2 region in 2015, limited to the technological fields relevant for the export of lithium-ion batteries. N.C. regions are regions for which there are not enough patents. The rest of the regions are split in equally populated quintiles.

A **second dual exercise** is naturally feasible with the same technique. It is indeed possible to look, for one region, to the exporting markets where it has a technological relative comparative advantage with respect to other markets. In practice, we will focus here on Provence-Alpes-Côte d'Azur and we will see in which export markets it performs better with respect to other European regions in terms of market specific Technological Fitness. The results are shown in Table 2. It is important to notice that, since this measure is based on technological capabilities, it works best in identifying competitiveness in high-technology products where

Table 1: Top 10 regions accordingly to their Technological Fitness related to the export of Lithium-ion batteries	
1.	Île-de-France
2.	Karlsruhe
3.	North Brabant
4.	Stockholm
5.	Lombardy
6.	London
7.	Stuttgart
8.	Greater Manchester
9.	Provence-Alpes-Côte d'Azur
10.	Oberbayern

technology is the main stage of competition. Indeed, by looking at High tech products, we see not surprisingly a strong prevalence of helicopter related markets (the seat of Eurocopter, the Helicopter division of Airbus, is in Marignane, near Marseille). It is worth it to point out one last time that this measure has been produced without having any information on the specific export basket of different regions, but only looking at the technological fields where they were patenting: the capabilities of the region in the Helicopter industries is an emerging property of the complex system analysis done at the country level to connect technologies and products, and it is not an input of the exercise.

Notice that this quantitative exercise, based only on technological capabilities, is complementary to any qualitative study and forms a basic objective and quantitative foundation for it. It does not in any way substitute the need of in depth analysis of the reality of the region in a combined effort with all stakeholders.

Table 2: Export Markets where the region Provence-Alpes-Côte d'Azur shows a relevant Technological Fitness with respect to other European regions.
High-Tech products
Navigational instruments for aeronautical or space navigation
Turbo-propellers engines (below 1100kW)
Engines; reaction engines, other than turbo-jets
Machinery; for liquefying air or gas, not used for domestic purposes
Aircraft and spacecraft; parts of aeroplanes or helicopters
Radar apparatus
Medium-High-Tech products
Engines; parts, for engines and motors
Heat pumps
Clocks; electrically operated
Medium-Low-Tech products
Paraformaldehyde
Vermiculite, perlite and chlorites
Printed matter; pictures, designs and photographs
Low-Tech products
Vegetable oils; cotton-seed oil
Gum Arabic
Cotton yarn
Silk Waste
Diamonds
Ferro-alloys; ferro-niobium
Steel, stainless

6. Policy Impact of the analysis and concluding remarks

The proposed exercises give an immediate grasp of complex issues related to local innovation systems. Indeed, while EU as a whole is lagging in several high technologies industries and value chains, the aggregate picture is not informative. On one side, a regional perspective can give a better understanding of the distribution of technological capabilities in the continent. At the same time, not all high technology markets are similar and the Economic Complexity framework allows grasping information on specific regional technological capabilities in specific export markets. This has a clear impact when designing the Smart Specialization Strategy for regions and sectors. Looking for example at the Lithium-ion batteries market it is possible to observe in Table 1 which regions have the technological capabilities to host a potential Lithium-ion battery industry in EU. In parallel, Table 2 tells us the export markets were a region – in this case Provence-Alpes-Côte d'Azur – shows a technological comparative advantage with respect to other EU regions. It is therefore possible for the policy maker to easily grasp the details of a complex issue, reduced now to a short list of options in a bilateral network: the best regions for a market and the best markets for a region. Combining this information with qualitative and quantitative knowledge on the specific market and on the specific region it is possible to provide informed policy strategies.

As mentioned in the introduction, this Policy brief is mostly meant to show the potential of this new framework. Being this a novel methodology and a new institutional activity in the JRC, most of its potential is still untapped, waiting as much for more refined answers as for relevant research questions. Both are relevant aspects of the future work on the topic at JRC. A relevant characteristic of the methodology is that – thanks to its quantitative approach, the well-defined assumptions, and the focus on forecasts – it is falsifiable. Since the results of forecasting can be tested on previous data in a standardized way, the methodology can achieve the high level of confidence typical of the scientific method. This process of validation of the methodology will be a central aspect of the future work on the topic. In parallel, it is possible to expand the scope of analysis toward other policy-relevant research questions. This policy brief should kindle a debate with other units and other DGs to intercept the interest of different groups and to apply this methodology and the capabilities developed in this project in different settings.

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Data Source and Methodology

The general workflow in EC is to start from micro-data at the level of industrial agents to build a network binary structure connecting countries and regions to the activities that the firms localized there excel at. This network – connecting technological, scientific or production activities to a geographical location – is the basic element of analysis. This map is used to infer information on the hidden layer of unobservable capabilities that was behind its dynamical evolution.

In this work two sources of data are used: patent data – localized through their applicant at the country and region level – extracted from OECD REGPAT (Maraut, et al. 2008), and trade data at the country level from UN COMTRADE.

The methodology used is in part novel and in part published and validated by the academic community. In particular in the first exercise it is adapted for technologies the methodology recently developed for export products called Exogenous Fitness (Operti, et al. 2018). The idea of Exogenous Fitness is to run the Fitness-Complexity algorithm in one setting in which there is abundance of information (all the World countries) to extract the complexity of products, and then use those complexities to infer the Fitness of geographical entities in a different setting where there is not as much information (subnational regions). As mentioned already, the idea of adapting techniques developed for products to be used with patents and technological classes is not new (Breschi, Lissoni and Malerba 2003, Balland, et al. 2018), as there are many similarities in the data structure.

The second exercise is heavily inspired by previous academic work (Pugliese, Cimini, et al. 2017), and the interested reader is pointed to such work for more information. Finally, the third exercise is introduced here. While it has foundation in well tested scientific work, at this point it is just a prototype that needs to be validated.

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