Economic Geography and Complexity Theory

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Abstract

The global economy operates as a complex system that allocates resources in a decentralized way across myriad agents. Over time, it exhibits an impressive rate of collective learning as evidenced by its growing productivity and the expanding variety of output it generates. However, growth, productivity and learning are not distributed equally across locations. On the contrary, wealth, opportunity, economic activity and innovation tend to all concentrate in a relatively small number of affluent places. Various strands of complexity Science have contributed to our understanding of these phenomena. However, they have done so in disconnected debates and communities. In this chapter, we use the framework of Economic Complexity to synthesize insights derived from three distinct literatures: urban scaling, evolutionary economic geography and global production networks. Economic complexity proposes that production requires access to capabilities, such that increasing the variety of economic production requires acquiring or accessing new capabilities. From this synthesis, we derive a research agenda that aims to understand how local economies develop, not only as individual units exploring their adjacent possible, but as parts of a system that allows local economies to mix their capabilities with those of distant counterparts by relying on the interplay of multinational corporations, global value chains and institutions to coordinate interactions at the local and global scale.

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1. Introduction

Modern economies combine a large range of inputs from various places to produce a wide variety of highly complex goods and services. Moreover, they manage to do so in quantities that meet consumer demand surprisingly accurately. The self-organized nature of this process has fascinated generations of economists since the works of Adam Smith. An early explanation for capitalist economies' success pointed to prices as an efficient information organizing principle (Hayek, 1945) that allowed a system without central control or planning to constantly adjust to changing consumer preferences and producer technologies. However, with time, evidence gathered that the bandwidth of price signals is too narrow for the complex coordination tasks that today's production processes require. Accordingly, economies are more than just abstract marketplaces where anonymous buyers and sellers meet. Instead, economies employ a mixture of narrow and high bandwidth communication, that utilize anything from markets to networks, corporate hierarchies and institutions to structure these interactions within and across territories.

Here, we discuss recent complexity-theory based advances in the field of economic geography that start from an *explicit* notion of complexity, namely, the complexity of products and services that a city or region produces. Following this literature, complexity is here taken to mean the number of inputs or *capabilities* required for an output to be produced. This starting point brings the role of firms to the fore – as well as of the value chains they participate in – as principal vehicles to coordinate an increasingly fine-grained division of labor. In doing so, it helps understand the diverse trajectories of urban and regional development that we observe in the real world as a result of differences in the complexity of goods that companies are capable of producing and of the territorial institutions that support the division of labor within and across companies.

In its explicit representation of "recipes" that transform inputs into outputs, this complexity approach differs from past contributions in complexity theory. In early theorizing, complexity scholars adopted the view of the economy as a self-organizing system (Krugman, 1997) in which the historical evolution of either transportation technology or entrepreneurship generates core-periphery structures in space. In the former case, geographic clustering is understood as a non-linear response to a fall in transportation costs, causing production to concentrate geographically (Krugman, 1991). In the latter case, geographic clustering is driven by a cumulative process of firm formation in which entrepreneurs establish spinoff companies close to their parent companies (Klepper, 2010). Instead, the more recent complexity-theoretical contributions in economic geography follow an evolutionary approach, modeling the growth of economies in terms of their expanding capability bases that gives rise to an increasing variety and complexity of the products they produce.[1] Here, we review this literature to identify neglected questions and directions for future research.

2. Economic complexity

In the late 1990s and early 2000s, a new research program emerged that was inspired by evolutionary economics (Nelson and Winter, 1982). This so-called Evolutionary Economic Geography (Boschma and Frenken, 2006) approach built on concepts taken from the literature

[1] Evolutionary economics has traditionally embraced metaphors from evolutionary biology. In the present case, capabilities are often regarded as defining an economy's genotype, whereas the concrete products and services that they allow producing are analogous to phenotypes (see Schetter et al., 2024). As in biology, whereas genotypic information is hard to observe, the phenotypical information is immediately available from the structure of its output.

on innovation and industrial dynamics. For instance, it analyzed the spatial consequences of industry life cycles (Klepper, 2010), showing that geographic concentrations and clusters undergo life cycle dynamics (Menzel and Fornahl, 2010; Neffke et al., 2011a). This literature also borrowed the biological metaphors of mutation and selection. For instance, like industries, geographical clusters are assumed to start with an expansion of novelty ("mutations") to later undergo rationalization in a so-called shake-out period ("selection"). Another example is the work that stresses the value of variety in economic growth, and in particular, related variety (Frenken et al., 2007).

One particularly prominent idea in EEG is that regional development is path-dependent (Martin and Sunley, 2006). When this idea is applied to the economic composition of a local economy – for instance, to describe the economy's export, industrial or occupational composition – it implies that regions diversify into activities that build on their historical strengths. That is, regional diversification can be seen as a branching process (Frenken and Boschma, 2007), a proposition that was later verified empirically (Neffke and Henning, 2008; Neffke et al., 2011b).

The idea of economic development as branching along paths of related activities mirrored work that emerged in parallel in complexity science by a group of scholars working on what they termed *economic complexity* (see also chapter 7 in this volume).[2] A core argument of this new generation of economic-complexity scholars holds that the total body of collective knowledge in a society exceeds by far the cognitive capacities of individual workers (Hidalgo et al. 2007; Hidalgo and Hausmann, 2009). In response, societies distribute knowledge across an increasing array of experts that specialize in different, yet complementary tasks (Neffke, 2019). To organize this distributed knowledge, societies need to orchestrate the interactions between individuals in teams (e.g., firms) and teams of teams (e.g., value chains). The depth of the division of knowledge that can be achieved in this way is limited, not by the extent of the market as in Adam Smith, but by the costs of coordination (Becker and Murphy, 1992). From this perspective, spatial concentration can help lower coordination costs, because face-to-face interactions make coordination of complex distributed knowledge much easier on short distances than over long distances.

Hausmann and Hidalgo (2011) model economies using the notion of capabilities as the set of inputs that are needed to produce a specific output. These capabilities are strictly complementary – as in a Leontief production function – such that production fails even when a single capability is unavailable, as for instance in Kremer's (1993) O-ring model. Consequently, regions move up the development ladder when their economies acquire a new capability. This new capability can be combined with existing capabilities in new combinations to allow for the production of new products, expanding the economy's variety of economic activities in a way that is consistent with empirical evidence (Van Dam and Frenken, 2022; Inoua, 2023).

Moreover, with a growing number of capabilities, products that are added to an economy's portfolio will on average be more complex than existing products, raising the economy's complexity. The greater number of capabilities that complex products require also make them harder to imitate. Complex products therefore often command higher prices. Provided that

[2] EEG and the work in economic complexity differ in a subtle way in how they motivate the prediction of related diversification. In the EEG literature, which emerged from the literature in evolutionary economics about innovation dynamics, related diversification is an expression of learning between technologically or cognitively related activities. In the literature on economic complexity, related diversification was originally motivated through economies of scope in production, where activities are related if they can share similar inputs, or "capabilities."

workers have some bargaining power, this increased profitability will be shared through higher wages. This explains why the average complexity of products in a city tends to be closely related to average incomes, as well as why complexity is often regarded as a measure of economic development (Hidalgo and Hausmann, 2009).

Following this logic, Frenken et al. (2023) argue that, because diversification is essentially a process of capability acquisition, the process of diversification itself tends to take the shape of related diversification. Moreover, capability acquisition is unlikely to be random. This is because the more complementary a new capability is – in terms of how easily it can be combined with existing capabilities –the greater the number of new products that can be produced becomes. Note, however, that these new products will be related to existing ones, making diversification even more prone to be related rather than unrelated.

Conceptually, the relatedness between two industries is defined as the number of capabilities that two industries have in common. However, directly measuring this relatedness is challenging. Consequently, capabilities themselves often remain unobserved in economic complexity frameworks. Instead, scholars have developed indirect ways to measure relatedness using co-occurrence analysis as pioneered by Hidalgo et al. (2007) and further developed in an information-theoretic framework by Van Dam et al. (2023). Moreover, recently some efforts have been undertaken to observe capabilities directly (e.g., Schetter et al., 2024). Regarding estimating the complexity of an economy, substantial debate remains about what is the best way to infer the number of capabilities in an economy from data on the structure of economic output (e.g., Hidalgo and Hausmann, 2009; Tacchella et al., 2012; Mealy et al., 2018; McNerney et al., 2021; Inoua 2023, see also chapter 25 in this volume).

3. Urban Scaling

Another approach to make sense of the spatial concentration of economic activities emerged in urban complexity research, where scholars identified striking empirical regularities in the spatial concentration of economic activity: urban scaling laws (Pumain et al., 2006; Bettencourt et al., 2007). Urban scaling laws describe how the size of a local economic activity grows with city size. In a log-log plane, basic services tend to scale linearly with city size. That is, the per capita intensity of such services tends to be similar across cities of different sizes, reflecting that such services locate close to demand due to high transportation costs. Infrastructure, instead, tends to grow less than proportionally with the size of a city. That is, infrastructure tends to scale sublinearly with city size, indicating that there are economies of scale in keeping a city connected. By contrast, knowledge-intensive activities grow more than proportionally with city size. Indeed, R&D, patents and total wage sums all scale superlinearly with city size.

Despite having developed in a disconnected manner, urban scaling and the new work on economic complexity are not in contradiction. On the contrary, Gomez-Lievano et al. (2016) show that urban scaling laws can in fact be derived from an economic complexity model that centers on capabilities. To do so, Gomez-Lievano and his co-authors propose that different types of social activities require different capabilities.

Here, we follow the presentation of a closely related model in Gomez-Lievano and Patterson-Lomba (2021). For an individual to engage in an activity, they must have access to all capabilities that the activity requires. However, they need not possess all capabilities themselves, but can borrow some from the urban environment in which they reside. Formally, the authors propose that the probability that an individual i in city c participates in activity p can be modelled as:

$$P(X_{icp} = 1|D_c) = s_i^{M_p - D_c} \quad (1)$$

where M_p is the total number of capabilities that activity p requires, which can be thought of as the activity's complexity. Furthermore, s_i is the probability that individual i has a certain capability (which is here assumed to be the same for all capabilities) and D_c represents the number of capabilities required by p that are available in city c.

In words, eq. (1) states that the likelihood that an individual participates in an activity, conditional on their city offering access to D_c of the capabilities that this activity requires, equals the likelihood that the individual has all other required capabilities themselves. Furthermore, let us assume that city c offers access to capabilities at constant probability r_c. Generally, r_c will be a function of city size and Gomez-Lievano et al. (2016) argue that the number of capabilities that can be accessed in a city grows linearly with the logarithm of its population size.[3] Now, conditioning out D_c yields the following expression for the unconditional probability that i participates in activity p:

$$P(X_{icp} = 1) = \sum_D s_i^{M_p - D} \binom{M_p}{D} r_c^D (1 - r_c)^{M_p - D} \quad (2)$$

This simplifies to $\left(r_c + s_i(1 - r_c)\right)^{M_p}$, which, for small s_i and r_c can be approximated by:

$$P(X_{icp} = 1) = e^{\ln\left(P(X_{icp}=1)\right)} \cong e^{-M_p(1-s_i)(1-r_c)} \quad (3)$$

This simple set-up predicts that the size of an activity in a city scales with population size exactly according to the scaling laws that had been documented in the urban scaling literature.[4] Moreover, taking the derivative with respect to the activity's complexity, M_p, shows that the more complex an activity is (i.e., the more capabilities the activity requires) the steeper the scaling relation gets. This proposition was later confirmed by Balland et al. (2020).

4. Value chains

What are capabilities? Gomez-Lievano et al.'s (2016) paper offers a useful clue: capabilities of cities need to be accessible to actors within, but not outside the city. Neffke et al. (2018) furthermore argue that capabilities bear a commonality with resources in the resource-based view of the firm as developed in management science. Accordingly, for something to count as a capability, it needs to be valuable, rare, non-substitutable and hard to imitate (Barney, 1991). For regional capabilities, much of the same holds: they need to be valuable and rare. Moreover, they need to be hard to substitute, a central assumption in economic complexity as we have seen above, and they need to be specific to economic activities. What sets them apart from firm-level capabilities is that they must be hard to access from *outside* the region, but be non-rivalrous among firms *inside* the region. Plausible candidates are skilled pools of workers, specific types

[3] The authors offer two explanations for this functional form. The first relies on models of skill-biased social-learning with incomplete inference developed in evolutionary anthropology (Henrich and Boyd, 2002). The second assumes that cities draw capabilities proportionally to the number of their inhabitants. Under certain assumptions, the expected number of different capabilities that cities draw increases linearly with the logarithm of population size.

[4] This would be captured by population size raising the probability that a city has any capability, i.e., $r_c \sim \log(population_c)$. Gomez-Lievano et al. (2016) derive further expressions for the intercept and variance around a scaling law, showing that these also depend on the complexity of the activity. In particular, more complex activities will have lower intercepts, meaning that they are relatively rare, and exhibit higher variance around, predictions that hold empirically for a wide range of social activities, ranging from crime and health to innovation and economic activities.

of infrastructure and specialized local suppliers of goods and services with high transaction costs.

Frenken et al. (2023), however, point out that, while the economic-complexity framework is consistent with evolutionary patterns towards increasing variety and complexity in cities and regions, the framework remains limited in that it views “regions as ‘containers’ of capabilities without explicitly accounting for the relational structures between firms operating in value chains within and across regions.” Instead, urban and regional economic development needs to account for the fact that modern production is organized in value chains that connect firms that may be, but generally are not all, co-located in the same city or region. Through these firms, local actors can tap into capabilities that reside in other cities.

Furthermore, more complex products will tend to have longer value chains, aggregating knowledge that is distributed across greater numbers of firms and their workforces. As value chains spread across sectors and geographies, urban and regional development becomes driven by more than the set of locally available capabilities and, increasingly, comes to depend on the ability of a city or region to participate in complex value chains. To do so, local economies require effective institutions that reduce transaction costs in value chains and collaboration costs in collective knowledge production.

While economic-complexity theory emphasizes that local economies tend to diversify and to increase their variety, adding a value-chain perspective also allows theorizing about specialization. By inserting local firms into multiple value chains, a city can exploit a regional focus on capabilities in support of certain common components of value chains, such as R&D, production, logistics, marketing and IT. This type of specialization is known as *functional specialization* in urban economics (Duranton and Puga, 2005). In this way, a region can sustain a large degree of product diversification, while at the same time maintaining only a limited set of capabilities associated with specific functions (Frenken et al., 2023). Examples of this are logistical hubs such as Rotterdam, financial centers like London, or IT hotspots like Silicon Valley.

A value-chain perspective on economic complexity also allows integrating of theoretical questions related to development and trade. The more open a local economy is to trade, the less it needs to rely on a local presence of capabilities for participating in high value-added, complex production processes. However, the same openness that supports development through value-chain participations also exposes it to value-chain disruptions. Our understanding of such trade-offs is currently limited but will benefit from efforts to map high-resolution supply networks by exploiting detailed, high-frequency transaction data derived from, for instance, value-added tax data (Pichler et al., 2023).

5. Conclusion

The economic-complexity framework as applied in economic geography reasons from local capabilities as the genotypes that express themselves in phenotypes of specific products or services that derive from these genotypes. In this framework, urban and regional economic development can be modelled as a process of related diversification, where locations acquire capabilities that raise their economy’s complexity. Moreover, urban scaling laws can be derived from this same framework. However, as economic geographers have long stressed, production is nowadays often organized in value chains that span across multiple regions worldwide. Consequently, economic development is not just conditioned by local capabilities but also dependent on the institutions that support local firms to participate in value chains that coordinate production across localities. This points to the value of an augmented capability framework as an analytical basis on which evolutionary and network approaches in economic geography can be integrated. Connecting work in complexity science on supply networks to the capability-based framework that studies how capabilities are coordinated across local economies through value chains should therefore present a particularly promising direction for future research.

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