Infrastructure Connectivity

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Introduction

Connectivity has become a defining feature of the modern economy and one of the significant trends of the 21st century. This is reflected in the increasing demand for resources to be invested in linking communities, economies and countries. In the Asia-Pacific region alone the Global Infrastructure Hub (GIH) estimates that investment in connecting infrastructure will more than double in ten years to reach $2.5 trillion per year by 2020 (Marsh and McLennan 2017). However, the needs remain significant, with the Asian Development Bank (ADB) estimating that Asia-Pacific region needs to invest some $26 trillion by 2030, while the global demand for investment in infrastructure over the same period is estimated by McKinsey Global Institute (MGI) and OECD at between $4.7 trillion and $6.0 trillion per year (MGI 2016; OECD 2018;). Middle-income countries account for about a quarter of this demand (ADB et al forthcoming). There are multiple initiatives to meet the growing demand for transport, energy and telecommunications networks spanning the globe, to lay the basic infrastructure for economic, political and social interactions of even greater intensity.

Connectivity is high on the policy agenda of most countries and global development and financial institutions. With the huge sums of money already being spent or needing to be spent, a question that is often taken for granted is why is it important to enhance connectivity? Why does connectivity matter? This short note offers a succinct answer to this question. After all, while there is little controversy over the resources that need to be invested in connectivity, there are varying expectations of what connectivity is intended to achieve. Suffice to say, improving connectivity is considered desirable as a public good. However, the transmission mechanisms for the impacts it is expected to have on economies, firms and society are at best taken for granted if at all they are explicitly stated.

What is connectivity? Different infrastructure financing agencies employ varying definitions of connectivity. An intrinsic characteristic of connectivity is that it is synonymous with networks, which in turn are a set of interconnected nodes. A node can be a person, firm, city, country or other spatial entity. A common thread running through the definitions is that connectivity is a multi-layer concept comprised of different types of networks, including those that are physical and virtual. It has hard and soft dimensions and includes concepts of access that determine the impacts as experienced by households, firms, cities, countries and regions. Connectivity can be explored at different scales, from the local to the regional and global scales. Connectivity is therefore, an attribute of a network and is a measure of how well connected any one node is to all other nodes in the network. The value of connectivity and therefore its significance lies in the role a node and its hinterland plays or is expected to play in a network, the cost of accessing that node and the reliability of connecting to the node. In this note we associate connectivity with interaction between social and economic agents along the links of, or in the nodes connected by, a network. When the cost of interaction is low then we are likely to achieve complete connectivity whereas when the cost is high interaction is limited.

The science of networks provides a common language that helps to unify the tools and approaches to understanding connectivity and why it matters. Network analysis is useful in showing how any connectivity initiative influences the distribution of power between the connected parties, be it regions, cities, firms or communities. Through a network approach we can understand how power is inherently relational. A node that is connected to other nodes has opportunities or faces risks only because it is connected to other nodes. It is for this reason that the position and importance of a node is fundamental in network science.

Connectivity has several important attributes and in its most common form has a physical domain and information. The large resources aimed at connectivity are therefore aimed at lowering costs, often with an emphasis on physical connectivity. However, and in addition, all network centric concepts share the simple idea that information sharing is a source of potential value. In commerce such value is measured in terms functionality, reliability, convenience and cost.

In addition, the quality of the connections matters. It is often the 'strength of weak ties' that sets the limits of interactions in a network. And there is ample empirical evidence that an entity (person, firm, country) can enhance its network by focusing more on their weak connections (Derudder, Liu and Kunaka, 2018). Improving existing weak connections to other networks brings benefits to the network at large. This is one reason why high priority is often attached to investments in those parts of a network that are weakest, such as having limited capacity, are in poor condition or have low performance.

Ultimately, connectivity is largely about increasing interactions, productivity, competition, and market opportunities between cities (see Straub, Vellutini, and Warlters 2008), and consequently, interdependence of multiple economies.[1] The intensity of interaction, both in terms of transportation and communications networks is a useful measure of connectivity between cities. To assess levels of connectivity, a measure such as centrality can be used. This can shed light on how well connected and integrated cities are along a corridor or between any group of countries, both with each other and to the rest of the world.

Why Connectivity Matters

Infrastructure connectivity within and between countries matters for several reasons, chief among them are the following three:

[1] "Infrastructure and Economic Growth in East Asia": https://openknowledge.worldbank.org/bitstream/handle/10986/6520/wps4589.pdf

Economic Growth

During the recent global financial crisis many advanced economies implemented various types of fiscal stimulus plans. The plans were based on Keynesian economics where increased government expenditure is used to stimulate demand and recover from a depression. A significant proportion of the deficit spending went towards infrastructure, particularly transport and energy networks. Feyrer and Sacerdote (2012) found that in the United States the fiscal stimulus expenditure on infrastructure (and low-income households) did have an expansionary effect. In fact, PricewaterhouseCoopers (2016) estimates that one extra dollar spent on infrastructure in Canada increased GDP in the long term by between $2.46 and $3.83. More generally, Straub (2008) reviewed research literature on infrastructure and growth in developing countries and found that many of the studies established a positive and significant link between infrastructure and development outcomes. Evidence abounds elsewhere on the positive effects that connectivity infrastructure has on the economy even at the micro scale. In addition to the short-term impact of investments in connectivity infrastructure, there are also medium and long-term effects in strengthening the foundation for future economic growth, including through making labor markets more efficient and productive.

Supply Chain Efficiency

Global value chains (GVCs) are a defining characteristic of the 21st century economy. They have totally transformed the links between firms and countries and redefined the relationships between trade and competitiveness. The growth of GVCs has been in tandem with improvements in transportation and communications technologies, which have allowed the fragmentation of production in tasks in different locations. Taglioni and Winkler (2016) maintain that among the actions that Governments seeking to join GVCs should create are world-class relationships and climates for foreign tangible and intangible assets. Both actions depend in part on connectivity to international markets and border efficiency. This is the reason why international indices such as the World Bank's Logistics Performance Index and the WEF's Competitiveness Index are important as global indicators of performance and competitiveness. The connectivity of factories and the ability to contract across countries are key determinants of GVCs and the decisions firms make to buy and whether to do so domestically or internationally. Under such circumstances, poor connectivity can mean high costs, low speed, and high uncertainty and can increase the risk of exclusion from GVCs. Thus, successful participation in GVCs requires not just to efficient cross-border linkages, but also resilient and efficient domestic segments of supply chains.

In addition to connectivity for the flow of goods, information and finance, the era of GVCs has also increased the demand for countries to cooperate more with each other, especially in trade. In fact, Buchan, Fatas and Grimalda (2012) argue that connectivity has greatly increased the prospects of cooperation between countries, which in turn has facilitated trade and economic growth. It is not a coincidence that enhanced global connectivity and shrinking trade and transport costs has grown in tandem with a proliferation of regional and multilateral trade agreements. Recent research has demonstrated the potential of trade facilitation, often based on global rules, to reduce logistics costs and boost trade (Hoekman and Nicita 2010; Portugal-Perez and Wilson 2008). However, most of the studies focus on the link between logistics performance and aggregate national trade flows. This in part due to a recognition that whereas distance and geography are fixed, connectivity and logistics performance are subject to change through policymaking in individual countries.

While the national level analysis is necessary to assess how countries fare in terms of overall connectivity, a more granular approach is needed to understand how particular supply chains are affected by the effects of geography. A common approach is to explore logistics performance through the concept of supply chain connectivity. The World Bank and UN-OHRLLS (2014, 9) define supply-chain connectivity as “the ability of the traders in one country to effectively establish reliable supply chains with their customers or suppliers” — their performance being dependent not only on the transport route but also on the logistics business environment, which might even change at the product level. They further argue that supply chain connectivity ultimately not only depends on the quality of physical infrastructure, but also on the quality and sophistication of services, including customs and border control, and trade or transportation policies that affect logistics performance (World Bank and UN-OHRLS 2014). Similar arguments can be extended to the other network industries where reliability and cost, for instance of information technology services or energy supply, are more important attributes rather than just being connected.

Related to supply chains, some of the impacts of connectivity are at the local level. A few studies such as Raballand et al (2010) and Kunaka (2010) have applied more micro-level analysis by looking at the relationship between road infrastructure and road transport and the access of small producers to markets. They conclude that the hurdles to connecting to markets are not so much infrastructure related but more to do with supply chain organization and institutions. An example that illustrates this phenomenon is the effect that investments in Vietnam’s National Highway No. 5 (NH-5) had on the development of private industrial zones and the local spillovers that it has had. The ADB, DFID, JICA, and the World Bank (forthcoming) find that regions adjacent to the highway have experienced rapid structural change, transforming from agriculture to industrial production largely due to enhanced transport capacity and attraction of foreign direct investment. The firms along the highway are part of major global value chains with leading firms in Asia, especially Japan. Ultimately, it is the effects of connectivity on supply chains that will determine the magnitude of the effects in an economy and the small and large scales.

Resilience

Between 2010 and 2011 there were three events that had significant effects on global supply chains, which served to underscore some of the effects of global connectivity. The first was the eruption of the volcano Eyjafjallajökull in Iceland and the other two were the Japanese tsunami in 2011 and floods in Thailand the same year. The three events between them caused major disruptions to supply chains across the world, affecting auto and electronics production in seemingly disparate locations across the globe. The events underscored the interconnectedness of supply chains across the world and the importance of investing in diversified connectivity links. Improvements in connectivity have enabled firms to enhance their supply chain efficiencies and to maintain very lean inventories. However, such reliance especially in an era of global value chains, on a limited set of suppliers and the maintenance of centralized inventories has exposed firms to increased risks from disruptions in their supply chains. A disruption, even a short-lived one, in one location can have ramifications across the world. Understanding network resilience is increasingly important in any connectivity program or project.

Disruptions can be experienced also with whole countries, especially landlocked ones that are dependent on one major trade route for access to overseas markets. There are many such countries including Armenia, Bhutan, Malawi, Nepal, Uganda, among others. With such countries, the risks associated with connectivity based on a few options are quite high. When Uganda in 2008 experienced a few weeks of disruption to traffic flows along the route to the Port of Mombasa in Kenya and Nepal in 2015 a blockade of the border crossing at Birgunj into India the events resulted in prices spiking within short periods, and significant economic losses. Consequently, diversifying trade routes is not just matter of economic efficiency but economic survival for such countries.

Reliability of connectivity can therefore have significant effects for firms and countries. It has therefore become important for firms and countries to invest in redundancy systems so as to enhance their resilience in the event of interruptions. However, the economic costs of such redundancy are not always straightforward to estimate.

Measuring the Impact of Connectivity

Based on the objectives of connectivity initiatives identified above, there are some general approaches to quantifying connectivity. The impacts can be transmitted through different channels depending on the scale of analysis, ranging from the global to local scale. The tools that can be used to assess impacts and quantify their magnitude would have to be suited to the scale. Fortunately, there is an increasingly robust suite of tools that is available to appraise programs and projects. However, the wider effects are the ones that are the subject of ongoing efforts to make sure they are well captured during program and project appraisal. However, there is a generally a growing body of empirical evidence on the impacts that can be expected from connectivity initiatives.

Objective	Examples empirical evidence of impacts
Promoting growth and productivity	Leduc and Wilson (2009) established that during the global financial crisis each $1 spent on highways increased state annual output by $2
Enhancing access to markets and opportunities	Djankov, Freund and Pham (2006) estimated that a day saved in international trade shipments was equivalent to 1% trade volume or a distance of 70km
Building network resilience	Wilmsmeier and Notteboom (2009) estimated that doubling liner shipping connectivity reduces freight rates by 15%

Some of the main issues to be considered for each objective of connectivity are summarized below.

Quantifying Connectivity for Growth and Development

Connectivity investments typically are large and lumpy, and it is often difficult to estimate their impacts. Cost benefit analysis is one of the most commonly used and well established techniques for estimating some of the direct impacts of connectivity, and is particularly employed to assess the impacts of specific projects. But it is generally not utilized for programs or wide area network assessments, nor for analysis of general policy measures. Cost benefit analysis has been found to be unsatisfactory for other reasons chief among them, its inability to assess the underlying conditions of some of the key dimensions of connectivity such as contestability of markets, increasing returns which are a key characteristic of most elements of connectivity, and externalities; a failure to distinguish between beneficiaries; and limited ability to assess the big picture, in terms of effects on growth and GDP.

One of the direct ways to measure the impact of connectivity is by focusing on specific value chains or product flows. Such supply chain assessments enable the analysis of impacts on the chains that would benefit from specific connectivity interventions. Supply chain analyses include investment costs as a component of the costs of the supply or value chain; estimating these costs is difficult and rarely done. Although supply or value chain analyses can add to the understanding of how the benefits of the connectivity investment might be realized, they are not usually used as part of the economic evaluation of proposed corridor improvements.

However, a focus on only the direct impacts of connectivity often misses some of the wider effects. For instance, Straub and Terada-Hagiwara (2011) found that in Asia investments in infrastructure had a strong positive correlation with growth. While in their case the correlation with productivity was inconclusive, the International Air Transport Association (2007) carried out a review of 48 economies over nine years and found a strong positive correlation between connectivity to the global network and labor productivity. In fact, IATA concluded that investment in aviation can generate significant wider economic benefits, and estimated that a 10 percent rise in connectivity, relative to a country’s GDP, will boost labor productivity by 0.07 percent (IATA 2007).

In addition to the wider affects, one of the ways that connectivity affects economic activity is through promoting agglomeration effects or integration of regional supply chains as is the case in East Asia in general. The concept of agglomeration has a long history in economics, going back to David Ricardo's theory of comparative advantage. Krugman and Venables (1990) show how regions can benefit from improvements in infrastructure, and easier access to factors of production and markets. In addition, Romer (1990) shows how a concentration of knowledge sustains innovation, giving rise to endogenous growth. Using panel data, De la Roca and Puga (2017) show that a Spanish worker joining a large agglomeration increases his or her productivity over the time (Quinet and Raj 2014). Similarly, improvements in infrastructure connectivity in East Asia have been found to have supported the growth of regional value chains which in turn have led to rapid reductions in poverty, social cohesion and mutual interdependence (ADB, JICA and World Bank, 2005)

The approaches to estimating the growth and productivity effects of connectivity include growth modelling, with labor, materials and capital — as main variables. The models can be sued to also explore changes in productivity according to a number of factors, including research and development and the level of capital assets available to each worker. Another common approach to assessing economy wide effects is Computational General Equilibrium (CGE), which is a multi-market model describing how individual businesses and households respond to price signals and external shocks, within the limits of available capital, labor, and natural resources (Dixon and Rimmer 2002). The advantage of this approach is that the model can take into consideration behavioral context and can also utilize prices and markets (Rose and Huyck 2016). However, the approach requires a lot of data, especially the input-output tables.

Connectivity and Economic Integration

A widely used approach to estimating interactions between any two nodes in a network is gravity modeling. Gravity Models incorporate a geographical perspective as a function of two criteria: mass (i.e., GDP, capital stocks, population, etc.) and distance. The models attempt to explain connectivity between two economic centers by their bilateral links assuming that infrastructure and institutional frameworks are conducive to increased interaction. For instance, gravity models can be used to assess the change in the volume of freight that might result from transport time or cost savings as a result of corridor improvements. However, gravity modelling is difficult to explore policy changes. The problem is that while cost can be a policy variable and we can use the model to estimate the impact of change in cost, distance is not a policy variable so we cannot use the model to estimate changing distances between the nodes. In addition, gravity modelling is generally not used to evaluate a package of corridor improvements. Moreover, the models can be difficult and time consuming to apply and rely on massive cost databases for their application. Extensive supply chains and access to outside markets, supported by connectivity, will also create economic interdependence, which can lead to further regional economic integration.

Estimating Impacts of Connectivity on Network Resilience

There are two divergent perspectives of network resilience — one applies to instances where a node is connected to the rest of the network by one major link or is reliant on one other node for access to the rest of a network. The other perspective is of a highly connected network where agglomeration forces or other scale effects have encouraged a concentration of activity in one of the nodes or along one link. While the causes may be very different the two networks face similar risks of vulnerability to disruptions to the node or link on which they are dependent. However, in the first instance the effects are isolated to one node while in the other the effects can be transmitted to the rest of the network and over a large area. An example of a « node » being affected by disruptions to the link on which it depends was Ethiopia in 1998 when its access to the seaport of Asmara in Djibouti was interrupted overnight due to the outbreak of war. An example of the second perspective was the flooding that occurred in Thailand in 2011 when it is estimated that the disruptions reduced Thailand's GDP growth rate from 4.0 percent expected to 2.9 percent (World Bank 2012, 202) and reduced global industrial production by 2.5 percent (UNISDR 2012). Even then the localized effects as measured by insured damage was assessed at only $10 billion (Munich Re 2012, 29). The effects were therefore significantly magnified as they were transmitted through the global production networks. On the flipside, the firms in Thailand that were connected to global networks were able to restore production much faster than those that were less well integrated.

The approaches to quantifying the effects of resilience in networks have evolved mainly from the financial sector and from information technology. They include path and node criticality analysis, network topology and resilience analysis and capital at risk analysis. The approaches are similar in that they focus on the likelihood of threats to the network, the identification of links and nodes that are most at risk, and determination of which of those elements are most vulnerable and their potential effects on the rest of the network. Using these approaches, it is possible to quantify the likely consequences of any part of the network not being available. The information can be used for project planning and justifying investments that may otherwise not seem obviously justified when employing standard approaches.

Potential Negative Consequences of Connectivity

In addition to the desirable impacts on connectivity it is also important to incorporate and factor in any analysis the likely negative spillovers that it can have. Some of the unintended effects, often due to poor planning and delivery of infrastructure, include:

- Social and environmental externalities such as from increased congestion or accidents from channeling traffic flows over a few links and nodes in a network;
- Increased risk to security and adverse health outcomes;
- Encouraging spatial distortions and disparities in an economy;
- Mismatches between where costs and benefits are incurred — for instance regions that serve as transit for network traffic that predominantly benefits the higher density nodes with the network; and

- Increased risks of contagion, through supply chains or effects that are health related, from being interconnected, e.g., the example above of flooding in Thailand or spread of diseases across several countries.

The approaches to quantifying the negative externalities of connectivity can be similar to those outlined above. The important issue is that estimating the impacts of connectivity should take into account the differentiated effects it can have on different regions, groups, firms or societies.

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