Growth Lab

Coordination Failures in Adopting New Technological Capabilities as the Binding Constraint to Growth

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Growth Lab Working Paper Series
No. 248

August 2021

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This paper may be referenced as follows: Barrios, D., Cheston, T., Cunningham, B., Hausmann, R. (2021). “Coordination Failures in Adopting New Technological Capabilities as the Binding Constraint to Growth.” Growth Lab Working Paper, John F. Kennedy School of Government, Harvard University.

Abstract

The process of structural transformation that has accompanied economic success stories requires an expansion of the technological capabilities held in society. Adding new technological capabilities faces several constraints related to coordination failures, information failures, and the asymmetric nature of technology itself. Although these coordination failures were included in the original Growth Diagnostics framework, practitioners have often found them challenging to analyze. This paper aims to provide a systematic framework and analytic techniques that bring clarity and rigor to the examination of potential constraints in this branch. We posit four different strategic approaches that countries face in the process of structural transformation, centering on two factors: are existing technological capabilities sufficient for growth? And: how easy is it to add the new technological capabilities required to develop new productive sectors? Countries that lack sufficient existing capabilities and must add several capabilities at once in order to enter higher-productivity sectors may be constrained by a capability trap resulting from coordination failures. Even for places where promising opportunities exist, they may be constrained by "low jumpiness" related to information externalities in the process of self-discovery. Diagnostic tests are detailed that can identify the necessary strategic approach. The paper also reflects on the policy space for addressing coordination constraints and outlines the central role of the public sector in enabling coordination of technological capabilities. Both public-private coordination as well as underappreciated elements of public-public coordination in the provision of public goods are addressed.

Table of Contents

I. Introduction

Growing dissatisfaction among economists with a literature more focused on the causes of growth than on the tools to identify constraints to growth in a specific context gave rise to Growth Diagnostics. The diagnostic approach proposed in Hausmann, Rodrik, and Velasco (2005) (from here on the HRV framework) laid the foundation for new research on identifying the binding constraints to economic growth in an individual country that generated a significant literature and attention in economic analysis and policy spheres.

All the while, the authors of the HRV framework did not stop researching the root causes of growth. Critically, they found that the growth process is not characterized by countries making more of the same goods or services. Instead, star performers on economic growth see a transformation of their production. They change what they do, through a process of structural transformation (Hausmann, Hwang, and Rodrik 2005; Hausmann and Klinger 2006; Rodrik 2016). This is at once a rather obvious stylized fact of economic growth, but also one whose implications have not been fully specified or integrated into growth diagnostic approaches. This paper aims to fill this gap in the literature through an understanding of how structural transformation is affected by constraints that stem from the nature of technology itself.

The economic success stories of the past half century have not been those of economies that focus on their narrow existing areas of comparative advantage, but those that evolve their comparative advantage over time. China and South Korea have realized record historical growth rates by following a common pattern: entering garments followed by electronics and then machinery (Figure 1).[1] Not every country has been able to manage this evolution: Sri Lanka successfully entered garments in the 1980s but has remained stuck in that sector.

Why have some countries managed this structural transformation while others remain stuck? Trade theory traditionally suggests that changes to the export basket are the (passive) consequence of changes to factor endowments. A growing literature points to a more complex picture for how the process of structural transformation occurs: learning-by-doing within industries (Arrow 1962, Bardhan 1970); industry externalities (Jaffe 1986); technological spillovers across industries (Jaffe, Trajtemberg and Henderson 1993); and information externalities in the process of "self-discovery" (Hausmann and Rodrik 2003). This research suggests that entering new productive activities, versus doing more-of-the-same, requires a distinct approach to economic strategy.

The original HRV framework considers these constraints to the process of structural transformation through the branch of "market failures"[2], divided into two elements of "coordination failures" and "self-discovery" problems. While its inclusion in the diagnostic tree was quite forward thinking for the time, this branch has been challenging to examine for many

[1] While China's primary export used to be rice, now smartphones and TV sets lead a highly diversified export basket. The growth of new sectors reflects further diversification by building on a range of electronics and machinery products, rather than depending on a single product for growth.

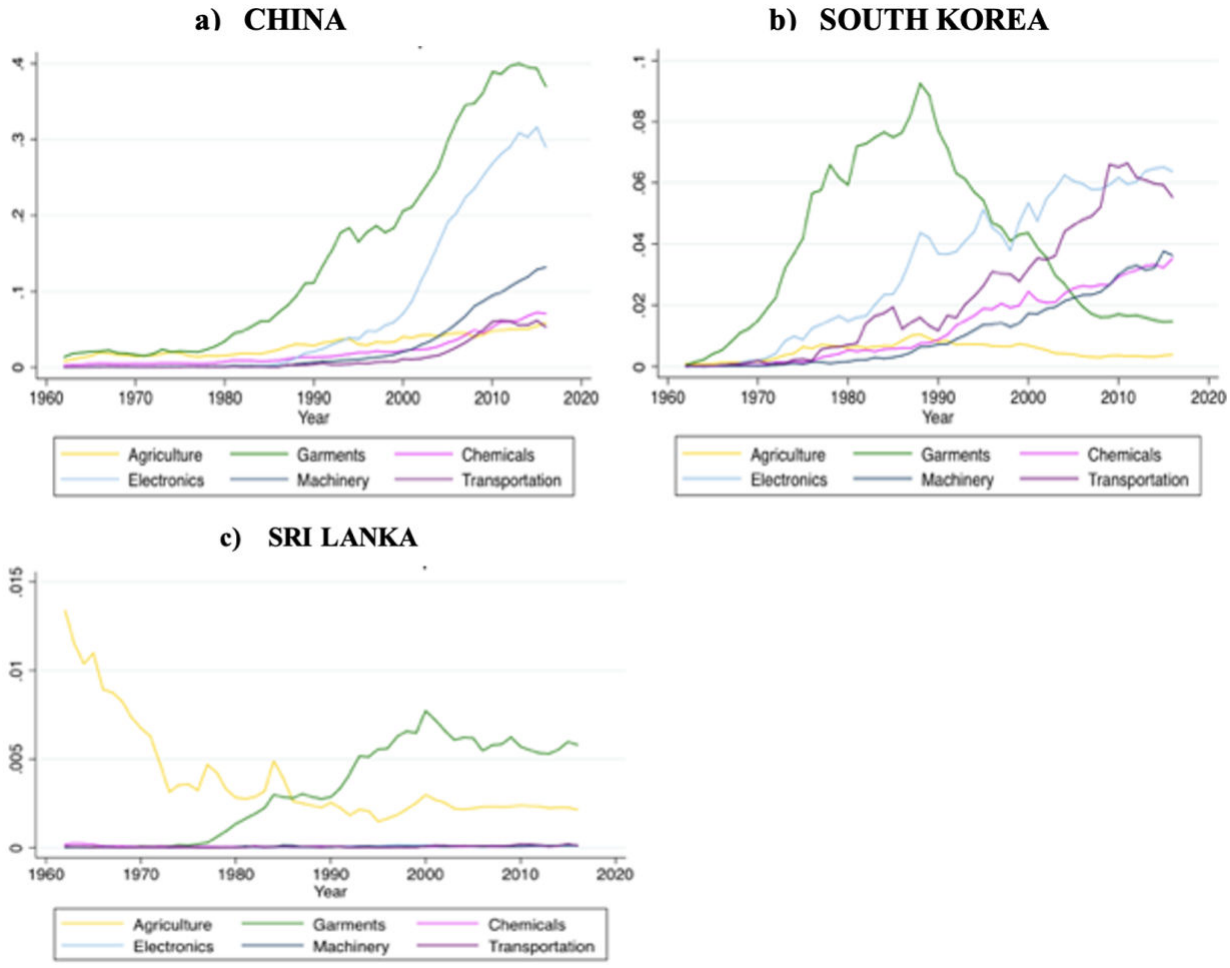
[2] Categorizing this branch as market failures, to contrast it with the branch of government failures, belies the role of the public sector in enabling coordination, including public-private coordination—and underappreciated elements of public-public coordination—in the provision of public goods

practitioners. This paper aims to provide a systematic framework and analytic techniques that provide clarity and rigor by bringing to bear the lessons learned over more than decade and a half of the practice of diagnostics. The result is an updated and more detailed decision tree that replaces the "market failures" branch, as well as tools and techniques for navigating the tree.

We presume working knowledge of the original Growth Diagnostic methodology and its practical application in the *Mindbook*. As discussed in the *Mindbook*, the first step of a growth diagnostic is to establish the framing of the analysis, or the "growth question" that the analysis seeks to answer. The approach to technological coordination outlined here is primarily intended to follow after practitioners have completed the framing step. However, as elaborated in subsequent sections, the techniques outlined here can also help to define or optimize the growth question.

The paper is structured in the following sections: we present a diagnostic framework for how coordination of capabilities can be constrained; the tests used to diagnose coordination constraints; how to consider when standard tests may not hold or mislead; real test cases; and the policy options to address distinct constraints. First, however, the paper begins by defining the nature of technology and capabilities in production.

Figure 1: Global Market Share by Sector of Goods Export: China, South Korea, Sri Lanka



Source: author's calculations using 2019 data.

II. Capabilities: Defining Technology and Knowhow

A growing consensus in the economic growth literature is that differences in the wealth of nations cannot be explained by the accumulation of factors of production (e.g., more land, more labor, more capital) but is determined by the remaining factor in the production function: technology. But what is technology? In the traditional Solow model, technology is captured as "total factor productivity" or the residual of the unexplained elements of the other dimensions in the production function. Modern growth theory conceived of technology as ideas that made output more efficient.

We define technology as being comprised of three forms of knowledge: codified, embodied, and tacit. Codified knowledge is knowledge that can be readily written down, e.g., blueprints, patents and documents. Embodied knowledge is the knowledge that is available simply by using a physical object, e.g. tools, iPhones, or supply chain inputs. For example, to clean your hands with soap, one does not need to understand the chemical properties of the lipid salts that went into that soap – you can access that knowhow simply by accessing the physical object. Tacit knowledge is also called "knowhow" and is the unconscious capacity of the brain to recognize patterns and respond appropriately. Knowhow was first conceptualized by Michael Polanyi (1958, 1966) and summarized by his phrase "you know more than you can say". The tacit nature of knowhow means it cannot be expressed verbally, written down, and codified. For example, we all have the knowhow to recognize the faces of others, but written instructions for this would be nearly useless. Thus, knowhow exists only in brains and can only move from brain to brain through a process of imitation and repetition, as argued by Arrow (1969). As a consequence, knowhow moves with difficulty between brains through often lengthy periods of interaction. In contrast, embodied knowledge can be shipped around the world and codified knowledge can be shared on the internet. Because the technology needed to be productive in any industry is comprised of all three of these forms of knowledge, it is the slow transmission of tacit knowledge that creates the largest obstacles to the diffusion of technology and thus to the transformation of economies.

Compounding this challenge is the fact that modern production requires the simultaneous presence of hundreds of inputs, each of which has its own mix of codified, embodied, and tacit knowledge. Production in any industry will require raw materials, machines, infrastructure, workers with specialized skills, financial payment systems, and more. In turn, each of these relies on other networks of supply chains, logistics, finance, human resources, worker housing, transport, regulatory framework, labor laws, etc. Because these networks extend well beyond the capabilities of any one firm, and rely on public goods provision as well, the coordinated adoption of new technological capabilities may not happen as a matter of course.

An intuitive metaphor that helps make sense of the challenge of structural transformation comes from the game of Scrabble. In the game, players arrange the tile letters available to them to produce words. In the same way, firms (the players) bring together a variety of different capabilities (the letters) available in the local economy to create a product (a word). These capabilities take the form of a set of knowhow (e.g., chemical engineer, assembly line worker), infrastructure (e.g., electricity, water), supply chains, public goods, or any of the other inputs identified above. Places with a limited range of capabilities (few letters) can produce a limited range of goods and services of low value – they can spell a few short words of limited value. As a place adds new letters (or

capabilities), the number of words that can be created increases exponentially and the words can grow longer or become of higher value. In this way, creating the most complex words requires the local availability of a wide range of letters. This plays out empirically: the most complex products are only produced in locations with the most diverse set of capabilities (Hausmann et al 2013).

Thus, the growth process is one of adding new capabilities to produce a more diverse set of goods and goods of greater value or complexity. The complementary nature of these inputs means the absence of any one input imperils the productivity of the entire process. Profitable investment in an economic activity may not be possible without coordinated investment in other activities or inputs. For example, it might not make sense for a firm to invest in fresh flower production if other firms have not already invested in cold chain technologies or air transport infrastructure, or if the government does not also invest in the customs or phytosanitary controls needed to export horticulture. In the absence of the coordinated arrival of all required capabilities, firms in the given industry are unlikely to thrive.

Consider a country trying to enter watchmaking. No individual wants to train to be a watchmaker in a place that does not make watches. Yet, no firm will enter a place if there are no watchmakers. Thus, each new productive capability that is required must resolve a chicken-and-egg problem. Government can hold a role in coordinating the match of the supply of new capabilities with the arrival of their demand by other producers. Most governments are not set up well to serve this role. This gives rise to the "coordination" problem that is identified in the original HRV growth diagnostic tree.

A related but distinct problem that is also included in the original HRV tree is "information externalities" or "self-discovery". The self-discovery process is one of figuring out which economic activities can be profitable given the existing set of capabilities in the local economy; analogous to a Scrabble player trying to figure out which words can be spelled with their given set of letters. For a sector that does not currently exist, first-mover firms take on significant risk exploring whether the capabilities exist to be profitable. At the same time, the success or failure of such investments provides potentially valuable information to subsequent entrants into the sector. Because the first mover is uncompensated for this information externality, there may be a lack of experimentation in the economy that constrains the growth process.

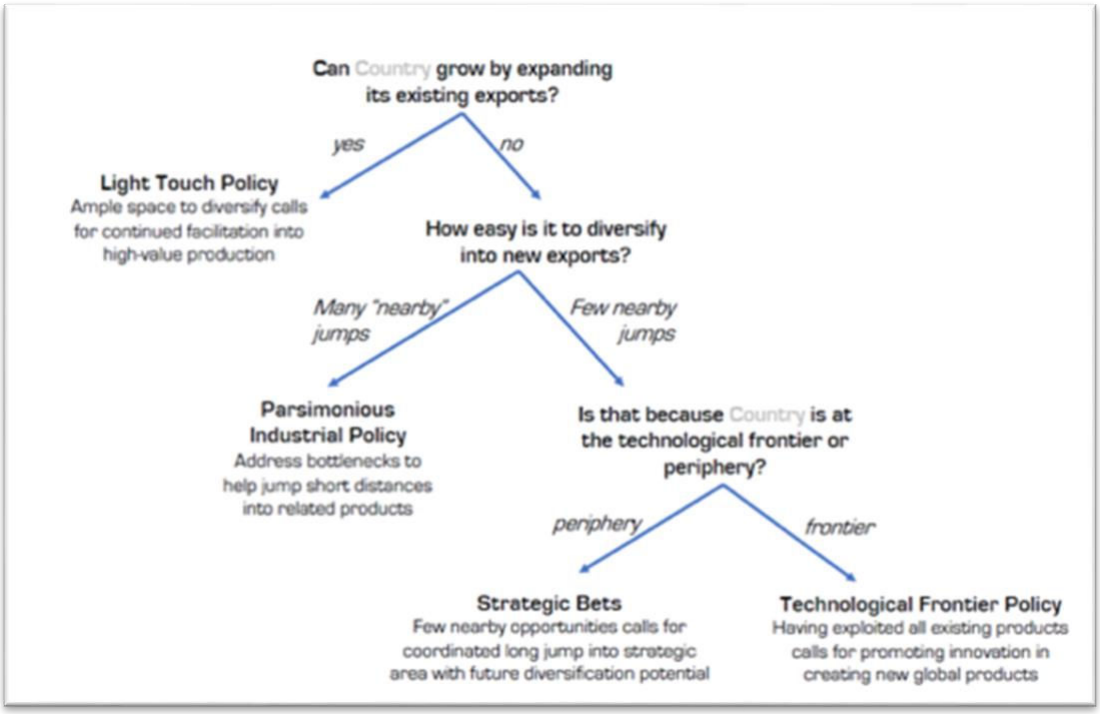
III. A Diagnostic Framework for Examining Coordination Constraints

A growth diagnostic seeks to identify the capabilities or inputs that are in scarcest supply and highest demand, and thus for which increased availability is most likely to lead to increased production and growth. The original HRV tree highlights capabilities and inputs that can be leveraged by a wide array of industries and might be the scarcest ingredient for growth – things like infrastructure, finance, and stable macro-economic conditions.[3]

[3] Revisiting the Scrabble analogy, these individual capabilities are like the vowels that are used in the spelling of many words. In contrast, the coordination problem arises around consonants – the capabilities that are required by certain specific sectors. While the consonant-vowel distinction may appear to map neatly into public versus private inputs, industry-specific consonants are often required from the public sector, broadband regulation for example.

For coordination to be a binding constraint to economic growth, it must be the case that the coordinated arrival of new capabilities is scarce relative to the availability of the other (vowel) inputs; and thus, when coordination does occur it leads to significantly increased investment, productivity, and/or output. Figure 2 provides a heuristic or decision tree for systematically thinking through the issues. It examines the core questions raised by this paper. Does economic growth depend on a country's ability to solve the coordination problem and enter new productive sectors? If so, what is preventing the economy from doing so?

Figure 2: Diagnostic Framework for Technological Coordination Constraints



Source: author's elaboration.

a. Can the Country Grow by Using its Existing Capabilities/Technologies?

The first branch of the tree asks whether the country can grow by doing more of the same, i.e., increasing output within existing industries, or whether new industries are needed to drive growth. A useful measure to assess whether existing set of capabilities are sufficient to drive growth is the Economic Complexity Index (ECI). A country's ECI measures the diversity and sophistication of the technological capabilities embedded in its exports (Hausmann, Hidalgo, et al 2013). The measure is found not only to explain differences in incomes levels between countries, but more importantly holds a high level of accuracy in predicting forthcoming growth. Countries where income is lower than the level that their ECI value would predict tend to grow more quickly than countries with a higher income than expected for their complexity level. Countries with a low ECI score relative to their income level will need to diversify into new, higher complexity industries in order to attain higher rates of growth. The diagnostic for such countries will follow the path to the right half of the decision tree to identify their technological coordination constraints.

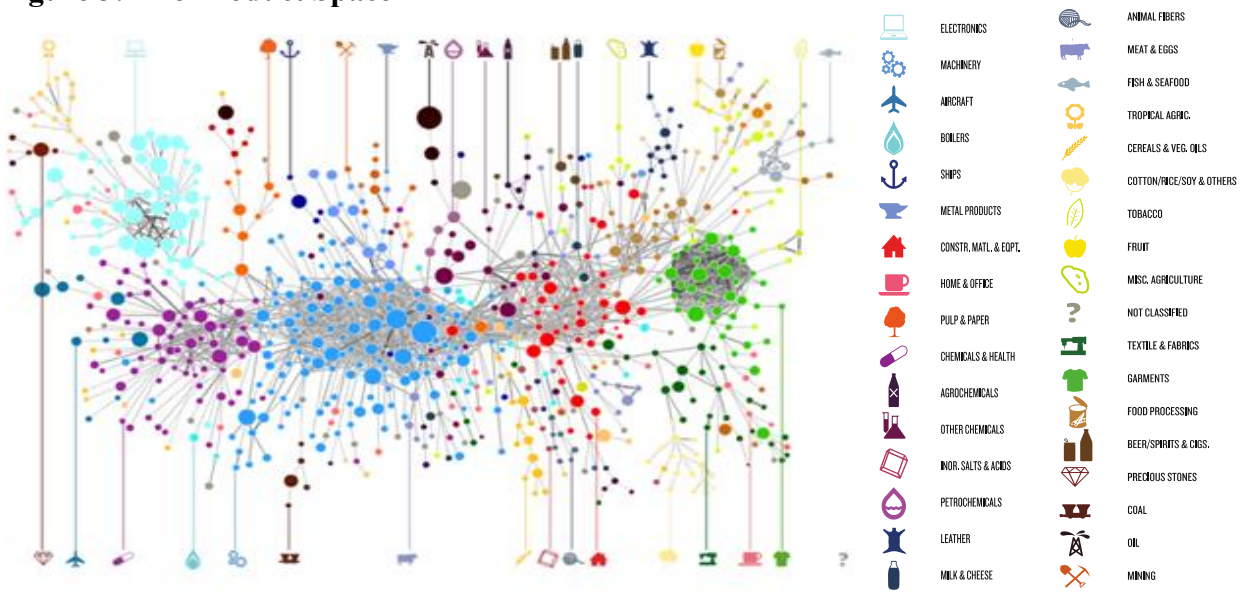
Countries with a high ECI score for their level of income have a sufficient set of technological capabilities to afford productivity and output growth (though they may still benefit from continuing to enter new, more complex industries). Thus, these countries would benefit from a ***"light touch approach"*** towards coordination of new technologies. If convergence toward the higher income level predicted by their ECI is happening relatively slowly, the analyst should aim to identify the constraints (such as those outlined in other branches of HRV's diagnostic tree) that are preventing the economy from better utilizing existing technological capabilities.

b. How Easy Is It for a Country to Move into New Exports?

If new, more complex economic activities are needed to facilitate growth, the next step in the technological coordination tree is to ask: how easy or difficult it is to diversify? The literature on industry relatedness identifies that the difficulty of moving into a new industry depends on how related it is to industries that currently exist in the location. This dynamic is captured in the Product Space (Figure 3), which illustrates the technological similarity between any two products. The strength of the connection between any two products in the Product Space is determined by how frequently both products are co-produced by countries rather than just one or the other. This provides a map of the industries that are "nearby" or adjacent to a country's existing set of technological capabilities, and thus how difficult it might be for the country to diversify.

The core-periphery shape of the Product Space reflects a key feature of structural transformation: technological capabilities differ in their connectedness to other capabilities. For example, products in the garments area of the product space (the light green area on the right side) are tightly clustered, which implies that the capabilities to produce men's shirts are similar to those needed for women's shirts. Computer screens, however, are not closely linked to any products in the garments cluster, implying men's shirts require few of the same capabilities in their production as electronics (the light blue area on the upper left).

Figure 3: The Product Space



Source: Hausmann et al 2013

As a result, some industries act as better stepping-stones for diversification than others. The periphery of the product space is occupied by many raw materials and agricultural goods, including oil. This suggests that the productive capabilities required in producing commodities like crude oil (e.g., drilling into the ground) are not readily shared with many other industries. Therefore, commodity-dependent economies face an added constraint to diversification: they have fewer opportunities to redeploy their existing capabilities to enter new industries.

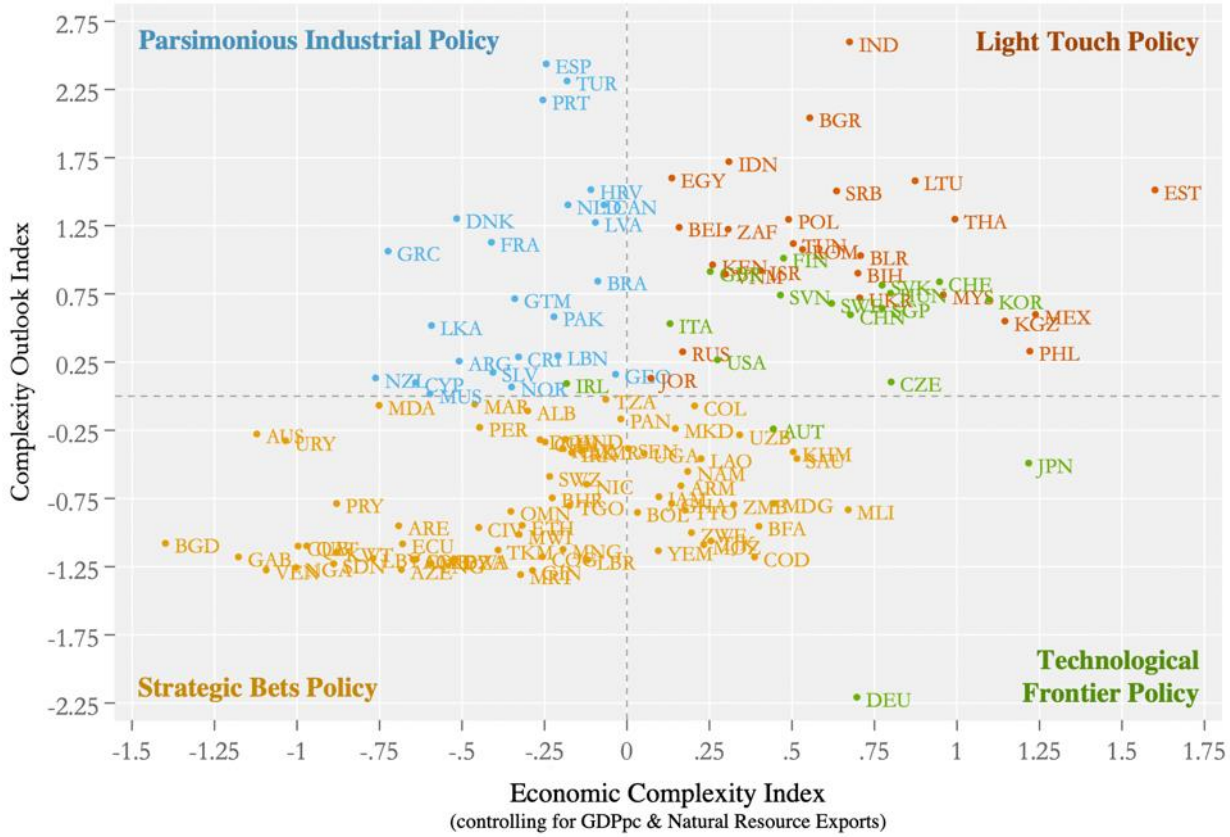
The number of well-connected, new opportunities in the Product Space that a country has can be quantified in a measure called the Complexity Outlook Index (COI). A country's COI captures the ease with which an economy can leverage its current technological capabilities to enter new sectors. This measure assesses not just the number of nearby opportunities, but the complexity of those products and the effect they would have at raising or lowering a country's ECI. A low COI reflects that there are few complex activities available that rely on existing technological capabilities.

For well-connected countries (with high COI) but lower than expected complexity (ECI) for their income level, which include Turkey and Brazil, there should be ample, related industries to move into using existing technological capabilities. Given ample room to leverage existing capabilities to enter new productive opportunities, this might point to specific types of coordination constraints, chief among them is the constraint related to "self-discovery".

This refers to the information externalities of figuring out which new economic activities can be profitably undertaken given the available set of capabilities in a location. This process comes at some cost, as pioneer firms take risks to attempt to enter new activities. While the pioneers bear the risk, the benefits of successfully demonstrating the profitability of a new product or industry are often shared with all potential entrants into the activity (Hausmann and Rodrik, 2003). Countries that face self-discovery constraints should evidence 'low jumpiness' into new economic activities despite ample, "nearby" opportunities. Countries in this space, would likely benefit from a "***parsimonious industrial policy***" to facilitate these relatively smaller jumps into related industries in the Product Space.

These two variables discussed in A and B, ECI and COI, can be summarized and visualized in the Strategic Space shown in Figure 4.

Figure 4: The Strategic Space for Approaches to Technological Coordination



Source: author's calculations using 2019 data.

c. Why Are There Few Opportunities -- Technological Frontier or Periphery?

Countries at all levels of economic development may be in a position of needing to diversify their economy while having few nearby opportunities to do so. However, the reasons for having few nearby opportunities can be dramatically different. Some countries, with high complexity, can find themselves in a position of already occupying all the high-complexity products in the Product Space. To further diversify their economies and drive growth, they must innovate to create new products and industries to add to the global product space, not only to their position in the product space. The high-risk, high-return nature of pushing the technological frontier is laden with coordination failures and other disincentives to the research and development of new technologies. The policy approach for these countries is one of "***technological frontier policy"*** to promote competitiveness and innovation to create new global products.

At the other extreme, many developing countries with a low level of economic complexity face the challenge that existing industries are located at the periphery of the Product Space and offer few connections to move into related industries. Furthermore, existing capabilities are not technologically related to many complex industries. Hence, in order to diversify, these countries must adopt new technological capabilities, often many at once, to develop new industries.

Countries in this predicament are likely to face a capability trap: the few capabilities that exist share few connections to new industries and those few connections to new industries do not incentivize the creation of the required capabilities. This trap points to a further challenge in achieving structural transformation: the convex returns to new capabilities. For economies with few capabilities, adding a new capability offers few opportunities, for example adding a trained software engineer to an agrarian economy may open the opportunity of tracking crop prices. By contrast, economies with a wide range of specialized capabilities offer the possibility of opening many new opportunities with the addition of a new capability, for example adding a trained software engineer to an advanced industrial economy may open a broad range of apps from payment system to industrial efficiency software (in addition to the same app to track crop prices).[4] Technological capabilities feature agglomeration effects in the vein of "the rich getting richer" where economies endowed with a broader complexity of capabilities are more readily able to utilize and sustain new capabilities.[5]

In a context of few, related opportunities, the policy imperative for these countries is to enable "***strategic bets policy"*** to enable coordinated, longer jumps into potentially fruitful parts of the Product Space that afford both higher complexity and further diversification opportunities.

IV. What Are the Key Tests to Diagnose whether Coordination Is a Constraint?

The diagnostic framework for coordination constraints in adopting technological capabilities also lends itself to a series of tests to analyze the presence of signals of a constraint. The approach of a differential diagnosis means that, for coordination of new capabilities to be constrained, specific symptoms should be evident.

In testing for coordination of new capabilities as a constraint, four diagnostic signals should be used:

i. **The (shadow) price of coordination should be high:** The first signal that coordination is constrained is that the supply of missing capabilities should have very high returns.

ii. **Movements in coordination of new capabilities should produce significant movements in the objective function (e.g., investment rate or GDP):** For coordination to be binding, increasing access to scarce capabilities should result in an increase in output variables.

[4] This plays out in the Scrabble analogy as well. For an economy with three letters (or capability sets) adding a fourth letter often adds a handful of new words that can be made (new industries). Compare that to an economy with 20 letters, for which adding an additional letter allows for hundreds of new words to be created. This has been found empirically and describes why many of the fastest growing economies (e.g., Vietnam) are those with many existing letters that continue to add new technological capabilities at high reward.

[5] Where those capabilities are mobile across countries, opportunities will be more plentiful and more rewarding in high complexity economies. Written another way, this describes why brain drain dynamics make it hard for low complexity economies to sustain the creation of new capabilities in a context of coordination constraints, i.e., more complex economies would hold more industries that could utilize that capability and often afford higher wages for that capability.

iii. **Agents less intensive in coordination should be more likely to survive and thrive, and vice versa (Camels and Hippos):** Where coordination is constrained, the economic sectors that are most dependent on coordination should be relatively less present, resulting in a low complexity economy.

iv. **Agents in the economy should be attempting to overcome or bypass the lack of coordination or missing capabilities (Hippos in the Sahara):** If coordination of new capabilities is constrained, there should be evidence of firms bypassing the constraint, either as evidence of positive deviance or in setting-up their own coordination mechanisms.

The remainder of this section details the different tests that can be used to diagnose the presence of a coordination constraint for the four potential strategic approaches that result from the decision tree in Figure 2: light touch policy; parsimonious industrial policy; technological frontier policy and strategic bets.

a. First Tests for Capability Traps and Shadow Prices

There are a series of tests that could be leveraged to assess both capability traps and shadow prices. A first-order test should be to diagnose whether growth depends on the creation of new technological capabilities. The most useful measure is a place's **Economic Complexity Index (ECI)**. ECI values are freely available on the Atlas of Economic Complexity (https://atlas.cid.harvard.edu/rankings) for 133 countries, including previous years as far back to the year 2000. A country's ECI measures the diversity and sophistication of the technological capabilities embedded in its exports, but is not limited to applications on exports, as has been demonstrated on employment data, social security data, city-level employment in global datasets. In addition, the economic complexity approach applies equally well sub-nationally, including at the state and city levels, where data are available. Practitioners are able to generate economic complexity values for their own datasets via the Atlas GitHub database (https://github.com/cid-harvard/atlas-economic-complexity).[6] Each measure is built from a series of relevant data points that are detailed and defined in Appendix A. Evaluating the economic complexity of a place is further enhanced when leveraged in conjunction with complementary information: Figure 4 controls for **GDP per capita** and **natural resource exports**.

Another measure used to assess the level of capabilities within an economy is **EXPY** in assessing the "productivity level associated with a country's specialization pattern" (Hausmann, Hwang, Rodrik, 2006). The authors effectively calculate the income level of a country's exports. While this measure is useful, such analysis is perhaps undermined by the circular logic of comparing income levels against a statistic that itself is constructed based on income. Fortunately, there are additional measures that can be used to assess capabilities that avoids this problem. The **Herfindahl-Hirschman (or HH) index** is a common measure of market concentration that can be applied to a country's export basket. If exports exhibit a high HH index, it is dominated be

[6] Other innovations to the ECI measurement have been to use population (RPOP) as the basis for evaluating revealed comparative advantage rather the relative share of a country's trade (RCA). Population may prove a more useful assessment of a country's productive capabilities for commodity-driven economies, where a single commodity dominates the export basket.

relatively few products, and thus is likely to exhibit relatively few capabilities. Yet a country may have a very large natural resource sector such as oil, thus producing a very large HH index, while still having a diverse economy.

An analyst might choose to measure how many different products the country produces with comparative advantage. This can be calculated as a simple count of the number of products a country produces with revealed comparative advantage.[7] The Atlas of Economic Complexity calls this measure **diversity** and offers a **diversity rank** of how diversified an economy is. The relative concentration of production to one small segment vs. a broad segment of the Product Space provides a ready sense of whether the necessary capabilities for growth are a far leap from existing knowhow, or relatively adjacent. However, diversity alone can still be misleading. A country that produces ten highly complex products would have the same diversity score as a country the produce ten low complexity products, despite the much higher level of capability needed to produce the more complex products. Thus, Hausmann and Hidalgo (2009) developed the method of reflections to account for the fact that, while diversity is a good starting point, not all products should count equally if the goal is to assess the capabilities of an economy. The resulting measure is the Economic Complexity Index.

An additional measure makes explicit the relationship between a country's economic complexity vis-à-vis its income level is the **Economic Complexity Growth Projection**, which provides long-run estimates of growth that are also freely available on the Atlas of Economic Complexity (https://atlas.hks.harvard.edu/growth-projections). Ultimately, the aim of this test (as captured by the x-axis of Figure 4) is to assess whether a country is complex enough to sustain its growth.

A complementary, first-order test is to assess how easy it is to move into new opportunities. This is best measured by the **Complexity Outlook Index (COI)** as a measure of the number of well-connected, new opportunities in the Product Space and the complexity of those industries. A low COI reflects that there are few complex activities that rely on existing technological capabilities. This increases the risk of diversification, by needing to add many capabilities at once. Thus, Figure 4 aims to answer (via the y-axis) whether a country is sufficiently connected to new, higher complexity industries given its existing technological capabilities to sustain its growth. The relationship of a place's complexity and its connectedness shape the strategic approach required into the four quadrants: light touch policy; parsimonious policy; technological frontier policy and strategic bets.

The presence of a coordination constraint in adopting new technological capabilities is not equally likely across these quadrants but a **capability trap is most likely to occur in a context of strategic bets policy**. Places that require a strategic bets approach must grow by diversifying into new, more complex activities – but hold few existing connections to those activities. Those places in greatest need of coordinating new capabilities are most likely to be constrained by coordination. These places[8] both lack the technological capabilities necessary to grow their economy and find those

[7] In the example of a country with a large natural resource export, the revealed comparative advantage calculation may need to be adjusted.

[8] This category is defined as those with a COI below zero, as they are not well connected to new opportunities, and with an ECI that does not fall at the technological frontier, as defined as the top 17 most complex economies.

same capabilities a far leap from what they currently know how to do. Given that they are many capabilities away from entering a product, supplying any one capability will not generate the returns necessary for investment without the coordination of the simultaneous investment in all missing capabilities. As a result, the investment is more coordination-sensitive and higher risk, in the hope that all missing capabilities can be provided efficiently.

The lack of assurance that new technological capabilities will be present results in a capability trap in which diversification is constrained by coordination failures. What defines coordination of new capabilities as constrained is the high price firms will pay for a more diverse range of technological capabilities. For technological coordination to be a binding constraint, the return to the provision of a missing capability should be high. At the same time, a coordination constraint should lower the return (price) of all the other constraints. For example, the returns to paving a new highway to the port should be low since there is not the supply of chemical engineers necessary to operate a new chemical industry that would take advantage of that highway.

b. Changes Beget Changes

For technological capabilities to be the binding constraint to growth, gains made in this improving the diversity and complexity of available capabilities should result in an uptick in growth. A useful test is to assess the **relationship between ECI and GDP growth per capita over time**: have gains in complexity been accompanied by a pick-up in growth rates? Has a stagnating ECI been accompanied by periods of low, or underperforming growth? In this same vein, the **association between COI and GDP per capita over time** also tracks the ability to develop new well-connected industries in relation to overall growth patterns. Countries that lose connectivity to promising sectors (declining COI) should also experience a slowdown in growth over time. Given that a country's complexity expresses the presence of internationally competitive exports, the loss of complexity is indicative of the inability to sustain an ecosystem for more complex technological capabilities.[9] Similarly, the fall in a country's COI may indicate the loss of competitiveness in technological capabilities that are more readily able to be used to enter new products to drive diversification. In effect, the capabilities that remain do not confer sufficient connectedness in the ability to redeploy those capabilities to enter new sectors that afford job creation and income gains to drive growth. It should be noted though, that changes ECI measures may not have an instantaneous effect on output. Hence, it might be beneficial to consider lagged effects.

c. Firm Intensity in the Constraint and Growth Patterns

A third type of test for the presence of technological coordination constraints is to measure how complex is the set of inputs required in production. If an economy is constrained by technological coordination, we'd expect that the economic stakeholders that thrive are less intensive in coordination and vice versa. In simplest terms, a location's ECI serves as a good proxy for how

[9] An alternative causal factor of a fall in a country's complexity is that its competitive exports have lost complexity as lower income countries have been able to become competitive in the product (thereby increasing the ubiquity of the product and reducing its complexity). A third cause is the effect of shift of commodity price fluctuations changing the Revealed Comparative Advantage (RCA) of other products above or below 1 that is discussed below.

coordination-intensive the economy is, where more complex economies are those that can coordinate a broad range of specialized knowhow in a firm.

Measuring technological coordination should be also assessed dynamically, to test whether the sectors that survive and thrive are those more or least intensive in coordination of a broad set of capabilities. This can be done by measuring the growth rate of different activities using the Product Complexity Index (PCI), freely available on the Atlas of Economic Complexity (https://atlas.cid.harvard.edu/rankings/product). A useful measure is to test **the ECI of fastest growing economic activities** (https://atlas.cid.harvard.edu/countries/61/growth-dynamics). Where growth is being driven by relatively low complexity firms that depend on a single raw material or limited coordination, there may be a constraint in the coordination or more complex technological inputs in production.

New datasets, building from Rajan and Zingales (1998) measures of the financial intensiveness of different sectors, analyze the **intensiveness of public sector coordination** for the production of different sectors. Indices have been constructed on the intensiveness of different industries in electricity, water, contractability (Nunn, 2006) and other inputs. Countries that face coordination constraints should not possess many industries that are intensive in public sector coordination.

d. Firms Bypassing the Constraint

If technological coordination is constrained, firms should be actively aiming to bypass the constraint. Where coordination failures are prevalent, new activities should tend to cluster in zones with special focus on coordinating inputs, as is the case of special economic zones (SEZs) or industrial parks. One test would be to measure the **prevalence of special economic zones** at both extremes of the reliance on SEZs to locate what complex production exists or the absence of SEZs as a possible explanation for the lack of complex activities. The creation of these zones recognizes financial limitations in the allocation of public goods, such that concentrating their provision in one location would allow more coordination-intensive or more complex activities to occur.

Another test for low-complexity settings is to identify cases of **positive deviance**, where complex production occurs in a low-complexity setting. Where the only complex activities are those located in SEZs, coordination may be a constraint to increase the complexity of the economy outside of the park. Similarly, it may be the case that the only complex activities are carried out by few large multinational firms that are able to leverage their resources and international presence to overcome coordination barriers.

The test would aim to **identify the most complex firms** in the location to study how they started and their dynamism. This can be done using the Product Complexity Index (PCI) freely available on the Atlas of Economic Complexity to identify relevant industries of interest, and consequently identify relevant firms within those industries. This can also be done by looking at the Product Space to **identify well-connected industries at the heart of the space** that a place is competitive in despite not being competitive in the adjacent activities.

In the case of Chiapas, Mexico, this test led to the identification of a car parts manufacturing firm in the middle of the lowest complexity region of the country (see Appendix B). Meetings with the

firm managers revealed that coordination of complex capabilities to be a constraint, particularly around the lack of public transport to ensure workers' arrival at the factory on time. The factory had expanded production in Chiapas, not by growing its original plant, but by creating a series of small, new plants across the region. This proved a clear signal that the constraint was in ensuring a sufficient workforce to operate the plant. At the same time, it disproved the prevailing hypotheses that low growth was due to a lack of infrastructure. Rather the coordination constraint reflected the means through which some land rights prevented workers from moving into urban centers to work in higher-complexity manufacturing, due to the risk of losing their family land plots to be redistributed to the community.

e. Additional Tests for the Other Strategic Approaches

Countries that require the other strategic approaches may still be constrained by coordination of new technological capabilities. Many well-positioned countries for diversification feature low dynamism.

Another constraint to technological coordination is not that the capabilities are missing, but that they are static: in the low rate of using those capabilities to enter new productive activities. This is a particular risk for places that require a parsimonious industrial policy or light touch approach, given that a high COI means that there should be ample number of adjacent industries to enter. One clear measure of this constraint is the "**low jumpiness**" in the Product Space, that the share of new economic activities that have been added in the recent past is relatively small relative to what would be predicted for the COI. This can be measured in several ways: the **number of new activities added** with revealed comparative advantage; their **contributions to the export basket in total volume** or as a contribution to **income per capita**; a **Diversification Rank Grade** of the number of products added versus global average; or the **change in Diversification Rank over time**, all of which are available on Atlas of Economic Complexity (https://atlas.hks.harvard.edu/countries/61/new-products). Admittedly, the presence of a low jumpiness constraint may, at its source, be due to another constraint that is binding in a different part of the decision tree (e.g., opportunities are in water-intensive industries for an arid country with high water costs), but coordination failures and self-discovery constraints may still thwart or impede diversification in many countries (see discussion below on identifying false negatives).

Many countries at the technological frontier are more sensitive to the need for coordination as more complex production requires the simultaneous presence of numerous capability sets to be productive (and profitable). The challenge for countries at the technological frontier is to create wholly new global products that require emphasis on innovation, often at the recombination of technological capabilities across fields to spark a new process or material. Studying dynamics of **investments in R&D**, or the number of **patents** being created, vis-à-vis the growth pattern, often Similar dynamics can be studied by using **investments in R&D**, or the number of **patents** being created, vis-à-vis the growth pattern.

V. Where Do These Standard Tests Not Hold or Mislead?

These tests are generally useful for identifying and typifying technical coordination constraints. However, as is further outlined in Appendix A, both the assumptions behind the calculation of Economic Complexity metrics and the nature of the datasets that are used have some structural limitations in aiming to describe all countries' economic structures in a single indicator. This section aims to discuss those results that may prove the exception to these rules. In some very specific instances, these limitations can lead to either false negatives (standard tests signal there isn't an active technical coordination constraint when there is one) or false positives (standard tests signal there is an active technical coordination constraint when there isn't one). In this section we briefly exemplify a few situations in which these standards tests may be misleading and outline the type of analyses that may be required to supplement the standard approach.

a. How Can You Confirm There Are No False Negatives from Initial Set of Tests?

The case of false negatives of a technological coordination constraint refers to places that achieve intensity in complex economic activities despite only engaging in those parts of the productive process that are relatively less sophisticated or where the final output is significantly less sophisticated than the international standard. The measure of a country's comparative advantage (RCA, see Appendix A for technical discussion) depends on export reporting that does not differentiate the stage of the production process where the country provides its value-added (e.g., basic assembly and high-tech electronic component production, when added to the same final product, are treated equally as exports within that product). Export datasets cannot differentiate the quality of the end products, beyond the overall value of production (often divided by the quantity exported to measure "quality") that fails to differentiate a flip phone from a smart phone in calling all those exports cell phones. These data limitations may lead to the overestimation of the knowhow embedded in places concentrated in products with these challenges. This may mislead in signaling that the current productive structure can sustain a much higher income per capita (via an artificially high ECI), that there is an abundance of feasible complex activities to diversify into (due to an artificially high COI).

Given this risk, how can we determine if we are likely overestimating the productive know-how of a place? There's no foolproof test for this, but the following analyses may be helpful: (i) analyze the relative prevalence and evolution of patents in high-complexity activities as these tend to be associated with knowledge intensive activities; (ii) analyze the composition of FDI in high-complexity activities with particular focus on efficiency-seeking FDI (investment directed towards supporting global operations rather than serving the local market) and FDI going to knowledge-intensive activities (headquarters, R&D center, design and testing centers, etc.); (iii) analyze the occupational vector leveraged in high-complexity activities, this includes both the occupational composition and the observable characteristics of workers in each occupation (i.e.: education, experience, etc.); (iv) analyze the relative productivity (i.e.: exports per worker) of firms in high complexity activities and; (v) analyze the relative prevalence of regional and global ultimate companies for firms engaged in the high complexity activities. On their own, none of these tests should override the baseline findings of the complexity analysis. However, if when compared to a

relevant peer group, the place seems to systematically fall behind in these complementary indicators of knowledge intensiveness, then the baseline findings of the complexity analysis should be interpreted with care.

If this risk of overestimating complexity is present, alternative approaches should be considered. The most generalizable approach would be to perform complexity analyses using other data sources, such as employment, or the wage bill, as a robustness check. If this overestimation risk persists, or data availability does not allow for alternative RCA calculations, then a more specific ad-hoc approximations may be required, which may include:

i. Recalculating comparative advantage (RCA) discounting the sales/exports/production associated to certain types of activities (i.e.: assembly).
ii. Using quality-adjusted measure of a product/activity's complexity.
iii. Using an occupation-complexity-adjusted measure of an activity, by generating the complexity of different occupations required as a proxy of knowledge intensiveness.

It should be noted that these ad-hoc approximations may not provide evidence of a technological capability constraint, but at best may indicate that one cannot be disregarded so easily.

b. How Can You Confirm There Are No False Positives from Initial set of Tests?

The case of false positives of a technological coordination constraint refers to places that are more diverse and complex than what can be gathered from traditional tests. This generally results from how export datasets inadvertently fail to capture part of the economic structure of the place. There are two main ways in which Economic Complexity calculations can underestimate the knowhow embedded in the economy. The first has to do with the prevalence of large commodity exports. Generally, a large dependence on commodities tends to be associated with low complexity, and in most cases this is correct. However, in select places, a dual economy exists with commodity exports being complemented with a large and diversified non-commodity economy. In these places the standard measure of comparative advantage (RCA) may end up excluding significant swaths of the non-commodity economy, as the measure is calculated as a relative share (see Appendix A for technical discussion). Where commodity exports represent a large share of total exports, it will be difficult for other economic activities to represent significant shares of total exports, even though they may be large.

The second way calculations may misconstrue the true knowhow of a place is in service-intensive economies. Service exports do not pass-through customs, and therefore are not captured in the same systematic fashion of detailed bilateral reporting that occurs with goods exports, limiting the granularity of the data and the resulting calculations. As a result, data on traded services are available in broad categories such as ICT without data on whether that is generated from call centers or business consultancy services, masking the wide range of complexity within the sector. Similarly, goods and services produced for domestic consumption are not captured in any publicly available dataset with global coverage.

How can we test if we are likely overestimating the productive knowhow of a place? There are no foolproof tests for this, but the following analyses may be helpful:

i. Using alternative measures of comparative advantage based on population (RPOP) or by excluding commodities may better capture the complexity of the economy (non-oil RCA).
ii. Measuring the relative prevalence and evolution of patents in non-commodity activities as these tend to be associated with knowledge-intensive activities.
iii. Analyzing the composition of FDI in non-commodity activities with particular focus on efficiency-seeking FDI (investment directed towards supporting global operations rather than serving the local market) and FDI going to knowledge-intensive activities (headquarters, R&D centers, design and testing centers, etc.); and
iv. Assessing the relative productivity (i.e.: output per worker) of firms in high non-commodity tradeable activities.

If when compared to a relevant peer group, the place seems to systematically outpace its peers in these complementary indicators then perhaps the baseline findings of the complexity should be subjected to further review. If we have reasonable cause to believe that we may be underestimating the productive knowhow of a place, the most generalizable approach to adjust the complexity metrics would be to perform complementary complexity analyses with other data sources as a robustness check. These underestimations tend to arise more frequently when using export data. Therefore, calculating alternative complexity measures using employment or wage bill may serve as the most appropriate adjustment. Using alternative measures of comparative advantage, while useful, is fraught with significant limitations. For one, it is hard to disentangle where the commodity economy ends and where the non-commodity economy begins (e.g., oil-derivate chemicals or construction of oil infrastructure). Additionally, if the analysis is still restricted to exports, this approximation doesn't account the service sector either. Lastly, these estimates are not necessarily informative of future growth or predictive of future diversification patterns.

Box 1: Identifying the Peer Group

Establishing a relevant peer group in order to contrast the performance of the analyzed location can prove to be useful, as there are additional insights that can be gained from understanding relative performance in conjunction with absolute performance. For instance, when analyzing constraints in technological coordination in a major city (i.e.: Buenos Aires) it might be beneficial to compare its recent performance to other cities that share similar key characteristics (i.e.: Mexico City, Madrid, Barcelona, etc.), rather than comparing it to the universe of all cities. The latter group is significantly more heterogenous, hence the risk of unobserved variables influencing the interpretation of the tests is likely to increase. In this sense, what are some variables to keep in mind when constituting a relevant peer group?

The ideal approximation would be to identify a set of locations that are like the subject of analysis in all other relevant areas of the constraint analysis, except in its ability to achieve self-discovery or address coordination failures. However, this approach would require a wealth of data that is unlikely to be available in most cases. Therefore, an alternative is to consider locations that were similar[10] in a limited set of variables that are generally available and that are largely correlated with performance in other areas of the constraint analysis, these include, but

[10] At a baseline period

are not limited to: GDP per capita, exports per capita, population and/or level of employment. Additionally, it may be beneficial to consider other qualitative variables such as: governance indicators, membership to the same trading block and/or geographic location. These variables may also be correlated with performance in other areas of the constraint analysis and might contribute to making the peer group more pertinent to policy makers.

Similarly, it would be beneficial to consider locations that shared some similarities in its productive structure at the baseline period. These types of variables can help disentangle (somewhat) the issue of baseline productive capabilities from self-discovery and coordination failures. In other words, if two places shared the same baseline know-how but arrived at very different productive structures, then these differences are less likely to be explained by the initial endowment of capabilities and more likely to be associated with issues of technological coordination. Some variables than can be considered in this regard include similarity in export composition, similarity in GDP composition, similarity in employment composition by economic activity, similarity in employment composition by occupation, Economic Complexity Index and Complexity Outlook Index.

c. When Is the Binding Constraint Coordination of Technological Capabilities vs. Human Capital Provision?

Given the chicken-and-egg problem of adding each new capability, the true test of a constraint in technological coordination must distinguish itself from other potential causes. One primary distinction is between a constraint of technological coordination versus the lack of supply of a skillset, in terms of human capital. One of the core methodological contributions of Growth Diagnostics is to differentiate factors that are in low supply from those in low demand. Factors that are in low supply drive a high price, i.e., where the return to extra supply is high. This also drives down the demand for other complementary factors, i.e., where the returns to extra supply are low. In many developing economies, many inputs are constrained as measured in low demand (or low quantities). Growth Diagnostics provides an empirical strategy to identify binding constraints as those inputs in relatively shortest supply, as measured by high returns to additional supply. This method renders many simple, quantitative benchmarks uninformative, if not harmful by being misleading or distracting from the true priorities.

The lack of the presence of a skill/capability set is not sufficient to prove a human capital constraint and not a technological coordination failure or other constraint. Tests should aim to assess the presence of skills that are not being incorporated in production (e.g., taxi drivers in Bolivia holding university degrees). The presence of needed occupations in other local industries, or university graduates trained in those areas without being incorporated into production that requires those occupations would provide evidence of a coordination constraint. The emigration of those with the specific skillset that is lacking is another way to diagnose the root cause in coordination (see Human Capital chapter of the Mindbook Paper Series for full diagnostic tests).

Technological coordination constraints result from areas where expanding the spectrum of human capital/skills does not generate returns in output, either in existing firms or generating new

activities, due to the lack of coordinated demand for those skills since the investments are not profitable without coordination (or resolving the constraint elsewhere). Coordination failure may be present in restrictions to worker mobility, in non-compete clauses that hamper innovation through the dissemination of knowhow into new firms or sectors. Restrictions on labor mobility, including barring immigrant or expatriate workers from freely changing employers or owning their own businesses, constrains the ability of new firms to coordinate recruiting the experienced knowhow to be competitive. In oil or commodity-dependent economies with excess demand for labor filled by expatriate workers, including many areas of the Gulf where expatriates comprise more than 80 percent of the private sector, these restrictions on the movement and ownership of those with experienced knowhow presents a severe constraint in the coordination of new firm entry, hindering diversification efforts.

When promising opportunities generally depend on existing occupations, but depend on specific finance-intensive investments, countries may be bumping up against a finance constraint. There are a series of tests of finance constraints that help to isolate a finance constraint from coordination failures. Similarly, when the missing capabilities depend on access to public goods, countries may be bumping against a public goods constraint. Ultimately, the need for a country to add new technological capabilities does not define the binding constraint as being one of coordination, but the use of these tests, along with those of other potential constraints can systematically isolate the constraint that binds.

VI. From Symptoms to Root-Cause: Real Case Tests

a) Sri Lanka's Need to Diversify

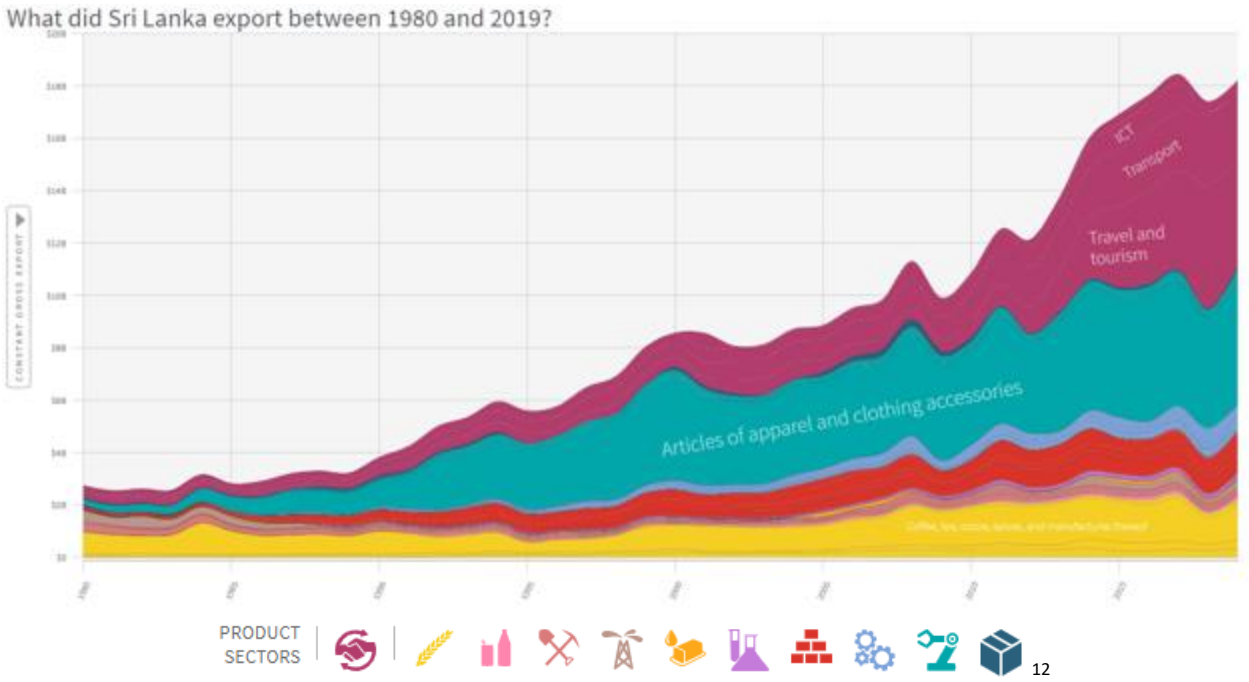
Sri Lanka provides a useful case for examining the role of technological coordination, structural change, and product complexity. As with any growth diagnostic, the first step in Sri Lanka's analysis is to examine the country's context to identify key growth trends or questions. One of the key takeaways from Sri Lanka's growth history is that balance of payments constraints and export growth have been key drivers of the country's growth dynamics.[11] A context of export driven growth highlights the first question in the diagnostic tree from Figure 2, namely:

Can Sri Lanka's existing set of exports drive growth, or is expanding into new export sectors necessary?

As a first step to answer this question, we can examine the evolution and current makeup of the country's export basket (Figure 5). The most significant development in Sri Lanka's export basket has the appearance and growth of apparel exports in the 1980s.

[11] Sri Lanka Growth Diagnostic Analysis, Harvard CID, January 2018

Figure 5: Sri Lanka's Exports over Time



Source: Atlas of Economic Complexity.

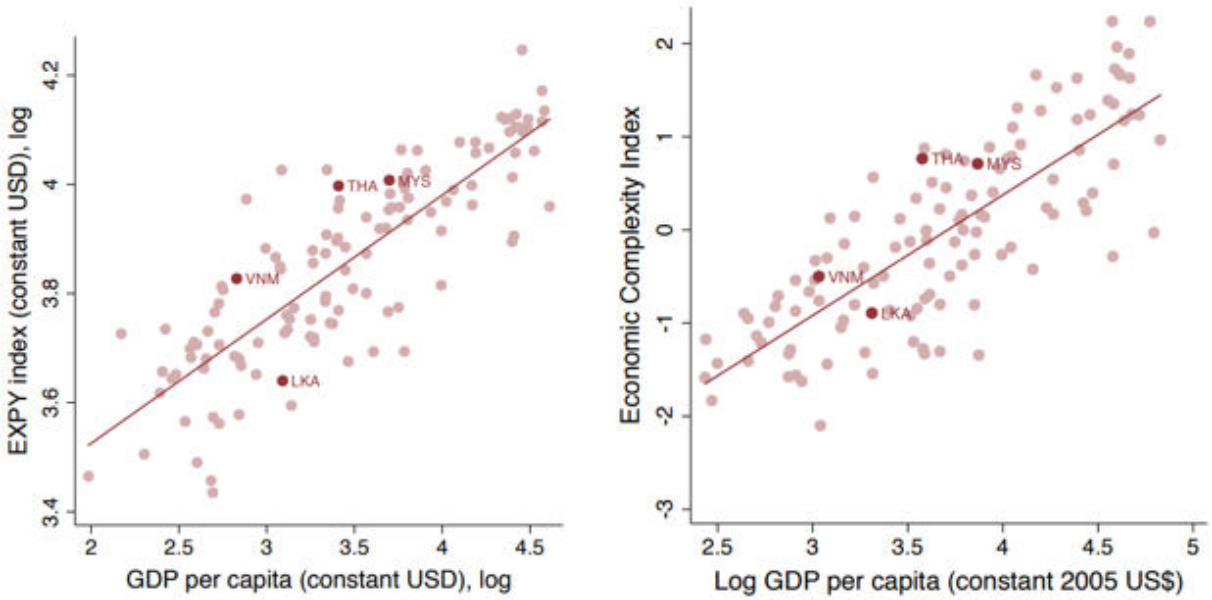
The lack of dynamism in the country's export basket has led Sri Lanka to become highly reliant on garment exports. Such an export basket is associated with low incomes (EXPY) and a low level of economic complexity (ECI) as illustrated in Figure 6. Additionally, further intensification in garments appears challenging as the country is already among the global leaders in garment exports per capita.

The low complexity of the country's export sector has slowed growth in part through the dynamics of the labor market and balance of payments. Because the export sector is engaged in relatively low margin and low complexity goods, wages in the export sector lag the rest of the economy. Whenever the economy begins a growth episode and wages are pushed up, the export sector with its below average wages struggles. The resulting contraction of the export sector creates a declining balance of payments that further stalls economic growth.

Taken together, these facts suggest that Sri Lanka will have difficulty growing by doing more of the same and will need new industries outside of garments to drive future growth. Thus, Sri Lanka clearly takes the right side to the first branch of Figure 2, leading to the second question:

[12] For more detail: https://atlas.cid.harvard.edu/countries/128

Figure 6: EXPY and ECI in Sri Lanka and Comparators

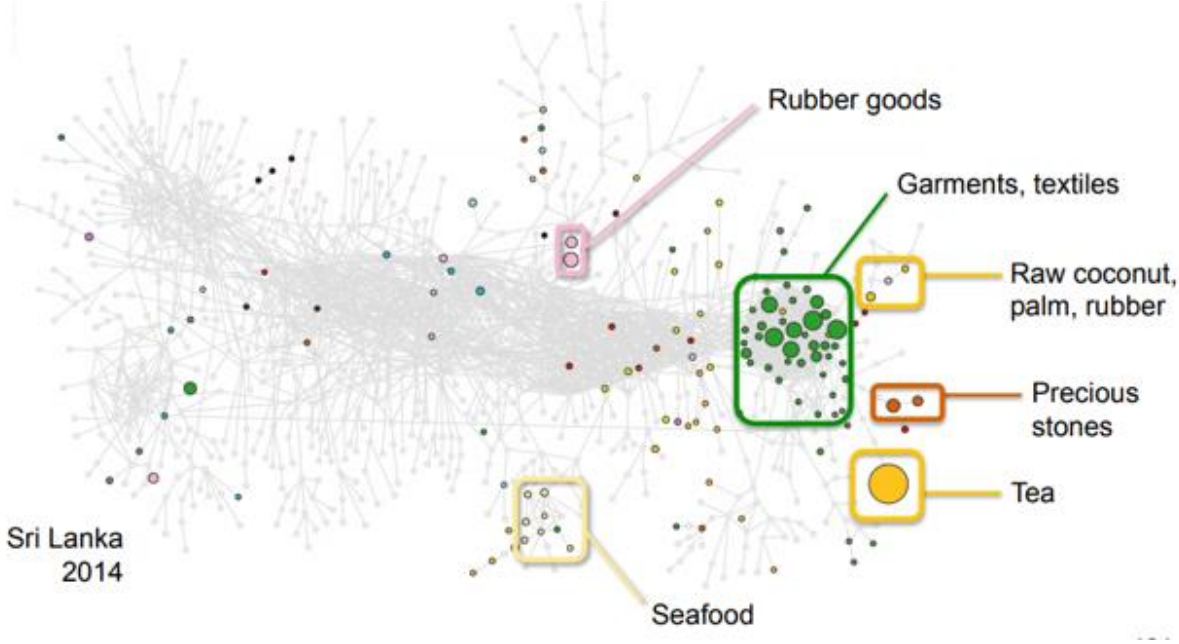


Source: author's calculations.

How easy is it for Sri Lanka to diversify into new exports?

The next question in the diagnostic tree asks us to consider how difficult it is for an economy to diversify based on their existing set of industries. This is most easily visualized through the product space. In Sri Lanka's case, areas in which the country has significant presence such as garments, seafood, rubber goods, etc., have been saturated – nearby opportunities have been taken.

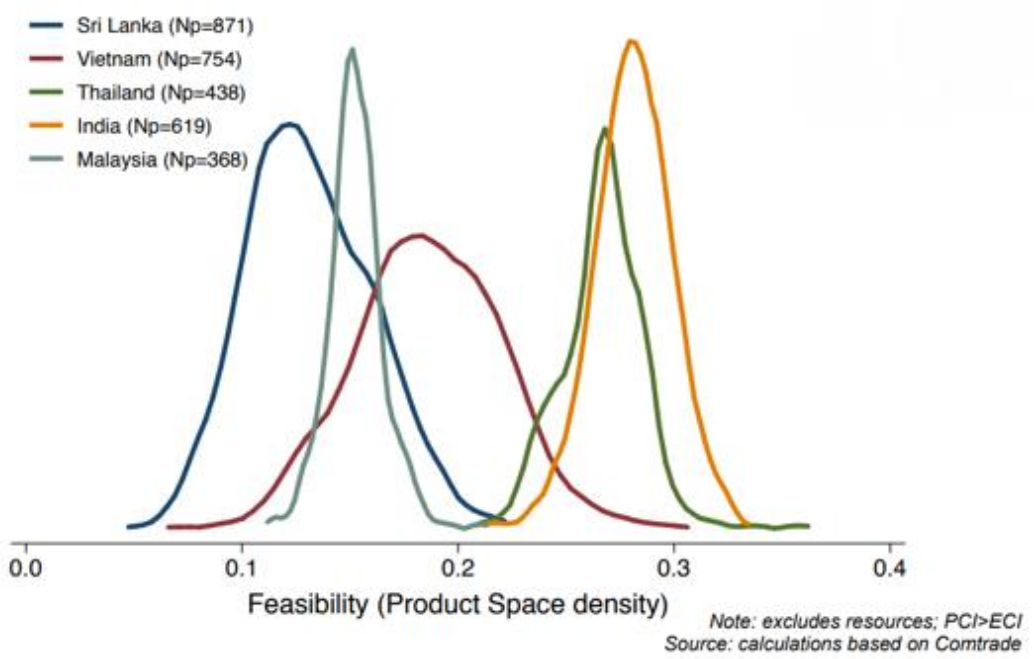
Figure 7: Sri Lanka in the Product Space



Source: author's elaboration.

Valuable opportunities for Sri Lanka to move into are relatively far in the Product Space (Figure 7), suggesting that the existing capabilities utilized in Sri Lanka's current sectors provide little benefit for new potential industries. COI quantifies the lack nearby opportunities in a way that is comparable to other countries, which can be measured as the average distance to new products (COI) or as the distribution of the distance to new products (Figure 8). Both approaches illustrate that Sri Lanka faces a significant challenge diversifying its economy.

Figure 8: Sri Lanka in the Product Space



Source: author's elaboration based on UN COMTRADE data.

Why are there few opportunities -- technological frontier or periphery?

Lastly, given that Sri Lanka's is low complexity economy, their difficulty diversifying is not because they are at the technological frontier and is in fact due to having a position in the product space with relatively few nearby opportunities. Thus, ***Sri Lanka's economy is in the "Strategic Bets" position*** of needing to make longer jumps into new areas of the product space to sustain economic growth.

b) Integration with Sri Lanka's Overall Growth Diagnostic

This analysis leads not only to identifying low complexity and poor position in the product space as binding constraints in and of themselves but also provides a useful framing for the rest of the growth diagnostic. The examination of technological capabilities and coordination in Sri Lanka helped inform the analysis of other potential constraints like infrastructure, human capital, access to finance.

Because large jumps and strategic bets are critical for Sri Lanka, it is particularly noteworthy that the country has sustained decades of very low levels of foreign direct investment. FDI is often a key driver of large jumps in the product space as it can help to solve coordination challenges by bringing tacit knowhow alongside financial capital. This raises a question of why Sri Lanka's FDI performance has been so poor. This led the analysis to examine the role of country risk, the ability of foreign investors to access land, and the related disfunction of industrial zones. While these issues constrain domestic investors as well, they were found to be especially severe for FDI sectors such as pharmaceuticals. Thus, the framing of the analysis led to the identification of constraints that otherwise might not have been identified without a focus on the need for investment in strategic bets.

VII. Policy Space: Examples of Policy Solutions to Coordination Constraints in Adopting New Technological Capabilities

The policy response to a coordination constraint must be as context specific as possible, and consider existing administrative capabilities, the relevant political economy around reform, and other policy constraints. Moreover, the policy space must consider the potential harm that certain policy responses can generate, by narrowly directing tax incentives, subsidies, or favorable regulation to a selected industries without fully understanding the dynamics that constrain productivity.

The policies initiatives described below take a distinct approach, one of creating problem-solving organizations that better listen, learn, and adapt to identify and address the missing inputs necessary for new activities to occur. One feature of this approach is for governments to build processes of information revelation at the core of public institutions tasked with advancing growth. This approach emphasizes the need for a distinct set of capabilities such as talking to those firms that do not exist in the place as to why they do not find it attractive, and to organize conversations amongst groups with shared, narrowly defined problems. Another feature is that governments should pursue solutions that are within reach of their administrative capabilities. In other words, it may not be feasible to address all relevant coordination issues affecting all potential industries in all relevant geographic areas. However, it may be possible to direct efforts towards a narrower set of issues, faced by specific industries or within a given set of geographic boundaries. The policy initiatives presented build from the work of Hausmann, Rodrik, and Sabel (2008), and Crespi, Fernández-Arias, and Stein (2014). The goal is to create organizations that are information-intensive, able to acquire new capabilities, and to identify and address the missing public goods that limit diversification to adopt new knowhow.

Policies worth consideration include but are not limited to: (i) public-private coordination mechanisms, (ii) Special Economic Zones, and (iii) investment promotion agencies.

a. Public-Private Coordination Mechanisms

Addressing technological coordination failures requires institutional mechanisms that facilitate constant interaction among relevant stakeholders within and across the public and private sectors.

The goals of this interaction should be to: more thoroughly identify industry-specific binding constraints; to coordinate initiatives to address market failures; and to adjust the initiatives put in place depending on its effectiveness. The "*Mesas Ejecutivas*" in Peru tend to be a prime example of this type of mechanism. Below we describe some of the key features of these coordination instances, borrowing heavily from the Peruvian experience.

Three types of stakeholders usually participate in these coordination instances. First, representatives of the private sector autonomously organized around a sector or cross-cutting factors of production. These representatives should be fully aware of the challenges faced by firms on a day-to-day basis, have a broad view of ways to address these issues, and be able to make concrete commitments in addressing these issues. Generally, these private sector stakeholders tend to be part of the senior leadership (e.g.: CEOs, CFOs, etc.) in leading firms in the industry. Second, representatives of the public sector, including any institution with a high degree of influence in the sector or with a responsibility for providing public goods relevant to the sector. These representatives should have a real ability to execute and a concrete mandate to do so. Lastly, the mechanism requires a full-time coordinating group, responsible for guaranteeing the fluidity and continuity of interactions, advancing work and research in between interactions, and facilitating the monitoring of progress of both concrete initiatives and projects. The coordination group can also facilitate access to independent technical advisory assistance in order to inform decision-making on matters outside the parties' areas of expertise (Stein, 2016; Ghezzi, 2017).

These instances are not focused on ways to directly increase firm profitability, but rather on tackling factors inhibiting productivity. Hence the discussion around subsidies or preferential tax treatments is usually off the table in these discussions. Rather, the discussion tends to center around sequentially prioritizing initiatives such as: dealing with market failures, aligning the availability of public goods and services with productive needs, updating regulatory frameworks and enhancing service delivery through improved public-public coordination.

Another distinctive feature of these instances is that meetings are held frequently to quickly move from deliberation to execution. Furthermore, the initiatives that are agreed upon are mostly concrete, specific, and doable in a relative short-term period. They also tend to be subject to adaptation during implementation. The principle is to get the ball rolling as soon as possible and to adapt as needed. From a strategic standpoint it makes sense to start with policies and interventions that are both highly impactful and uncontroversial, before moving on to issues that require long-term planning and that may prove to be more contentious.

Given the intensiveness of the interaction, the number of players involved in implementing specific initiatives and the iterative nature of these initiatives, the coordination mechanism requires intensive monitoring. The objective of the monitoring efforts is to follow-up on the goals and commitments undertaken and to detect implementation problems as they arise (Ghezzi, 2017). Lastly, the mechanism requires a mechanism to effectively raise impasses or issues to the right level of policy decision-making, in order to avoid stagnation and resolve disputes.

It should be noted that the public-private coordination mechanisms described above are not intended to substitute for the findings of Constraint Analysis, but rather to complement them. The results of Constraint Analyses tend to be informative on the most binding constraints faced by the

median firm in the economy and the policy recommendations informed by these findings may lead to structural reforms. Meanwhile, the public-private working groups are focused on constraints faced by specific industries and the policy reforms informed by these discussions tend to be enforceable in the short term.

b. Special Economic Zones

Special Economic Zones (SEZ) have been leveraged globally as a tool for promoting productive transformation efforts. The terms "Special Economic Zones," "Free Trade Zones," and "Special Export Zones" are used interchangeably to refer to specific geographic areas in which companies benefit from relative improvements in the business environment (Farole, 2011). Although the specific nature of the SEZs may vary, they generally have common objectives (Hausmann et al. 2016; Engman et al., 2007; FIAS, 2008; Farole, 2011): (i) to attract foreign investment; (ii) to experiment with disruptive public policies; (iii) to promote productive transformation processes; and/or (iv) to incentivize employment in disadvantaged areas. Another goal is that the SEZ serves as a link with the rest of the local economy, promoting the dissemination of productive knowledge and enabling the local economy to acquire new productive capabilities (Hausmann et al., 2016).

One of the key features of SEZ is that they help solve coordination issues, by allowing firms to benefit from agglomeration. Agglomeration makes a set of indirect benefits possible, most notably savings in transportation costs, general availability of qualified workers, and a shared infrastructure (Glaeser, 2010). Moreover, firms based in the SEZ benefit because their relative concentration may make it easier to safeguard access of access to sector-relevant key inputs.

Another feature of SEZs is that firms may be able to circumvent sector-relevant bureaucratic restrictions in key dimensions of their productive process. These benefits may include exemptions from duties and VAT for temporary imports. Also, the companies in these zones may qualify for immigration exceptions, enabling them to hire specialized personnel with productive knowledge that is very hard to come by. Additionally, SEZs may also provide the type of long-run regulatory stability that may not be necessarily available outside the zone.

Lastly, many successful SEZs tend to have an industrial vocation. The restrictions that affect the development of each industry tend to be extremely specific, so it would be difficult for the agency in charge of managing the zone to address all the potential restrictions associated to all potential industries. Identifying vocations, even in a relatively broad sense, makes it possible to narrow down this problem, paving the way for mechanisms to address specific industry-place restrictions. This approach likely enhances further the benefits of agglomeration.

c. Investment Promotion Agencies

Foreign Direct Investment (FDI) is an important channel for introducing new knowhow in a place. However, in many instances the agencies leading these investment attraction efforts can be revamped by considering a few guiding principles.

FDI promotion agencies can leverage the insights of complexity analysis to identify target sectors with high feasibility (that can leverage existing knowhow) and potential high impact (that can directly or indirectly enable higher complexity). These insights allow places to go beyond

traditional sectors as well as to discard potentially appealing sectors in which the place may not be a competitive destination.

Once target sectors are identified these agencies can attempt to understand key requirements for the development of these industries and the current ability of the place to match them. Some potential requirements may include the availability of a given occupational vector, access to specific public goods, access to localized intermediate inputs or perhaps a baseline regulatory framework. Additionally, it may be worthwhile to identify if the sector may be particularly affected by constraints in other policy areas (i.e.: congestion in ports, poor provision of electricity, etc.). Lastly, it may be fruitful to analyze the competitive landscape, in terms of the ability of other competitive destination to enable access to key inputs. It should be noted that this implies that the agency has the requisite technical skillset to conduct this type of analysis. Additionally, it implies that it has access to industry experts that can help tease out the most relevant areas to focus on.

Based on this analysis the agency can identify policy areas in which the place is well suited to meet these basic requirements and areas in which gaps may still exist. For those instances in which the area is well suited, the agency can document quantitative (i.e.: metrics on the quality of provision of a specific public good) and qualitative (i.e.: testimonials of firms in other industries that are also intensive in the use of the same public good) evidence of this fact. Where gaps may exist, the agency can work with the relevant public and private sector stakeholders to identify prospective policy solutions to these issues. More so, it can also document previous experiences in addressing industry specific constraints in the same quantitative/qualitative fashion. These potential policy solutions may also be informed or complemented by studying the policy offerings of places that were able to effectively attract significant FDI in the sector in the recent past. Additionally, FDI agencies may set up coordination mechanisms with the rest of the public sector in order to help troubleshoot common issues generally associated with setting up new firms in the place.

All this information can be consolidated in industry specific pitchbooks, which essentially highlight the ability of the place to match the basic requirements of the industry, its proposed (preliminary) approach to address policy gaps and troubleshooting mechanisms. These pitchbooks can serve as a mechanism to jumpstart conversations with key industry players either in a bilateral fashion or in the context of conventions, fairs, roadshows and other diffusion mechanisms.

It is worthwhile mentioning that pitchbooks are a living document. Initial interactions with potential investors will rarely lead directly to investment commitments. In many instances, these interactions will serve as a mechanism to identify previously unobserved additional constraints. Hence, these discussions may lead to revisiting the potential feasibility of the industry in the place or inform the true nature of policy gaps which in turn would shape new versions of the pitchbook.

d. Other Policy Initiatives

There is wealth of other potential initiatives to address technical coordination failures, here we briefly describe three of them. One of these alternatives refers to agencies that promote high-impact entrepreneurship. The type of support provided to these private initiatives does not have to be restricted to fund allocations, but rather can be focused on helping address information

asymmetries that limit access to key resources. Some strategies to consider include connecting high-potential local projects with networks that support start-ups (incubators, accelerators, venture capital), facilitating shared temporary office space for entrepreneurs in early development stages, facilitating access to advisory and support services in key areas (marketing, acquiring business, recruiting investors), and other initiatives that can minimize the scale of up-front costs that usually occur in innovative projects and that hamper "self-discovery".

Another relatively common initiative in this regard is focused on diaspora engagement. Traditionally, it has been difficult for developing countries to compete globally in attracting highly skilled professionals. However, the return of migrants who have productive experience abroad can be a highly effective mechanism for the transfer of technology and knowledge. Similarly, entrepreneurs or pioneers in the diaspora can help establish backward linkages between firms in the host country and their home country which may else serve as a knowledge diffusion mechanism. In both cases, diaspora engagement can assist in accelerating the acquisition of capabilities.

Lastly, broader policies focused on urban planning and /or enhancing quality of life may also prove useful in promoting productive diversification. When firms decide where to set-up, they also consider whether the place attractive to live and work in (Mulligan and Carruthers, 2011). Glaeser, Kolko, and Saiz (2001) describe four types of urban amenities that have a positive impact on the perception of quality of life in an area. The first amenity is the diversity of consumer and leisure goods and services (such as restaurants, cultural meeting spaces, shopping centers). The second type refers to public space is configuration. Namely, the physical and aesthetic appearance of the city (for example, revitalization of historic centers and architectural rebuilding, creation of pedestrian zones, etc.). The third type is centered around the provision of public services such as schools, hospitals, and public safety. The last type concerns mainly connectivity. This refers both to a good transportation system and greater urban density. Overall, interventions in these fronts might make the place more attractive to highly skilled workers, and by extension to the corporate headquarters, R&D centers, and testing and design centers that could employ them. Even though these amenities may not be part of explicit set of capabilities required by industries in order to thrive, they may be implicitly required by high-productivity or high-impact stakeholders in these industries, and their provision also requires complex coordination.

VIII. Concluding Thoughts

Countries rarely experience rapid, sustained growth by producing more of the same production. Rather, sustained growth is achieved by evolving one's comparative advantage to produce a diverse set of goods, of greater complexity, that require an ever-widening set of technological capabilities. The final set of technological capabilities look dramatically different than the initial factor endowments, in their diversity, specialization and sophistication. In this process of structural transformation, it is the slow accumulation and transfer of knowhow, or tacit knowledge that is the limiting factor on technological transfer of capabilities across individuals, firms, and societies. As a result, new technological capabilities are not added all at once, but through narrow channels and with high sensitivity. Where modern production requires many technological capabilities to be

present at the same time, the complementary nature of these inputs in production means that the absence of any one input imperils the productivity of the entire process. Investment in a new complex activity may not be possible or profitable without coordinated investment in other activities or inputs.

This process of evolving the technological capabilities required for growth bumps up against coordination failures and information externalities. The risk of coordination failures hampering the process of structural transformation is further heightened by the asymmetric nature of technology, in the unequal relatedness of different economic activities. For countries that lack sufficient capabilities and do not find it easy to enter new activities as the promising activities are too far from a leap in requiring too many new capabilities at once, coordination frictions may present a capability trap.

The economic growth literature has a wealth of studies on the risks of depending on a single driver of growth (e.g., oil or other commodities) given risks that would result from the stagnation or volatility of that main activity. Studies consider how the concentration or dependency on those activities may further complicate the diversification process, by affecting the exchange rate or terms of trade, for example in well-studied Dutch Disease dynamics. This chapter aims to include constraints in adding new technological capabilities to the list. Challenges may arise from the lack of connectedness of the technology or capabilities required to produce that commodity and many other products, limiting the paths to diversification (or making the high-value opportunities too far a leap from current capabilities).

Growth that occurs by adding new technological capabilities to enter new activities versus trying to grow the main existing sector requires distinct capabilities. Admittedly, few governments are well set up with the capabilities to not only identify opportunities, but to reveal the information on why investment is not occurring and to troubleshoot and coordinate missing capabilities for investment to occur. Ultimately, the way out of a capability trap is by building the capabilities to organize better information and conversations to reveal and address constraints – until the next constraint is binding.

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Appendix A: Data Guidance

As was detailed in the previous section, Economic Complexity is significantly related to the ability of places to achieve growth either in the intensive or the extensive margin. Hence, a constraint analysis focused on technological coordination necessarily requires some understanding of the core concepts of Economic Complexity and (broadly) how they are calculated.

To start off we have **Revealed Comparative Advantage (RCA)**. If a place has a higher-than-expected participation[13] (either in exports, employment or wage bill) in each economic activity, then we can argue that the place has an RCA in the activity or that it is intensive in that activity. This means, that the place (probably) has all the productive capabilities required in order to engage in this activity. The collection of activities in which a place is intensive makes up the **Productive Matrix** of a given place. The number of activities in which a place is intensive is referred to as the **Diversity** of the place, meanwhile the number of times a place is found to be intensive in each activity is referred to as the **Ubiquity** of the economic activity.

Based on these core concepts, the complexity of each economic activity can be approximated. Namely, by leveraging the average diversity of places that are intensive in each economic activity and the average ubiquity of the other products that these places are intensive on the **Product Complexity Index/Industrial Complexity Index (PCI)** can be estimated. In general, the most complex activities happen in places with high diversity and that are mostly intensive in activities that are relatively rare (low ubiquity). Meanwhile, less complex activities are frequent in places with little diversity and that are mostly intensive in rather common activities (high ubiquity). The PCI is indicative of the relative sophistication of the know-how required by each economic activity, hence by calculating the average PCI of all the activities in the productive matrix of a place, the **Economic Complexity Index (ECI)** can be estimated.

Up to this point, the concepts outlined are mostly helpful in describing the current productive structure of a place. In order to understand its potential structure, the first relevant concept is **Proximity.** Proximity is a measure that seeks to capture the similarity of the know-how required by a pair of economic activities. This measure can be approximated through several different methodologies depending on the data available.

The sum of all proximities between the activities in the productive matrix and a given activity (normalized from 0 to 1) is called **Density** and the inverse of density is called **Distance.** These measures can be thought of the relative likelihood of a place being able to become intensive in a given activity. Activities that require very similar know-how to the one in the productive matrix of the place are thought to be at a short distance (high density). Meanwhile, activities that require very different capabilities than those existing in the place are thought to be a farther apart (low density).

In order to understand the relative abundance of complex activities at a short distance of a place's current productive structure the **Complexity Outlook Index (COI)** can be calculated. COI is equivalent to the sum of the PCI of the activities not in the productive structure of the place,

[13] A share that is equal or higher to the global share for instance

weighted by the density with respect to each activity. This measure captures the likelihood of a place being able to leverage its current productive structure to transition into a more complex economic structure. In other words, a low complexity outlook reflects that a place has few complex activities that are a short distance away, so will find it difficult to acquire new know-how and increase their economic complexity and vice versa.

In addition to understanding core concepts of Economic Complexity, it is also valuable to have a sense of the type of datasets that can be leveraged for this type of analysis as they can shape the way some of the previous measures are calculated and can have significant implications on how to interpret them. We will focus on three sources of information: (i) Atlas of Economic Complexity, (ii) Anonymized Social Security information aggregated at the industry level, (iii) Dun & Bradstreet dataset

Perhaps the most commonly used data source for Economic Complexity calculations is the Atlas of Economic Complexity. The Atlas contains trade information for 250 countries and territories and over 5000 products (6-digit level in the HS classification). It is updated annually by taking raw data from UN COMTRADE that is later cleaned using the Bustos-Yildirim method in order to enhance reliability of the recorded trade flows. Furthermore, the Atlas also provides ready-made access to the previously discussed measures of complexity. Namely: the ECI and COI for each country in a given year, the PCI for a given product in a given year, and both RCA and the distance for a given product-country pair in a given year. With this information, measures of density, diversity and ubiquity can easily be estimated.

Leveraging this data source implicitly leads to choices on how some complexity measures are calculated. More precisely, RCA is determined by the relative share of exports of a given product in a given country when compared to the rest of the world. Meanwhile proximity is determined as the minimum conditional probability of two products being intensively exported by the same country. Additionally, this dataset has some limitations which should be considered when interpreting results. Mainly, it solely focuses on goods (not services), which means that this approach gives an incomplete view of the economic structure of places. Additionally, the information is only representative at the national level, meaning that it cannot be used for subnational work.

In order to address these limitations, other datasets can be leveraged. For instance, (anonymized) social security data aggregated at the industry level gives a much clearer composition of the productive structure of places as it displays both the production of goods and services. Additionally, it allows complexity analysis to be carried out even at a municipality level. As before, the choice of dataset has implications on how complexity metrics can be calculated. In this case RCA is determined by the relative share of employment (or wage bill) in a given activity relative to the rest of the country. Meanwhile, proximity can be determined in three distinct ways: (i) the minimum conditional probability of two activities being intensively present in the same place, (ii) probability of two activities demanding intensively the same occupational vector, or (iii) probability of more intensive labor force flows between two activities.

This approximation has its own set of caveats. In this case, the main limitation is that the analysis can only be carried out at the sub-national level. Given that social security information tends to be highly specific to each country, it is hard to access a consistent data source that allows for comparisons across countries. Therefore, with this approximation we can only assess the relative sophistication of the productive structures of states and cities of a given country, compared to other states and cities in the same country. This may not be particularly informative for policymakers in the most complex places in the country and does not solve for the lack of service information when analyzing countries. Additionally, it can be argued that RCA of employment (wage bill) is a less stringent measure of productive capabilities than RCA of exports, as the former can be distorted by the dynamics of the local labor market.

Alternatively, the Dun & Bradstreet dataset -which seeks to function as a global registry of private businesses- can also provide a holistic view of the productive structure of places (including services), but in this case allowing for international comparisons at the national and subnational level. In this instance RCA can be determined by either the relative share of employment in a given activity relative to the rest of the world (or country). Meanwhile, proximity can be determined in two distinct ways: (i) the minimum conditional probability of two activities being intensively present in the same place, (ii) the minimum conditional probability of two activities being produced in the same establishment. As with the previous cases, this dataset has its own set of limitations. First, the representativeness of the data is not consistent across all geographies. Hence it is important to validate that the place subject of analysis and all relevant comparators display information that is consistent with local data sources. Second, this dataset is a sort of living registry which is consistently updated, meaning that we can't assess the complexity of products or places over time, just when the dataset was accessed. Third, the predictive power of future performance/diversification paths has not been as thoroughly tested and validated as the previous sources of information. Fourth, just as before, RCA of employment may be a less robust measure than RCA of exports.

For all datasets previously described there is an additional limitation. The way in which PCI is calculated implies that the same activity requires the exact same set of capabilities regardless of where it is produced. In other words, it implies that it uses the same (implicit and explicit) inputs and occupational vectors and (presumably) generates the same output. We know that this is not the case. Phases of the productive process are routinely broken down across different establishments for the same firm, and these establishments may be in different cities, states or countries. For instance, the same car manufacturer may showcase intensive presence in Japan, the US and Mexico and carry out very distinct parts of its productive process in each of these places, each with its own level of relative sophistication. In Section 4, we briefly review an example of how this assumption can lead to false negatives/positives and strategies to diminish this effect.

Appendix B: Testing for Positive Deviance in Chiapas, Mexico: A Visit to Yazaki

Chiapas is the poorest state in Mexico – and among the lowest complexity (ECI) states as well. Six, simple agricultural exports account for 92 percent of non-oil exports in Chiapas, i.e. existing exports require little coordination or technology. And yet, by constructing the Product Space for Chiapas, the Harvard Growth Lab team found the economy has comparative advantage in car parts, a relatively complex industry. This led the team to find out who the firm is that operates in this relatively complex environment.

The answer was Yazaki, a Japanese company in origin (operated in Mexico as Arnecom S.A.) that produces the wire harnesses that serve as the central nervous system of a car's basic function and safety features.[14] Facing rising wage levels in the northern states of Mexico, Yazaki had already begun diversifying its production base to new states. Not all of them were successful. A plant in Oaxaca never took off. One in Campeche faced an overabundance of incentives—free land and subsidized infrastructure—that led to a wave of incoming firms competing for workers, who repeatedly left for a better offer. High turnover and escalating wage rates led to the close of the Campeche plant.

In Chiapas, Yazaki's trajectory has been distinct—and, from a Growth Diagnostics perspective, those distinctions are meaningful. Yazaki's presence in Chiapas started in 1997 with one large plant in the capital, Tuxtla Gutierrez, with around 3,000 workers. By 2015, the firm's operations had expanded to six plants across Chiapas, employing 3,850 workers. The Tuxtla Gutierrez plant took off well. Yazaki placed key importance on bringing experienced knowhow to Chiapas, with the plant manager being an experienced plant manager brought down from Nuevo Leon along with a handful of experienced engineers. The majority of workers have less than a high school education, but with only a six-day training they are able to operate the production line. Business was humming along as the first large, modern production plant found roots in Chiapas.

The success of the Yazaki plant in Chiapas led to requests for new orders, only to be repeatedly rejected by the Chiapas plant manager. What constrained the growth of the Yazaki plant in Chiapas? Ultimately, the constraint was not in electricity, road infrastructure, or availability of skilled labor, but in retaining a sufficient size of line workers to run the line. The capital of Chiapas, Tuxtla Gutierrez is not densely populated and lacks a public transport system to connect workers from home to work. In part, the lack of urban agglomeration is due to indigenous land rights, where those who move to urban centers to seek employment in high-productivity activities risk losing their family land plots to be redistributed to the community. As discussed above, the chicken-and-egg problem of urban agglomeration is also that few complex firms are willing to locate in a place where there are few workers, perpetuating low agglomeration. Whether the coordination failure is from workers' unwillingness to migrate to cities or from firms being unwilling to move to a place without a ready workforce or proven ecosystem goes to the heart of the technological coordination constraint that is present in Chiapas. Even in offering higher wages than many surrounding

[14] Yazaki has operations across much of Latin America and started in Mexico in the automobile cluster in the state of Nuevo Leon. Following the Zapatista uprising in Chiapas in 1994, the federal government aimed to incentivize companies to locate production in Chiapas to offer job opportunities and income growth.

communities could find locally, the cost of transiting to work, in time and money, was prohibitive for many workers, if transit was available at all. Against this constraint, offering higher wages was less efficient than creating Yazaki's own transportation system for its workers in surrounding communities. The Tuxtla factory now operates a bus system that covers a 30-kilometer radius around the factory. Even so, employment in the Tuxtla plant remains slightly lower today than at the start of the factory.

Given this coordination constraint, Yazaki preferred to grow by dividing up its production process and developing new, smaller plants in various areas of Chiapas, instead of increasing the size of its plant in Tuxtla Gutiérrez. The fact that it went from one plant in 1997 to five in 2015, shows that it is more efficient for them to move the jobs to where the workers live, rather than to move the workers to the jobs. While technological coordination prevailed as a constraint in Chiapas, this study of positive deviance also shed light that the binding source of the constraint lied in transport systems and land rights.