Where Micro meets Macro in Technology Space

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Abstract:

We describe three key elements in economic growth models: general purpose technologies (GPTs), institutions, and infrastructure. In existing growth models, these are addressed from a very aggregate perspective, but we emphasize that their microeconomic structures are complex and often involve commons aspects. We discuss the similarities and differences between GPTs, institutions, and infrastructure from both the demand and supply side perspectives. We use that comparison to draw more specific lessons from growth models on the contributions of each of the growth drivers and the policy implications for how they can be managed.

Keywords: *infrastructure, general purpose technologies, institutions, economic growth, spillovers*

1. Introduction

Important elements in recent *macroeconomic* growth – globalization, integration of economies, outsourcing, information and communication technology driving growth – are clearly driven by key infrastructure, such as the Internet, fiber-optic networks, and container transport by ship, rail, and truck. This emphasizes a greater need to understand the infrastructural foundations of macroeconomic growth.

Macroeconomic growth models study the performance of the economy on the whole. Increasingly these models are built from micro foundations, but they typically emphasize capital accumulation and technological change at the aggregate level. Thus, macroeconomic models are best characterized as studying the behavior of economic systems, or simply, *system behavior*.[2] Some recent macroeconomic growth models delve into technological change more specifically, and emphasize *general purpose technologies* as key drivers of growth. Another recent literature focuses on *institutions* as drivers as growth. Far fewer models focus on infrastructure.

All three of these growth drivers – general purpose technologies, institutions, and infrastructure – are highly complex systems in their own right. Microeconomics studies the behavior of individuals, firms, and other organizations with regard to

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[2] The global economy is an "economy of economies" in the same sense that the Internet is a "network of networks."

theses systems, most often with respect to the allocation of resources. While often associated with the study of market behavior – or the behavior of various participants in markets, microeconomics also studies the behavior of participants in non-market systems as well. This is important because there is a growing focus in microeconomic studies on cooperative aspects of markets, whether through *network economics, game theory,* or *commons*. Thus, microeconomics is best characterized as studying resource allocation within economic systems, or simply, *in-system behavior*.

In this paper, we seek to contribute to the struggle to reconcile macroeconomic models that focus on the aggregate effects of general purpose technologies, institutions, and infrastructure with microeconomic models that describe those growth drivers in more detail. The focal point of our analysis is that infrastructure, general purpose technologies and institutions are intermediate forms of capital which create spillovers and systemic effects that are not easily observed (or well understood) within microeconomic analysis but more easily observed (and better appreciated) within macroeconomic analysis. In essence, we see these intermediate capital resources as critical foundations for productive behavior within economic systems. While this view is hardly new in itself, a careful examination of the microeconomic and macroeconomic perspectives on these resources reveals some holes in our understanding of how these resources generate value for society. In particular, the importance of open infrastructure and user-generated spillovers at the microeconomic level and the relationship to technological innovation and growth at the macroeconomic level deserve attention.

The paper is organized as follows. Section 2 presents a short literature review giving some idea of how the three growth drivers have been defined and analyzed in macroeconomic growth models. Section 3 lays out our scheme for differentiating the three effects. Section 4, which is not finished, will present some analysis of how macroeconomic growth models might improve if adjusted to account for infrastructure and infrastructure-derived spillovers. Section 5 concludes.

2. Literature Review

2.1 Perspectives on General Purpose Technologies

The seminal work on GPTs in growth is Besnahan and Trajtenberg (1992). They argue that GPTs have three main features: *pervasiveness, technological dynamism,* and *innovational complementarities.* Their model is stylized – one GPT is provided by a monopolist, there is no uncertainty, and the main question is whether there is coordination among all the complementary uses of the GPT in order to achieve the highest growth rate. While not explored in their paper, the problem of achieving coordination obviously has commons aspects.

Helpman and Trajtenberg (1998) extend the model to allow for multiple GPTs, which arrive exogenously and unexpectedly. Their model is consistent with a stylized fact that new GPTs initially cause a slowdown in growth, as resources are consumed to diffuse it throughout the economy.

2.2 Perspectives on Institutions

Institutions, both formal (legal) and informal (social), are understood to be essential precursors to economic development and robust markets. Economic systems can be called "systems" in large part because of the set of institutions that structure and stabilize relationships among economic actors. Generally, institutions can be defined as humanly developed constraints that structure human interaction.

2.2.1 Microeconomic perspective on institutions

From a microeconomics perspective, institutions directly structure the environment within which actors behave and influence in-system behavior. Institutions both define the "rules of the game" and provide for their enforcement. This definition of institutions encompasses both formal constraints, such as law, and informal constraints, such as societal behavioral norms, conventions, and self-imposed codes of conduct. Institutions determine transaction costs, and along with technology and infrastructure, dictate production costs. (Douglass North, *Nobel Prize Lecture*).

Ronald Coase (*The Problem of Social Cost*) first made the link between transaction costs and institutions, the importance of which can be seen in Douglass North's empirical study that found that 45% of U.S. GNP was devoted to transaction costs. Of most importance, perhaps, are those institutions that facilitate exchange, investment, risk sharing, and cooperation. Property and contract law, for example, coupled with a legal infrastructure for the adjudication of disputes and enforcement of judgments, enable economic actors to "plan and do" so much more with so much less. Since transaction costs comprise 45% of a productive economy like the United States, it is easy to see that inefficient institutions could paralyze an economy.

Informal (non-legal) institutions may be provided privately or collectively, may or may not be publicly accessible, and develop largely through emergence, which occurs when a number of people operate in an environment in such a way that the group as a collective exhibits more complex behaviors. While formal institutions may be intentionally modified or transplanted, informal institutions arise through emergence. Formal (legal) institutions are government supplied and made available on a nondiscriminatory basis to the public. Although the development and evolution of legal institutions can be seen as a series of arbitrary decisions of lawmakers with little understanding of underlying economic forces, some theorists suggest that legal institutions evolve when the potential

gains from institutional change exceed the costs of effecting that change. (Harold Demsetz, *Toward a Theory of Property Rights*). In this way, both formal and informal institutions can be seen as the product of emergent systems.

The emergent nature of institutions leads to a close relationship between supply and demand forces. As the world changes and transaction costs rise, modified behavioral patterns bring new or modified institutions into being. Thus, we see that the primary factor in demand for institutions is the amount of drag that transaction costs impose on productive activities. (Douglass North, *Nobel Prize Lecture*). Demand for formal institutions generally manifests through political processes, although rules also may arise and evolve through common law processes as judges apply rules to new cases. Like infrastructure and GPTs, institutions are a special form of capital resource that generates value when used productively in a wide variety of settings.

2.2.2 Macroeconomic perspective on institutions

Economists tend to identify property, contract, and corporate (limited liability) law as being within the set of institutions essential to economic growth. Baumol et al., influenced by North's institutionalist perspective, delineate four different types of capitalism – state-guided, big firm, oligarchic, and entrepreneurial—and contend that different sets of institutions may promote one type of capitalism over another. Baumol relies heavily on an institutional perspective. While North may be content to sit back and allow institutions to emerge, Baumol advocates proactively promoting those institutions that best promote an optimal blend of big firm and entrepreneurial capitalism.

Baumol et al. argue in favor of a mixture of big firm and entrepreneurial capitalism and contend that a particular set of institutions is essential. In particular, they argue in favor of the following four (institutionally-derived) conditions: (1) Easy to start and grow a business (depends upon business and property registration, ease of hiring and firing, bankruptcy laws; (2) Reward useful entrepreneurial activity once started (depends on property and contract rights); (3) Discourage activities whose goal is to reallocate wealth rather than create it; (4) Encourage successful companies to continue to innovate and grow (depends on openness to trade and antitrust law). Baumol does provide some guidance for institutional reforms, suggesting lowering barriers to business formation, formalizing legal systems, improving access to capital, and education, and it would be very interesting to see how those would play out in practice. (Baumol et al., *Good Capitalism, Bad Capitalism, and the Economics of Growth and Prosperity*).

In essence, Baumol et al identify a particular set of microeconomic activities—in-system behaviors – that may be promoted and sustained through particular set of institutions, and argue that such institutional structuring of in-system behavior will lead to macroeconomic (system-wide) growth.

Recent decades have seen remarkable, sustained, and unprecedented economic growth. However, mainstream economic theory has failed to explain differing growth rates across countries. As some developing economies join the growth surge (notably India and China), others have failed to make significant progress (sub-Saharan Africa). (Stephen Parente and Ed Prescott, *Changes in the Wealth of Nations*). The fact that some areas of the world have persistently posted abysmal growth rates constitutes the central "growth puzzle".

Both empirical (Robert J. Barro, *Determinants of Economic Growth*) and anecdotal (William Easterly, *The Elusive Quest For Growth*) evidence suggests that institutions play a significant role in economic growth. Barro's exhaustive study found that rule of law is positively correlated with economic growth.

Returning to North's institutionalist perspective, one characteristic of emergent processes is that the emergent properties of the collective behavior are neither possessed by any of the individual agents nor predictable from observations of the individual agents. (Friedrich Hayek, *Law, Legislation, and Liberty*). A crucial implication of this is that efforts to transplant institutions in order to promote economic growth have been largely futile. (North, *Nobel Prize Lecture*; William Easterly, *The Elusive Quest For Growth*).

Some new research attempts to formally model the effect of institutions and norms on economic growth, and it will be very interesting to see this approach. (Mark Gradstein and Kai A. Konrad, *Institutions and Norms in Economic Development*, released August 31, 2007).

2.3 Perspectives on Infrastructure

3. The Interrelationships of GPTs, Institutions, and Infrastructure

First, we identify infrastructure, general purpose technologies, and institutions and explain *how* these resources both *structure in-system behavior* and have *system-wide impacts*. It is not enough to posit at a relatively abstract and general level that these resources are foundational precursors for productive economies.[3] Economists need to develop deeper and more nuanced explanations for the dynamic relationships between these resources, how they are managed and made available to the public, the productive activities engaged in by users, the generation of spillovers, and systemic effects.

Key to our plan is to differentiate GPTs, institutions, and infrastructure by their

[3] As history reveals, merely investing in infrastructure does not ensure economic growth; nor does merely adopting laws and institutions, such as intellectual property regimes; nor does diffusion of general purpose technologies.

attributes on the supply side and demand side.

3.1 The Demand for GPTs, Institutions, and Infrastructure

On the demand side, all three generate value in similar ways.

All three are *nonrival* or *partially nonrival* inputs into wide variety of productive activities by users that generate private, public, and nonmarket goods; Lipsey, Carlaw and Beckar (2006) call this *range*. (They also note *variety,* meaning many uses within one part of the economy.) The most productive way to think about *range* of uses for infrastructure is that it is all on the demand side. For example, a road can be used by cars, trucks and motorcycles, which we can just think of as analogous to Internet packets. It is on the demand side that these different vehicles, and different origin-destination pairs, different cargoes, etc. create different sources of value.

Sometimes the demand side changes, reducing the range of uses. When this happens, a facility can cease to be infrastructure. An example of this happening is railroads in South Dakota and Wyoming. Although these were built for a wide range of uses, such as farm-to-market and production center-to-hinterland transportation, demand for these activities has fallen greatly. But several railroads in this region are very successful because they carry coal from the Powder River Basin to power plants further east. While these railroads are still infrastructure in the sense that they are connected to the national rail system, they are no longer infrastructure for the region when viewed in isolation. Note that this is almost entirely a change on the demand side. On the supply side, almost nothing happened other than removing some sidings that are no longer needed and strengthening bridges and rails for heavy coal trains.

When GPTs, institutions, and infrastructure are consumed, they generate substantial spillovers. This creates a case for managing all three as commons, depending on the benefits of competition over coordination (by government or infrastructure owner). An advantage of commons is to avoid “picking winners.“ See Frischman, *Minn. L. Rev.*

3.2 The Supply of GPTs, Institutions, and Infrastructure

On the supply side, the three resources all produce narrowly defined goods, for example steam and electricity produce power, roads produce *trips*, computers produce calculations, etc. But the details of how the three resources are supplied are quite different:

(Traditional) infrastructure is partially nonrival and thus congestible. It is sometimes privately owned and provided, and supply side incentive issues matter and can be complicated. Infrastructure is usually most efficient as a large network, hence there are very large economies of scale and limited scope for

competitive markets. A key feature of infrastructure is that it requires a physical connection, and thus access can often can be closed based on nothing more than traditional physical property rights.

On the supply side, *GPTs* are a subset of *technologies* in general. Technologies may be *composed* of individual rival and nonrival goods, but the design and standards – and of course the general purpose principles (GPPs) behind them – tend to be nonrival. Because some of the individual goods are rival, GPTs are often disseminated to consumers via private providers, but the initial R&D is often done in universities with public funding; supply side incentive issues matter; usually efficient in much smaller modules than infrastructure, hence more scope for competitive markets. Generally the designs and standards are open and can only be closed using very powerful intellectual property rights. Note that specific implementations of a GPT, e.g. MS Windows as an implementation of computer OSs, may not be open.

Institutions are nonrival and publicly provided, so supply side incentive issues do not matter. They are generally open, and in fact may not be possible to close.

Let us concludes by noting the *complementarity* among GPTs, institutions, and infrastructure. For example, Internet infrastructure is much less valuable if no general purpose computers (imagine remote terminals instead); and general purpose computers are much less valuable without the Internet infrastructure. Different bundles of infrastructure, GPTs, and institutions may lead to very different outcomes.

4. Modifying Existing Macroeconomic Growth Models

Given the above discussion, some of the insights of macroeconomic growth models may be modified when adjusted to account for infrastructure and infrastructure-derived spillovers.

In particular, Romer seems to focus on knowledge spillovers in a rather generic way. There are other types of spillovers that may not be associated with shared knowledge, infrastructure in particular.

4.1 Example: Universities

One type of infrastructure that economists have focused on as promoting growth is universities. Universities,[4] particularly research universities, are an interesting

[4] Economists recognize the importance of universities, primarily as a source of education. Education plays an important role in both microeconomics and macroeconomics, and one might wonder why we have not chosen to focus on education more broadly, perhaps in terms of aggregate educational investments

example of infrastructure that provide a wide range of *human capital outputs* – individuals with varying levels and types of education, skills, training, and socialization; *research outputs*, including various types of research along the full spectrum of basic to applied as well as a wide range of subject matter; and *other outputs*, including social networks, new businesses, and cultural outputs.

From the demand-side, universities generate value for society in a similar fashion as traditional infrastructure. From the supply-side, universities often involve different degrees of public and private support.

Delineating what we mean by openness might be interesting; it could refer to admissions policy, including for foreigners, and it also could refer to the allocation of university resources to "users" which would include researchers.

While the contributions of universities may appear small in comparison with other private companies, universities often lead to the creation of the very companies at the heart of the new economy. Each of the categories of university-generated outputs is relevant to innovation- and entrepreneurship-based theories of economic growth. So it would seem that universities are at least to some degree relevant to those theories, but perhaps only partially. An infrastructure approach might integrate usefully across macro theories.

4.2 Example: Institutions that Support a Non-profit Sector

While the connection between a non-profit sector and economic growth may seem tenuous, a more careful examination may suggest otherwise. The non-profit sector depends upon a series of institutions, rather than infrastructure or GPTs. There are two theoretical arguments that suggest that sustaining a non-profit sector is important to growth:

First, we could argue that the non-profit sector is complementary to the for-profit sector and activities in the former spill over to the latter. [we can explain this in terms of R&D; management on environmental resources; provision of public and nonmarket goods in a cheaper fashion than government]

Second, Baumol et al. spend considerable time developing a distinction between productive and non-productive entrepreneurship, where the former concerns innovation and the search for opportunities to "grow the size of the pie" while the latter concerns mere redistribution and the search for opportunities to "grab a larger slice of the pie." They argue that institutions that support productive entrepreneurship and discourage non-productive entrepreneurship are critical to economic growth. In essence, the idea is that desirable institutions affect in-

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or the educational system itself. Education is a product of many different types of public and private investments and is not in itself infrastructural within the meaning of our paper.

system behavior by channeling entrepreneurs to productive activities. It would seem likely that those entrepreneurs unsatisfied with the allocation of wealth or having other related distributional concerns—who might tend toward criminal behavior or rent seeking—are best channeled toward legitimate social entrepreneurship.

The reason I introduce these institutions is that I imagine it might be empirically testable. Of course, the institutions would vary based on the ease of setting up and operating a non-profit, the conditions imposed on operating entities, the incentive structure (taxes, subsidies, etc.), and so on; and states or countries could also be compared based on the size of the non-profit sector, openness to foreign entry, and so on.

5. Conclusion

We have described three key elements in economic growth models: general purpose technologies (GPTs), institutions, and infrastructure. We have described how they are addressed in some existing growth models. Then we have examined more carefully the similarities and differences between them. We will use that comparison to draw more specific lessons from growth models on the contributions of each of the growth drivers and the policy implications for how they can be managed.