Technology infrastructure: Introduction to the special issue.

By: Albert N. Link and Stan Metcalfe

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Abstract:

Technology infrastructure supports the design, deployment and use of both individual technology-based components and the systems of such components that form the knowledge-based economy. As such, it plays a central role in the innovation process and in the promotion of the diffusion of technologies. Thus, it is an important element contributing to the formation and operation of innovation systems and innovation performance in any modern economy. It is a characteristic of the innovation process in such economies that it depends not only upon the internal innovative efforts of firms but additionally on their links with a wider framework of innovation supporting activities, that is to say, as Alfred Marshall once expressed it, it depends on the internal and the external organization of the firm. It is to the formation of the external organization of innovation processes that technology infrastructure makes its vital contribution.

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Technology infrastructures have many dimensions. They can be classified first, and typically, by the set of physical and virtual tools, methods, and data that enable all three stages of technology-based economic activity: the conduct research and development R&D, the control of production processes to achieve target quality and yield, and the consummation of market place transactions at minimum time and cost. The underlying ‘infratechnologies’ – including measurement and test methods, process and quality control techniques, evaluated scientific and engineering data, and the technical dimensions of product interfaces – are ubiquitous in the typical technology-based industry. The collective economic benefits of such infrastructure are therefore considerable, as are the consequences of not having it in place at critical points in a technology's life cycle.

Characterization of technology infrastructure can also include organizational or institutional forms that leverage knowledge creation and knowledge flows in technology developers and users, including research/science parks, incubators, university research centers, and focused public–private partnerships. The efficiency of these institutions in providing infratechnologies and related infrastructure services are essential to an efficiently functioning national innovation ‘ecology’ and to the capacity of that ecology to form and reform innovation systems around innovation problems.

Technology infrastructure, either in the narrow or broad sense, is not well understood as an element of a sector's technology platform or of a national innovation system. Similarly misunderstood are the processes by which such infrastructure is embodied in standards or diffused through various institutional frameworks. In fact, because of the public and quasi-public good nature of technology infrastructure, firms as well as public-sector agencies underinvest in it, thus inhibiting long-term technological advancement and economic growth.

This issue brings together a collection of papers from eminent scholars on all of the various dimensions of technology infrastructure mentioned above. To our knowledge, it is the first such collection of papers and we expect this scholarship to become the foundation for future research in this area.

Greg Tassey argues that designing and managing an economy's technology infrastructure requires both accurate economic models and data to drive them. Previous models treat technology as a homogeneous entity, thereby precluding assessing investment barriers affecting infrastructure elements. The model he presents overcomes this deficiency by disaggregating the knowledge production function into key elements of the typical industrial technology based on the distinctly different investment incentives associated with each element. Without such a model, the economist's and the policy analyst's ability to assess important market failures associated with investment in the major technology elements, including those with infrastructure (i.e., public-good) characteristics, is compromised. Unfortunately, even with the correct knowledge production function, the required data are difficult to collect. This forces government agencies, which fund a majority of technology infrastructure research, to use second-best approaches for economic and policy analyses. The second half of his paper therefore presents an analytical framework that can be driven by more accessible data and provide reasonable impact assessments until better data become available.

Adams, Marcu, and Wang define public technology infrastructure to mean public resources that bring new R&D into existence. Examples are public research that yields knowledge spillovers and government contracts that broker new research. Using this definition they explore the role of public infrastructure on cooperative R&D, especially R&D sourcing and research joint ventures (RJVs). Their findings strongly suggest that public infrastructure promotes cooperative R&D. The author's evidence comes from two different sources. First, they study the role of federal laboratories in R&D sourcing by private laboratories as a whole. Even controlling for simultaneity bias they find that private sourcing increases as a result of federal laboratories. Second, they examine patents that arise from individual projects within private laboratories. These are RJVs sponsored by the Advanced Technology Program (ATP). They find that R&D subsidies as well as difficulty and novelty increase patents produced by the RJVs. Oversight by ATP has no direct effect, but an indirect governance effect seems to exist, since firms value oversight more in the case of more difficult and novel projects, which produce more patents.

O'Connor and Rowe present a quantitative case analysis of one US ATP public–private partnership that advanced the technology infrastructure of molecular diagnostics, resulting in substantial downstream economic and public health benefits. Biotechnology R&D, they argue, is generally characterized by technologies requiring substantial investments in time, money, and energy to develop and sustain concepts through long incubation times. Public sponsorship made possible a partnership between two firms that would have not otherwise collaborated. Affymetrix and Molecular Dynamics accelerated the development of DNA analysis technologies and induced innovation at competitor firms. The research conducted by these firms accelerated the completion of the human genome project and improved both the quality and speed with which the biotechnology industry and medical science could acquire genetic information. The authors rely on counterfactual scenarios to quantify net public benefits by estimating the hypothetical costs of achieving the same outcomes as using the processes and technologies the ATP-cofunded innovations leveraged.

Cassi, Corrocher, Malerba, and Vonortas examine the role of research network infrastructure in fostering the dissemination of innovation-related knowledge. They emphasize the structure of collaborative networks and of knowledge transfer between research, innovation and deployment activities in the field of information and communication technology (ICT) for the European Union as a whole, and for several European regions. Research networks complement diffusion networks by providing additional links and by increasing the number of organizations involved in sharing and exchanging knowledge. Two types of actors, they argue, are key players in these networks: hubs and gatekeepers. Hubs maintain the bulk of ties in the networks, also helping the smaller and more isolated members remain connected. Gatekeepers bridge research and diffusion networks. Such organizations naturally offer greater policy leverage in establishing a European knowledge infrastructure. Moreover, they conclude, strengthening inter-network connectivity among research and diffusion activities (deployment) would raise the effectiveness of European research in terms of accelerating innovation.

Leech and Scott provide preliminary estimates of the productivity impact of intelligent machine technology (IMT) and the rate of return to IMT R&D over the next two decades. They argue that IMT is, in part, enabling technology in that it will allow new machine-intensive and labor-saving production techniques across a wide range of industries; and it is, in part, infrastructure technology in that it ideally will conform to standards ensuring it will provide access across industries to human performance-like, machine-based, generic technology that is necessary for the development of innovative labor-saving processes. Their paper adapts the economists' traditional, residual productivity growth model to enable the use of industrial experts' forecasts of a few key parameters of the model to form the estimates of productivity growth and rate of return. Respondents—from a sample of firms operating in IMT development and applications in the automotive, aerospace, and capital construction industries—anticipate that IMT will generate substantial productivity growth over the next two decades, and the estimated social rates of return to IMT R&D are substantial.

Layson, Leyden, and Neufeld offer a theoretical model to explore the determinants of the optimum size of a private research/science park and the effect of university affiliation on that optimum size. Parks provide a venue for research firms and organizations to operate in close proximity, thus enabling easier communication among professionals in different organizations, enhancing the research productivity of all of them. Parks also enable communities to leverage economic development through technology-based investments, and they facilitate advancement through the stages of technology-based economic activity by reducing relevant market transactions especially with respect to technical labor. In their model, parks are assumed to operate as cooperatives where costs are equally shared among the member firms, and optimality occurs when the firms' average net benefits are maximized. To achieve this, existing members of a park will limit the park's size, denying entry to firms who wish to join and are willing to share the costs. University affiliation may either increase or decrease the optimum size of a park.

Consoli and Patrucco view innovation as a collective process that entails the coordination of distributed knowledge across diverse organizations. Technology infrastructures, within their framework, provide innovation systems with governance mechanisms to create and sustain complementarities across otherwise dispersed competences. Innovation platforms are discussed as a specific case of technology infrastructure. Operating strategically at the interface between the public and the private sectors, platforms enable capacity- and capability-building for individuals, teams and organizations. Illustrative evidence on innovation platforms in the United Kingdom and Italy confirms the importance of institutional strategies to stimulate variety and ensure coordination in the context of collective innovation processes.

Siegel, Wright, Chapple, and Lockett examine an institutional technology infrastructure, namely university technology transfer offices (henceforth, TTOs). TTOs play a critical role in the diffusion of innovation and the development of new technology infrastructure. Studies of the relative efficiency of TTOs have been based on licensing output measures and data from a single country. In contrast, the authors present the first cross-country comparison of the relative performance of TTOs, based on stochastic multiple output distance functions. The additional dimension of output considered is the university's propensity to generate start-up companies, based on technologies developed at these institutions. They find that US universities are more efficient than UK universities and that the production process is characterized by either decreasing or constant returns to scale. Universities with a medical school and an incubator are closer to the frontier.

Auerswald and Kulkarni utilize a novel approach to measuring innovation in order to identify emergent technology clusters. They illustrate their approach by using US patent counts to compare established technology regions within the country with emerging ones and to describe how technologies migrate as they develop and mature over time.

Finally, Bozeman, Hardin, and Link provide the first empirical information about barriers related to the diffusion of nanotechnology – a general purpose technology and a key element of technology infrastructure that is the foundation to the design, development, deployment, and use of other technologies and technology-based products and processes that are or could be central to the innovation process. Their empirical analysis is based on the findings from a state-wide survey of companies in North Carolina, USA. The primary diffusion barrier is lack of access to early-stage capital, and the extent of this barrier is greater when the company contributes to the value chain for nanotechnology through R&D as opposed to through products or services. Another barrier is lack of access to university equipment and facilities, a problem greater in companies involved in nanotechnology research. From a policy perspective, their analysis suggests that state governments could act as venture capitalists to overcome market failure in the capital market, and that states could provide incentives to universities through public/private centers of excellence for sharing capital equipment and facilities with nanotechnology companies.

From this rich set of findings, we may expect new studies of technology infrastructure to be developed especially ones engaging in international comparative work and the particular problems of creating and sustaining technology structures in developing economies. More work is needed to on the conceptual foundations of technology infrastructures in relation to the formation of innovation systems and in relation to the way they shape the emergence of particular sequences of innovations. What we have before us in this special issue is surely a major step along this road.