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Greater Boston's industrial ecosystem: A manufactory of sectors

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ABSTRACT

This paper examines the sources of the emergence in greater Boston of a large population of technology differentiating enterprises and the systemic processes by which new opportunities for innovation are both created and enacted in the form of emerging, co-adapting, and growing high tech sectors. I argue that Greater Boston's population of small- and medium-sized high-tech enterprises offers a systemic form of opportunity creation and enacting processes for industrial innovation. But they do not do so alone. The population of enterprises is embedded in a regional industrial ecosystem that facilitates ongoing reshuffling of the region's expertise, technology capabilities and financial resources for not only a single company but for a cluster of companies to grow fast. The concept of a regional industrial ecosystem suggests a locality analogous to Darwin's 'small area' in which a 'manufactory of species' is active but applied to the emergence, coadaptation, and growth of diverse sectors.

> Innovations, almost by definition, are one of the least analyzed parts of economics, in spite of the verifiable fact that they have contributed more to per capita economic growth than any other factor (Arrow, 1988: 281).

1. Introduction

New England has been highly successful at creating and growing new sectors during two phases of its industrial history. The first and the basis for establishing American industrial leadership, was referred to by British engineers and the leading contemporary British economist Alfred Marshall as the American System (1920: 257–258). It involved establishing the world's first machine tool industry based on the production principle of interchangeable parts (Roe, 1937; Rosenberg, 1963; Hekman, 1980). The second is the post-World War Two period in which a successive range of new sectors have emerged and grown in the greater Boston area. In between, Massachusetts did not have the industrial innovation capability to create and grow new sectors. But it came back (Dorfman, 1983; Glaeser, 2005; Todtling, 1994).

Today, Greater Boston has a regional competitive advantage in early-stage technology development, rapid business growth and new sector formation. Most accounts attribute the region's industrial innovation to business opportunities for technology transfer created by federally-funded scientific research conducted by the region's famous universities. But the linear, science-push, technology transfer model of opportunity creation and industrial innovation is not the whole story. It obscures the dynamic processes by which innovation opportunities are discovered, created, and enacted.

I propose an alternative 'industrial ecosystem' approach to innovation, opportunity discovery and creation, and sector emergence that draws on systems thinking and evolutionary metaphors. The idea of an industrial ecosystem evokes an economic world analogy to Darwin's habitats that act as a 'manufactory of species' but applied to the emergence and growth of high tech sectors (1979: 110).

Darwin writes of the "constant tendency…in the economy of nature" to divergence in the character of species, a divergence which is most pronounced in any "small area" where species "come into the closest competition" (1979: 398). Competition in Darwin's metaphorical economy is not the cost of production competition concept of neoclassical economic theory. Rather it suggests technological competition amongst heterogeneous firms and sectors. Whereas sex and random mutations are the source of genetic variation in the natural world, experiments by technology-driven enterprises are the immediate sources of opportunity identification, increasing technological differentiation, industrial innovation and sectoral growth dynamics within Greater Boston's population of high tech companies.

The business enterprise, in this interpretation, is the entrepreneurial agency in which opportunity discovery and distinctive capability development meet and mutually condition the other (Penrose, 1959; Blundel, 2013). The degree of success depends upon the technical capabilities, expertise, and past achievements of both the enterprise and the region. Opportunities are discovered and acted upon at the enterprise level; they are created and enabled at the system level.

Opportunity creation involves multiple agents that mutually drive a combined process of increasing technological differentiation and integration (Best, 2001). Thus opportunity discovery, at the enterprise (micro) level, and opportunity creation at the system

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(macro) level are mediated and enhanced by the process of increasing technological differentiation in the region.

In the case of Greater Boston the population of small- and medium-sized enterprises (SME), in turn, is embedded within Schumpeterian “shaping” institutional environment in which new and re-positioning firms can grow rapidly to take advantage of emerging opportunities (1947: 153). But the region's shaping environment is not external to the population of firms; instead it is an inter-institutional assemblage, including the enterprises that functions as a regional industrial experimental laboratory. As a metaphorical laboratory it contains the requisite complementary activities, scientific and technical expertise, financial and other resources that can be rapidly assembled and integrated by entrepreneurial agents into innovation process networks which, described below, institutionalize the region's dynamic system integration capability.

The focus on industrial ecosystem complements the business ecosystem literature (Adner, 2012). Both focus on network linkages. But whereas the business ecosystem concept highlights the business model as a recipe for business managers, the industrial ecosystem concept draws attention to a region's business model as a variable of economic and theoretical enquiry. Here the biological metaphor is not that of an evolutionary theory of the firm (Nelson and Winter, 1982) but of capability differentiating enterprises as agents within a complex, regional co-adaptive system (Beinhocker, 2007; Johnson, 2001; Garnsey, 1998; Iammarino, 2005).

Darwin illustrated the evolutionary research methodology with a history of technology example: “…when we regard every production of nature as one which had a history…nearly in the same way as when we look at any great mechanical invention as the summing up of the labour, the experience, the reason, and even the blunders of numerous workmen…how far more interesting…will the study of natural history become!” (1979: 456). This paper builds on empirical studies of engineering evolution and sector growth dynamics informed by a panel dataset of over 3000 Massachusetts-located, high-tech firms and their products classified by a fine-grained technology taxonomy. But instead of ‘even the blunders of numerous workmen' we might say ‘even the failures of numerous experiments'.

The paper is organized as follows. The next section examines the nineteenth century origins of specialized engineering expertise and evolved technology threads manifest in present day companies. This engineering-based legacy was not sufficient to create and grow new sectors in the first half of the twentieth century. The third section examines the transformative effects on the region's productive structure of the wartime creation of a federal government-led, technologically-advanced weapon systems industry. A much expanded basic research capacity of the region's universities combined with the applied research strengths of the region's engineering-driven enterprises to design, develop and produce a range of weapon systems in record time.

The fourth section maps the postwar consequences for Greater Boston's business and industrial organization. For the first time the region's business enterprises of all sizes could engage in manage innovation process chains that linked basic, applied, and developmental research with new product development and production process activities. As more SMEs pursued ‘focus and network' strategies a mutually-reinforcing, open-system business model emerged with collective system integration capabilities. The core external relationship of the high-tech enterprise is not participation in supply chain networks but the multi-level coordination of innovation process activities to pursue technological leadership. National government, mission-driven R&D fostered and interacted with Greater Boston’s population of technologically-differentiated high-tech enterprises to establish a regional industrial ecosystem with a competitive advantage in the creation and rapid growth of new technology-driven sectors.

The fifth section presents examples of rapid growth sectors including perhaps the most important, the region’s differentiated but integrated business development finance sector. The paper concludes with a literature review and discussion.

2. Descent with modification: Engineering expertise and specialist technologies

America’s early industrial leadership can be traced to the establishment in New England of a machine-based, as distinct from craft-based, manufacturing system to meet the uniformity requirements of interchangeable parts (Thomson, 2009: 54–65). This meant every part of the Springfield musket, for example, was ‘engineered’ for manufacture by a series of specialized machine operations. It was the basis for the emergence and growth of a community of machinists skilled in product engineering and it activated a technology roadmap without an endpoint: the pursuit of ever smaller critical size dimensions (Best, 2001: Figure 5.2: 133). Every success reset the parameters of the challenge and created a new opportunity for technological innovation. Precision engineering remains a regional signature capability to the present time.

The creation of a large community of machinists and the proliferation of machine shops became a unique regional productive resource in the form of ‘capital goods’ that created opportunities for novel application in virtually all existing and emerging industrial sectors (Meyer, 2006). The increasing diversity of technical expertise in itself created opportunities for new technology combinations (Schumpeter, 1934: 65). Again, analogies from natural science can be suggestive: “Every technology has traceable ancestry” (Ridley, 2009) and “to create is to recombine” François Jacob (1997). Jacob, a geneticist adds: “Novelties come from previously unseen associations of old material”.

This paper draws upon vTHREAD (Techno-Historical Regional Economic Analysis Database in which the letter v stands for making visible) organized around a finely-granulated engineering-based taxonomy and populated with a national, longitudinal dataset of 55,000 high tech companies and their products. Eighteen sectors explode out to 280 major product codes and 3000 extended product codes. See Best (2003), Best et al. (2004), and Best (2006a).

Applications of vTHREAD to Greater Boston’s population of high tech companies reveals traces of engineering expertise and specialized technology that track back to the region’s early industrial history. A series of examples of specialist engineering and technology expertise that link the distant past to the present follow.

2.1. Turbine technology

The nation’s first scientific engineering experiments were designed to increase the energy generating capacity of the turbine blades that powered the Lowell textile mills on the Merrimack River. They were conducted by the British born engineer James B. Francis (Francis, 1871; Layton, 1992; Hekman, 1980). Francis turbines are the most common water turbine in use today.

In the postwar era most design and development of US jet engine turbines was conducted in GE’s plant in Lynn, Massachusetts and Pratt & Whitney’s Hartford, Connecticut facilities. The historical company genealogy or family trees do not currently exist to track the concentration in the design and development of jet engine turbines to early water turbine experiments. But perhaps the deep craft skills combined with engineering expertise in turbine