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STRECO-683; No. of Pages 14
ARTICLE IN PRESS
Structural Change and Economic Dynamics xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Structural Change and Economic Dynamics
journal homepage: www.elsevier.com/locate/sced

Pervasive technologies and industrial linkages: Modeling acquired purposes

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ARTICLE INFO

Article history:
Received 31 August 2017
Received in revised form 19 October 2017
Accepted 6 November 2017
Available online xxx

Keywords:
General purpose technology
Industrial linkages
Pervasiveness
Star economy
Competing technologies

JEL classification:
C63
D24
L14
O32

ABSTRACT

What makes an industry a *dominant filiére* and a particular technology a so-called general purpose technology (GPT)? The paper contributes to a microeconomics of vertically related and networked industries by framing GPTs as a peculiar case of technological connectivity between sectors and provides a simple model that accounts for the endogenous success (failure) of GPT-based industries in a competing technologies setting. In a nutshell, we explore the process potentially leading to technological pervasiveness and dissect it in its structural elements. The model takes into consideration several conditions under which an upstream technology increases its pervasiveness in the economy or remains constrained as a component used by a small subset of downstream applications only. Hence, the model shows how 'purposes' are acquired by a technology struggling to dominate the downstream market. Policy implications of the analysis are highlighted, and dynamic implications of the model are discussed. Two main features of the study are that (i) we go beyond the a priori assumption that a pervasive GPT-like technology already exists in the economy and (ii) we bring GPT theorizing under the umbrella of studies of structural change through the dynamics of industries' linkages.

1. Introduction

The pervasiveness (or generality of purpose) of technologies is a feature that economic theory usually disregards or assumes *a priori*. In this paper, we posit that the process through which a technology gains pervasiveness matters: the evolution of a technology can result in a broad diffusion or in a failure to spread. The main question to be answered is: how are purposes 'acquired'? Purposes are meant here in the sense of 'applications', or uses for a given technology that can serve as a component, or input, to other technologies or economic activities. Relatedly, we define *purpose acquisition process* the dynamics leading a technology – developed to deploy specific functions or to solve specific problems – to identify further purposes and uses beyond the ones the technology was originally planned or designed for. We focus on a particular setting in which the protagonists are general purpose technologies (hereinafter GPTs), upstream technologies (input) characterized by a spectrum of application ranging beyond a single industry or sector and by the capacity to induce economy-wide transformational effects (Bresnahan and Trajtenberg, 1995; Bresnahan, 2010; Lipsey et al., 2005). The relation between GPTs and their applications is a particular case of linked markets, that in which an upstream industry serves multiple downstream industries. Relatedly, pervasiveness can be thought as some function of the installed base of downstream user industries; thus, in a sense, this paper establishes a link between GPT theory and network externalities literature (Shy, 2011). This conceptual 'bridge' is not the only one we perform in this study. In fact, by shifting GPT theory to a theory of linked markets whose structure evolves in time, we bring GPT literature under the umbrella of studies on structural change (Pasinetti, 1983). In a nutshell, we answer the question 'how are purposes acquired' by filling a gap in the literature concerned with the nature of pervasive technological change; we do that providing a microeconomic formulation of the purpose acquisition process and the factors influencing it.

The study of the process of purposes acquisition is relevant because it captures the multilevel nature of the determinants shaping technological trajectories (Dosi, 1982) and the configuration of technological systems. A contemporary example useful to make clear the issue at stake is that related to the energy-storage and battery sector. As Crabtree recalls,

> In 1991, the year that the lithium-ion battery was commercially released, no one foresaw the disruption that it would cause in personal electronics. After initially being used in portable music

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https://doi.org/10.1016/j.strueco.2017.11.002
0954-349X/

players and camcorders, lithium-ion batteries later found their way into, and spurred the development of, laptops, tablets and mobile phones – technologies that have permanently changed how much of society works. Yet there is an even bigger revolution on the horizon. In the same way that telephones had a rotary dial for most of their existence, the electricity grid and cars have mostly existed in a single, unchanged format. But as we move beyond lithium-ion technology, a new generation of cheaper and more powerful batteries will completely rejig the power grid and usher in an age of electrically powered transportation. (Crabtree, 2015)

The example mentioned above is a case in point that allows to capture at least two deeper pieces of evidence regarding technological pervasiveness. First, input technologies are usually introduced for specific purposes and gain pervasiveness later on; second, the pervasiveness of an upstream incumbent input can be challenged by entrant technologies that try to increase their downstream market share of applications. Furthermore, as argued in a more general argument by Stephan et al. (2017), the pattern of change of a given technological system is affected by its sectoral configuration (namely the number and types of sector linked in a technological system value chain); this suggests that the structural relations in an economy – industries' vertical relations for what concerns this paper – influences the dynamics of purposes acquisition. This paper takes these stylized facts as the point of departure to develop a general microeconomic approach to describe the process of purposes acquisition.

We propose a model of technological competition in a setting featuring vertically-linked markets. A set of downstream industries can adopt one of the possible alternative upstream input technologies that struggle for pervasiveness. The competition among those technologies can result either in the establishment of a new pervasive GPT or in the persistence of the existing GPT as the dominant one. To understand this dynamics, we extend the Schumpeterian concept of 'competition for the market' (Geroski, 2003) to the case of vertically related industries, introducing a 'competition for the downstream market'. As the competition for the downstream market unfolds, the process of acquisition of purposes might take place if the new upstream technology prevails on the established one.

We borrow a simple analytical framework used in the literature on international trade to model acquired purposes and to offer a description of how, in a setting featuring linked markets and upstream technological competition, a newly introduced specific purpose technology can become pervasive and, hence, general purpose. The factors affecting the 'specialization' of the downstream industries in one of the alternative upstream technologies are identified and discussed. To summarize our argument, two main features of this study are that using our framework (i) we go beyond the a priori assumption that a pervasive GPT-like technology already exists in the economy and (ii) we bring GPT theorizing under the broad umbrella of studies of structural change through the dynamics of industries' linkages.

In a nutshell, the issue at stake for our study is the representation of the process leading to technological pervasiveness. To uncover such process, we build on and extend the theory of general purpose technologies filling a main gap of this body of literature: the microeconomic modeling of general purpose technologies as a special case of technological competition displaying vertically-linked payoffs. Furthermore, we combine different strands of literature to offer a contribution encompassing a handful of issues in innovation economics.

The paper proceeds as follows: Section 2 defines the building blocks used to intersect theories of linked markets, GPTs, technology evolution, and structural change. Section 3 set up a simple Ricardian model in the spirit of Dornbusch et al. (1977) and Cantner and Hanusch (1993), and outlines a static and dynamic analysis. Section 4 concludes discussing the results and suggesting directions for further research.

2. Connectivity and general purpose technologies

We consider the study of the process of purposes acquisition part of a more general investigation into the nature of economic connectivity and structural changes therein. To support this claim, we now show how different phenomena taken up in seemingly unrelated strands of literature share similar conceptual features and, therefore, can be used to setup a broad framework linking industrial organization, general purpose technologies, and appreciative theorizing in the spirit of Neo-Schumpeterian economics.

First, input–output theorists and development scholars have always been interested in the inner structure of connections and bottlenecks (Hirschman, 1958) shaping economies, in order to fine-tune public intervention and to identify the best routes for industrialization processes to escape a handful of 'traps'; on the contrary, standard economic modeling mostly focused its attention either on aggregate dynamics or on industry level structural features.

Second, the analysis of the linkages between industries is recently experiencing a silent resurgence. We outline three main (not mutually exclusive) reasons for that: (i) New Growth Theory and Schumpeterian Growth Theory fail to explain complex market dynamics; this induces scholars to investigate beyond the surface of aggregation and to frame macroeconomic issues (e.g. fluctuations) as phenomena emerging from localized and micro-level shocks (Acemoglu et al., 2012); (ii) network models developed in the context of complexity sciences made their way into economic theorizing, revamping the input–output view of economic activities as a fruitful way to understand and represent production relations, industrial transformations (Carvalho and Voigtländer, 2014; Contreras and Fagiolo, 2014; McNerney et al., 2013), specialization and international trade (Hausmann and Hidalgo, 2011) and the dispersion of manufacturing in global value chains (Timmer et al., 2014); (iii) the economic crisis and a timely rediscovery of the role of the public sector in the economy boosted a novel discussion on the aims and tools of industrial policy (Cimoli et al., 2009; Hausmann and Rodrik, 2006; Mazzucato, 2013; Stiglitz et al., 2013) and on the intertwined channels transmitting policy impulses to firms and markets. The idea that ties matter in influencing economic behaviors is certainly not new in innovation economics: the literature on open innovation, collective invention, R&D collaborations and patent networks (Cantner and Graf, 2006) is well developed. Also, the very idea at the basis of the Pavitt taxonomy (Pavitt, 1984) is to highlight industries' external sources of technical change – hence the role played by the connectivity with suppliers, an exercise further developed by a rich literature on rent and knowledge spillovers (Verspagen and De Loo, 1999) and technology flows analysis (Scherer, 1982).

Third, the diffusion of a network-inspired theorizing due to reasons described above allows for an increased use of concepts that were confined until recently to niches of the economic discipline as evolutionary, innovation and development economics. Concepts such as multiple equilibria (Hoff, 2000; Stiglitz, 1987; Stiglitz and Greenwald, 2014), learning, ergodic and out-of-equilibrium processes (Arthur, 2013), positive feedbacks, linkages (Hirschman, 1958), all blossom again in the economic literature. These building blocks are helpful to reformulate economic stylized facts as dependent on linked payoffs. More specifically, stating that economic outcomes depend on connectivity – that is on the strength and distribution of linkages among the units of analysis – has consequences for the study of industry dynamics, especially for what