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# Structural learning: Embedding discoveries and the dynamics of production☆

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ABSTRACT

Production and learning of productive knowledge are profoundly intertwined processes as the activation of either process triggers the other, very often implying interdependent transformations. The paper aims to open the 'production black box' by proposing the analytical map of production as a tool for disentangling the set of interdependent relationships among capabilities, tasks and materials. The concept of structural learning is introduced to identify the continuous process of structural adjustment triggered and oriented by existing productive structures at each point in time. Structural learning trajectories allow for the transformation of structural constraints such as bottlenecks and technical imbalances into structural opportunities. Complementarities, similarities and indivisibilities are essential focusing devices for activating compulsive sequences of technological change as well as discovering structurally embedded opportunities. The paper then investigates the tension between structure and agency present in structural learning trajectories, and examines the form it takes in different productive organisations.



## 1. Introduction

Production and learning of productive knowledge are profoundly intertwined processes as the activation of either process triggers the other, very often implying interdependent transformations. Production theory has conventionally explained production processes as relationships between combinations of productive factors – i.e. input quantities – and certain quantities of outputs. By assuming that producers 'know how' certain inputs may be combined and transformed to obtain certain outputs, production functions do not make any explicit reference to the capabilities needed to perform real production processes. Thus, in standard production theory, there is no production process strictly speaking (Loasby, 1999). Not only is the production process treated as a black box, also the learning dynamics occurring in given production structures are fundamentally ignored. Indeed, economists often treat learning as a costless and automatic process functionally dependent on cumulative output, time, or investment, whose main effect is to reduce average production costs.

A very influential attempt to cope with the fundamental limitations of more conventional production models can be found in the *capability theory of the firm*, an approach that emerged at the intersection of various research fields, specifically organisational studies (March and Simon, 1993; Penrose, 1959; Richardson, 1960, 1972;

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Teece, 1980; Langlois, 1992; Morroni, 2006; Pitelis and Teece, 2009; Jacobides and Winter, 2012), and institutional and evolutionary economics (Nelson and Winter, 1982; Cohen and Levinthal, 1990; Lundvall, 1992; Dosi et al., 2000), and empirical work in development economics (Bell, 1982; Lall, 1992). With a particular focus on the transformation of cognitive contents and evolving capabilities, these contributions have shown how the knowledge of productive possibilities – i.e. input combinations – has to be complemented by the availability of relevant capabilities for productive tasks being performed. Most notably *evolutionary economics* has highlighted the complex cognitive dynamics underlying learning processes. It has drawn attention to the multifaceted nature of knowledge, its tacit components as well as the complexities connected to its creation, diffusion, adaptation, adoption and accumulation in organisational 'routines'.

By integrating the above mentioned research streams with *structural theories* dealing with the complex 'architecture of production', this paper analyses production structures in transformation, examining the embedded constraints and opportunities which are responsible for learning dynamics. From this perspective, learning is understood as a dynamic process triggered and constrained by existing production structures. This means that production structures set the stage for learning dynamics, that is, they prepare human minds for the intuitive discovery of new productive possibilities. The paper also recognises that structures of cognition and structures of production are linked by a bundle of bidirectional transformative relationships.

The goal of the present paper is two-fold. Firstly, the paper embeds different forms of learning such as 'learning by doing' and 'learning by using' in production structures. The paper therefore proposes an 'analytical map of production' as a stylised representation of the system of interrelated tasks through which transformations of materials are performed according to different patterns of capacities/capabilities coordination, subject to certain scale and time constraints (Section 2). Within this new analytical framework, the second contribution of the paper is to introduce the concept of 'structural learning'. In conventional approaches learning is simply described as a cognitive/behavioural dynamic involving production agents. In contrast, in our analytical framework, learning is understood as a process through which 'structural constraints' in production such as bottlenecks and technical imbalances are transformed into 'structural opportunities'. In this context, static and dynamic complementarities, as well as similarities and indivisibilities, are essential focusing devices for triggering compulsive sequences of technological change which permit the discovery of new 'worlds of production' (Section 3). Productive possibilities have to be 'seen', that is discovered and 'actualised' by productive organisations, for structural learning to be feasible. The concept of structural learning highlights a fundamental analytical tension between structure and agency or, more specifically, between productive structures and productive agents (the latter including both individuals and collectivities). Given the same productive structures, structural learning may follow different patterns according to different *forms of productive organisation* (Section 4). The analytical account of specific historical cases is adopted as main heuristic for disentangling structural learning dynamics.

## 2. Embedding learning in production dynamics

### 2.1. Learning in production: a taxonomy

In their critical review of learning curve studies,[1] Adler and Clark (1991, p. 270) proposed a fundamental distinction between first-order and second-order learning.

First-order learning refers to those 'learning by doing' processes directly experienced by workers via repetition of productive tasks and the resulting incremental development of expertise. Here, learning is both an individual and collective process as interactions among workers within the firm are integral parts of their learning by doing. The concept of 'learning by doing' expressed in Kenneth Arrow's (1962) seminal contribution captures the Smithian intuition that the accumulation of production experience increases workers' productivity. In particular, Smith mentions three 'different circumstances' responsible for this increase in labour productivity: 'the increase of dexterity in every particular workman', 'the saving of the time which is commonly lost in passing from one species of work to another', and 'the invention of a great number of machines which facilitate and abridge labour' (Smith, 1976[1776], p. 17).

Conventional learning models based on 'learning by doing' and learning curves have been mainly used for explaining productivity growth at the sectoral and macro level (Malerba, 1992, p. 846; Thompson, 2010). In these models, production is treated as a *timeless black box* and heroic assumptions are made concerning producers' knowledge of the entire spectrum of production possibilities as well as the availability of appropriate productive capabilities.[2] On the contrary, as the literature on localised technical change (Atkinson and Stiglitz, 1969) has shown, given the local and cumulative character of knowledge, producers are only aware of a limited number of factors composition laws – i.e. proximate production possibilities. Moreover, as shown in the capability literature, production "has to be undertaken by human organisations embodying specifically appropriate experience and skills" (Richardson, 1972, p. 888).[3]

Second-order learning refers to those managerial or engineering actions *purposefully* aimed at changing the internal structure of production by introducing new technologies, new equipments or investing in workers training. Learning dynamics of this second kind tend to be triggered by a series of factors which are both internal and external to the firm (Malerba, 1992). In terms of the former, not

[1] The long tradition in learning curve studies is usually associated with the empirical analysis of 'learning by doing' effects on productivity and was initiated by Wright (1936) and his work in the aircraft industry.

[2] The stochastic model by Jovanovic and Nyarko (1995) is an exception in providing a microfoundation of Arrow's. . .'learning by doing'.

[3] The analytical and technical limitations of the production function models are discussed in Georgescu-Roegen (1970), Scazzieri (1993).