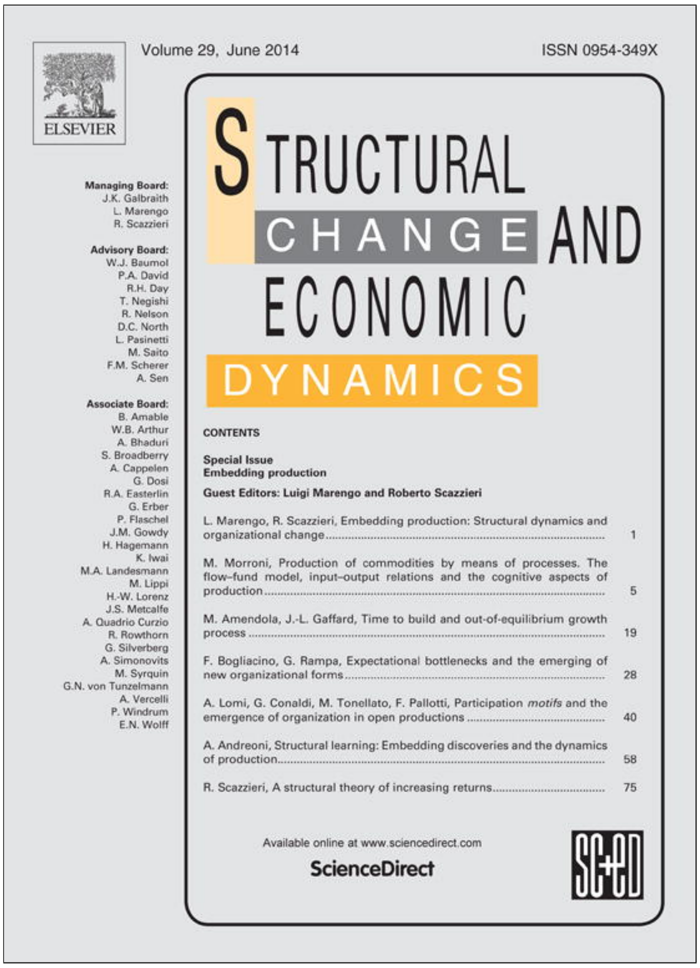

Volume 29, June 2014 ISSN 0954-349X

ELSEVIER

STRUCTURAL CHANGE AND ECONOMIC DYNAMICS

CONTENTS

Special Issue
Embedding production

Guest Editors: Luigi Marengo and Roberto Scazzieri

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Structural Change and Economic Dynamics 29 (2014) 75–88

Contents lists available at ScienceDirect

Structural Change and Economic Dynamics

journal homepage: www.elsevier.com/locate/sced

A structural theory of increasing returns☆

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ARTICLE INFO

Article history:
Received February 2012
Received in revised form March 2014
Accepted March 2014
Available online 20 March 2014

JEL classification:
D20
L23
L25
O33
O40

Keywords:
Production dynamics
Increasing returns
Structural change

ABSTRACT

The long-standing interest in increasing returns stems from the attempt to identify causal relationships internal to the production system that would provide adequate explanations for the improvement of technical practice and production organization. What is missing both in classical and modern literature is an explicit discussion of (i) whether a general causal principle may be identified behind Smith's classical trio of advantages, and (ii) whether those advantages may be realized independently of specific conditions of the behavioural or institutional type. This paper addresses those issues by outlining a structural theory of increasing returns based on Babbage's law of multiples. The paper explores the implications of the law of multiples for decomposition or integration of production units and outlines the distinction between enabling conditions for increasing returns and their realization. The argument paves the way for the design and implementation of increasing returns policies, which are discussed in the concluding section.

1. Introduction

Increasing returns are a vexed issue in economic analysis. Interest in this phenomenon stems from the age-old attempt to identify causal relationships *internal* to the production system that would provide adequate explanations for the improvement of technical practice and production organization. Differently from technical progress, increasing returns can never be explained by the operation of purely exogenous conditions and causes: they are inherent to the dynamic potential of any given economic system provided certain conditions are satisfied. Features that keep increasing returns apart from technical progress as such are: (i) the role of enabling conditions independent of behavioural or institutional assumptions; (ii) the role of behavioural and/or institutional conditions that may or may not be satisfied in the context under consideration; (iii) *lack* of cumulative causation for realized increasing returns, due to the distinction between enabling conditions and the behavioural or institutional conditions making increasing returns an actual feature of technology and organization: for example, agents' behaviour may interrupt a trajectory of realized increasing returns, and thus interrupt a cumulative causation process, even if no change has taken place at the level of enabling conditions. Increasing

☆ This paper develops a line of research initially presented at the DIME workshop 'Production Theory-Process, Technology and Organisation: Towards a useful Theory of Production' (LEM, Scuola Superiore Sant'Anna, Pisa, 8–9 November 2010). I am grateful to Antonio Andreoni, Patrizio Bianchi and Ivano Cardinale for comments and discussion, and to Giovanni Dosi for comments on an earlier draft of this paper. I am also grateful to two anonymous referees for enlightening comments and suggestions. The usual caveat applies.

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http://dx.doi.org/10.1016/j.strueco.2014.03.001
0954-349X/

returns are thus inherently dual: on the one hand, certain enabling conditions must be satisfied for increasing returns to be *feasible*, on the other hand, enabling conditions are not sufficient for increasing returns to be *achieved*. Economic theorists have seldom acknowledged this dual character of increasing returns. This is already apparent in Adam Smith's classical analysis of increasing returns in the *Wealth of Nations*: there increasing returns are explained by the operation of a trigger (the increasing extent of the market) that works itself out via division of labour *but through a plurality of causal mechanisms* (from increasing human dexterity to reduction of idle times and increasing likelihood of mechanical inventions). It is worth to recall Smith's 'advantages', as they have often reappeared, jointly or in isolation, in most subsequent treatments of increasing returns:

> This great increase of the quantity of work which, in consequence of the division of labour, the same number of people are capable of performing, is owing to three different circumstances; first to the increase of dexterity in every particular workman; secondly, to the saving of the time which is commonly lost in passing from one species of work to another; and lastly, to the invention of a great number of machines which facilitate and abridge labour, and enable one man to do the work of many (Smith, 1976 (1776), p. 17).

What is missing both in classical and modern literature is an explicit discussion of whether a general causal principle may be identified behind Smith's advantages, and of whether those advantages may be realized independently of specific conditions of the behavioural or institutional type.

This paper addresses the two above issues by outlining the fundamentals of a structural theory of increasing returns. The organization of the paper is as follows. Section 2 discusses Adam Smith's advantages in the light of Charles Babbage's 'fourth advantage' (a proportionality condition). This section argues that Babbage's analysis provides the cue to the identification of a fundamental causal principle behind the full range of Smith's advantages (Babbage's law of multiples). Section 3 explores the implications of the law of multiples for the decomposition and the integration of production units. Section 4 addresses the distinction between enabling conditions for increasing returns and their realization. This section argues that the law of multiples introduces a specific relationship between the scale of the production process and the set of technical practices that are feasible for any given scale (*scale-technology expansion*). The section also argues that activating increasing returns presupposes the proportionality condition expressed by the law of multiples, but also that such a condition is compatible with a variety of technological and organizational arrangements. The plurality of arrangements compatible with the law of multiples for any given scale of the production process highlights the role of behavioural patterns and institutions in determining the specific features of any historically given trajectory of increasing returns. It also highlights the central role of policy decisions (by public or private bodies) in turning increasing returns from a possibility grounded in existing technology and organization into an accomplished sequence of technical arrangements. This approach paves the way for the design and implementation of *increasing returns policies*, which will be briefly discussed in the concluding section of the paper.

2. Smith's advantages and the law of multiples: a unifying framework

As noted in the Introduction, the building blocks of a structural theory of increasing returns are Smith's propositions on the relationship between 'extent of the market' and division of labour and Babbage's law of multiples. In some of the best known passages of the *Wealth of Nations*, Smith argues that '[t]he greatest improvement in the productive powers of labour, and the greater part of the skill, dexterity and judgement with which it is anywhere directed, or applied, seem to have been the effect of the division of labour' (Smith, 1976 [1776], p. 13), and that '[a]s it is the power of exchanging that gives occasion to the division of labour, so the extent of this division must always be limited by the extent of that power, or, in other words, by the extent of the market' (Smith, 1976 [1776], p. 31). As noted above, Smith mentions three 'different circumstances' as giving rise to this increase in the productive powers of labour: increase of dexterity, saving of time, and invention of machines (see Section 1). *Prima facie*, only the saving of time is directly associated with the rearrangement of the internal structure of the production process, and it does not presuppose further conditions concerning a change in the set of available and known technical practices (learning and invention). However, Smith's argument can be and has been extended so as to cover cases in which previously unknown technical practices can be learned or invented through exploration of the new problem space generated by the division of labour and the specialization of workers in specific tasks. In particular, Nathan Rosenberg has called attention to the problem-solving character of learning and innovation. In the case of learning, this can be seen in the way in which 'increasing skill in production' is developed through involvement in productive activity 'after the product has been designed' (*learning by doing*) (Rosenberg, 1982, p. 121), or in the way in which better understanding of the 'minutiae of the productive sequence' are obtained through the utilization of intermediate goods (generally machines) whose performance results from interaction between parts whose outcome 'cannot be easily predicted' (*learning by using*) (Rosenberg, 1982, p. 122). In the case of invention, its problem-solving character has been emphasized, especially in view of the fact that 'inventive activity is [...] best described as a gradual process of accretion, a cumulation of minor improvements, modifications, and economies, a sequence of events where, in general, continuities are much more important than discontinuities' (Rosenberg, 1972, p. 7). Here, the discovery of technical imbalances between components of a production process *in operation* is a critical factor in the search for new technological and organizational solutions: '[c]omplex technologies create internal compulsions and pressures which, in turn, initiate exploratory activity in particular directions' (Rosenberg, 1969, p.4).

Smith's approach to increasing returns shows a combination of structural and behavioural components closely intertwined with each another. On the one hand, the 'extent of the market', which is primarily a scale measure of any given set of productive activities connected with each other through division of labour (see also Young, 1928), determines the degree and pattern of the feasible decomposition and specialization of production processes (division of labour).[1] On the other hand, division of labour brings about structural opportunities concerning learning and invention (that is, the degree to which new organizational patterns associated with increasing specialization may generate problem spaces in which new abilities can develop and previously unknown tasks or task arrangements can be introduced).[2] Babbage's law of multiples adds to Smith's 'classical trio of advantages' of the division of labour (Edgeworth, 1911, p. 554) the explicit consideration of a *structural principle*, that is, of a condition expressed in terms of proportions between different components of the production process. In Babbage's view,

> [T]he master manufacturer, by dividing the work to be executed into different processes, each requiring different degrees of skill or of force, can purchase exactly that precise quantity of both which is necessary for each process; whereas, if the whole work were executed by one workman, that person must possess sufficient skill to perform the most difficult, and sufficient strength to execute the most laborious, of the operations into which that art is divided (Babbage, 1835, pp. 175–176).

As a consequence of this, a specific scale requirement for productive efficiency can be identified:

> '[w]hen the number of processes into which it is most advantageous to divide [the production process], and the number of individuals to be employed in it, are ascertained, then all factories which do not employ a direct multiple of this latter number, will produce the article at a greater cost' (Babbage, 1835, p. 211).

In short, Babbage identifies a consequence of division of labour that is immediately relevant to the arrangement of the components of the production process relative to each other: the splitting of a complex production system into sub-systems (work units) and the organization of those sub-systems according to definite proportions allowing maximum utilization of productive inputs within the production process. It is worth noting that Babbage identifies the roots of the advantages of the division of labour in indivisibilities arising from relative proportions between components of production activity rather than in indivisibilities due to inputs' technological units. This feature of Babbage's approach highlights process indivisibilities rather than input indivisibilities and is reflected in his formulation of a 'law of multiples'.[3] This law expresses two scale requirements at the same time: (i) a constraint on the minimum process scale allowing full and continuous employment of all work units in the productive workshop: (ii) a constraint on the pattern of scale increase that would allow full and continuous utilization to be maintained with an expanding scale.

The analytical structure of Babbage's law of multiples is discussed below. Let p_i be the elementary production process delivering one batch of output i ($i = 1, \ldots, k$), v_j the technological units of productive inputs j ($j = 1, \ldots, m$), and c_j ($i = 1, \ldots, m$) the own capacities of those inputs. Babbage law combines a condition on the utilization of productive capacities *at any given time* with a condition on capacity utilization *over time*. The standard formulation of Babbage law presupposes given lengths for each productive task, and thus also given lengths for each type of elementary process. This means there are productive inputs used at certain times and not used at all at other times, depending on the sequencing of tasks within the productive establishment. In short, two different dimensions of input utilization are covered by Babbage law: (i) *capacity utilization*, which is about the number of elementary processes p_i's carried out by using any given productive input at any given time; (ii) *time utilization*, which is about the number of elementary processes p_i's carried out by using any given productive input over a certain time interval. Capacity utilization and time utilization should be clearly distinguished. There are cases in which the utilization of a productive input is full at given points

[1] Smith's emphasis on the relationship between 'extent of the market' and 'division of labour' presupposes a condition on the 'power of exchanging' (see above). The latter may be interpreted as 'the sphere within which the economic subject may exert his "market power", thereby adapting the productive structure in view of that goal' (Bianchi, 1991, p. 33; see also Bianchi, 1984, p. 28). The implications of this condition for the dynamics of increasing returns are far reaching as it points to a direct relationship between division of labour and market power seldom explicitly examined in the literature.

[2] Smith's view of division of labour as a condition favouring changes of technical practice within a given technological horizon calls attention to the structural prerequisites of learning and discovery (these prerequisites are discussed in the paper by Andreoni in this issue Andreoni (2013)). On the other hand, the consequences of increasing returns due to division of labour and learning are at the core of Arrow's analysis of 'learning by doing', and of the subsequent developments along this line of investigation (Arrow, 1962; Romer, 1986; Arrow et al., 1998; Ng, 2009). Arrow's approach to increasing returns in terms of learning by doing, and the subsequent extension of learning by doing to 'learning by using' (see above), point to a cumulative process characterized by the self-sustained accumulation of technical knowledge: '[t]here are many strong incentives for the allocation of inventive efforts to be shifted toward the variant of technology that has been advancing most rapidly' (Dosi and Nelson, 2010, p. 94). At the same time, knowledge-based increasing returns may presuppose technological and organizational conditions that may in turn lead to a less continuous and 'punctuated' trajectory, and even to breaks and sharp deviations from the existing trajectory (Carrà, 2013). In this connection, connecting principles among specialized tasks and/or productive operations are of central importance (Arrow, 1974; Becker and Murphy, 1992; Loasby, 1998, 2001; Porta and Scazzieri, 2001; Marengo and Dosi, 2005).

[3] The production possibilities compatible with Babbage's principles are different from those that can be derived from the assumption of indivisible commodities (see Frank, 1969, p. 43). This distinction highlights the difference between the classical theory of increasing returns (as formulated by Smith and Babbage) and the postclassical theories derived from the law of variable input proportions (Edgeworth, 1911; Sraffa, 1925, 1926; Chamberlin, 1948; Hahn, 1949; Scazzieri, 1982).

of time but only discontinuously so due to idle times, and other cases in which productive inputs are continuously used below full capacity. Correspondingly, the conditions for maximum utilization are different in the two cases, as shown below.

Proposition 1 (Capacity-utilization law of multiples). If elementary process p_i requires the utilization of productive inputs v_j ($j = 1, \ldots, m$) having capacities c_j ($j = 1, \ldots, m$) such that, for every c_j and c'_j, we have $c_j \neq c'_j$, a technical practice allowing full utilization of capacities is feasible only if the over-all scale of the production process allows utilization of an integer multiple of the lowest common multiple of the c_j's.

This proposition follows from the definition of each productive input's own capacity c_j as the maximum number of elementary processes p_i's (say, p_i^*) that can be operated in parallel at any given time using that input. This definition entails that the scale of production allowing operation of all productive inputs at their respective own capacities would be such as to allow, for any given productive input, the operation of that maximum number of elementary processes (p_i^*). Clearly, this condition is satisfied for a number of elementary processes (a process scale) equal to the least common multiple of all the own capacities c_i's, or to an integer multiple of the latter number.

Proposition 2 (Time-utilization law of multiples). If elementary process p_i requires the utilization of productive inputs v_j ($j = 1, \ldots, m$) for performing productive tasks τ_k ($k = 1, \ldots, r$), and any productive input v_j performs m_i times in immediate succession a fixed set of tasks lasting a fraction $(n_i/q_i)\, T_W$ of the working day T_W, then continuous utilization of productive input v_j requires that, in each working day, input v_j be operated $m_i = (q_i/n_i)$ times in immediate succession.

This proposition follows from the assumption of fixed task-lengths for each productive input, which entails that any productive input v_j cannot repeat its task (or set of tasks) more than m_i times in each working day. This implies that if $m_i < (q_i/n_i)$, productive input v_j would only be utilized for a period:

$m_i\,(q_i/n_i)\,T_W < T_W$. This proves the proposition.

A more general condition would allow both full and continuous utilization of productive inputs. Let utilization function $F_i(t)$ denote the amount of productive input' v_j's services needed by elementary process p_i at time t. Let T_i denote the total duration of p_i. In most elementary processes, $F_i(t)$ is greater than 0 at some times and equal to 0 at some other times. On the other hand, let the utilization function $C_i(t)$ denote the number of elementary processes p_i that make use of productive input v_j at time t. Let C_i^* be the maximum number of elementary processes that can make use of productive input v_j at any given time (full capacity utilization).In many circumstances, $C_i(t) < C_i^*$, so that the actual utilization rate of existing capacity would be lower than full capacity utilization. It is possible to formulate a general law of multiples that identifies the condition for both full and continuous utilization of productive inputs (see below).

Proposition 3 (General law of multiples). If elementary process p_i requires the utilization of productive inputs v_j's ($j = 1, \ldots, m$) in order to perform productive tasks τ_k ($k = 1, \ldots, r$), full and continuous utilization of productive inputs v_j's requires a batch p_i^* of elementary processes to be carried out at any given time, and also requires that a different p_i^* batch be started at regular intervals, so that inputs v_j's can be operated $m_i = (q_i/n_i)$ times in immediate succession.

This proposition follows from Propositions 1 and 2 under the assumption that each elementary process p_i consists of tasks of fixed length, and that each productive input v_j has a fixed own capacity.

Babbage's principles reflect the internal structure of the production process, in so far as the latter includes not only the actual (realized) arrangement of process components but also those arrangements that are not yet realized but would be feasible if process scale were to increase.[4] In particular, Babbage' s law of multiples calls attention to a *set of general structural conditions* that need to be satisfied by any production process requiring the operation of sufficiently heterogeneous and interdependent components. If the heterogeneity of components derives from the heterogeneity of material capacities and human capabilities, then the 'most effective' utilization of those capacities and capabilities entails a condition on the minimum scale at which the relevant set of processes must be operated. In this case, the expansion of process scale is compatible with maintenance of the above pattern of capacity and capability utilization as long as input proportions allowing full and continuous utilization are maintained. In the Babbage framework, input indivisibilities and process indivisibilities (or, frequently, a combination of both) bring about a pattern of *scale-technology expansion* such that the switch to a higher scale of production opens up the possibility of introducing a more effective structure of the production process. A *law of definite proportions* governs the internal arrangement of any given production process as long as that process requires a sufficiently differentiated range of capacities and capabilities.[5] An important consequence of that constraint is that a continuously increasing process scale may be associated with frequent drops in the effectiveness of realized productive arrangements, except in the special cases in which (a) scale is increased by exactly following the law of multiples associated with the technical

[4] An important consequence of scale-constraints on the arrangement of process components is that 'the relations of complementarity among inputs tend to change in response to a different dimension of scale' (Morroni, 1998, p. 400).

[5] The law of definite proportions was originally introduced by the chemist Joseph Louis Proust in his work on the rules governing the formation of chemical compounds (Proust, 1794) and extended to the field of life sciences with Liebig-Sprengel's 'law of the minimum' (Sprengel, 1828; Liebig, 1855; Van der Ploeg et al., 1999). Valenti (1905) introduced a law of definite proportions (*legge delle proporzioni definite*) in the economic analysis of production arguing that 'the factors of production must always stand to each other in a definite quantitative and qualitative proportion, in order to achieve a given favorable yield' (Suranyi-Unger, 1932, p. 194).

practice in use or (b) the increasing process scale allows further scale thresholds to be attained and is thus 'supported' by further technology expansion.[6] This argument entails that the same structural conditions allowing technology expansion provided the production process meets certain scale constraints are at the origin of *scale-technology contraction* whenever process scale is increased independently of those constraints.[7]

Scale-technology expansion makes increasing returns *feasible* but not necessarily likely (see above). In addition, technology expansion associated with an increasing process scale is compatible with a variety of organizational arrangements, which highlights that structural conditions may generally be satisfied along a *multiplicity of routes*. In particular, Babbage's proportionality condition is compatible with two seemingly opposite transformations of the production process: (a) the fragmentation and specialization of industries, (b) the standardization and integration of products and product components. As we shall see below, either case is associated with the compositional requirements of any given set of interrelated productive activities in which heterogeneous capacities and capabilities must be jointly operated, and/or heterogeneous material transformations must be simultaneously carried out.

3. Decomposition and integration of production units

3.1. Minimum redundancy and expansion by integer multiples

Babbage's compositional principles address two different but closely related scale constraints: (i) the *minimum-redundancy condition*, and (ii) the *expansion-by-integer-multiples condition*. Condition (i) concerns the criterion by which capacities and capabilities are assigned to tasks and fabrication stages; condition (ii) highlights the requirement of discrete variation of process scale beyond the scale which allows minimum redundancy. Taken together, the two principles point to structural requirements governing the relationships among components of any given production process. In particular, conditions (i) and (ii) determine the proportions in which interdependent capacities and capabilities may be assigned to tasks in order to achieve minimum redundancy, and to maintain minimum redundancy as process scale is varied.

The *minimum-redundancy condition* and the *expansion-by-integer-multiples condition* have important implications for the integration or decomposition of processes under conditions of scale-technology expansion. In general, capacities and capabilities, tasks and materials reflect the use of a given technology, but for any given technology in use, the arrangement of capacities and capabilities, tasks and materials within the productive unit is open to a variety of different organizational patterns. However, there are also cases in which technology in use almost completely determines the arrangement of the different elements of the production process. For example, automotive manufacturing (or, for that matter, clock-making) allows manifold arrangement opportunities for the assembly of partial-product components (see Piore and Sabel, 1984; Barbiroli, 1997; Fujimoto, 1999; Landes, 2000). On the other hand, most chemical processes (such as iron smelting or polymer manufacturing) show much less flexibility as to the arrangement of process components once a certain technology is introduced (see Wright et al., 1991; Wood, 1989).

In general, the degree to which the technology in use within any given production organization allows full and continuous utilization of capacities and capabilities reflects the relationship between the tasks to be carried out and the productive operations (functions) to be performed. In fact, the relationship between tasks and functions provides the engineering background for the different organizational solutions that may be introduced to meet the general law of multiples (see Cardinale and Scazzieri, 2011, 2013). Another fundamental set of constraints determining whether the law of multiples may or may not be satisfied under given conditions is provided by the existing structure of interdependencies between production processes at the level of firms or firm networks at the national or supranational level. For it may happen that the proportionality conditions for full and continuous utilization of capacities and capabilities can only be satisfied with certain structures of interdependence to the exclusion of others. For example, the full and continuous utilization of capacities and capabilities may be compatible with a certain configuration of input and output flows but incompatible with other configurations of those flows.[8] Finally, social structures

[6] In the latter case, of course, higher scale opens up technological and organizational opportunities that are not necessarily taken up by producers active in a specific context (see above, this section).

[7] Technology contraction (as induced by a change of process scale) is a situation in which, given any two process scales s and s', such that $s' > s$, there is at least one technical practice θ that is feasible at s and not feasible at s' (see Scazzieri, 1993, p. 138). This contraction of the set of feasible technical practices is at the root of classical decreasing returns as a result of an increasing process scale for any given endowment of non-produced resources, as well as of 'technological' decreasing returns stemming from imbalances within the production structure. The possibility mentioned in the text suggests that, under specific conditions, a kind of 'co-ordination' between scale-induced expansions and contractions of technology is to be expected. This co-ordination is grounded in the internal structure of the production process and should not be confused with the alleged 'correlation' between increasing and decreasing returns envisaged by Marshall (see Marshall, 1961a [1890], pp. 314–322). As a matter of fact, Marshall's correlation presupposes conditions external to the production process narrowly identified, such as positive interaction effects between productive units within a given industry (increasing returns), and given availability of an essential input to the productive units in the same industry (decreasing returns). As Piero Sraffa noted, Marshall's correlation points in reality to a kind of ex ante *co-ordination*, which is seldom observed (see, on this Sraffa, 1925, pp. 356–363).

[8] See, in particular, Quadrio Curzio (1986, 1996) and Quadrio Curzio and Pellizzari (1999), for the investigation of conditions upon the relative proportions of interdependent production processes that make, respectively, possible or impossible sustained accumulation and growth within a system of interdependent processes subject to the limited availability of non-produced resources. We may conjecture that intersectoral bottlenecks of this type will have a significant impact on the possibility to meet Babbage conditions in each sector and thus also on the possibility for the economy to follow an increasing returns trajectory (see also Scazzieri, 1998, 1999). The splitting of production processes through introduction of modular activities is another important factor influencing the dynamics of interdependencies in the production system, and thus the conditions

embedding production processes are of critical importance in determining the composition and internal configuration of the 'fund' of tasks and skills that is available at any given time for the performance of productive operations.[9]

3.2. Proportionality conditions and organizational types

In short, the relationship between technological requirements and the arrangement of production elements within the productive unit shows no uniform pattern. Indeed, it is generally the case that Babbage conditions have very different implications depending on whether we consider *assembly-type manufacturing* or *integrated manufacturing*.[10] In assembly-type manufacturing, minimum redundancy can be achieved (and maintained) *either* through the decomposition *or* through the integration of sub-processes as long as the minimum scale requirement for the integrated process or the individual sub-processes is satisfied (and scale is increased, if at all, according to the corresponding law of multiples). On the other hand, in integrated manufacturing, scale-technology expansion may follow different routes depending on whether minimum redundancy and integer expansion are compatible with alternative patterns of specialization for tasks and/or productive operations. If alternative specialization patterns are possible, an increasing process scale can bring about technology expansion by allowing the splitting *or* the merging of tasks and operations according to the available capabilities and capacities of workers and machines. If, on the other hand, only a single specialization pattern is feasible, increasing process scale can bring about technology expansion by allowing the introduction of technical practices associated with a given type of integration among tasks and/or operations. In this latter case, capacities (or capabilities) appear to be *endogenously* generated within the plant structure itself (as in the case of cement plant design discussed in Sakamoto and Kawata, 1990), so that decomposition and integration are no longer left free to follow the boundaries between existing capacities or capabilities (as it may happen when capacities and capabilities are generated outside the production process).

In either case (assembly-type manufacturing or integrated manufacturing) two distinct reasons are at the root of scale-technology expansion: (i) productive activity is physically impossible unless the production process is operated beyond a certain minimum scale, (ii) there is no minimum scale for productive activity to be feasible, but certain arrangements of capacities and capabilities, tasks and materials are only feasible once the over-all production process has attained a given minimum scale.

In case (i), there are essential tasks that are size-constrained due to the objects appearing in the task's definition (see Scazzieri, 1993, p. 107). For example, a certain chemical reaction has to be carried out within a sphere, in which the relationship between the reaction output and the volume of the sphere is expressed by the formula $q = ar^3$, where q is the reaction output, r is the radius of the sphere, and a is a constant. Once the technical practice that uses the smallest feasible sphere has been defined, output can be increased by external or internal addition, that is either by adding up several small spheres side by side or by introducing a single sphere of greater radius (Scazzieri, 1993, p. 107).[11] If the adding-up arrangement is followed, there is no change of technical practice. If a greater-radius sphere is introduced, there will be a change of technical practice due to a change of its constituent tasks.[12]

In case (ii), scale-technology expansion follows a different course: task-definitions are not significantly size-constrained and remain unchanged as we move from one process scale to another but certain arrangements of capacities and capabilities, tasks and materials are only feasible (and may eventually be introduced) beyond a given minimum scale.[13] In this case, the source of technology expansion is the possibility to switch to a different pattern of utilization for capacities, capabilities and materials due to the different distribution of tasks that an increasing scale allows.

A variety of situations falls into the latter category. For example, a production process requiring the simultaneous operation of plants of different own capacities c_i ($i = 1, \ldots, m$) allows full capacity utilization of the different plants as long as process scale is equal to an integer multiple of the least common multiple of the different plants' own capacities (Schneider, 1934; Scazzieri, 1993, p. 109). In this case too, full capacity utilization must be distinguished from continuous utilization. For example, in

for Babbage Law to be satisfied (Frenken et al., 1999; Langlois, 2002; Buenstorf, 2005).

[9] James March and Herbert Simon noted that social structures exert an important influence on the cognitive frames of people addressing specific problems, and thus on the possible solutions that may be identified and eventually adopted (March and Simon, 1958; see also Poni and Scazzieri, 1994; Zeitlin, 1994; Sabel and Zeitlin, 1997; Poni, 1997; Padgett et al., 2003).

[10] The related issue of near-decomposability and modularity in manufacturing processes is discussed in Buenstorf (2005).

[11] The distinction between external and internal addition is due to Georgescu-Roegen (1971, pp. 107–109). In the case of external addition, two processes, say P' and P'', are 'lumped together' while preserving 'their individuality (separation) *in vivo*' (Georgescu-Roegen, 1971, p. 108). In the case of internal addition, it is possible 'to subsume' two distinct instances P_1 and P_2 of a given process 'into another instance P_3 of the *same* process' (Georgescu-Roegen, 1971, p. 108). An interesting implication of the distinction is that 'we should clearly distinguish the process of a unit of production (plant or firm) from that of *industry*. The point is that an industry may expand by the accretion of *unconnected* production processes, but the growth of a unit of production is the result of an internal morphological change' (Georgescu-Roegen, 1971, p. 108).

[12] The switch to a sphere of greater radius is made feasible by the shift to a greater output level and is thus an instance of scale-technology expansion. In this case technology expansion takes place by allowing the introduction of a technical practice in which certain task-definitions (such as the chemical reactions taking place in the larger sphere) are different from the task-definitions associated with the spheres of smaller radius.

[13] It is worth noting that different scale variables are relevant to cases (i) and (ii). In case (i), the relevant scale variable is plant size, and the change of technical practice follows from an increasing plant size independently of the number of output units that are actually produced; in case (ii), the relevant scale variable is the over-all scale of the production process, whose variation may or may not be associated with the change in the output level of particular commodities (see Scazzieri, 1993, pp. 210–219). The above distinction calls attention to the plurality of scale variables that may be relevant in the analysis of technology expansion, and highlights that the latter may take place on a variety of dimensions.

a productive unit of the job-shop type (such as an artisan workshop, or the workshop of a mediaeval painter), the inherent flexibility of task-lengths, as well as the flexibility of precedence patterns among tasks, entails that continuous utilization of capacities and capabilities is possible either (i) by maintaining a given pattern of capability utilization and increasing process scale by integer multiples of the minimum scale that allows continuous utilization, or (ii) by increasing process scale in a continuous way and allowing a change in task-definitions and task-lengths (Scazzieri, 1993, pp. 112–116). In a job-shop productive unit, Babbage conditions apply only indirectly, in so far as the identification of exact task-lengths is avoided. Continuous capacity and capability utilization may nonetheless be achieved through a line balancing that includes the endogenous determination of task-lengths depending on the scale and composition of the production process. A different set of conditions applies in a productive unit of the straight-line type (such as a factory organized according to standard assembly line principles, or a fully specialized workshop undertaking the 'in series' operation of processes consisting of a single task). Here task-lengths are fixed and continuous utilization requires each capacity and capability to be used in performing, during the working day, a number of tasks whose durations add up to the length of that particular time period (Scazzieri, 1993, p. 119). In this case, Babbage conditions apply directly, and scale-technology expansion results from discrete jumps of process scale that are consistent with the law of multiples. This means that, by increasing over-all process scale in a discontinuous way, it is feasible to introduce one (or more) technical practices that allow continuous utilization of capacities or capabilities (or a satisfactory approximation to it). However, tasks of fixed length are compatible with continuous capability utilization under seemingly opposite organizations of production, such as a large factory following task specifications attained on the basis of 'time and motion studies' (Taylor, 1911; Gantt, 1912; see also Landesmann and Scazzieri, 1996a, p. 27; Landesmann and Scazzieri, 1996c, pp. 270–294), or a specialized small workshop undertaking highly simplified and standardized tasks during the working day (Scazzieri, 1993, pp. 124–132).

The concept of scale-technology expansion covers a variety of constraints and opportunities that may affect different production processes in different ways and make structural change feasible along a variety of routes. In particular, different sets of structural constraints are at work depending on the dynamics of process scale and on the specific output composition at each particular scale.[14]

3.3. Task definitions and task arrangements: alternative scale constraints

If process scale is increased by following the *expansion-by-integer-multiples condition*, minimum redundancy of available capacities and capabilities can be achieved in a variety of technological and organizational settings. For example, we may conjecture that productive activities primarily affected by size constraints on *task-definitions* (such as certain chemical processes) would follow a path of scale-technology expansion governed by the integer condition on plants' own capacities (see above). On the other hand, productive activities primarily affected by scale constraints on *task-arrangements* (such as most mechanical processes) would follow a path of scale-technology expansion governed by the integer condition on the number of tasks executed by any given work unit during a given time period (such as the working day). Either type of change ultimately affects the relationship between capacities (or capabilities) and tasks, or *job-specification programme* (Landesmann and Scazzieri, 1996b, p. 198), and is compatible both with an increasing or a diminishing size of the productive unit. Size constraints upon *task-definitions* make an increasing process scale compatible with a variety of plant sizes through introduction of new manufacturing tasks (such as smelting reduction in the iron making process) (Wright et al., 1991). On the other hand, scale constraints upon *task-arrangements* make an increasing process scale compatible with the splitting *or* the merging of already existing activities, depending on the specific features of tasks in each process, and on the organizational configuration of tasks within processes.[15] For example, an increasing scale under conditions of *fixed task-lengths* could make an increased division of labour compatible with continuous utilization of existing fund-inputs. But for this to be possible, the capacities and capabilities utilized in each specialized process should perform in each working day a number of tasks allowing continuous utilization.[16] Fixed task-lengths may be incompatible with an increased division of labour if the above condition is not satisfied. In this case, continuous (or approximately continuous) capability utilization would require an appropriate staggering of tasks during the working day.[17] Here, the merging of different productive activities in a single process may be more likely. The consequences of an increasing process scale may be entirely different under conditions of *flexible task-lengths* (as in the job-shop case). In this case, a scale increase by integer multiples of the minimum process scale compatible with continuous capacity and capability utilization allows continuous utilization at the higher scale, but is not necessarily conducive to scale-technology expansion. For flexible

[14] This point raises the issue of the relationship between process scale and establishment size along a trajectory of scale-technology expansion (Chandler, 1990; Scazzieri, 1993; Cheung, 2013).

[15] In this case, the most important organizational feature is whether tasks have fixed or flexible durations, and whether they are coordinated with each other according to a rigid or a flexible criterion (Scazzieri, 1993, 2001; Landesmann and Scazzieri, 1996c).

[16] Formally, if n_i/p_i is the fraction of the working day taken by a given capability to execute a particular task, or group of tasks, i ($i = 1, \ldots, s$), specialized *and* continuous utilization of the capability presupposes the execution during the working of a number of tasks (or task-groups) given by p_i/n (see Scazzieri, 1993, p. 124).

[17] Conditions making it possible to introduce a staggering of tasks compatible with the continuous utilization of workers and machines (*in-line arrangement*) have been investigated by Georgescu-Roegen (1969,1970). Further developments may be found in Morroni (1992, 1998, 2013), Scazzieri (1993), Landesmann and Scazzieri (1996c), Piacentini (1995), Mir-Artigues and Gonzales-Calvet (2007), and Vittucci Mazzetti (2013).

task-lengths may be adjusted *precisely* in order to cope with (unpredictable) small changes in process scale and output composition.[18] However, the outcome of a large increase of process scale may be different. This is because continuous utilization in a job-shop critically depends on the existence of differences in the precedence patterns of tasks carried out along the different production lines within the workshop, and on the existence of adequate proportions among tasks on each production line (Scazzieri, 1993, pp. 114–116; Landesmann and Scazzieri, 1996c, pp. 255–261). This condition is often difficult to meet (as it depends on demand conditions determined outside the productive unit), so that a large increase of process scale under flexible task-lengths is more likely to be associated with technology contraction rather than technology expansion.[19]

There is no reason to assume that an increasing scale would be consistent with the full capacity requirements of plants associated with new task-definitions, nor that it would be consistent with the scale and compositional requirements of task-arrangements allowing continuous capability utilization. However, we may conjecture that an increasing process scale (whether at the level of the firm, industry, or network of firms) would make the exploration of structural opportunities within existing technology more likely, and that it will also make increasing capacity differentiation more likely. We may also conjecture that an increasing process scale unrelated to the structural requirements of the production process will make visible technological and organizational opportunities that cannot be taken up, and will trigger the search of ways to relax scale constraints.

3.4. *Scale-technology expansion: alternative routes*

One route likely to be followed (under *fixed* task-lengths) is the separation between conditions on *overall* process scale and conditions on the composition of output. In this case, an increase or decrease of consumers' demand for particular commodities will not immediately translate into a change of over-all process scale for the relevant productive unit. This means that the structural requirements for a task-arrangement compatible with full and continuous utilization of capacities and capabilities may be satisfied with more than one product mix provided the overall scale condition is satisfied.

Another route to be followed (under *flexible* task-lengths) would be to increase the differentiation of technical practices within the productive unit, so as to further increase the versatility of the whole productive organization. In this case too the structural requirements for task-arrangements compatible with the full and continuous utilization of capacities and capabilities are disconnected from the product mix, but the scale condition for full and continuous utilization may be satisfied by increasing the internal differentiation of the production process, rather than by varying the composition of output.

To sum up, scale-technology expansion may take a variety of routes depending on task-definitions, task-lengths and task-arrangements. It follows that the structural conditions for increasing returns discussed in this paper are subject to variation as we consider tasks of fixed or variable lengths, and/or changes in the way tasks are defined (see Cardinale and Scazzieri, 2011, 2013). An increasing process scale *may or may not* be associated with technology expansion, depending on the way scale is increased, and on, how the scale increase translates into the commodity composition of output and into the technical composition of the production process. Increasing returns are grounded in the structural bottlenecks and opportunities of productive organizations, and their actual dynamics are highly context-dependent and policy-sensitive. Some implications of this state of affairs will be examined in the following section.

4. Enabling conditions and implementation requirements: the duality of increasing returns

The above discussion of increasing returns presupposes the distinction between productive improvements that may be expected 'to arise naturally out of adaptations of existing ideas' (Marshall, 1961b (1898), p. 71), and those improvements 'that may result from substantive new inventions' (Marshall, 1961b (1898), p. 71). The former improvements are associated with *increasing returns*, the latter with *technical progress*.

Since its classical (and pre-classical) formulations, the theory of increasing returns rests upon a combination of structural and behavioural elements, which makes it difficult to disentangle the fundamental causal processes at work. This problem has also been discussed, in a more general setting, by Luigi Pasinetti who has argued that 'we must make it possible to disengage those investigations that concern the foundational bases of economic relations [. . .] from those investigations that must be carried out at the level of the actual economic institutions, which at any time any economic system is landed with, or has chosen to adopt, or is trying to achieve' (Pasinetti, 2007, p. 275). In order to disentangle the structural (compositional) elements making increasing returns feasible from the behavioural or institutional conditions governing their actual dynamics, it may be useful to distinguish, for any given production process, between (a) the *technological use-times* of production elements (such as workers, tools, materials-in-process) and (b) the *actual use-times* of the same production elements. As we shall see below, this distinction is instrumental in separating the conditions

[18] Characteristically, the job-shop is effective in providing to the needs of different customer requirements at the same time.

[19] The features of the job-shop described in the text are at the root of the historical dynamics that have characterized this form of production organization. The splitting of integrated processes into specialized, and organizationally independent, productive units is a case in point. As Karl Bücher noted for mediaeval job-shop production: 'Whenever any one line of handicraft threatens to become too large, new handicrafts split off from it and appropriate part of its sphere of production. This is the medieval division of labour, which continually creates new and independent trades' (Bücher, 1968 [1893], p. 171). These dynamics closely resemble structural changes in early 21st century electronic data-processing firms. In this case, the diffusion of job-shop production reflects the need to allow for quick changes in product composition, and to increase the variety of goods delivered at any given time (see also the paper by Lomi et al., 2014).

enabling increasing returns to develop from the conditions *triggering* increasing returns once the enabling conditions are fulfilled.

From an operational point of view, any given process of production, say P_j ($j = 1, \ldots, r$), may be represented by the corresponding vector of technological use-times $\boldsymbol{T}_j = [t_{1j}, t_{2j}, \ldots, t_{nj}]$, where the elements of $\boldsymbol{T}_j$ are the total working times for which workers, tools and machines must be employed in the process to deliver one product unit (or a unit batch of products), and the length of time for which the materials within the process are subject to actual transformation to the same purpose (see Scazzieri, 1993, p. 98).[20] Any given technology is associated, in general, with a specific $\boldsymbol{T}_j$. However, multiple organizational arrangements are compatible with the same vector of technological use-times. In particular, different arrangements of capacities and capabilities, tasks and materials may at the same time be compatible with a given technological specification (that is, with a given $\boldsymbol{T}_j$) and yet be conducive to entirely different patterns of utilization of capacities and capabilities and of transformation of materials within any conventionally determined period of time. This can be seen by associating $\boldsymbol{T}_j$ with the vector of physical input requirements delivering the technologically required use-times within the chosen time period:

$$\boldsymbol{v}_j = [\boldsymbol{v}_{1j}, \boldsymbol{v}_{2j}, \ldots, \boldsymbol{v}_{nj}].$$

Alternative productive arrangements compatible with any given $\boldsymbol{T}_j$ would be associated with k different vectors of input use. $\boldsymbol{T}_j$ will thus be associated with a set $\boldsymbol{\Phi} = [v_1, v_2, \ldots, v_k]$, which includes the vector of input uses (say, $\boldsymbol{v}_j^*$) associated with the productive arrangement actually adopted. In practice, this means that alternative arrangements of the production process (that is, alternative utilization patterns of capacities and capabilities, and alternative transformation patterns of materials) are compatible with the same technical specifications as shown by any given vector of use-times $\boldsymbol{T}_j$. This means that, for any given production process P_j, there will be a multiplicity of technologically feasible vectors of input-output coefficients associated with it. Any such vector may be derived from knowledge of (i) the output q delivered from $\boldsymbol{P}_j$ during the relevant time period (say, the working day), and (ii) the specific $\boldsymbol{v}_j^*$ vector corresponding to the productive arrangement in use during the same time period:

$$\boldsymbol{v}_j^* = \left[\frac{\boldsymbol{v}_{1j}^*}{q}, \frac{\boldsymbol{v}_{2j}^*}{q}, \ldots, \frac{\boldsymbol{v}_{nj}^*}{q}\right],$$

or in more compact form:

$$v_j^* = [a_{1j}^*, a_{2j}^*, \ldots, a_{mj}^*].$$

For any given set of production processes in use at any given time there will be a collection of $\boldsymbol{v}_j^*$ vectors expressing in synthetic form *both* the current state of technical specifications (that is, the technological recipes associated with any given collection of $\boldsymbol{T}_j$ vectors) and the current configurations of the different production processes simultaneously activated at the given time. The structure (at time t^*) of any given economic system, considered as a system of actual input-output flows 'supporting' a set of interdependent production processes $[P_1, P_2, \ldots, P_n]$, may be represented by the matrix $\boldsymbol{A}^*(t^*)$ of realized input-output coefficients as shown below:

$$A^*(t^*) = \begin{pmatrix} a_{11}^* & a_{12}^* & \cdots & a_{1n}^* \\ a_{21}^* & a_{22}^* & \cdots & a_{2n}^* \\ \cdots & \cdots & \cdots & \cdots \\ a_{m1}^* & a_{m2}^* & \cdots & a_{mn}^* \end{pmatrix}$$

Matrix $\boldsymbol{A}^*(t^*)$ presupposes a dual set of information about the structure of the economic system. On the one hand, this matrix is generated by a specific vector of technological use-times $\boldsymbol{T}_j$. On the other hand, the matrix records input-output flows that reflect the adjustment of technological recipes to the existing arrangements of capacities (or capabilities) and materials (as shown in the vector $\boldsymbol{v}_j^*$ of actual input uses). Any change of $\boldsymbol{A}^*(t^*)$ may thus be due either to a change of $\boldsymbol{T}_j$, or to a change of $\boldsymbol{v}_j^*$ (or to both).

Any given matrix $\boldsymbol{A}^*(t^*)$ may be associated with a dual family of generators, as shown below:

$$T_j, v_j^* \rightarrow A^*(t^*)$$

This means that, for any given $\boldsymbol{T}_j$, multiple patterns of input use are technologically feasible. Any given set of technological use-times for capacities, capabilities and materials may be compatible with manifold arrangements of those capacities, capabilities and materials for the execution of the required tasks in the production processes under consideration. Such manifold arrangements would generally be associated with different vectors of input use (these would be the different vectors $v_1, v_2, \ldots, v_k$ compatible with any given $\boldsymbol{\Phi}$). Conversely, we may conjecture that any given vector $\boldsymbol{v}_j^*$ of realized input uses would generally be compatible with a variety of alternative vectors of technological use-times. These alternative $\boldsymbol{T}_j$ vectors are not necessarily known ex ante but they are inherent to the existing productive arrangement and may eventually be discovered if suitable learning (learning of productive opportunities *within* the existing productive arrangement) is triggered (see Andreoni, 2013, this issue; see also Rosenberg, 1969, pp. 6–9).[21]

Scale-technology expansion takes place whenever a technical practice unfeasible at s becomes feasible at $s' > s$. The previous argument in this section suggests that an increasing process scale may be associated with

[20] The above formulation entails the analytical representation of productive activity in terms of tasks, processes and use-times (Scazzieri, 1993). A general discussion of analytical representations of production may be found in Georgescu-Roegen, 1970, 1990; see also Scazzieri and Witt, 2005; Witt, 2005).

[21] According to the classical definition suggested by Edith Penrose, the *productive opportunity* of any given firm 'comprises all of the productive possibilities that its "entrepreneurs" see and can take advantage of' (Penrose, 1972 (1959), p. 31).

technology expansion as a result of two different (although closely related) sets of conditions. On the one hand, the higher process scale may allow the introduction of a $\boldsymbol{T}_j$ vector (technological use-times) that is not feasible at any lower scale of production. On the other hand, the higher process scale may allow the introduction of a $\boldsymbol{v}_j^*$ vector (realized input uses) unattainable at the lower scale. We may conjecture that these two cases of technology expansion are inherently different, in so far as the former points to a change of strictly technological opportunities, whereas the latter may be associated with the feasibility of productive arrangements unavailable at the lower scale.

For any given $\boldsymbol{T}_j$, a change of $\boldsymbol{v}_j^*$ (realized input uses) may point to a transformation in the way tasks are arranged within the production process, or in the way workers and tools (or machines) execute tasks, or in the way different processes are arranged within the productive unit. We may conjecture this is the case whenever a change from s to s' (with $s > s'$) makes it feasible to vary the associated quantities of inputs in a non-proportional way relatively to process scale or relatively to one another. Any non-proportional change in one or more column vectors of matrix $\boldsymbol{A}^*(t^*)$ may ultimately be associated with a change in the arrangement of tasks, capacities or capabilities, and materials within the productive unit. It may also be associated with a change in the distribution of tasks, capacities or capabilities and materials across different productive units, that is, with the switch to a different pattern of division of labour in the economy. In particular, a change in the pattern of input use across productive units may reflect a different distribution of production processes among those units and ultimately also a change in the specialization (*or* integration) of industries This change may in turn be associated with the shift to a different pattern of capability specialization for workers, tools and machines (see Ames and Rosenberg, 1967a).

The arrangement of capacities and capabilities in the production process is compatible with *alternative patterns of specialization* depending on the state of technology and the form of productive organization. In this connection, relatively undifferentiated productive factors, that is, productive factors with the highest degree of versatility, are likely to be at the origin of the splitting among productive activities: '[i]n a pre-industrial society of unspecialized labor and specialized machines, the boundary between firms was apt to be the boundary between kinds of labour [. . .] Conversely, in contemporary industry, labour is specialized and machines unspecialized, so that the boundaries between firms in a process are apt to be at the boundaries between the activities of different machines' (Ames and Rosenberg, 1967a, p. 354). If we follow the above stylized picture of the 'progressive division and specialization of industries' (Ames and Rosenberg, 1967a, p. 1), it emerges no single pattern as to the organization of production around clusters of processes. Depending on which capacity or capability (or set of capacities/capabilities) we are considering, the splitting or the integration of processes may prevail. Indeed, a phenomenon that looks like a decomposition of productive activities from the point of view of a given set of capacities or capabilities may turn out to involve the integration of other activities if a different capacity or capability set is considered. In the historical cases discussed by Ames and Rosenberg (1967b), differentiated (single-purpose) tools go hand in hand with unspecialized workers in the age of craft production, whereas general-purpose machines go hand in hand with unspecialized workers in more recent forms of manufacturing organization. This flexibility of specialization patterns suggests to look more closely into the structural conditions that may influence the splitting or integration of productive activities for any given technological set-up.

To sum up, the distinction between *enabling conditions* and *implementation requirements* suggests the following causal structure for a theory of increasing returns:

(i) There is a set Θ of (virtual) technical practices, which is exogenously given;
(ii) There is an efficiency ranking on Θ;
(iii) A given process scale s is considered;
(iv) A subset $\Theta^*(s)$ of Θ is determined, such that there is at least one technical practice θ^* that (a) can produce s, (b) can only be introduced if certain *lower bounds* on process scale are satisfied (that is, θ^* can be introduced if and only if $s \geq s_l$);
(v) Technical practice θ^* is the 'best' technical option available to produce s, and there are reasons for producers to introduce it.[22]

The above causal structure entails that the set Θ of technical practices that are already known or that may arise 'naturally out of adaptations of existing ideas' (Marshall, 1961b (1898), p. 71) is *internally structured* so as to allow for technology expansion to take place as the over-all scale of the relevant set of production processes switches from $s < s_l$ to $s \geq s_l$. In this case, any actual increase in process scale (say, from $s < s_l$ to $s \geq s_l$) may or may not be associated with the introduction of a 'better' technical practice (that is, of a technical practice occupying a higher position in the efficiency ranking on Θ). But the increase in process scale is always associated with scale-technology expansion, such that there is at least one 'better' technical practice unfeasible at $s < s_l$ and feasible at $s \geq s_l$. This means that the increasing process scale removes constraints and makes the introduction of productive improvements possible, even if no necessity is implied. This analytical framework calls attention to the differentiation of productive tasks *within* the production process and *across* processes, and examines what this entails as to the clustering of capacities (or capabilities) and materials, within productive units. As a result, increasing returns are explained by the compositional principles governing the relationships among elements of the production process and by the opportunities arising from within existing production organizations. This, as Marshall had pointed out (see above), is the distinctive feature of increasing returns compared with technical progress.

[22] The above causal structure is discussed from a different point of view in Scazzieri (1982).

5. Production dynamics and increasing returns policies: a framework

This paper has outlined a structural theory of increasing returns on the basis of the following set of premises: (i) any given arrangement of capacities (or capabilities), tasks, and materials-in-transformation is associated with internal constraints on what may be achieved and with internal opportunities for improvement of the existing arrangement; (ii) the distinction between 'virtual' and realized technical practices is central to the analysis of the structural opportunities making increasing returns possible under specific conditions; (iii) the structural (or 'objective') conditions for increasing returns presuppose a general principle of relative invariance by which 'any given economic system subject to an impulse or force is allowed to change its original state by following an adjustment path that belongs to a limited set of feasible transformations' (Landesmann and Scazzieri, 1990, p. 96; see also Simon, 1962). In particular, as we have seen, the onset and continuation of an increasing returns trajectory presupposes a process of scale-technology expansion, which is subject to specific complementarities and constraints (see also Scazzieri, 2012).

The above argument suggests that the realization of increasing returns presupposes a combination of intended and unintended outcomes. On the one hand, technology expansions presuppose scale and proportionality conditions on the arrangement of capacities and capabilities, tasks and materials; indeed, some of these conditions are independent of producers' explicit intentions, as it happens when opportunities for technology expansion in a given process are triggered by technological or organizational developments in other processes. The interdependence between production processes may be an important source of scale-technology expansions, and ultimately of increasing returns, in processes *prima facie* unaffected by the increasing process scale and the associated expansion of production possibilities.

A number of issues are left open in the above analysis, and are briefly considered below:

(i) Where (that is, in which specific process or set of processes) will technology expansions appear as a result of an increasing scale?
(ii) To what extent are increasing returns likely as a result of scale-technology expansions?
(iii) Which route will increasing returns follow among the many routes that would become potentially available?

Answering in detail the above questions is beyond the scope of this paper. However, we may provide tentative answers, which also suggest lines of further research by the author of this paper or others. First, it is far from true that technology expansions are narrowly located in the clusters of production processes that are closer to the processes most directly affected by the increasing scale.[23] As a result, the empirical issue arises of how to locate the most sensitive clusters, that is the clusters most likely to generate widespread scale-technology expansions, and therefore *enabling* widespread increasing returns. Second, the distinction must be introduced between *possibility* and *likelihood*: the former points to objective conditions making increasing returns feasible (or not), the second calls attention to uncertainty and its assessment (see Zadeh, 2011, p. 104). This paper has emphasized the former rather than the latter. At the same time, it has called attention to the indeterminacy of increasing returns (will they arise? which course will they take?) unless their structural prerequisites are specifically addressed. Finally, structural conditions on scale-technology expansion allow a finite multiplicity of increasing returns trajectories, depending on the interplay between technology and organization, and on the producers' ranking of technical opportunities.

To conclude, a structural theory of increasing returns points to a complex web of interdependent possibilities associated with scale-technology expansions. Increasing returns may take more than one route, some of which may be more effective than others in realizing the production opportunities associated with the increasing scale. This highlights the possibility of targeted policy actions (by public or private decision makers) in ensuring that technology expansions are detected and that increasing returns are actually brought about (see Andreoni and Scazzieri, 2011, 2013).

The above analysis has shown that structural conditions must be fulfilled for increasing returns to be feasible. These conditions are *prima facie* independent of behavioural and institutional features and are ultimately derived from the proportionality requirements of the law of multiples (see Section 2 above). However, we cannot assume that meeting the structural conditions for increasing returns would be sufficient for increasing returns to set in. Targeted policy actions may be useful (or even necessary) in inducing the behavioural patterns, as well as the institutional and macroeconomic conditions, which are needed to realize the increasing returns potential existing in a given context.[24] In particular, different increasing returns trajectories may be feasible and can be triggered by different actions by public or private bodies. This raises the important issue of the level at which decisions must be taken (and behavioural patterns triggered) for specific increasing returns trajectories

[23] Rosenberg's research on technological change in the machine tool industry points to interrelationships that may also be relevant to the study of the diffusion of scale-technology expansions and increasing returns (Rosenberg, 1963, pp. 420–421; see also Rosenberg, 1969, 1972).

[24] The special relationship identified by Nicholas Kaldor between macroeconomic productivity growth and output growth in the manufacturing sector is a case in point. For demand conditions characteristic of an intermediate stage of development would involve a concentration of demand on goods produced in the manufacturing sector, and would trigger technology expansion in this sector. This would in turn lead to an increasing returns trajectory provided behavioural responses and the institutional context induce the appropriate transformation of production structures (Kaldor, 1966, 1967; Rowthorn, 1979; McCombie, 2003; Amendola et al., 2005). Increasing returns may also have important consequences for the way in which changes of activity levels in the macroeconomy may influence relative proportions among productive sectors along specific trajectories of structural change (Scazzieri, 2009; Silva and Teixeira, 2008).

to develop. In general, scale-technology expansions at the level of individual firms are different from scale-technology expansions at the level of localized productive units, national systems, and cross-national networks of productive units.[25] This entails that public or private decisions are likely to impact very differently upon increasing returns depending on the level at which they are taken, and thus on the range of behaviours they are likely to affect.[26]

The structural theory outlined in this paper highlights the proportionality requirements for increasing returns and calls attention to the scale thresholds at which changes in behavioural patterns may trigger (or, alternatively, thwart) the onset of an increasing returns trajectory. This theory also highlights that a deliberate increasing-returns policy is not always necessary, but that such a policy may be needed if a production system has to overcome bottlenecks (or to exploit opportunities) by *moving discontinuously* across different configurations of productive arrangements. The aim of this paper has been to open a research agenda for a political economy of increasing returns.

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[25] Trajectories of scale-technology expansion and increasing returns reflect which schemes of economic organization are feasible at each level of organization. For example, certain schemes of division of labour are feasible in certain organizations but not in others (see Yang and Ng, 1993). This condition raises the important issue of the political–economic prerequisites of different increasing returns trajectories.

[26] This point entails that alternative distributions of power within and between firms, firm networks, or national systems may trigger different schemes of division of labour, and thus alternative trajectories of increasing returns (see, in particular, March, 1962; Bianchi, 1991).

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