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Production of commodities by means of processes The flow–fund model, input–output relations and the cognitive aspects of production

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ABSTRACT

The purpose of this paper is to demonstrate the potential contribution of the flow–fund model to analysing the organisation of production processes by exploring the links with two other levels of analysis: namely, the input–output relations and innovative activity through the development of new knowledge.

The flow–fund model focuses on the time dimension of production activities which require specific 'knowledge how', in addition to 'knowledge that'. The flow–fund methodology allows us to analyse the task distributions and the organisation of production processes that are both absent from input–output models. The time-dimension of the flow–fund analysis provides the necessary bridge to explain the co-evolution of organisational settings and new productive knowledge.

1. Introduction

In economic literature the study of the boundaries and functioning of business organisations involves three levels of analysis regarding: (i) the production of commodities by means of commodities; (ii) the production of commodities by means of processes; (iii) the production of processes by means of the creation of knowledge.

The first level of analysis – the production of commodities by means of commodities – focuses on the relationship between output and input quantities. Production function applications, input–output models and activity analysis investigate this first level.[1] The representation of production activity as a mere relation between inputs and outputs might be compared to a cookery book which only lists the quantity of the ingredients needed for each recipe, without mentioning either the sequence of operations or the assignment of tasks.

The second level of analysis – the production of commodities by means of processes – addresses the time dimension and the task distributions of production

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[1] The expression "Production of commodities by means of commodities" has been drawn from the title of Piero Sraffa's, 1960 book that proposes a revival of the classical approach. An interesting attempt to develop a linear model that describes the dynamics of the economy as driven by changes in knowledge over time is in D'Agata and Mori (2012). As far as implementations of the input–output model and the activities analysis approach are concerned, see, for instance, Leontief and Duchin (1986), Manne (1961) and Manne and Markowitz (1963). The literature on neoclassical production function, within an optimisation framework, is vast, and applications of this analytical tool are innumerable. For a clear and thorough exposition of production theory based on the production function, see Gravelle and Rees (1981, chapter 7). For a critical appraisal of the aggregate production function see, for instance, Mo-huan (1992) and Sylos Labini (1995).

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activities using a flow–fund model. This model permits the study of the efficiency properties of different patterns of the division of labour and knowledge adopted in relation to specific organisational settings. So far, this model has been implemented, adopting slightly different methodologies, in order to investigate a wide range of problems regarding task distribution, warehouses, production flexibility, productivity, costs and profitability in various sectors of activity.[2]

The third level of analysis – the production of processes by means of the creation of knowledge – concerns the creation of new production processes through innovative activity. This third level is investigated by the various cognitive perspectives concerning innovative activity.[3] These perspectives recognise that the firm's knowledge may differ between firms and may change over time, quite possibly as a consequence of its own activities. It is stressed that innovation implies the development of equipment and organisation as well as capabilities by cognitive processes.

The purpose of this paper is to demonstrate the potential contribution of the flow–fund model to the study of the organisation of production processes by exploring the links with two other levels of analysis: the input–output relationships and innovative activity.

The paper illustrates how the implementation of the flow–fund model makes it possible to study the properties of different possible patterns of the division of labour each of which is associated with a particular arrangement of tasks and characteristics of productive knowledge. It also demonstrates that the flow–fund model allows us to open the black box of production, evaluating the effects of innovative activity on the organisation of production processes and the relative performance of firms. In so doing it is possible to investigate the close interdependency between organisational changes and the development of capabilities. The time-dimension of the flow–fund model provides the necessary bridge to explain the co-evolution of organisational settings and new productive knowledge.

The remainder of the paper is organised in four sections. Section 2 is dedicated to a concise presentation of Georgescu-Roegen's original flow–fund model. Section 3 focuses on the potential offered by the flow–fund model in representing different organisational settings of production processes with differing distribution of tasks and division of productive knowledge. Section 4 addresses the links between the flow–fund model and the first and third levels of analysis indicated in this Introduction. Finally, Section 5 outlines some possible directions of further research.

2. The analysis of production processes: the flow–fund model

Let us start illustrating Georgescu-Roegen's original production model by discussing the fundamental distinction between flows and funds.

A flow is utilised in only one process as input, or can emerge from a single process as output. A flow always corresponds to a certain quantity of material, substance, or energy, which enters into or exits from the process in a given instant. A flow may result either from the decumulation of a stock or from the transformation made by the production process.

A fund, on the other hand, provides its services in several processes that occur over time and consequently cannot be decumulated in an instant. This definition allows us to make an important distinction between the agents of production processes and the services that they provide. For the sake of simplicity, let us assume that funds are maintained in efficiency by outside processes. Accordingly, funds are conceived as agents of constant efficiency.[4]

Interestingly, the same commodity may be a flow in one process and a fund in another. For instance, a computer is a flow in its process of production, but it is a fund in the processes in which it provides its services (Georgescu-Roegen, 1965, pp. 83–84, 86).

The flow and fund definitions make it clear that there is no possibility of substituting a fund with a flow in the same production process. For example, in making a shirt one cannot replace the sewing machine, which represents a fund, with the fabric, which is a flow element transformed in the production process thanks to the services of the funds, or vice versa (Georgescu-Roegen, 1979, p. 129).

A production process is defined by its analytical boundaries that determine the object of our analysis, that is, the output flow to which the elementary process refers, and by the input flows and funds used in that process. The analytical boundary is considered in relation to the possibility of giving to various semi-processed products an independent existence from one place to another as commodities. On this Georgescu-Roegen (1971a, pp. 40–41) gives a clear example: "[a]n engineer, for example, may draw a boundary between the furnace with melted glass and the rolling machines of a plate glass factory, but not so an economist [. . .]. For melted glass is not [. . .] a commodity".

The elementary production process is that whereby an economically indivisible unit of output is obtained by means of an elementary technical unit, or chain of elementary technical units, operating in sequence. An

[2] On Nicholas Georgescu-Roegen's flow–fund model see Georgescu-Roegen (1965, 1970). Developments of this model can be found, for example, in: Tani (1986), Morroni (1992), Scazzieri (1993), Piacentini (1995), Bertolini and Giovannetti (2003) and Mir-Artigues and González-Calvet (2007). The flow–fund model has been applied to some case studies regarding the textile industry and electronic devices for telecommunication networks (Morroni, 1999, 2003), the shoe industry (Birolo, 2001) and the tile industry (Mir-Artigues and González-Calvet, 2003). For a recent thorough critical survey on this literature and further bibliographical references, see Vittucci Marzetti (2012).

[3] By the expression "cognitive perspectives" I refer to the largely overlapping streams of research on the nature and functioning of business enterprises, which include behavioural theories, capabilities-based approaches, evolutionary and Neo-Schumpeterian theories of technical change. See among the numerous contributions: Montgomery (1995), Teece et al. (1997), Hodgson (1998), Loasby (1998), Dosi et al. (2000, 2008), Egidi and Rizzello (2003), Antonelli (2005a,b), Dosi and Marengo (2005), Augier and Teece (2006), Von Tunzelmann (2009), Hall and Rosenberg (2010) and Jacobides and Winter (2012).

[4] This is a simplifying hypothesis which does not affect the analysis of efficiency and organisation of a single production process. This hypothesis should be abandoned if several processes over time are analysed.

economically indivisible unit is the minimum exchangeable unit not subsequently reducible for exchange purposes in a specific market (for instance, a length of cloth or a box of laundry detergent), while technical indivisibility refers to the impossibility of dividing a particular item, once exchanged, into amounts usable for production or consumption (for instance, a length of cloth or a box of laundry detergent are technically divisible, while a refrigerator or a loom are not). An elementary technical unit is the minimum set of production elements that can be activated separately to produce a unit of output (Morroni, 1992, pp. 25–28).

Let TEP be the duration of an elementary process from the starting time (0), when the process begins with the input of raw materials, to the moment (T), when the process is completed with the production of a unit of the commodity under consideration, obtained through the transformation of those raw materials. For each individual element of the production process, whether input or output, Georgescu-Roegen determines a function of time within the closed interval TEP[0,T]. The production process is thus represented by the following functional, which is "a relation from a set of functions to one function" (Georgescu-Roegen, 1971b, p. 236):

$$O(t) = G[G_1(t), G_2(t), \ldots, G_I(t), F_1(t), F_2(t), \ldots, F_H(t), U_1(t), U_2(t), \ldots, U_K(t)], \quad (1)$$

where $G_i(t)$ ($i = 1, 2, \ldots, I$) are the functions indicating, at any time t, the cumulative quantity of the ith outflow; $F_h(t)$ ($h = 1, 2, \ldots, H$) are the functions indicating, at any time t, the cumulative quantity of the hth inflow; and $U_k(t)$ ($k = 1, 2, \ldots K$) are the functions indicating, at any time t, the degree of use of the kth fund. By convention, we can give a positive sign to the functions of outflows $G_i(t)$, and a negative sign to both the functions of inflows $F_h(t)$ and the functions of funds $U_k(t)$.

$G_i(t)$ are non-decreasing monotonic output functions of t, while $F_h(t)$ are non-increasing monotonic inflow functions of t. Functions $G_i(t)$ and $F_h(t)$ may be discontinuous because some flows may be accumulated or decumulated in a single instant. The value of $U_k(t)$, which indicates the degree of use of the fund, may vary between 0 (presence of the fund without being used) and −1 (maximum use of the productive capacity of the fund). Therefore functions $U_k(t)$ show the fund idle times when the value is zero. The function $U_k(t)$, which indicates the degree of use of a fund, may be transformed into a function that represents the cumulative quantities of the services provided by a fund (cf. Tani, 1986, pp. 203–206; Morroni, 1992, pp. 58–60).

Fig. 1 provides an illustration of a possible shape of these functions in the case of the following list of coordinates.

Output flows: (1) product $G_1(t)$; (2) waste $G_2(t)$.
Input flows: (3) raw material $F_1(t)$; (4) energy $F_2(t)$.
Funds: (5) worker $U_1(t)$; (6) loom $U_2(t)$; (7) area of plant $U_3(t)$.

In the list of flow coordinates, two outputs are shown (i.e. the product and waste), but we can assume any number

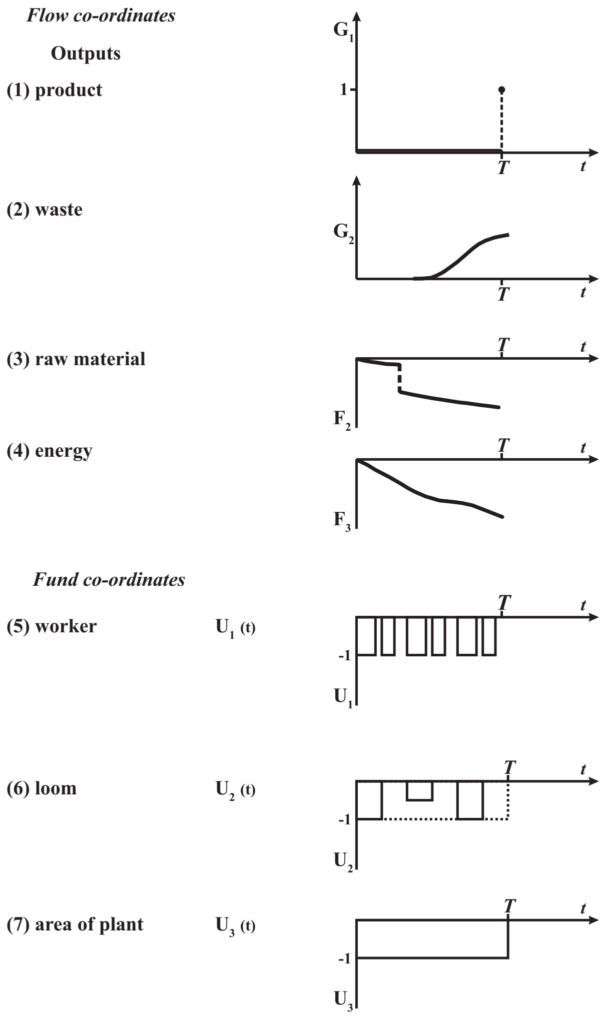

Fig. 1. Flow and fund co-ordinates.
Source: Based on Georgescu-Roegen (1970, p. 89).

of output flows.[5] Functions $U_k(t)$ allow for the various time profiles of funds to be compared. For instance, in Fig. 1 the time profiles of the three funds considered are different because of the unequal distribution of the fund times of presence and utilisation times. The worker is present only when the process is in operation. By contrast, the loom, in the same example, is present during the whole duration of the elementary process, even if it remains inactive during the pauses when the process is suspended – unless, as we shall see, it is used in other processes. In Fig. 1, the time of presence is indicated with a dotted line and utilisation time with a continuous line.

[5] This is a simplified exposition of the flow–fund model. In Georgescu-Roegen's original example (1965, p. 88), different symbols are used and more production elements are included.

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3. Different production arrangements

This section is aimed at illustrating the possibilities offered by the flow–fund model to analyse the arrangements of inputs according to various organisational settings. The implementation of the flow–fund model makes it possible to study the properties of different possible patterns of the division of labour – among a plurality of feasible patterns – each of which is associated with a particular sequence of activities, arrangement of tasks and characteristics of productive knowledge.

To illustrate this point let us give an example. Suppose that initially a worker performs all operations needed for the production process to be completed. As illustrated in Fig. 2, function $W_1(t)$ indicates, at any time t, the degree of use of the services provided by the worker during the elementary process. Functions $U_k(t)$ indicate the degree of use of the four funds which correspond to as many tools, one for each fund. In this example, depicted in Fig. 2, the worker carries out an elementary process performing four different activities. Activities consist of different operations which require the performance of one or more elementary tasks. An elementary task is an operation which, by definition, is not further divisible (for instance, loading or unloading an intermediate product or cutting a piece of fabric). Suppose that the first activity performed by the worker requires the execution of three elementary tasks (ET1.1, ET1.2 and ET1.3), the second and the third require the execution of two elementary tasks (respectively ET2.4, ET2.5 and ET3.6, ET3.7), and the fourth the execution of four elementary tasks (ET4.8, ET4.9, ET4.10 and ET4.11). Therefore the whole elementary process implies eleven elementary tasks to be performed one after another. For the sake of simplicity, let us assume that activities are divided in such a way that each activity takes the same time (say an hour) and that each task requires a distinct productive knowledge. The productive knowledge corresponding to various elementary tasks is indicated at the bottom of Fig. 2. The duration of the elementary process (TEP) is 4 h. The worker starts an elementary process when the previous one ends (Georgescu-Roegen, 1971a, p. 43). This arrangement in series of the production processes is typical of artisan production in which a single unit of output is produced at each time according to the customer's specification. The worker uses four funds (U_1, U_2, U_3 and U_4): one for each activity. These four funds are tools available in the plant, but three of them (out of four) remain constantly idle throughout the duration of the process because the worker performs one activity at a time. For simplicity we abstract from the possible presence of other physical or intangible funds.

This kind of production, labelled artisan or craft production, has three basic characteristics:

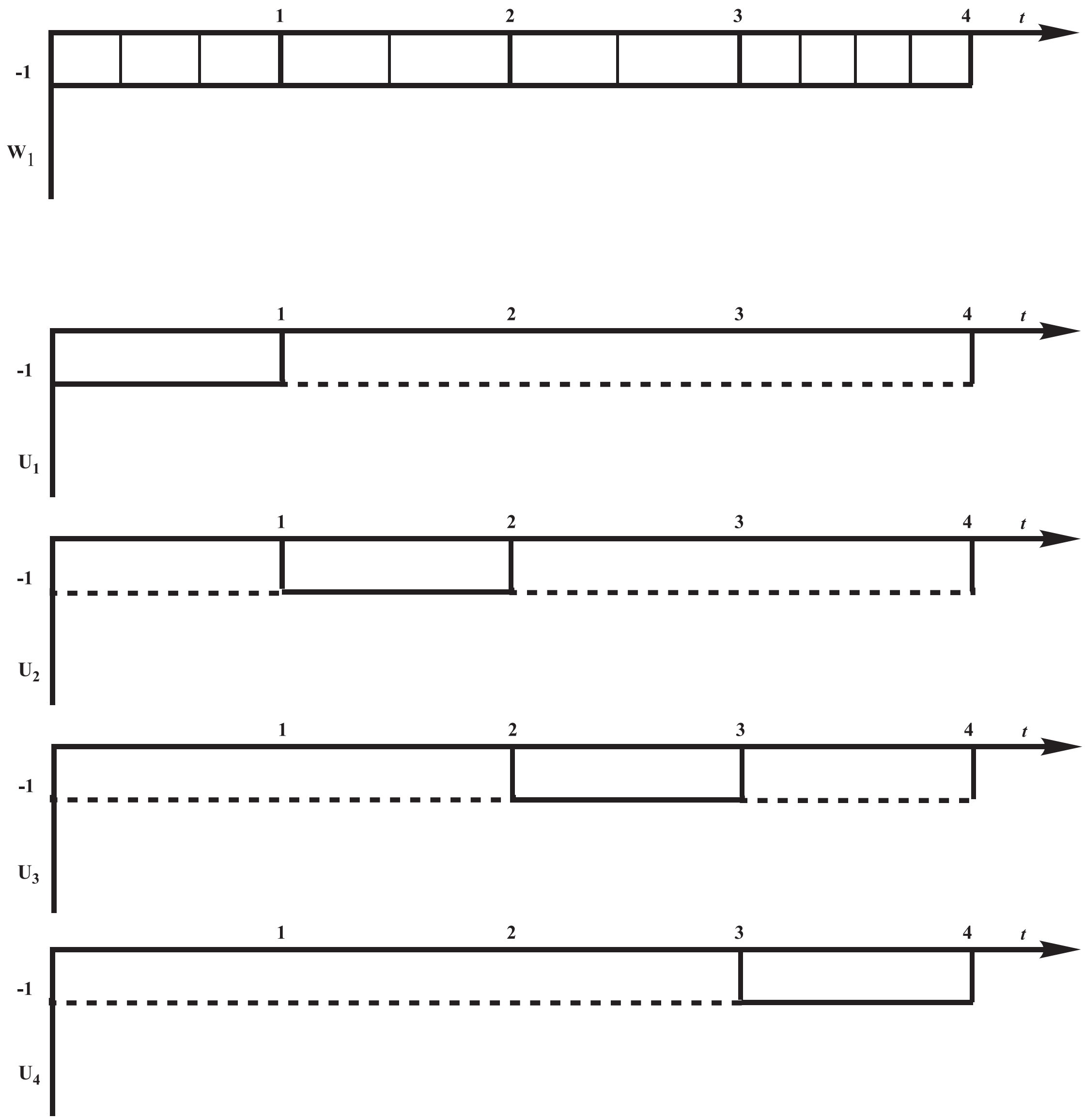
(a) High flexibility because the production process allows for single units to be produced, and virtually every product may be different from any other.
(b) Long idle times for tools since the artisan moves from one operation to the other, using his or her tools one at a time. However, long idle times for tools are not a problem if the cost of tools is negligible, as is often the case in artisan production.
(c) Long training times and long on-the-job experience for workers due to the fact that in artisan production they carry out all activities and perform all the elementary tasks and therefore they must have wide productive knowledge, which implies a great number of abilities and skills. The need for a wide productive knowledge implies long idle times for task-specific knowledge. This provides an incentive for devising alternative forms of organisation.

Let us now suppose that demand increases to the point that it would be possible to hire four workers (W_1, W_2, W_3, W_4). If the organisation of production processes remains unchanged, each one of the four workers carries out in parallel an entire elementary process performing all four activities one after another according to the arrangement in series. Each worker utilises four tools and performs consecutively all eleven of the tasks required to complete the production process. By comparison with the previous example with only one worker, in this second case the number workers, the number of tools and volume of production increase fourfold. Both idle times for tools and the required productive knowledge remain entirely unaffected (Fig. 3, example a).

With the adoption of the factory system (arrangement in line), the various operations can be assigned in sequence to different workers and idle times for funds can be eliminated. The maximum technical division of labour is achieved when the volume of production increases to the point that each worker performs only one elementary task. The reshaping of workers' tasks according to the factory system generates a radical change in the nature and distribution of productive knowledge.

Let us consider the same level of demand assumed in the previous example, which implies the utilisation of four workers. If production is re-organised according to the factory system, each worker can perform only one activity in a linear sequence (see example b in Fig. 3). Then, the various elementary processes can start in succession with every interval corresponding to an equal fraction of the duration of the elementary process (TEP). It becomes possible to divide labour among the four workers, who now perform from two to four elementary tasks (according to which specific activity is undertaken) instead of eleven elementary tasks. This reduction in the number of elementary tasks performed by each worker entails a subsequent decrease in the range of abilities and skills required. Most of the productive knowledge of each individual worker is no longer required, and therefore loses its value. Furthermore, moving from craft production in parallel to factory production in line makes it possible to save in fixed capital: the set of funds previously needed by one worker is now sufficient for four because idle times for funds are now zero. It is evident that the higher the cost of fixed capital, the greater the need to decrease idle time.

The difference between artisan and industrial production lies in the fact that the latter permits a reduction in idle times for funds and a radical modification in the



A 1			A 2		A 3		A 4				ACTIVITIES
U 1			U 2		U 3		U 4				FUNDS
ET 1.1	ET 1.2	ET 1.3	ET 2.4	ET 2.5	ET 3.6	ET 3.7	ET 4.8	ET 4.9	ET 4.10	ET 4.11	TASKS
PK 1.1	PK 1.2	PK 1.3	PK 2.4	PK 2.5	PK 3.6	PK 3.7	PK 4.8	PK 4.9	PK 4.10	PK 4.11	PRODUCTIVE KNOWLEDGE

Fig. 2. One worker, four activities and eleven elementary tasks.

abilities and skills required as a consequence of the change of the distribution of tasks. In the example described above changes brought about by the factory system, without any change in the quality of tools, result in major changes in individual abilities and, as a consequence, in the firm's knowledge and capabilities.

As highlighted by Georgescu-Roegen (1971b, pp. 248–249), the economy of time achieved by the factory

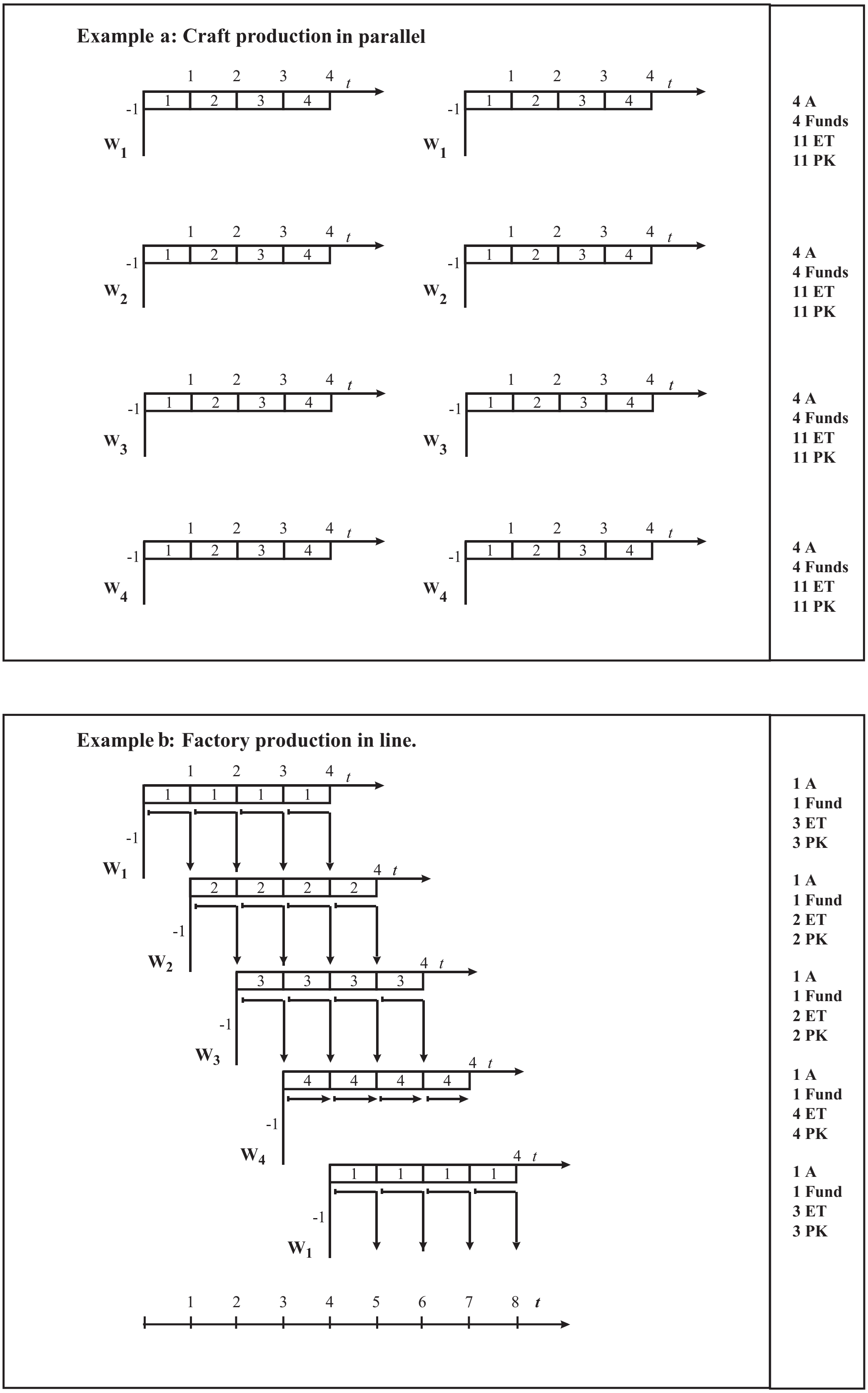


Fig. 3. Four workers, four activities and eleven elementary tasks.

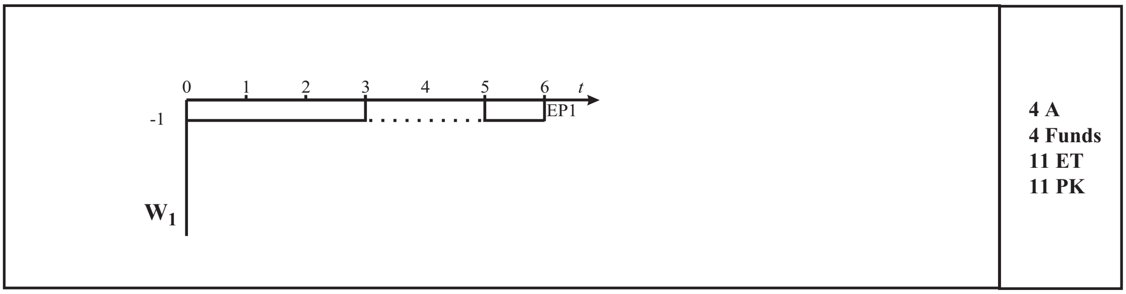


Fig. 4. An elementary process with idle times.

system is independent of technology. For instance, nothing prevents us from using the most primitive technique of cloth weaving in a factory system. The factory system is not a technological innovation; it is rather an "economic" and organisational innovation. According to Georgescu-Roegen, it is, together with money, one of the most important organisational and economic innovations of human beings.

Let us now examine a further example in which there are idle times for workers and tools. Suppose that a worker (W_1) performs all four activities required, implying eleven elementary tasks, and works for four units of time, as in the above example, but now the duration of the elementary process (TEP) is 6 h. This includes 2 h of idle time owing to a break in which the semi-finished product is kept in a technical warehouse in order, for instance, to settle or dry (Fig. 4). Therefore the worker and the four tools are active for 3/6 of the duration of the elementary process, inactive for 2/6 and active again for the remaining 1/6.

Idle times for workers can be eliminated by activating one process after another in a predetermined sequence. In our example, this is obtained by employing four different workers (W_1, W_2, W_3, W_4). The first three workers (W_1, W_2 and W_3) undertake three different activities (1, 2 and 3) for a total of seven elementary tasks, while the fourth worker executes only the fourth activity, which implies four elementary tasks. The three first workers each use three tools (fund U_1, U_2 and U_3). Two of these three tools remain constantly idle throughout the duration of the process because the three workers perform one activity at a time. By contrast, the fourth tool (fund U_4), utilised by the fourth worker (W_4), does not remain idle because the fourth worker continuously repeats the fourth activity. The duration of the elementary process is still 6 h and every semi-finished product is stored in the warehouse for 2 h (2/6 of the duration of the elementary process) before passing to worker W_4 (see Fig. 5). Clearly, in line production, once the process is established, finished products will come off the line regularly in rapid succession. In the present case the interval between them will be an hour (TEP/6). The number of elementary processes carried out in 6 h changes from one to six, with an increase in productivity. In fact, in our example the new organisational setting involves a fourfold increase in the number of workers but the volume of production undergoes a sixfold increase. It is evident that this improvement in efficiency derives from the elimination of idle times for workers. The larger growth of output, in proportion to the increase in labour input, gives rise to increasing returns. An interesting property of increasing returns is highlighted by this example: increasing returns are associated with a scaling up of a process that involves *a change in proportion* among inputs. By contrast, traditional microeconomic theory assumes that processes "would be scaled up or down at will while maintaining the same proportional relations among inputs and outputs, and the results of activities performed simultaneously would be additive" (Winter, 2005, p. 228). The practice of separating the analysis of variations in proportions (partial or short-term adaptation) from variations in quantities (full or long-term adaptation) seems to be misleading, as there are good reasons for thinking that the proportions and quantities vary together. As pointed out long ago by Piero Sraffa, increasing returns to scale derive from the possibility of augmenting the inputs in the proportions which are required by complementarity relationships among inputs and processes, while decreasing returns to scale occur when there is a restriction that prevents some elements of production from increasing in the required proportions.[6]

A scaling-up of the production process is a necessary, but not sufficient, condition that allows for an increase in the division of labour and knowledge. This is clear if we compare Figs. 5 and 6. In both examples, which illustrate two out of many conceivable patterns of the division of labour, we have an elementary process performed by four workers and activated in line at regular intervals of TEP/6. However, in the example of Fig. 5, workers W_1, W_2, W_3 perform in sequence three different activities which imply seven elementary tasks, while worker W_4 always repeats one activity, which involves the execution of four elementary tasks, throughout the whole duration of the elementary process. Therefore only worker W_4 is specialised in a single activity and only the fourth tool (fund U_4), used by worker W_4, does not experience idle times. In the example depicted in Fig. 6, idle times for workers are zero, as in Fig. 5, but the division of labour and knowledge is greater because the four workers each perform only one activity out of the total of four activities. This makes it possible to eliminate idle times for all four

[6] Sraffa (1925, pp. 7, 23–24; 1926, p. 44ff.), cf. Marshall (1890, pp. 125, 265–266), Morroni (1998a, p. 209ff., 1998b, pp. 400–402) and Loasby (2010, p. 1311). Scazzieri (2010, pp. 1, 20–21) calls attention to the important role of positive and negative complementarities in explaining increasing returns.

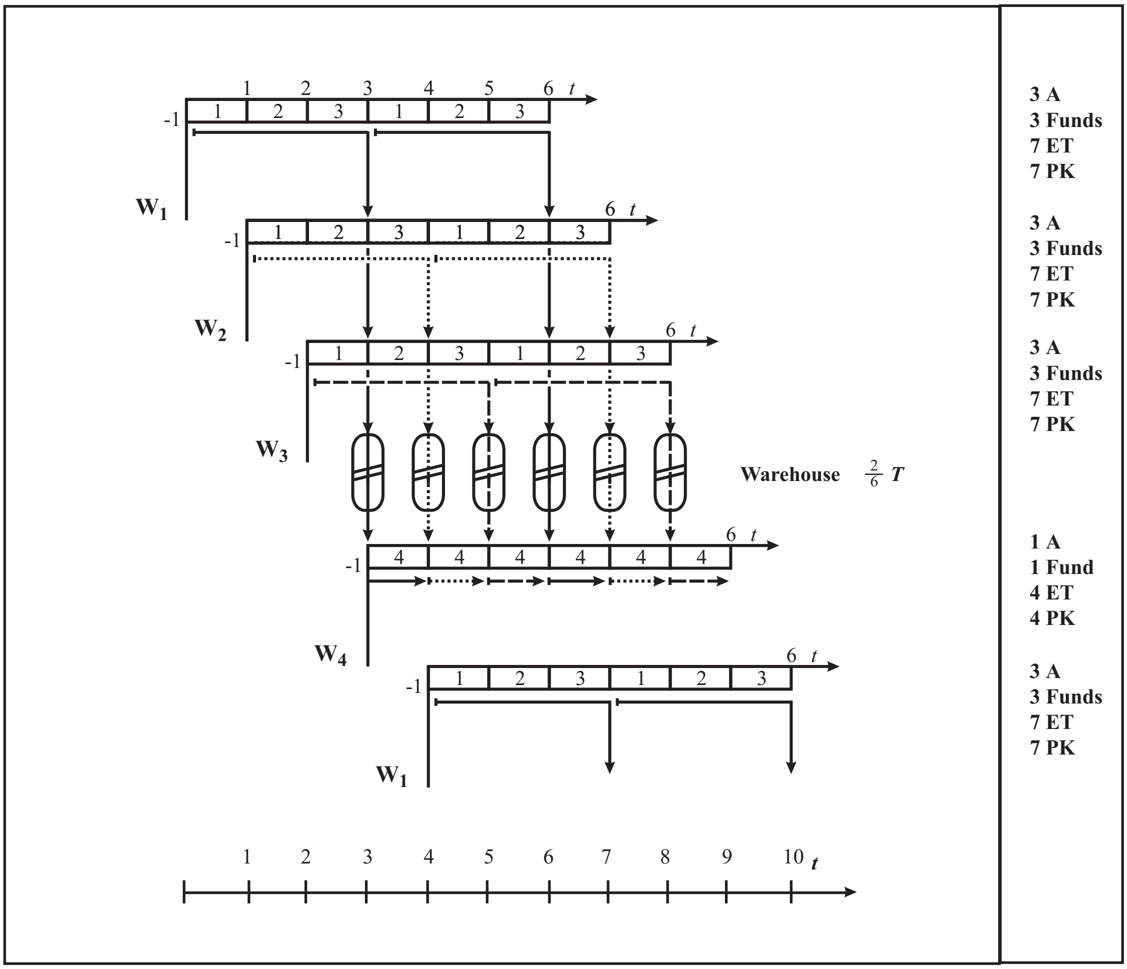


Fig. 5. Line production with idle times. Four workers and eleven elementary tasks: example a.

tools and, as a consequence, the total number of tools used by the four workers decreases from ten to four. Worker W_1 continuously repeats the first activity (three elementary tasks), worker W_2 the second (two elementary tasks), worker W_3 the third (two elementary tasks) and worker W_4 the fourth (four elementary tasks). This organisational setting brings about a growth in productivity because it reduces idle times and thereby favours a more efficient utilisation and allocation of productive capacities of different production elements (cf. Leijonhufvud, 1986, pp. 206–212; Morroni, 1992: Chapter 4). Moreover, this minute division of labour implies a reduction in the number of tasks executed by the first three workers and therefore implies skills that require less lengthy learning times with a decrease in labour costs.

The technical division of labour not only has the effect of simplifying and reducing learning time, but it also has other well-known important effects that are worth mentioning. First, the division of labour facilitates repetition-based improvements that augment workers' dexterity (Smith, 1776, pp. 17–21). It also leads to a reduction in production costs because, by dividing the work to be executed into different operations each requiring different degrees of skill, the firm can pay for the precise skill required for each operation (Babbage, 1832, pp. 169, 172–173). Each fresh division of labour, which reduces the complexity of a given operation, might lead to the introduction of machines to carry out the simplified operation and to take over tasks formerly performed by workers (Smith, 1776, pp. 17–21; cf. Young, 1928, pp. 529–530). Therefore the introduction of new machines gives opportunities for the selective replacement of skills. The adoption of new machines could not be specifically predicted in advance. Potential innovations which are generated by competitors enhance radical uncertainty that entails threats and novel possibilities for each producer (Knight, 1921, pp. 20, 37–38, 48). The importance of organisational innovation extends to consequences that were often not intended.

The substitution of workers with machines depends on the respective comparative advantages in performing specific tasks. Machines are assigned tasks based on explicit knowledge. However, fully codified tasks do not necessarily have to be performed by machines. As observed by David Autor, "[w]hen Nissan Motor Company builds cars in Japan,

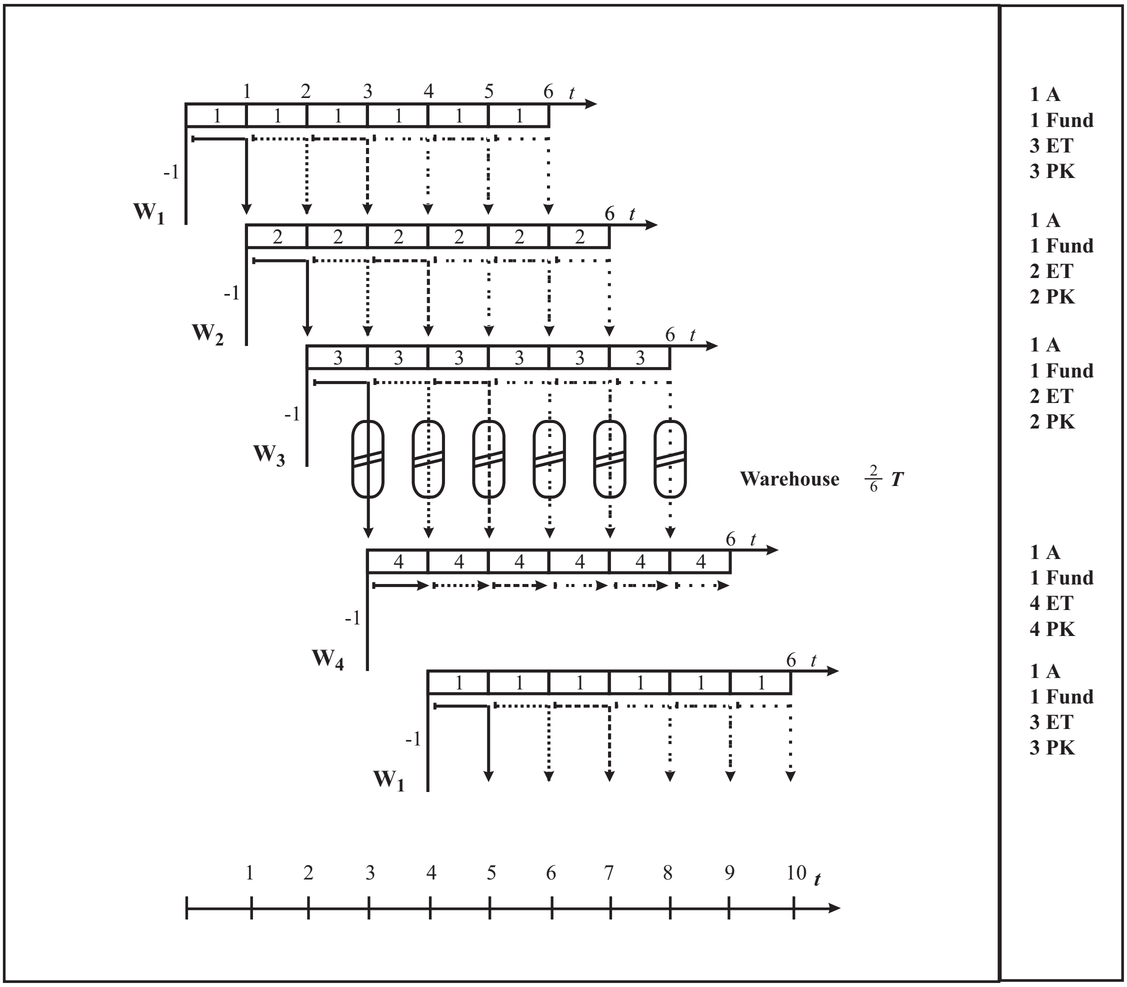


Fig. 6. Line production with idle times. Four workers and eleven tasks: example b.

it makes extensive use of industrial robots to reduce labour costs. When it assembles cars in India, it uses robots far more sparingly. The key difference between production in India and Japan is not technology but cost: labour is comparatively cheap in India. . . . [H]ence Nissan hires Indian workers to perform assembly tasks that are roboticized in Japan".[7]

As shown in the examples illustrated in Figs. 5 and 6, different degrees of division of labour may be adopted even in production processes that utilise the same tools. The actual degree of the division of labour and the distribution of tasks depends on entrepreneurial choice according to the comparative advantages in performing tasks. These comparative advantages are affected by environmental and internal basic conditions in which the firm operates, namely labour costs, skills, occupational structure, characteristics of techniques and equipment, level of uncertainty and market conditions.[8]

In short, there is no "one best way" but rather a multiplicity of organisational solutions according to the peculiarities of variables that make up the environment, and the adaptive responses provided by production units on the basis of their own interpretations of their experience. Line production is a pre-condition for the division of labour, but does not in itself make the technical division of labour necessary. The factory system and line production may be compatible with very different degrees of technical division of labour and different distribution of tasks and productive knowledge.

4. Links between the three levels of analysis

In the Introduction we made a distinction between three levels of analysis regarding the production of

[7] Autor (2013, pp. 4–5) who presents a model of the allocations of workplace tasks between capital and labour on the basis of respective comparative advantages. This model addresses the permeable and shifting boundaries between labour tasks and capital tasks.

[8] For an analysis of the basic conditions in which firms operate, see the organisational coordination approach in Morroni (2006a: Chapter 1).

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commodities by means of commodities (i.e. the analysis of the relationship between inputs and outputs), the production of commodities by means of processes (i.e. the flow–fund analysis of the organisation of production processes, applied in the previous section), and the production of processes by means of knowledge (i.e. the cognitive perspective regarding innovative activity). In the remaining part of the paper, let us briefly consider dissimilarities and links between the flow–fund model and the first and third level of analysis.

The first level focuses on the relationship between output and input quantities. It tells us nothing about functioning – since no processes are specified – or organisation, abstracting from the sequence of operations, the speed of rotation of inputs and the assignment of tasks. Addressing only the relationship between inputs and outputs is not sufficient in the study of production processes since input–output coefficients depend on the speed of rotation of flows, which is affected by the actual arrangement of production processes and in particular by the scale of production (Piacentini, 1995, p. 465, cf. Vittucci Marzetti, 2010, p. 36). A given input–output relation may correspond to numerous different ways of organising production. The economic problem of production is far more complex than choosing the combination of inputs within the individual firm because it involves the temporal coordination of the various intermediate processes and individual tasks which are linked to the pattern of division of labour and knowledge actually adopted.

The investigation of these latter aspects is made possible by the implementation of the flow–fund model, which allows us to consider the time profile, the speed of rotation of flows and the organisation of production processes. As we have seen in the previous section, the flow–fund model is not only an input–output representation with a time dimension, but puts to the forefront the analysis of the organisation of processes which require specific "knowledge how", in addition to "knowledge that". The flow–fund model permits the examination of the efficiency properties of different patterns of division of labour associated with the distribution of tasks and the division of productive and transactional knowledge adopted in relation to specific organisational settings.[9] The flow–fund model can consider explicit and codified knowledge as a fund (for instance, software, patents, copyrights, databases and so on).

As far as the third level of analysis is concerned, the cognitive perspective addresses the creation of new production processes and recognises that the state of the firm's knowledge may differ between firms and that each firm's knowledge may change over time, quite possibly as a consequence of its own activities.

Equipment and organisation as well as capabilities are developed by cognitive processes. The firm's capabilities consist of the abilities to produce and sell specific goods and services that satisfy potential demand. Capabilities are related to the set of specialised activities, routines and skills that are embodied in a firm and are built up according to the entrepreneur–manager's strategy and "business conception", which involves judgement and conjectures that are mostly firm-specific and largely non-tradable.[10] Designing a strategy entails the formation of new skills, enhancing the firm's ability to learn and to introduce new processes and products. Innovative activity is the result of an accumulation of experience and takes place in historical time, in which different "states" represented by successive techniques are not independent but are linked by a causal relationship (Hicks, 1976, p. 135).

Innovative activity is a source of substantive radical uncertainty since it creates the possibility of unexpected outcomes. In fact, post-invention applications and improvements are at first very difficult to forecast or even imagine because judgements about the feasibility of an activity of a novel kind are subject to hazards. In this context the role of the Schumpeterian entrepreneur is essential in organising new ideas, technologies and markets. But even after the technical feasibility of a new activity has been established, the inability to anticipate the future impact of innovations may still remain. Substantive radical uncertainty implies incomplete theoretical knowledge of the list of possible outcomes and therefore prevents agents from computing any probability distribution of future contingencies and from knowing future pay-offs. The outcome cannot be predicted as it represents a novelty for the decision-makers. Since substantive uncertainty refers to a situation that may change in an unexpected manner, it is independent of personal abilities to process information. An endogenous creation of a novelty causes incomplete theoretical knowledge in that a party may be surprised by unexpected actions of other agents. Indeterminacy of outcomes is linked to interdependence and subjective reaction based on individual interpretation of private information.[11]

Innovative activity not only creates radical uncertainty, but it also requires radical uncertainty since the absence of knowledge gives "freedom for imagination and conjecture". In other words, uncertainty is a precondition for innovation (Shackle, 1972, p. 18; Loasby, 2010, p. 1302; 2011, p. 774).

Learning and the "process of creation of new processes" are not considered in the analysis of the relations between inputs and outputs, since knowledge is assumed as given and unchanging. In this context, changes in techniques do not involve changes in productive knowledge because they do not take place in historical time, but in a logical time in which it is possible to move in either direction, as in space. Accordingly, the production possibility set is "a description of the state of the firm's knowledge about the possibilities of transforming commodities" (Arrow and

[9] See for instance, Morroni (1992, pp. 39–41, 96–79, 111–123, 166–169). In the same vein, Scazzieri (1993, pp. *vi*, 83–84) explicitly represents production as a network of tasks. On the assignment of tasks see also Landesmann (1986, pp. 288–289) and Autor (2013).

[10] On the entrepreneurial strategy and business conception, see Teece et al. (1997, p. 205), Cohendet et al. (2000, pp. 96–98, 106) and Witt (2000, p. 735). On the non-tradability of entrepreneurial judgement and conjectures see Knight (1921, pp. 211, 251).

[11] For the definition of substantive uncertainty see Dosi and Egidi (1991, pp. 183–185); cf. Morroni (2006a, pp. 61–70, 2006b, p. 47ff.). On genuine innovations which are characterised by a high degree of uncertainty, see Rosenberg (1996, p. 334) and Winter (2005, p. 235).

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Hahn, 1971, p. 53, quoted in Winter, 2005, p. 229). An analysis of "the process of creation of new processes" requires the consideration of historical time because this creation is made possible only thanks to the accumulation of experience that takes place over time. Moreover, in standard microeconomics, heterogeneity and scarcity of productive knowledge are ignored because it is necessarily assumed that knowledge is homogeneous, full and free, i.e. that production techniques are readily available to all firms. In other words, all agents must know all the viable input–output combinations that are available for the commodity that they wish to produce. The assumption that all commodities, apart from knowledge, are scarce is due to the fact that the hypothesis of scarcity of knowledge is not compatible either with partial equilibrium price theory or the Arrow-Debreu model, in which the market develops its own informative and self-regulatory role only if we assume that individuals are able to acquire or are already in possession of all the relevant information (cf. Stiglitz, 1989, p. 23; Egidi, 1992, p. 9; Loasby, 1999, pp. 72, 84; Levinthal, 2006, p. 391). Therefore radical uncertainty is incompatible with such a model. This explains Robert Lucas's declaration that "in cases of uncertainty, economic reasoning will be of no value" (Lucas, 1981, p. 224).

As far as the relationship between the flow–fund model and the cognitive perspective is concerned, there is a close link between the organisation of processes and the development of knowledge because the choice of organisational forms influences the generation of new knowledge, which results in the capabilities of the firm.

Unlike traditional microeconomic theory, both the flow–fund model and the cognitive perspective address processes which take place in historical time. Moreover, cognitive perspective assumes that knowledge could be tacit, local, non-tradable and heterogeneous across firms. These characteristics are incompatible with the assumptions made by traditional microeconomic theory, but they are not incompatible with the flow–fund model.

Interestingly, if we take into account the links between the three levels of analysis considered in this paper the upward levels are not incompatible with the analysis contained in the downward levels. In fact, the flow–fund model addresses the relationship between input and output (which is considered in the first level), while the third level of analysis is not incompatible with the analytical representation of production processes provided by the second level through the application of the flow–fund model. The creation of new processes greatly influences organisation settings and the time profile of production. However, cognitive perspectives have so far paid little attention to the second level of analysis regarding production process organisation. Sidney Winter has stressed this lacuna, arguing that: "the major investment in building a truly knowledge-based production theory [. . .] was never made" (2005, pp. 223–224). The flow–fund model can fill this gap. As we shall see in the following section, the flow–fund model can be useful in the investigation of the effects of innovative activities on the organisation of production processes.

The second and the third levels of analysis are also closely interdependent since the development path of a firm is characterised by the co-evolution of production settings and productive knowledge. This co-evolution consists of a continuous interaction between organisational changes, mutations in productive knowledge and technical innovations regarding equipment (cf. Endres and Harper, 2010, p. 11). Each given organisational setting and technique, which can be chosen by the firm, corresponds to a different stage of the development of abilities facilitating the use of specific machines and equipment. Any given pattern of production is associated with a particular arrangement of tasks and with the specific characteristics of the firm's capabilities. For instance, the adoption of Toyotism involved a major redefinition of the nature and distribution of productive and transactional knowledge (Coriat and Dosi, 1998, p. 114ff.; cf. Chandler, 1992, p. 84; Dosi et al., 2008, p. 1167).

Moreover, the actual operational scale depends on the technical and organisational knowledge that makes it possible to take advantage of the particular properties of production elements and processes. On the other hand, a re-organisation that involves an increase in the dimension of the scale of production processes entails a modification in the abilities and skills of some members of the firm, in accordance with the new tasks linked to the changed organisational structure (cf. Morroni, 2006a, pp. 177–188, 240ff.).

The co-evolution of a firm's capabilities and organisational settings may take on a wide variety of forms bringing about the development of a plurality of organisational solutions resulting from trial-and-error processes. Successful re-organisation processes may have radically different features. This variety of organisational settings and results is due to differing basic conditions and in particular to the heterogeneity of productive knowledge and the presence of radical uncertainty.

There is a two-way relationship between the division of labour and the firm's capabilities. On the one hand, the division of labour and the subsequent distribution of tasks are shaped according to the development of the firm's capabilities. On the other, a re-organisation of production processes and the assignment of tasks may cause a transformation of individual abilities and skills, leading to a modification of the firm's capabilities. In other words, problem-solving activity leads to modifications in the internal division of labour by breaking down complex problems recursively into sub-problems that can be solved more easily by different functional sub-systems of the firm (Egidi and Rizzello, 2003, p. 8; Loasby, 1998, p. 178). This splitting of activities into elementary operations may promote the creation of new abilities that influence the firm's capabilities. Therefore, in the former case division of knowledge precedes division of labour, while in the latter case division of labour drives division of knowledge (Becker et al., 2005, pp. 8–10).

5. Directions of further research

The analysis of the two-way relationship between the organisation of production processes and the development of capabilities is undoubtedly a promising line of enquiry. The flow–fund model could be a useful tool that can be implemented when looking into the effects of innovations on the organisation of production processes, task distributions and relative performance. This last section outlines possible directions of further research regarding the application of the flow–fund model to the investigation of innovative activities.

The analytical framework based on the application of the matrix of production could be utilised to this end. The matrix of production, which has been proposed in Morroni (1992: chapters 8 and 9; 1999, pp. 209–224), enables us to deal with interconnections between the different intermediate stages and to take into account the quantitative, temporal, organisational and dimensional aspects of production. This matrix can be transformed for empirical analysis into three separate tables: (i) the output table, indicating the characteristics of the product under consideration (technical and service characteristics, production time of the output flows, annual production, adaptability and level of utilisation of the plant); (ii) the process matrix, which includes prices, costs and the cumulative quantities of single production elements; and (iii) the organisational scheme that provides indications for dimensional, temporal and organisational aspects of the production unit (Morroni, 1992: chapters 8 and 9; 1999, pp. 209–224). This framework makes possible the standardisation of the data of the various elementary processes under consideration in order that a homogeneous database can be created. This can be used to make the comparisons required for empirical research. In other words, these three tables for empirical analysis are designed to transform information present in the theoretical model into numerical data, thus allowing for the comparison of data of single production processes in operation before and after the introduction of some technical or organisational innovation.

In investigating the economic effects of technical changes on production processes two lines of research can be followed: at the microeconomic level considering individual case studies, or at the aggregate level analysing a set of production units in different sectors of activity.

At the microeconomic level, a flow–fund model could be applied in order to collect a time series of data regarding the same production processes at successive moments. Comparing data concerning the same production unit at different times enables quantitative and qualitative input variations and differences in production times to be evaluated. In this way it may be possible to evaluate the effects of technical change at individual firm level on: margins and costs, input requirements, demand for labour, inventories, degree of utilisation of equipment, dimension of scale, adaptability, operational flexibility, and, more generally, the way of organising production.

At the aggregate level, by choosing a statistically representative sample of production units and processes one could analyse – through the flow–fund model – the evolution of different industrial sectors regarding not only variations in productivity, costs and profitability, but also organisation, production time, inventory management and degree of production flexibility. This data could then be used to study the effects of technical change on the demand for labour and the distribution of tasks.

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