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Manufacturing Agrarian Change. Inter-sectoral learning, agricultural production and technological capabilities

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Abstract
The aim of this essay is to investigate how industrial development, manufacturing in particular, has been contributing to agrarian change. In order to address this issue, it analyzes the technical bases and structural specificities ? i.e. time and scale constraints ? of agricultural production. Technical change in agriculture involves both improvements in organic transformation processes ? i.e. biological production ? and in the mechanical functions that have to be performed for obtaining a certain output ? i.e. agricultural work. The paper shows how in-farm technological capabilities building as well as inter-sectoral learning are necessary in order to acquire and adapt biological-chemical innovations and mechanical technologies. The analysis of agrarian technical change ? both in-farm learning and inter-sectoral learning ? is developed by integrating peasant studies with evolutionary approaches to economic development. The relationship between agrarian change and manufacturing development is highly context specific, thus comparative historical analysis is adopted in order to shed light on the abovementioned processes of learning. Building on the analysis of agriculture-manufacture interdependences and technological change, the paper concludes by stressing the need to rethink today?s agricultural policy agenda.

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Manufacturing Agrarian Change

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Introduction

The structural relations between agriculture and industry in the process of economic development is at the very root of development studies. Although some classical development economists like Arthur Lewis were aware of the strong interdependencies between industrialization and agricultural improvements, throughout the last century the debate has been dominated by the 'industry first' *versus* 'agriculture first' debate. The 'industrialisers' maintain that the ultimate road to modernization and independence for less developed countries (LDCs) is the one of structural change triggered by manufacturing development. Thus, agriculture is asked to contribute to industrialization in multiple ways such as by transferring agricultural surplus to industry, by supplying cheap food and labour and, finally, by supporting internal demand for domestically manufactured products. On the contrary, the 'agrarianists' support the comparative advantage argument according to which LDCs should specialize in exporting agricultural and primary commodities. Moreover, on the basis of efficiency and equity arguments agrarianists criticize industrialization for generating an *urban bias* that, in turn, would be responsible for increasing inequalities and decreasing rates of growth in LDCs. In spite of some minor updates, the recent influential *World Development Report 2008* has restated the Bank's 'agrarianist' perspective rooted in the 'neo-institutionalist' development view.

Apart from few exceptions, industrialisers and agrarianists frame the relation between agriculture and industry as a unidirectional one – i.e. going from agriculture to industry – instead of one of cumulative and circular interdependence. In the few cases in which intersectoral interedependencies are addressed, scholars have focused their attention to backward and forward linkages as broadly defined macro intersectoral relations. Although these contributions recognize how increasing agricultural productivity arises from adopting/adapting/applying in agriculture technological innovations intra or intersectorally developed, largely unexamined is the way in which these technological innovations can reconfigure *agricultural production*. In particular, what is missing is an attempt in the direction of understanding processes of inter-sectoral learning and in-farm learning.

The aim of this essay is to investigate how industrial development, manufacturing in particular, has been contributing to agrarian change. In order to address this issue, it analyzes the technical bases and structural specificities – i.e. time and scale constraints – of agricultural production. Technical change in agriculture involves both improvements in organic transformation processes – i.e. *biological production* – and in the mechanical functions that have to be performed for obtaining a certain output – i.e *agricultural work.* The paper shows how in-farm technological capability building as well as intersectoral learning are necessary in order to acquire and adapt biological-chemical innovations such as new seeds, fertilizers, pesticides and mechanical technologies such as agro-processing machines, tractors, water pumps. The analysis of agrarian technical change – both '*in-farm learning*' and '*inter-sectoral learning*' – is developed by integrating peasant studies with evolutionary approaches to economic development. This integration seems to be particularly promising in order to stress in today's revival of classical development economics the central role of agricultural-manufacturing synergies.

The relation between agrarian change and manufacturing development is highly context specific, thus comparative historical analysis is adopted in order to shed light on these processes of learning. Historically, countries develop agricultural technologies on the basis of their structural characteristics, both at the sectoral and intersectoral level, as well as by intentionally configuring interfaces between manufacture and agricultural sectors. Given a sustained process of industrialization, the development of agricultural technologies gradually becomes more complex and science-based. As a result, it moves away from the 'farm' to the 'firm' and to research agrarian institutes. Although on-farm testing, adaptation and evaluation of new technologies are still in need, agricultural machineries, especially those adopted by large scale farms, are manufactured in the industrial sector. Complementarities among different productive functions and technological innovations can be identified and exploited according to given structural constraints and organizational forms.

Building on the analysis of agriculture-manufacture interdependences and technological change, the paper concludes by stressing the need to rethink today's agricultural policy agenda.

1. Agrarianist versus industrializers: moving the debate ahead.

It is widely acknowledged that the development of a socio-economic system substantiates in a process of structural change, that is, a process of change of the sectoral composition of the economic system and underlying transformation of its productive structures and demand composition (Deane and Cole, 1969; Kuznets, 1973; Pasinetti, 1981; Scazzieri, 2009). In this connection, increasing consumer, technological and social capabilities result to be the main drivers of the process of development and, thus, of *sectoral transition* (Myrdal, 1958; Abramovitz, 1989; Lall, 1992). At both the intra and intersectoral level, consumers' capabilities and producers' capabilities interact in a circular and cumulative process of mutual reinforcement in which the introduction of new technologies leads to new productive activities and opportunities of consumption that, in turn, spurs on new technological innovations. Thus, capabilities' dynamics are the ultimate responsible for the process of sectoral transition from agriculture to industries and services.

The very circular and cumulative nature of these causational dynamics led Nicholas Kaldor (1969) to analyze the role played by effective demand (in particular the quality and the composition of external and domestic demand as well as the reciprocal demand at the inter-sectoral level) in activating an evolving structure of sectoral productions and the exploitation of increasing returns, external economies and productive/technological complementarities. Gunnar Myrdal (1958), on the other side, focused on the role played by 'non economic factors', namely institutional, cultural and ideological in leading a country towards a virtuous or vicious circle of cumulative development or underdevelopment. At the core of Myrdal's theory, it is suggested that different endowments of what Abramovitz (1989) defined 'social capabilities' can strongly affect the speed, depth and sustainability of a process of structural change and thus, of sectoral transition.

As sectoral transition constitutes the structural basis of the development process, it does not come as a surprise if during the last century the development studies debate has centred on the process of transition from an agricultural based economy to an industrialized one – i.e. industrialization – and, more recently, to a service based economy – i.e. servitization. Two main contrary visions promoted respectively by 'industrializers' and 'agrarianists' have dominated the debate

(Bernstein and Byres, 2001). Their visions with respect to the role of agriculture in the process of economic development, as well as the timing and models of industrialization, were influenced by the previous 'Soviet Industrialization debate'.

The first twenty years after the II WW witnessed the proliferation of many contributions in which, in various degrees, classical development economists supported the so called '*industry first'* argument (Toner, 1999; Kay 2009). The transfer of a large agricultural surplus was recognized as a necessary precursor for structural change and, thus, the agricultural sector was mainly treated as instrumental to industrialization (Johnston and Mellor, 1961). Mandelbaum's pioneering idea (1945) of transferring surplus of labour from less to more productive sectors was formally developed in the celebrated 'dual economy model' by Arthur Lewis (1954). According to this model, given unlimited supply of labour in the 'traditional' sector, the increasing employment of labour at subsistence wages in the technologically superior sector triggers in this latter 'modern' sector a process of capital accumulation and, thus, economic growth. The other fundamental theoretical contribution came from the 'un-balanced development model'. By embracing an intersectoral perspective, Albert Hirschman (1958) provides a strong rationale in favour of industrial development. In his model, each sector is linked with the rest of the economic system by its direct and indirect intermediate purchase of productive inputs and sales of productive outputs – i.e. backward and forward linkages. According to its system of linkages, each sector exercises on the rest of the economy push and pull forces. Unlike agriculture, the industrial sector is characterized by both strong backward and forward linkages and, thus, emerges as the main driver of development. Given these theoretical pillars, industrializers mainly focused on the relationship going 'from agriculture to industry', that is, in which ways was possible to extract surplus from agriculture to push industrial development.

After two decades of import-substituting-industrialization (ISI), around the mid 1960s, the agricultural sector in many countries started showing signs of suffering, production began to decrease and, as a result, critiques of the industrializers' position arose. Both neoclassical agrarianists such as Schultz (1964) and neopopulist agrarianists such as Lipton (1968; 1977) and the followers of Chayanov (1966; 1925 orig.) found a fertile ground for their ‘agriculture first’ argument. Agrarianists’ main point was that, as poverty has a rural face, development policies should prioritize this sector. Grounding their vision on the neoclassical theory of comparative advantage, they advocated LDCs to specialize on exporting primary commodities and raw materials and importing manufacturing goods from industrialized economies.

The strong contraposition, both theoretical and ideological, which have characterized the industrializers versus agrarianists debate has obscured what in a recent contribution Kay (2009) describes as a ‘synergy perspective’, that is, a perspective focused on the complex and dynamic synergic relationships linking the development of agriculture and industry sectors. An increasing attention for these intersectoral relationships and, thus, overcoming a unidirectional vision of structural change in favour to one in which development is perceived as a circular and cumulative process, seem to be promising ways to make the debate discussed above more productive.

2. The matrix of intersectoral interdependences

Between the two opposite dominating positions, reviewed above, a series of contributions have recognized the risks connected to a unidirectional understanding of the relationship between agriculture and industry (Kuznets 1964 and 1968; Martin, 1982; Hwa, 1989; Kay, 2009). As these studies have been showing, a focus on the way in which surplus is (i) generated in the agricultural sector, (ii) transferred to the industrial sector and (iii) used for fostering manufacturing production and technological innovation, cannot prescind from the consideration of a sustainability problem. Namely, how much and for how long the agricultural sector is able to nurture industrialization without any significant change of the production techniques adopted in agriculture. As a matter of fact, as perceived by Arthur Lewis (1958:433), ‘economies in which agriculture is stagnant do not show industrial development’. This sustainability problem, that is, guarantying sustained level of agricultural output, is especially critical in the early phases of development, when manufacturing growth is still strongly depended from agricultural surplus of labour and savings, supply of inputs for industrial processing and demand of manufactured goods. At more advanced stages of industrialization, the manufacturing sector tends to 'self-reproduce' itself while the intersectoral transfer of resources from agriculture to other sectors tends to be balanced and, finally, eventually reversed.

With respect to the sustainability problem, Kuznets (1964; 1968) observed how a self-sustained process of structural change requires technological advancements and, thus, increasing productivity, in industry *as well as* in agriculture. In his view, the shifting of the productive structure towards manufacturing and the redistribution of employment from agriculture to industry, more than being the causes of industrialization are the results of technological change (Vogel, 1994). This vision suggests how increasing productivity in the agricultural sector arises from 'manufacturing agrarian change', that is, by adopting/adapting/applying in the agricultural sector those technological innovations both intra or inter-sectorally developed[1].

Thus, the consideration of how much and how long agriculture can support industrialization, has to be complemented with the consideration of how much and in which ways industrialization can foster agrarian change. Precisely, if from one side, as argued by industrializers, industrialization requires extraction of resources from agriculture; on the other side, the same agricultural sector in order to support this process has to be 'technologically pushed' by the development of specific industries such as manufacturing, chemical and biotech. This observation directs our attention to the identification of a *focal interdependence* existing between agriculture and manufacturing, a relationship that can also be extended to services. This focal interdependence is a technological one. Precisely, it refers to the transformative power that an increasing technologically advanced manufacturing sector can have with respect to the agrarian sector.

The existence of a technological relationship going 'from industry to agriculture' was stressed by Kurt Martin (1982:7) who argued how 'resource outflows from agriculture' and 'rising agricultural productivity (…) can go together, provided that the productivity gains in agriculture do not themselves

[1] Interestingly the importance of technological advances in agriculture was also stressed by Kalecki (1976) who dedicated much attention to the existence of bottlenecks in the agricultural sector.

necessitate large-scale capital investment *within* agriculture', also adding that 'quite often they do not require that'. As documented in Mellor (1973:2) in a detailed comparison of Taiwan and India's development patterns, the specific condition described by Martin (1982) realizes exactly 'when technological change in agriculture sharply increases returns to investment in agriculture and consequently sharply reduces the capital-output ratios'.

Moreover, according to Martin (1982), the allocation of part of investable funds (coming in part from agricultural surplus) for the establishment of agro-industries in rural areas can stimulate agricultural progress in two main ways: firstly, by allowing a Lewis-type process of intersectoral transfer of labour, without urban migration; secondly, by creating industries whose production process is strongly interconnected to the agricultural one through strong backward and forward linkages (Martin, 1982). These linkages going 'from industry to agriculture' as well as 'from agriculture to industry' express what Hwa (1989:107) defined 'the relationship of interdependence and complementarity between agriculture and industry'.

Technological interdependences between agriculture and industries are structurally embedded in a bundle of intersectoral interdependencies characterized by multidirectional, circular and cumulative dynamics. A way to visualize these interdependences and, among them the technological ones, is to think of a *matrix of intersectoral interdepencies*, that is a matrix defined by both supply side and demand side linkages among different sectors[2]. Inside the matrix, although at different degrees, industries within the manufacturing sector are characterized comparatively by a higher density of interindustry and intersectoral forward and backward linkages (Hirschman, 1958). However, these intersectoral linkages are destined to change and 'vary according to the particular phase of the development process and as structural conditions and international circumstances change' (Kay, 2009:116). For example, it has been observed how, with the increase of productivity in agriculture, backward linkages between agriculture

[2] Different methodologies aimed to shed light on the matrix of intersectoral interdependencies have been developed over the years. Starting with Leontief's production matrix for input-output analysis, going through the social accounting matrix (SAM) and various econometric models such as the computable general equilibrium model (CGE).

and services have been expanding in magnitude and quality. Examples are post-harvest facilities such as transport, communication, information services for production control in agriculture, market services etc.

A part from these sectoral specificities and changes in historical time, any sectoral activity persistently affects the rest of the economy through both direct and indirect linkages which cumulate in successive rounds of intersectoral expansion of the productive matrix. This is the reason why, for example, Park and Chan (1989:211) showed how ‘the evolution of the intersectoral relationship between services and manufacturing in the course of development is symbiotic, in the sense that (…) structural change of the former is bound to affect that of the latter’. The existence of a ‘symbiotic’ evolution of intersectoral relationships between agriculture and manufacturing has found empirical support in various studies too. Interestingly, in the context of Malaysia, it has been shown how an expansion of manufacturing output, though associated with a contraction of agricultural output in the short run, is correlated with a process of agricultural expansion over the long run (Gemmell, et al. 2000). Moreover, experiences of highly industrialized countries such as Japan and U.S. in which a comparatively higher multiplier effect of the agricultural sector is registered, demonstrate how agro-based industries can effectively emerge from the increasing exploitation of intersectoral synergies and complementarities (Park and Chan, 1989 and Park 1989). In sum, these studies confirm the idea according to which structural change does not simply imply a process of *sectoral transition* but also one of *sectoral deepening*, that is, a technological transformation of production processes performed in each sector.

As a matter of fact, inventing new technologies, improving certain techniques, discovering complementarities with new or existing technologies, are all learning processes which result in the qualitative transformation of production processes. This is the reason why, as suggested by Nicholas Georgescu Roegen (1969), it is necessary to shed light on the peculiarities characterizing production processes in different sectors, manufacturing and agriculture. As it has been highlighted (Scazzieri, 1993; Landesmann and Scazzieri, 1996), the production process in manufacturing can be represented as a particular sequence of interrelated tasks through which transformations of materials are performed according to different patterns of capabilities coordination, subject to certain scale and time constraints. Few contributions in the economic literature, have systematically attempted to look ‘under the surface’ of agricultural production. An attempt in this direction should aim not only to the identification of structural specificities in agricultural production – i.e. constraints, bottlenecks and complementarities – but, also, to address the various mechanisms of intersectoral learning which are responsible for the massive increase in agricultural production in many regions of the world.

3. Looking ‘under the surface’: agricultural work, biological production and biological reproduction.

The fundamental structural feature of the agricultural sector is that its output results from three distinct, although interdependent, processes of production – i.e. agricultural work, biological production and biological reproduction. Each of these production processes, in which agricultural production has been analytically decomposed, are organized according to different rules/conditions – i.e. socio-economic, biological and environmental – and, thus, realizes according to different dynamics in ‘historical and seasonal’ time. The existence of structural interdependences among these processes generates constraints, but also opportunities for change.

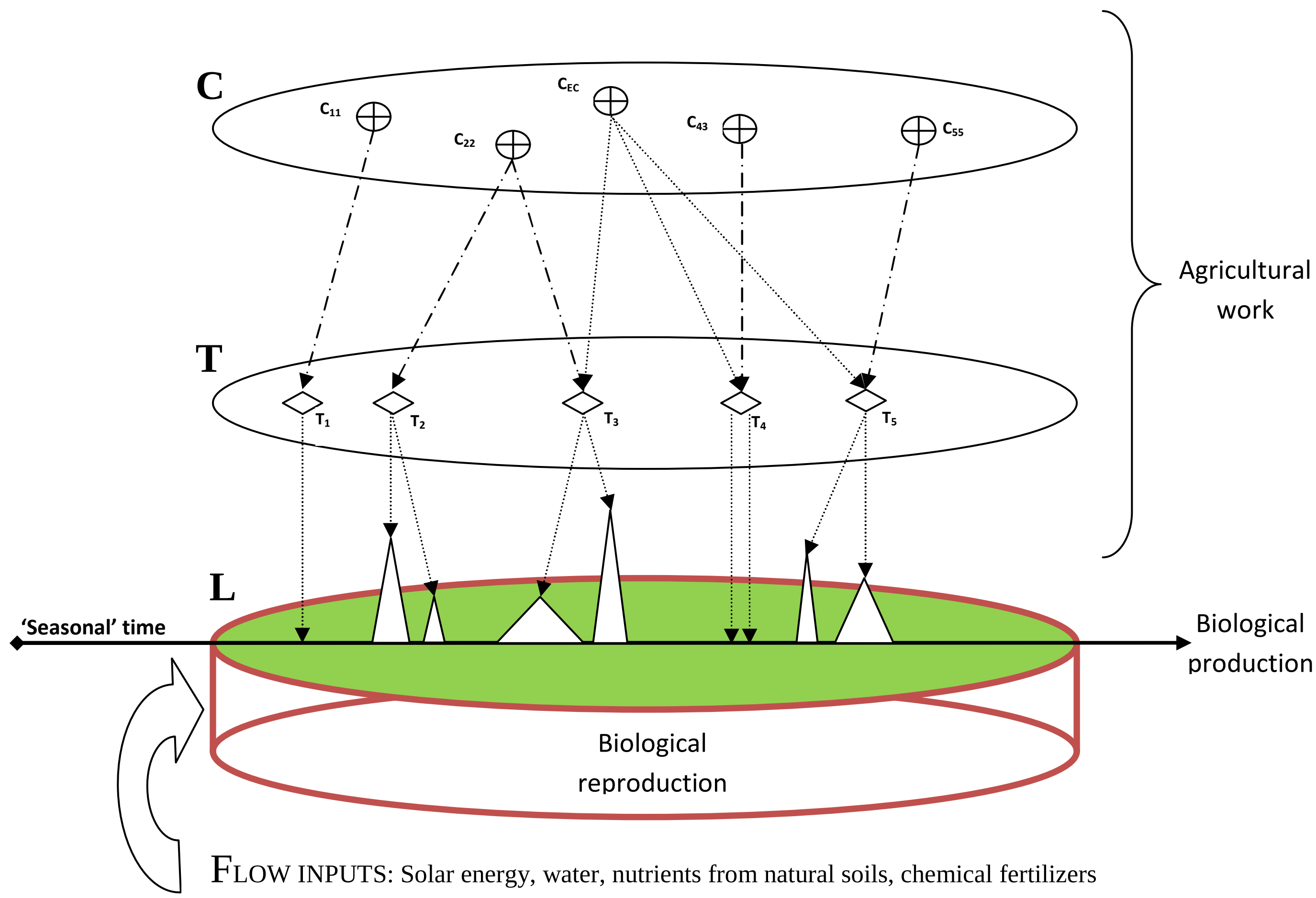
Agricultural work consists of a set of interrelated tasks such as plowing, planting, fertilizing, inspecting, harvesting, storing, transporting. Each of them is performed by coordinating productive capabilities embedded in workers and various ‘cooperating instruments’ such as animals, mechanical equipments and engines. The last ones complement and empower workers by (i) allowing the performance of particular tasks in specific ways – e.g. more accurately, with higher strength or intensity; (ii) allowing certain tasks to be executed at the same time; finally, (iii) increasing the speed of production operations or by reducing idle times (Georgescu Roegen, 1969). In one word, ‘cooperating instruments’ are aimed to increase the productivity of labour. Unlike manufacturing production where productive capabilities transform and recombine materials into goods, the agricultural work 'has only the task of creating the more suitable environment for the life of the cells (…) and of picking up the result of their work at the end' (Bolli and Scotton, 1987:19-20).

Biological production realizes in land and consists in a process of transformation of biological materials triggered and fostered at subsequent intervals by agricultural work. For land being able to perform a specific biological production process – i.e. the life of the cells –, agricultural work and flow inputs are both required. Specifically, land can be thought as a 'photosyntethic machine' whose working requires solar energy, water, carbon dioxide and other nutrients from natural soils – i.e. flow inputs. As land is part of an ecosystem, biological production 'can be controlled by human beings only partially because it consists of a sequence of operations whose *order*, *duration* and *respective distances* are significantly dependent on weather conditions' (Romagnoli, 1996:234). In turn, being biological production dependent on seasonality and affected by soil differences, agricultural work will be constrained in its tasks organizations by seasonal patterns – i.e. time constraint – and by the specific local conditions and geographical dispersion – i.e. space constraint. By relaxing these constraints through various social and bio-technological innovations it has been possible to increase the land productivity, that is, its biological production.

The last process in which agricultural production has been decomposed is the one of *biological reproduction*. This is a process which is necessary for restoring the land capacity to perform biological production. One of the most effective answer to these agronomic constraints has been the development of rotation schemes. It is revealing how the well known Norfolk four-year rotation scheme was introduced in England in the eighteenth century. The need to follow a particular time sequence of crops in the same plot of land in order to allow biological reproduction, introduces further time constraints in agricultural production. Historically, however, the introduction of a rotation scheme induced technological advances in agriculture techniques and tasks organization. Specifically, adopting rotation schemes with multicrop production not only allows to preserve land's fertility but also to: (i) diversify the climate risk of biological production; (ii) to distribute agricultural work during the year; (iii) to increase agricultural work by introducing ‘inserted crops’ and ‘associated crops’. The development of chemical industries and the massive production and utilization of fertilizers have allowed agricultural production to adopt free sequences and, thus, the possibility very often to specialize in mono crops.

The fact that agricultural production is characterized by multiple interdependencies among the three different production processes described above can be visualized as follows (see Figure 1). Given a certain amount of productive capabilities **C**, a system of interrelated tasks **T** will be organized in agricultural work according to the set of constraints imposed by biological production and reproduction in land **L**.

Figure 1: The analytical map of agricultural production



For any given amount of land **L**, the 'crop-growing technique'[3] is defined by:

(i) a certain combination of productive capabilities **C**

(ii) a set of interrelated tasks $\mathbf{T = [\ T_1; T_2; \ldots T_J \ldots; T_r]}$

(iii) a certain amount of flow inputs $\mathbf{F = [\ F_1; F_2; \ldots F_J \ldots; F_m]}$

A way to represent for each 'crop-growing technique' the set of productive capabilities is to consider a matrix $\mathbf{C = [c_{ij}]}$ in which any element $\mathbf{c_{ij}}$ denotes the relationship between the productive capability **i** and the task $\mathbf{T_j}$.

$$\mathbf{C} = \begin{bmatrix} \mathbf{c_{11}} & & & & \\ & \cdots & & & \\ & & \mathbf{c_{ij}} & & \\ & & & \cdots & \\ & & & & \mathbf{c_{qr}} \end{bmatrix}$$

[3] The concept of 'crop-growing technique' is inspired by Romagnoli (1996).

‘Crop-growing techniques’ are by definition context-dependent. Causes for that are that no land has the same biological capacity to produce; environmental conditions are different; finally, different socio-cultural and economic contexts determine in different ways if a certain task is going to be performed by exploiting the productive capabilities embedded in one factor or another – e.g. labour, animals, machines (see below).

Starting from the ‘analytical map of agricultural production’ proposed above (Figure 1), a series of fundamental issues can be visualized. In particular, the relationships between productive capabilities and tasks with respect to biological production; problems related to the scale and timing of agricultural production; finally, different organizational forms and combinations of productive capabilities.

Scale of production and agricultural mechanization

Given a certain ‘crop-growing technique’ the scale of agricultural production is determined by the extent of cultivated land. If the amount of flow inputs **F** such as water or fertilizers can be determined simply by multiplying the unit amount of **F** for the land extension – i.e *divisible inputs* – other fund inputs and, in turn, tasks performed by them, are not scale invariant. Fund inputs, such as tractors, water pumps, mechanical equipments are *indivisible inputs*. This implies that having access to their productive capabilities requires an initial investment which is affordable and economically reasonable only at a certain scale of individual farm production or by collective action among farmers. The same problem arises, also, with those flow inputs such as fertilizers, pesticides or high yield varieties (HYVs) that, in spite of being divisible inputs and, thus, scale neutral, are not easily adoptable in small production units. As critically stressed by Martin (1982:3) ‘even if this argument [scale neutrality of land-saving modern technologies] as applied to rice cultivation makes some technical sense, it is obvious that the new inputs of the Green Revolution call for financial resources beyond the reach of the poorer peasants’. This point stresses how, not only complementary services are necessary, but also how specific technological capabilities are in need for adopting new inputs – both divisible and indivisible – and to manage production/innovation related risks.

Scale is also strategically important for managing production/innovation related risks and for developing in-farm specific capabilities. As clearly stated by Sunding and Zilberman (2000:56), ‘one of the main advantages of large farming operations is their in-house capacity to handle repairs, breakdowns, and maintenance of equipment. That makes them less dependent on local dealers and repair shops, and reduces the risk of having to purchase (in many cases) new products’. In other words, overcoming certain scale thresholds may turn to be particularly important for enabling processes of in-farm learning and technological capabilities development. Mastering these latter capabilities becomes of greater importance with the mechanization of agriculture in modern agro-industries.

However, differently from the manufacturing sector, the utilization of machines in agriculture is limited by biological production in many ways. In particular, mechanical equipments can perform simultaneously only a very limited set of tasks, only those which are required in that specific moment of biological production. In spite of these limits in comparison to manufacturing, the introduction of machines clearly obliges/allows the farmer to change its ‘crop-growing technique’ and, thus, to rearrange agricultural work in time and space. Very often moving from a pure-labour production process to one in which machines are involved corresponds to a passage from a form of simple cooperation to one of *complex cooperation* (Scazzieri, 1993). If the first one is characterized by multi-tasks fund inputs, the second one implies a certain degree of specialization of certain productive capabilities in the execution of one specific task, or, specific set of strictly complementary tasks.

Arrangement of production in ‘seasonal time’.

Biological production impresses a ‘time-rigid’ structure to agricultural production. In particular, as biological production is performed by land in ‘seasonal time’ the entire process will be affected by seasonal bottlenecks. As a direct consequence of them, agricultural work in farms, contrary to the manufacturing process in firms, is characterized by a series of discontinuities and exogenous unexpected events.

As for the first issue – i.e. discontinuities in agricultural work, it is extremely important that productive capabilities as well as flow inputs are available in the right place and at the right time. As it has been stressed, ‘even though the available labor pool might be more than adequate to provide the required number of workers per hectare over an entire year for all the crops being grown, if certain tasks must be performed very quickly at specific times to ensure maximum yields, important labor bottlenecks might occur in the midst of an average surplus labour pool’(Timmer, 1988:295). Even when the right amount of productive capabilities is provided, the time setting of biological production allows tasks in agricultural work to be organized only in parallel, not in line as it would be possible in manufacturing production (Georgescu Roegen, 1969). In other words, there is a rigidity in the sequential ordering of tasks in agricultural work.

With respect to the second problem, that is, the existence of unexpected and uncontrollable events, farm organizations have to develop a high flexibility and responsiveness to situations such as shifts in climatic conditions or alterations in cropping patterns. In many regions, even one or two days of delay in harvesting may expose biological production to the risk of being destroyed by climatic change such as hail or pests. This situation may provoke direct value destruction as well as market prices variations up to 30% - 40% (Parker and Zilberman, 1993). The supply of pesticides or the utilization of modified seeds in the sowing time are the most evident modern measures adopted to prevent these unexpected and uncontrollable events.

From historical cases, we also know that another way adopted by farms to tackle these problems is to maintain a certain level of excess capacity. That is, to equip themselves with a certain amount of productive capabilities in excess for performing vital activities exactly when required ($C_{EC,}$ see Figure 1). In peasants communities, this excess capacity is provided collectively by developing institutional arrangements for mutual help in situations of emergency or breakdown of equipments. The need to cope with these and other specific structural characteristics of agricultural production is one of the factor that has to be taken in consideration when an analysis of peasant communities is attempted. An illuminating example is the study of the ‘anatomy of the peasant village’ by

Georgescu Roegen (1976: 206) in which the agricultural community – i.e. the village – is described as an organized and self-acting 'unit of production'. Other ways to assure the availability of productive capabilities in the right time and space, is to increase the scale of agricultural production (see the scale section above) or to develop in-farm technological capabilities which increase the degree of flexibility in the crop growing techniques adopted (see below).

In-farm learning and technological capabilities development

Martin Bell (1982) distinguishes two kinds of a *firm*'s fundamental resources: those needed to 'operate' existing production systems – i.e. productive capabilities – and those needed to 'restore / adapt / improve / change' production systems – i.e. technological capabilities[4]. As in manufacturing, also in agriculture in-farm learning processes and technological capabilities development are triggered by the need to respond to multiple constraints and bottlenecks in production – i.e. *endogenous dynamic* – or by intrasectoral transfer of technologies and organizational models – i.e. *exogenous dynamic*. Even in the latter case, that is, of innovation coming from outside the farm gate, a certain level of basic technological capabilities have to be present inside the farm if it wants to adopt and apply to its specific context a new agricultural technology, such as a mechanical equipment or a chemical fertilizer.

The reason why farm have to be equipped with not only productive but also technological capabilities is related to two main issues: firstly, the fact that 'there is a tendency for agricultural technology to become location-specific' and, secondly, the fact that the 'direct transfer [of agricultural technologies] is limited within a small area of similar environmental conditions' (Hayami, 1974:131). The existence of highly contextual interdependences between agricultural work and biological production/re-production has profound consequences among which the impossibility to fully standardize the production process or the need to continuous adaptation, monitoring and improvements after each seasonal cycle. In other words, as stressed by Clark (2001:11) 'in terms of the production and dissemination of usable knowledge, it is on the whole much more difficult to develop generic technology with universal applicability that is the case with

[4] See also, Lall, 1992; Bell and Pavitt, 1995; Romijin,1999; Dosi et al. 2000.

industry'. Given some of these factors, technological change in agriculture can be even more complex than in manufacturing, thus, developing technological capabilities can be even more important (Biggs and Clay, 1981).

Both productive and technological capabilities may be characterized by different degrees of effectiveness and their development is cumulative in the sense that 'the acquisition of certain kinds of know-how facilitates the acquisition of further knowledge of the same kind, and impedes the acquisition of knowledge of incompatible kinds' (Loasby 1999:58). Technological capabilities inside the farm emerge and accumulate through a continuous process of trial and error, testing of different 'crop-growing techniques', on the basis of an experimental and pragmatic approach to the solutions of problems. This articulated process is what we have called *in-farm learning*.

However, as many flow inputs – e.g. fertilizers, pesticides, HYVs – and fund inputs – e.g. mechanical equipments, electrical water pumps, tractors – adopted in modern agricultural production are supplied by the manufacturing and other industrial sectors – namely, the chemical, biotech, bioinformatic, nanotech and ICT industries (FAO and UNIDO, 2009) – the process of technological capabilities development in the agricultural sector is increasingly expected to result from inter-sectoral interactions. Thus, understanding agrarian change requires a specific focus on three main dynamic processes of learning: (i) a process of capability building at the farm level; (ii) a process of technology transfer at the intrasectoral level; finally, (iii) a process of technological change at the intersectoral level. In-farm learning and intersectoral learning presuppose specific technological efforts and can be triggered only by adopting specific institutional tools and policy measures.

As some contributions have shown (Ruttan and Hayami, 1973; Rosenberg, 1969 and 1979; Chang, 2002, 2009a), in order to capture the qualitative transformations and dynamics underlying processes of in-farm learning and intersectoral learning, historical analysis can provide an invaluable support. The adoption of an analytical approach to economic history can be a vehicle for developing a 'quasi-theory', that is, a stylized representation of economic facts through which theories and, more importantly, effective policy measures can be developed.

4. *Intersectoral learning*: technological capabilities building in agriculture

Since the ‘First Green Revolution’, dated by van Zanden (1991) in the period 1870-1914, throughout the last century, the agricultural sector has undergone a tremendous process of technological and organizational change. Although not homogenously, many countries have experienced a massive increase in productivity as a result of significant changes in ‘crop-growing techniques’, commercialization models and productive/technological capabilities building. Different patterns have been followed which focus on mechanical (tractors, combines, equipments), biological (new seeds varieties), chemical (fertilizers and pesticides), agronomic (new management practices), biotechnological and informational innovations (Sunding and Zilberman, 2000).

The influential ‘theory of induced innovation’ (IIT) proposed by Hayami and Ruttan (1970; 1971; 1985), argues that the process of transformation of the agricultural sector has been led by ‘continuous sequence of induced innovations in agricultural technology biased towards saving the limiting factors’ (Hayami and Ruttan, 1970:1115). Specifically, according to them ‘changes in input mixes represent a process of dynamic factor substitution accompanying changes in the production surface induced by the changes in relative factor prices’ (Hayami and Ruttan, 1970:1135). This theory has been tested empirically by comparing the process of agricultural development in Japan and U.S. in the period 1880 – 1960 (Hayami and Ruttan, 1970), finding also support in other historical/empirical contributions (Binswanger and McIntire, 1987; van Zanden, 1991).

Clearly, factor-supply conditions – i.e. scarcity of one or more factors – as well as economic opportunities are important inducing factors, as they create a potential demand for new technologies – e.g. land-saving or labour-saving. However, they are not sufficient conditions. For understanding why, it is necessary to investigate the role that technological complementarities and technological capabilities play in agrarian change dynamics.

Complementarities, Structural learning and Intersectoral learning

As stressed by Rosenberg (1979:26-27) in his analysis of technological interdependence in the American economy ‘inventions hardly even function in isolation'; instead they 'depend upon one another and interact with one another in ways which are not apparent'. As a result, the productivity of one technology or organizational innovation depends on the availability of complementary innovations. Complementarities, in particular, have historically resulted in being crucial focusing devices in the process of choice and exploration of new techniques (Rosenberg, 1969; Richardson, 1972). Recognizing complementarities as focusing devices means to investigate how '[c]omplex technologies create internal compulsions and pressures which, in turn, initiate exploratory activity in particular directions' (Rosenberg, 1969:4). Rosenberg (1969) identifies three main inducement mechanisms, namely technical imbalances or bottlenecks, labour-saving/uncertainty-reducing machines, substitutes or alternative sources of supply.

A pervasive element of '*grounded virtuality*' characterizes this approach. The virtual component results from the fact that the coordination problems in the space of productive agents, materials and tasks can be solved in multiple, although interdependent, ways. In other words, as stressed by Salais and Storper (1997), there are 'worlds of production' – i.e. a variety of production programmes. Thus, 'worlds of possibilities' are open for transforming production and its outcomes – i.e. process and product innovations (Sabel and Zeitlin, 1997). This statement does not want to underestimate the fact that these possibilities – i.e. feasible organizational and technological arrangements – have to be known to be exploited and that the existence of indivisibilities, bottlenecks, technical imbalances, complementarities, materials/biological characteristics are pervasive constraints. On the contrary, it does stress how discovering these possibilities, given certain structural constraints, is the very essence of a fully endogenous process of learning.

The concept of structural learning in agricultural production is introduced here to identify a continuous process of structural adjustment triggered by the need to overcome indivisibilities, bottlenecks, technical imbalances, as well as the possibility to exploit new complementarities[5]. Constraints as well as opportunities, all rise from the necessary coordination of the three interdependent processes in which agricultural production has been decomposed – i.e.

[5] See Andreoni, 2010 for an analytical discussion of the concept of structural learning in manufacturing.

agricultural work, biological production and reproduction. Many stylized facts in the history of agrarian change would support the existence of these processes of learning in the agricultural sector.

For example, the introduction in California of a new harvesting technique was accompanied by the need to introduce a new complementary tomato variety (de Janvry, LeVeen and Rusten, 1981). Another documented case can be found in the Punjab region, where during the 'Green revolution' farmers realized how the full exploitation of new HYVs was constrained by irrigation and fertilization practices. The intensification of the latter, in turn, induced farmers as well as providers of 'extention services' to focus their attention towards the discovery of more adequate 'crop-growing techniques' and the introduction of new organizational forms (McGuirk and Mundlak, 1991). This latter issue – i.e. the redefinition of organizational forms – typically emerges every time farmers have to coordinate themselves in the building of common infrastructures such as roads and canals. '[B]ecause of their network nature' and 'public good character' (Chang, 2009a:499) these projects require institutional engineering and innovative organizational design.

A final example of structural learning can be found in the early nineteenth century US agricultural sector. Before tractors were introduced thanks to the strong 'push' provided by the manufacturing sector, John Deere, a farmer from the Illinois, invented the steel plow. A 'biological constraint' was at the very basis of this innovation, as well as a series of complementary ones. Traditional wood plows could not plow the rich soil of the Middle-West without breaking. At that time given the scarcity of steel and the need to import it from Great Britain, John Deere made his first plow out of an old blade saw. After a series of tests on different types of soil, the new steel plow was ready to be absorbed into the 'crop-growing technique' adopted at that time. In turn, the introduction of the steel plow triggered new complementary discoveries. As recognized by Rosenberg (1979:37) 'the substitution of new materials (e.g. aluminium and rust-resistant steels) for old ones, improved techniques of friction reduction (lubrication and roller bearings) have led to a considerable extension of the useful life of a wide range of capital equipment' as well as to other 'cumulative improvements'. The John Deere Company was able to internalize this process of learning and qualitative improvement of mechanical tools by establishing its own research and development infrastructure. As a result, it became the world's leading manufacturing *firm* of innovative mechanical equipments (Sunding and Zilberman, 2000).

As this last case has shown, the process of structural learning in the agricultural sector has gradually developed an intersectoral character, that is, it has moved 'from the farm to the firm' and other science-based organizations. As a result, technological complementarities have spread from one sector –i.e. intrasectoral complementarities – to the space of intersectoral interdependences – i.e. intersectoral complementarities.

In this respect, there is strong historical evidence that the emergence of technical and organizational innovations in agriculture has been triggered by the expansion of metallurgic, mechanical, biotechnological and energy industries (van Zanden, 1991; Olmstead and Rhode, 1993). Innovations in power generation and, in turn, in cost transportation have been identified by Rosenberg (1979) among the main drivers of increasing productivity in American agriculture. A series of possibilities were opened. Firstly, 'to engage in a greater degree of regional specialization [by] devoting heterogenous agricultural resources to their best uses'; secondly, 'to concentrate output in a smaller number of more efficient units' (1979:27); finally, to develop 'a truly world-wide agricultural division of labour (…) as a result of refrigeration techniques' (1979:28). Moreover, 'the introduction of techniques for the mechanical harvesting of crops has been sharply accelerated by the advances in genetic knowledge which permit a redesigning of the plant itself to accommodate the specific needs of machine hundling' (Rosenberg, 1979:31). These examples show how, not only an innovation arising from one industry may reduce the cost in the receiving industry, but also how it does open to a series of opportunities for change, in products and processes.

By stressing the contribution that manufacturing development has given to agrarian change, these examples seems to suggest a relationship of unbalanced interdependence among sectors. However, even today, when basically all fund factors adopted in agriculture are produced in other industries – e.g. manufacturing, chemical, biotech, ICT – the great variability and unpredictability of biological production implies that field experience and small adjustments/improvements on the field are still very important in inspiring innovations. In other words, a relationship of intersectoral interdepence based on an interactive process of learning is at work.

Intersectoral learning can be defined as a dynamic process of interlocking and mutual reinforcing technological development which links the innovative patterns of two or more sectors in a relationship of complementarity. As a result of this process ‘many of the benefits of increased productivity flowing from an innovation are captured in industries *other* than the one in which the innovation was made’ (Rosenberg, 1979:41). Interestingly, the suggestive idea of ‘innovation by invasion’ among and across sectors proposed by Little (1963) finds in the concept of ‘intersectoral learning’ its analytical and structural ground.

The process of intersectoral learning described above can link the agricultural sector to the manufacturing one, but also the agricultural sector to the service industry. Going back to our case study ‘many of the marketing strategies, including warranties, money-back guarantees (…) were introduced by agricultural firms including John Deere’ (Sunding and Zilberman, 2000:59). This is because the design of services such as credit schemes or assurances requires a profound understanding of the structural features of agricultural production, its ‘seasonal timing’ as well as its constraints, bottlenecks and risks. With this respect, rural banks and cooperative banks have traditionally shown a particular capacity to deal with the specific needs of agricultural production. This is one of the main factor which explains their success in promoting ‘productive development’ in rural communities (Andreoni and Pelligra, 2009).

With the blurring of intersectoral interfaces and the increasing importance acquired by marketing and processing techniques in modern agriculture, new spaces for processes of intersectoral learning are emerging (FAO and UNIDO, 2009). In particular, as stressed by Chang (2009a:508) ‘relatively simple processing of agricultural raw materials can add significant value and in the process promote industrialization and overall economic development’. However, the development of agro-processing industries as well as the activation of processes of intersectoral learning are becoming increasingly dependent on the development and transferring of technological capabilities.

Technological capabilities building and technology transfer

Technology historians and development economists inspired by evolutionary approaches (Rosenberg, 1976, 1979; Lall, 1992; Romijin, 1999; Chang, 2002, 2009a) have shown how technological innovation does not come from providing the 'right' answer to the 'right incentive'. As stressed by Chang (2007b:8), 'giving producers the right incentives is not enough to make them more productive because they may not have the capabilities to productively use advanced technologies that ultimately lie at the heart of higher productivity'. This implies, for example, that even if the introduction of tractors in a labour-scarce country is consistent with IIT, without a manufacturing sector which is able to produce, adapt, repair and improve tractors, the agricultural sector will not be able to benefit from this labour-saving technology – i.e. the tractor.

Technology transfer has been one of the main drivers of agrarian change both during the 'first' green revolution' in the late nineteenth century (van Zanden, 1991) and the 'Green revolution' in the mid of the last century (Byerlee and Fischer, 2002; Chang, 2009). According to Hayami and Ruttan (1973), technology transfer realizes in three main phases. During the first one – i.e. material transfer – new seeds, plants, animals, machines are imported and utilized without any attempt to 'naturalize' them. As soon as adaptability problems become evident, farmers as well as public actors start to import blueprints, designs, formula and to decrypt the new 'crop-growing technique' – i.e. design phase. At the end of the process of technology transfer, that is, the phase of capacity transfer, farmers and public actors start attracting foreign experts, creating specific research institutions, adapting foreign technologies and, finally, experiencing processes of intersectoral learning.

The transfer of tractors from US to Russia and Japan is an interesting case for understanding that, firstly, countries can actually follow different patterns of technological capabilities building; secondly, that, as a result, they will benefit from foreign technologies in different ways. Since the 1920s Russia massively invested in introducing U.S. tractors (primarily *Fordson*) in agricultural production. The strategy followed was one of massive import of U.S. mechanical tools accompanied by a passive replication of foreign technologies. Lacking technological capabilities necessary for repairing and adapting the imported machines, during the 1920s tractors operated at a quite low level of efficiency. On the other side, Japan introduced U.S. tractors only on a experimental scale with the specific purpose of developing the necessary technological capabilities required for mastering mechanical tools. This allowed Japan to adapt U.S. mechanical technologies and to introduce 'mini-tractors' (less than 10 h.p.) which were more suitable to their context.

The historical comparative analysis of Russia and Japan, but also national case studies of small European countries such as Denmark or the Netherlands (Chang, 2009b) as well as case studies taken from the Green revolution's laboratory (Byerlee and Fischer, 2002; Kay, 2009), all suggest how technological capabilities development has been responsible for sustained processes of agrarian change. They also stress how the speed of technological adaptation and the benefits that technologies can generate strictly depends on efforts made by countries in developing technological capabilities. Specific public policies and institutional tools are required to allow endogenous processes of technological capabilities building as well as trigger processes of intersectoral learning.

5. Concluding remarks: rethinking the policy agenda

After two decades of neglect, the publication of the *Agriculture for Development* report by the World Bank (WDR, 2008) clearly reflects a renewed interest in agriculture and its role in the process of development. Although it is not explicitly acknowledged, the analytical framework underlying WB's policy recommendations is still very much grounded in the agrarianists' perspective and in the New Conventional Wisdom (Chang, 2009; Kay, 2009). Revealing are the first lines of the WDR (2008:1-2) where the two main pillars of these views are restated. Firstly, the idea that still today poverty has a rural face: 'three of every four poor people in developing countries live in rural areas'. Secondly, that agricultural development is a necessary, although not sufficient, condition for development: '[a]griculture alone will not be enough to massively reduce poverty, but it has proven uniquely powerful for that task'. Interestingly, it is added that '[u]sing agriculture as the basis for economic growth in agriculture-based countries requires a productivity revolution in smallholder farming'.

This last recommendation – i.e. to increase productivity – is also stated by other international organizations such as FAO, UNIDO and UNCTAD (see FAO and UNIDO, 2009; UNCTAD, 2009) which believe that technological innovations in agriculture is the only possible response to the ongoing substantial increase in global demand. However, how to achieve this increase in productivity is a controversial issue which calls for a political economy answer. As critically suggested by Woodhouse (2009), among the others the *Agriculture for Development* agenda presents two strong internal tensions.

First of all, although the agricultural sector is positioned at the centre of the development strategy, the way in which it can interact with other sectors in a process of circular and cumulative transformation is not considered. Instead of focusing on the identification of focal interdependences in the matrix of intersectoral relationships, '[t]he central question remains what agriculture can do for development. The question of what industry can do for agriculture is largely forgotten' (Kay, 2009:128). A unidirectional model of development is preferred to one in which structural change arises from a circular and cumulative process of increasing systemic capabilities.

Secondly, if from one side the WBR (2008) recognizes the pervasiveness of market failures in 'agriculture-based' economies – e.g. access to credit, flow inputs such as fertilizers and HYV, various technologies – on the other side, it assumes that solutions to inefficient market allocations has to be found in 'other markets'. The possibility that states can play a 'developmental' role is not recognized, although the history of today's developed countries (as well as the international experience of the Green Revolution) testify the effectiveness of selective public policies in fostering agrarian change (Chang, 2002 and 2009a). Public interventions such as subsidized fertilizers, tariff protection, artificially cheap credit and prices control, are all considered as 'distorting factors'. However, as stressed by Chang (2009a:480) 'if markets are not working well, distorting the prices that prevail may be a good thing, if that is done for the right purpose'.

The identification of the *right purpose*, and more importantly understanding *how* to achieve that, can widely benefit from opening the black box of agricultural production and focusing on intersectoral dynamics. The possibility to influence and direct these structural dynamics through selective policies is mainly in governments' hands. According to Chang's definition (1994:60) industrial policies are policies 'aimed at particular industries (and firms as their components) to achieve the outcomes that are perceived by the state to be efficient for the economy as a whole'. Together with an increasing reaffirmation of the role of ' selective industrial policies' (Chang and Lin, 2009; Cimoli, Dosi and Stiglitz, 2009), in line with others, this paper argues that agriculture needs a new set of 'selective agricultural policies'. These latter, named here *transformative policies* has to start from a 'contextualized' identification of the channels through which an increase in agricultural productivity may realize. The process of intersectoral learning for example can be facilitated and triggered by designing a whole range of public institutions and organizations for the provision of innovative 'extension services'. The future of a productive agrarian sector is not only in the hands of the wise farmer, but also in those of innovative manufacturers and imaginative politicians.

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