GLOBALIZATION LOCALIZED TECHNOLOGICAL CHANGE AND THE KNOWLEDGE ECONOMY[1]

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ABSTRACT. This work elaborates a dynamic version of the H-O model based upon the hypothesis that technological change is endogenous and biased towards the most intensive use of production factors that are locally most abundant in comparative terms. In the standard H-O model, the difference in the levels of the output elasticity of inputs is assumed to be exogenous. This approach rests upon the Schumpeterian notion of innovation as the result of the creative reaction where firms caught in out-of-equilibrium conditions by the changing conditions of both factor and product markets try and react by means of the introduction of biased technological changes directed towards the most intensive use of inputs that are locally most abundant in relative terms. The actual introduction of technological innovations, however, will depend upon the availability of appropriate knowledge externalities. According to this framework, countries exposed the out-of-equilibrium conditions engendered by globalization with the introduction of the technology production function that makes intensive use of technological knowledge as the most abundant input. Technological knowledge in fact is characterized by its strong collective and systemic character that limits its dissemination and use outside its context of origin.

KEY WORDS: LOCALIZED TECHNOLOGICAL CHANGE; LOCALIZED TECHNOLOGICAL KNOWLEDGE; DYNAMIC HECKSHER-OHLIN MODEL.

JEL CODES: O33, F12, F43

1. INTRODUCTION

This paper elaborates a dynamic version of the Hecksher-Ohlin (H-O) model of international trade based on the notion of localized technological change. Recent advances in the economics of knowledge have made it possible to understand technological knowledge as a collective activity with strong systemic characteristics. Technological knowledge, in fact, is neither a pure private good nor a pure public good. Its appropriability is indeed limited, but it does not spill freely in the atmosphere.

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Dedicated and intentional efforts and interactions between producers and users are necessary to use it again as external knowledge into the generation of new knowledge. The new understanding of technological knowledge as a collective and localized activity that is both an output and an input contrasts the basic assumptions of the extensions of the new growth theory to international trade based upon the free flow and imitation of technological knowledge by industrializing countries. The rest of the paper is organized as it follows. Section 2 summarizes the foundations of the localized technological approach. Section 3 elaborates its application to the H-O model of international trade. The conclusions summarize the main results.

2. LOCALIZED TECHNOLOGICAL CHANGE

2.1 THE NEW ECONOMICS OF KNOWLEDGE

The new economics of knowledge is the result of a sequence of major theoretical steps initiated with the path breaking analysis of Kenneth Arrow and Richard Nelson of technological knowledge as an economic good. This first attempt made it possible to highlight its intrinsic limitations in terms of non-appropriability, non-divisibility, cumulability and complementarity and the consequent incentives mismatch, market failure and ensuing undersupply, (Arrow, 1969; Nelson, 1956).

A second step has bee marked by Zvi Griliches (1979, 1992) who brought about a major discontinuity with the identification of the positive effects of non-appropriability, in terms of technological spillovers. Other firms can take advantage of the non-appropriability of technological knowledge.

The contributions of Griliches paved the way to the new growth theory where technological knowledge spilling from one firm in the atmosphere contributes the technological advance of other firms. In this approach external technological knowledge has been viewed as an augmenting and facilitating factor in the introduction of technological innovations. Such a role has taken the form of a 'technological' externality, that is an unpaid production factor that enters freely into the production function of other firms. The extensions of the new growth theory to international economics impinge upon this second phase, technological knowledge is regarded as if it were perfectly codified with no need for learning efforts for perspective users. Technological knowledge is expected to spill freely across international markets and industrializing countries can imitate it with no costs (Grossman and Helpman, 1991; Long and Wong, 1997).

The foundations of the new growth theory approach to the economics of international trade became obsolete since it has been understood that technological knowledge has a strong tacit and sticky content that makes it very difficult to identify, learn about and use it without major efforts and the actual interaction between users and the original possessors and inventors (Coe and Helpman, 1995; David, 1993).

Because of its strong and irreducible tacit component technological knowledge is inherently sticky as it is embedded in the mind of inventors as well as in the protocols, procedures and routines of the organizations where it has been generated (Von Hippel, 1988 and 2005).

The new understanding about the relevance of the tacit and sticky component and the major learning efforts that are necessary to use the knowledge that is not fully appropriated by the possessor, makes clear that external technological knowledge is not a pure public good that spills freely in the atmosphere. In order to use it again relevant search, screening, identification, learning, absorption, and assimilation costs should be taken into account (Cohen and Levinthal, 1989 and 1990).

Most importantly systematic and structured interactions between users and possessors are necessary to use tacit and sticky knowledge again as an input into the generation of new knowledge. The notion of generative interactions plays a central role in this approach (Lane and Maxfield, 1997). The amount of knowledge externalities and workable interactions available to each firm influences their capability to generate new technological knowledge. When the access conditions to the local pools of knowledge make possible the actual generation of new technological knowledge and feed the introduction of innovations, actual gales of technological change may emerge. The easier is the access to the local pools of knowledge and the larger is the amount of knowledge that firms can generate (Page, 2011).

Proximity plays a central role in this context. Geographical proximity helps knowledge interactions to take place and to make them effective. Proximity and agglomeration help implementing the working of the personal networks that support knowledge interactions. Distance hinders knowledge interactions that need to take place along time and require repeated occurrences to be established (Antonelli, 2011).

Firms can exploit external knowledge only locally through the accurate planning of a strategy aimed at acquiring bits of knowledge that are complementary to their own competences. In this perspective external knowledge, as a necessary input into the generation of new technological knowledge is acquired at costs that include a variety of efforts and dedicated activities such as the screening, identification, interaction and purchase, and eventual absorption. Such costs increase with distance and across economic systems. According to the structural conditions of the system into which firms are embedded, the actual access to external knowledge differs. The availability of low cost external knowledge reflects the quality of the governance mechanisms and of the levels of knowledge connectivity of the system into which firms are localized (Nelson, 1982 and 1993; Adams, 1990Antonelli, 2013a).

In the new economics of knowledge internal knowledge and external knowledge are two complementary and indispensable inputs into the recombinant generation of knowledge as an output (Weitzman, 1996 and 1998). Technological knowledge is intrinsically localized into the system. The actual amount of knowledge that can be generated by each agent and by the system at large is strongly influenced by the structural characteristics of the system into which firms are embedded. Technological knowledge is inherently rooted in the system into which firms are based because it is localized in the network structure that shapes the knowledge interactions (Antonelli, 2011).

2.2. INNOVATION AS AN EMERGING PROPERTY OF THE ECONOMIC SYSTEM

The new understanding of technological knowledge as a collective and localized activity makes it possible to reconsider the Schumpeterian notion of innovation as a creative reaction that can take place in a system where technological knowledge is the result of the active participation and interaction of a myriad of –tentative- innovators.

Following Schumpeter[2] (1947) firms try and activate the knowledge production function when un-expected events take place in product and factor markets in order to face them by means of the introduction of technological and organizational innovations. The eventual reaction of firms to the changing condition of their economic environment can be either adaptive or creative. Reaction can be simply adaptive and consist just in

[2] Schumpeter (1947) is very little cited in the literature. It seems that after a period of great consensus it disappeared from the cone light of scholars' attention. For this reason the following –long- quote of a key period seems appropriate: "What has not been adequately appreciated among theorists is the distinction between different kinds of reaction to changes in 'condition'. Whenever an economy or a sector of an economy adapts itself to a change in its data in the way that traditional theory describes, whenever, that is, an economy reacts to an increase in population by simply adding the new brains and hands to the working force in the existing employment, or an industry reacts to a protective duty by the expansion within its existing practice, we may speak of the development as an *adaptive response*. And whenever the economy or an industry or some firms in an industry do something else, something that is outside of the range of existing practice, we may speak of *creative response*. Creative response has at least three essential characteristics. First, from the standpoint of the observer who is in full possession of all relevant facts, it can always be understood *ex post*; but it can be practically never be understood *ex ante*; that is to say, it cannot be predicted by applying the ordinary rules of inference from the pre-existing facts. This is why the 'how' in what has been called the 'mechanisms' must be investigated in each case. Secondly, creative response shapes the whole course of subsequent events and their 'long-run' outcome. It is not true that both types of responses dominate only what the economist loves to call 'transitions', leaving the ultimate outcome to be determined by the initial data. Creative response changes social and economic situations for good, or, to put it differently, it creates situations from which there is no bridge to those situations that might have emerged in the absence. This is why creative response is an essential element in the historical process; no deterministic credo avails against this. Thirdly, creative response –the frequency of its occurrence in a group, its intensity and success or failure- has obviously something, be that much or little, to do (a) with quality of the personnel available in a society, (b) with relative quality of personnel, that is, with quality available to a particular field of activity relative to the quality available, at the same time, to others, and (c) with individual decisions, actions, and patterns of behavior." (Schumpeter, 1947:149-150).

traditional price/quantity technical (as opposed to technological) adjustments when firms are not able to generate appropriate amount of new technological knowledge and cannot actually innovate. For given levels of internal efforts, appropriate structural and institutional characteristics of the system qualify the reaction of firms and make it actually creative favoring the introduction of productivity enhancing innovations. Innovations are the result of the creative reaction of firms that emerge when external knowledge is actually available at low costs.

The amount of knowledge externalities and interactions available to each firm influences their capability to generate new technological knowledge. Hence the actual possibility to make their reaction adaptive as opposed to creative and able to introduce localized technological changes The larger the number of firms that react and the better the access conditions to external knowledge and the stronger are the chances that their reaction are creative: technological change becomes a generalized and collective process (Arthur, 1990, 1994 and 2009).

The organization of the system plays a key role as it shapes the access to external knowledge. When the role of the external context is properly appreciated, it becomes clear that innovation is not only the result of the intentional action of each individual agent, but it is also the endogenous product of dynamics of the system. The organization of the system in terms of access conditions to the external pool of technological knowledge is the crucial and complementary ingredient, together with the quality and intensity of internal research efforts that explain the emergence of innovations (Lane, 2009).

Agents succeed in their creative reactions when a number of contingent external conditions apply at the system level. Innovation is the result of the collective economic action of agents: innovation is a path dependent, collective process that takes place in a localized context, if, when and where a sufficient number of creative reactions are made in a coherent, complementary and consistent way. As such innovation is one of the key emergent properties of an economic system that takes place when complexity is 'organized', i.e. when a number of complementary conditions enable the creative reaction of agents and makes it possible to introduce innovations that actually increase their efficiency (Antonelli, 2011).

The dynamics of complex systems is based upon the combination of the reactivity of agents, caught in out-of-equilibrium conditions, with the features of the system into which each agent is embedded in terms of externalities, interactions, positive feedbacks that enable the generation of localized technological change and lead to endogenous structural change (Anderson, Arrow, Pines, 1988; Arthur, Durlauf, Lane, 1997).

The introduction of radical technological changes, in fact, parallels secular movements in the structure of the economic systems. When new technological systems emerge and are gradually put in place by the converging efforts of a myriad of innovations that are sorted out according to their complementarity so as to form a Schumpeterian gale (Schumpeter, 1939), the economic structure of the economic system faces drastic changes in the sectoral composition. New fast growing sectors substitute the sectors that –because of satiation and the effects of the international division of labor- exhibit diminishing rates of growth so as to modify radically the composition of the economic system (Kuznets, 1966 and 1971).

2.3. THE DIRECTION OF TECHNOLOGICAL CHANGE

The new approach to localized technological change and its attention to the properties of the system into which innovation –can- take place, enable to integrate in a single analytical framework the analysis of induced technological change so as to account the study of the determinants and effects of the direction of technological change.

The analytical core of the induced technological change literature explores the determinants of the direction of technological change. This literature recognizes that technological change is not neutral, as it is currently assumed in standard economics. Technological change is intrinsically biased, i.e. it is either capital intensive and hence labor saving, or labor intensive and hence capital saving, as it is the result of the attempt of innovators to cope with the opportunities and constraints of the factor markets (Ruttan, 1997 and 2001).

More specifically, we can identify and retain, within the induced technological change approach, two different arguments. According to the first, the rate of technological change is determined by the changing characteristics of factor markets. The tradition of analysis that impinges upon the Hicksian reinterpretation of the hypothesis, first provided by Karl Marx, suggests that technological change is induced by changes in the relative price of production inputs in the factor markets and directed towards the increase of the factor intensity of the production factor that became less expensive (Hicks, 1932; Binswanger and Ruttan, 1978).

Kennedy and Kennedy-von Weiszacker elaborated a very simple model of induced technological change, in which the direction of technological change was determined by the efforts to reduce the factor costs that were larger. The model of induced technological change elaborated by Kennedy did not make any reference to the production function framework, providing Samuelson (1965) with the opportunity to apply the Euler's theorem and note that the share of revenue paid to each production factor would coincide with its output elasticity. According to Samuelson, technological change would be labor saving when the output elasticity of labor would be larger than the output elasticity of capital. The result of Samuelson's point was clearly that in the long-run the output elasticity of labor and capital would gravitate towards parity. This brought the induced technological change debate to a long-term forestall.

The notion of technological congruence plays a central role in this context. Technological congruence consists in the matching between locally abundant inputs and their output elasticity. Technological congruence is high when the output elasticity of an input, say knowledge, is large in a country where knowledge is abundant. The appreciation of the strong effects of technological congruence defined as the matching between the value of the output elasticity and the relative abundance of production factor in local factor markets enables to understand that, at each point in time, technological change is directed towards the most intensive use of the production factor that is locally more abundant (Antonelli, 2012).

3. LOCALIZED TECHNOLOGICAL CHANGE IN AN OPEN ECONOMY

This section provides an extension of the localized technological change to analyze the dynamics of international trade so as to elaborate a dynamic version of the H-O model. We assume as a starting point that unexpected events have brought the international economy in an out-of-equilibrium condition and we explore how endogenous and localized technological change can be integrated into the traditional H-O approach. For the sake of historic likelihood we shall assume that the pre-existing equilibrium in international markets has been shacked by the entry of new labor abundant countries and the parallel liberalization of international capital markets.

3.1. GLOBALIZATION AND FACTOR MARKETS

The well-known Hecksher-Ohlin (H-O) model provides the classic static framework to analyze the effects of the entry of new labor abundant countries in international product markets. The integration of new labor abundant countries in international product markets can be portrayed as an increase in the size of the production frontier of labor-intensive products. The consequence is straightforward as it consists in the change in slope of the isorevenue, due to the reduction of the relative price of labor intensive products, the consequent reduction in the equilibrium output of labor intensive products in capital abundant countries and a new international division of labor based upon higher levels of specialization of capital abundant countries in capital intensive products and, last but not least, the reduction of wages in capital abundant countries.

INSERT FIGURE 1 ABOUT HERE

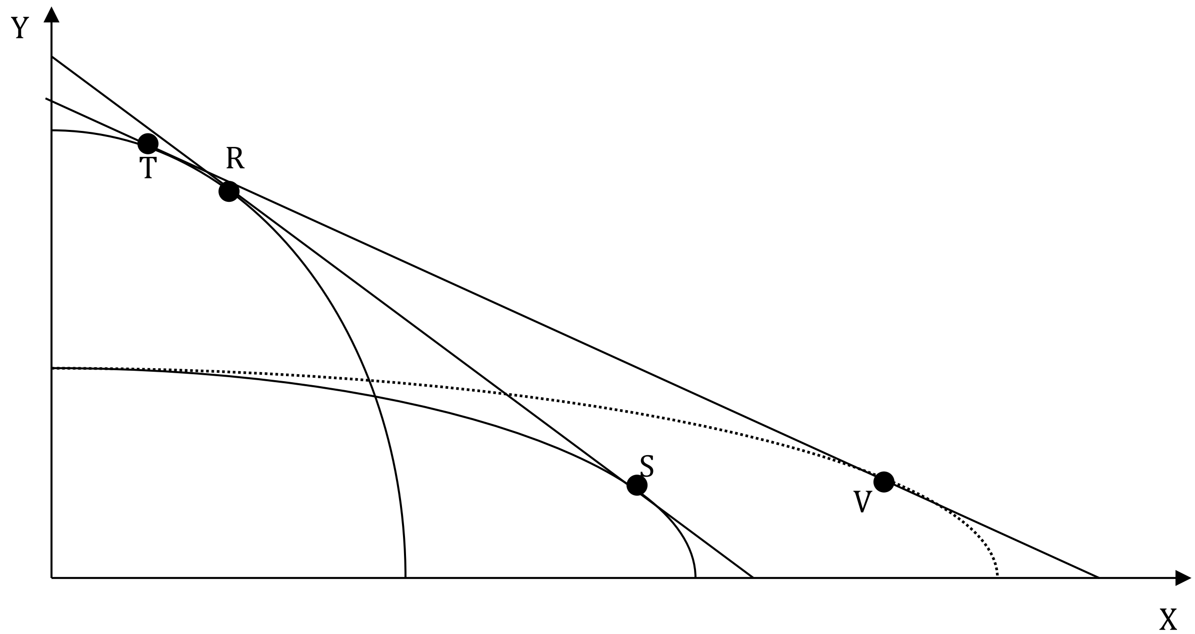


Figure 1 represents the classical overlapping of the production possibility frontiers of two trading countries or groups of countries. On the vertical axis the intercept of the production possibility frontier of capital abundant countries identifies the maximum amount of Y goods that can be produced while the intercept on the horizontal axis identifies the maximum amount of X goods that labor abundant countries can produce. The tangency with the isorevenue identifies the two equilibrium conditions for the two trading countries S and R. The entry of new labor abundant countries in international product markets affects the shape of the production possibility frontier of the group of labor intensive countries and consequently the slope of the isorevenue: the new equilibrium solutions T and V replace the old equilibrium solutions R and S, respectively in the capital and labor abundant countries.

This is the result of the following steps. Let us assume that the two overlapping frontiers of possible production are identified by 4 simple Cobb-Douglas production functions in two trading entities. The first two represent the two frontiers of possible production of the aggregate Z of the European countries; the second couple identifies the frontiers of possible production of the rest of the world T. They are characterized by their diverse endowment of capital and labor. Capital is abundant in countries Z and labor is abundant in the rest of the world:

(1) $Y_Z = A_Z (K_Z)^{\square} (L_Z)^{\square}\square$
(2) $X_z = A_Z (K_Z)^{\square} (L_Z)^{\square}\square$

(3) $Y_T = A_T (K_T)^{\langle} (L_T)^{®}$
(4) $X_t = A_T (K_T)^{\langle} (L_T)^{®}$

where A_Z and A_z measure the levels of total factor productivity in the Z countries in the production of Y and A_T and A_t measure the levels of total factor productivity in the T countries in the production of Y and X, K_Z and L_Z are capital and labor in countries Z and K_T and L_T are capital and labor in countries T; □□□□, 〈, ® measure the output elasticity of the production factors.

Moreover, the following cost functions apply:

(5) $C_Z = W_Z L_Z \; r_Z K_Z$
(6) $C_T = W_T L_T \; r_T K_T$

where W_Z measure the unit wages in countries Z and W_T measures the average unit wage of all the other countries that interact in the globalized international product markets. For the same token r_Z stands for the user costs of capital in countries Z and r_T for the average user costs of capital in all the other countries.

The standard, albeit often tacit, assumption that a>b in Z countries and 〈<® in T countries and respectively that $A_Z > A_z$, and $A_T > A_t$ makes possible the overlapping of the two different possible production frontiers so as to yield gains from trade and international specialization. Actually the larger is the difference between a/b and 〈/® □□□ A_Z / A_z and A_T / A_t and □□□□□□□□□□□□□□□□the gains□□□□□□□□□□□□. In the standard H-O model these difference are assumed to be exogenous.

Following the standard procedure for the construction of the frontiers of possible production we assume that:

(7) $X_Z = nY_Z$

(8) $X_T = mY_T$

Their slopes identify the Marginal Rate of Transformation, respectively MRT_Z and

MRT_T .

The isorevenue, describing the maximum production combination of goods X and Y, is defined as it follows:

(9) TR = Py Y + Px X

The equilibrium conditions of the slope of the isorevenue are easily identified as it follows:

(10) Px / Py = MRT_Z = MRT_T

The entry of new low wage, labor abundant competitors makes L_T and the supply of X_T larger in global markets. This reduces the slope of the isorevenue, i.e. the conditions for the international division of labor and the specialization of countries, and changes the relative conditions of the domestic factor markets. Wages in Z countries should fall. Firms in Z countries cannot but adapt to the new factor costs choosing –within their given production possibility frontier- a new technique with higher levels of capital intensity,

In the standard static context, firms based in capital abundant countries can face these relative changes in the new globalized factor markets only by means of textbook substitution, moving upon the existing maps of isoquants towards higher levels of capital intensity. The shape, position and slope of the production possibility frontier cannot be changed by the intentional conduct of firms. Firms can cope with the new conditions of international factor and product markets only moving on the existing frontier so as to reach the new equilibrium point identified by the tangency between the MRT and the slope of the new isorevenue.

Attempts have been made to elaborate a dynamic version of the standard H-O model allowing for the mobility of inputs and more specifically for both labor and capital flows among countries. Even in the dynamic version of the H-O model, however, firms are not allowed to change their technologies: technological change is exogenous. (Rybczynski, 1955).

When endogenous technological change is taken into account, instead, firms can cope with the new conditions of international product and factor markets by means of the introduction of new technologies that change slope, position and eventually the shape of the production possibility frontier.

The levels of total factor productivity can play a crucial role in this context. The negative effects of the entry of new, huge, labor abundant ad low wage countries T in the global economy can be contrasted if and when European countries Z were able to increase their total factor productivity. The negative effects of the entry of labor abundant countries on the wage levels of Z countries can be compensated by the increase of A_Z as well as by the changes in the output elasticity of abundant production factors brought about by the introduction of biased technological change.

This is possible if we move away from the static H-O model and elaborate its dynamic version. So far the main efforts have been made to provide a dynamic version of the H-O model have impinged upon the new growth theory. These attempts have paid little attention to the analysis of the localized and systemic character of technological knowledge and the effects of the endowments upon the direction of endogenous technological change (Eaton and Kortum, 1999, 2001 and 2002).

Our approach instead builds upon the new achievements of the new economics of knowledge and its integration with the Schumpeterian notion of creative reaction and the analysis of technological congruence and structural change. The focus of our approach is directed to understanding the effects of the changes in the differences of factor costs between trading partners on the introduction of localized and hence biased technological changes.

3.2 THE DYNAMIC H-O MODEL WITH TWO INPUTS

In the standard H-O framework of analysis countries are not expected to be able to change their technologies. The entry of the new labor abundant economies into the global economy had the direct effect to reducing the average unit wage within the globalized labor markets so that European countries discovered that their relative wage were too high. In a H-O framework of analysis countries could react only with an adaptive technical change searching for new capital intensive techniques within the existing map of isoquants and hence the existing production possibility frontier. In the dynamic version of the H-O framework, instead, firms, and at the aggregate level, countries, can react by means of the introduction of technological innovations so as to change position, slope and shape of the production possibility frontier.

The dynamics version of the H-O model rests upon the integration of the elements considered: a) firms caught in out-of-equilibrium conditions try and react; b) their reaction can be creative when appropriate knowledge externalities are available in the system, c) the direction of the technological change will be biased towards the intensive use of production factors that are locally most abundant. This approach can be successfully implemented and applied to international economics. The application of the notion of technological congruence to an open economy context yields important analytical results (Antonelli, 2012).

The analysis elaborated so far can be usefully framed with an approach based upon a Cobb-Douglas production function. In a standard two basic input production function, the dynamics version of the H-O model consists in the possible introduction of endogenous and biased technological change directed to increase total factor productivity and the output elasticity of the production factor that is locally more abundant.

Assuming that after the 'unexpected changes in international product and factor markets, the transient out-of-equilibrium across countries is such that:

(12) $(w_Z/r_Z) > (w_T/r_T)$

the search for technological congruence leads to introduce a new capital intensive production function in Z countries. After the introduction of the biased capital intensive technological change the new production function in Z countries can be represented in formal terms as it follows[3]:

(13) $Y = A_{ZZ} (K_Z)^A (L_Z)^B$

where $A>a$; $B<b$; $A_{ZZ} > A_Z$

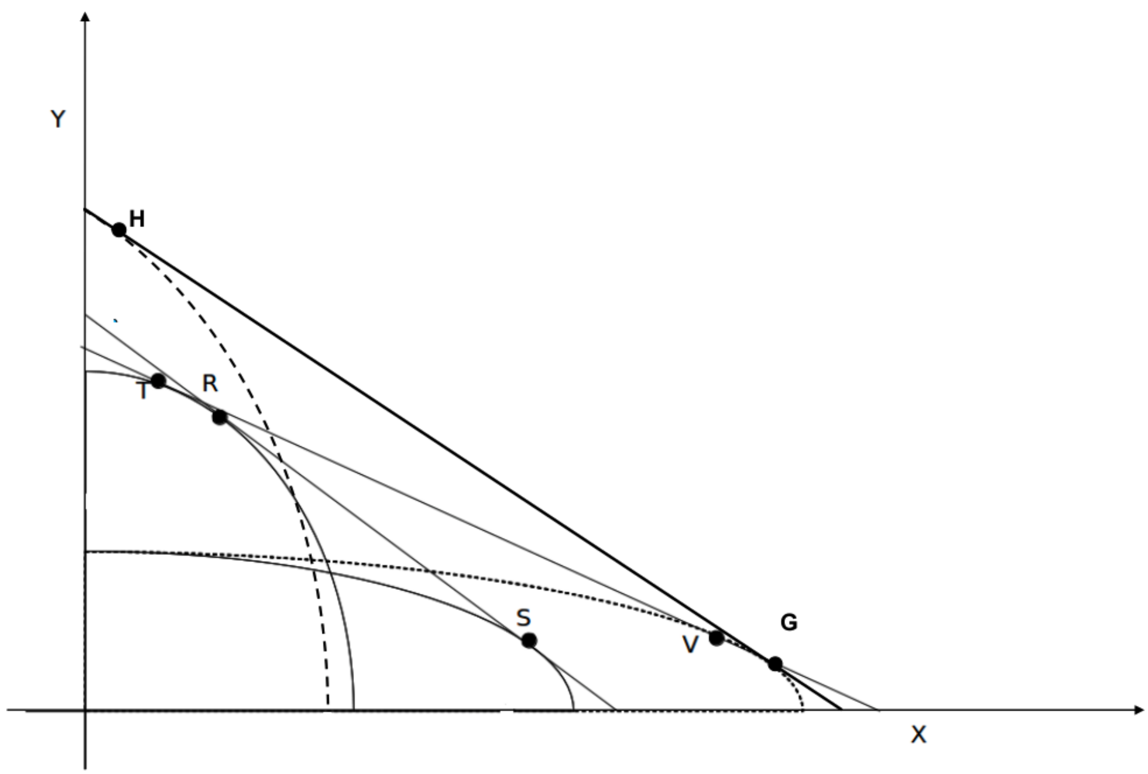
The endogenous introduction of biased technological change directed to increase the output elasticity of capital -the production factor relatively more abundant in local factor markets- changes the position, slope and shape of the production possibility frontier of the innovating countries and the international division of labor favoring an augmented – with respect to the static H-O model- specialization in capital intensive products.

The analysis of the dynamics of learning processes makes this argument stronger. Z countries had the opportunity to accumulate more experience and competence based upon learning processes in Y goods than in X goods. Hence they have the opportunity to react to the new conditions of international product markets with the introduction of new superior and directed technologies that rely on the directed knowledge externalities available in their countries. The accumulation of tacit knowledge in capital intensive products provides larger knowledge externalities in the generation of capital intensive technologies than in the generation of labor intensive technologies. This arguments applies and confirms the incentives to introduce biased technological changes even if

[3] The introduction of new biased technologies can take place also in the production of X. This, however, is not strictly necessary.

factor equalization were instantaneous so that the hypothesis of transient asymmetries in factor abundance and hence of transient differences in the slope of the isocosts could not hold.

INSERT FIGURE 2 ABOUT HERE
GLOBALIZATION AND SPECIALIZATION: THE H-O DYNAMIC VERSION



As Figure 2 shows the production possibility frontier of the European countries has changed position and shape because of the endogenous introduction of biased technological change directed to using more intensively the input that is locally and relatively most abundant i.e. fixed capital[4]. This takes place assuming that the cost of fixed capital in Z countries be actually lower in relative terms than in the rest of the world. The changes to the production possibility frontier do have direct effects to the

[4] Note that the intercept on the X axis of the production possibility frontier of the Z countries in this Figure 2 depends on the hypothesis that the introduction of innovations takes place only in the production of Y goods. The intercept can be larger if technological change takes place in Z countries also in the production of X goods. These alternative possibilities do not affect the outcome of the model that depends upon the changes in the maximum output of the Y goods in the Z countries

international division of labor. The slope of the isorevenue is indeed affected by the changes of the production possibility frontier introduced in the Z countries. As a consequence the equilibria are no longer found respectively in R and V, but in H for the Z countries and in G for the rest of the world.

Figure 2 makes clear that the changes in the position and shape of the production possibility frontier of Z countries, brought about by the introduction of productivity enhancing and biased technological changes directed towards the more intensive use of the production factor that is locally most abundant, changes the slope of isorevenue and hence the conditions of factor markets, with direct effects in terms of higher equilibrium wages with respect to the static H-O model. The new production possibility frontier of Z countries is in fact farther away from the origin and taller.

The difference between the levels of total factor productivity and of the output elasticity of the inputs in the two production functions, respectively that of the Z and the T countries, is not exogenous or random. It is, quite on the opposite, the long-term consequence of the effects of international trade on the direction of endogenous technological change in trading partners. Each country has in fact an incentive to try and increase the efficiency and the output elasticity of the production factor that before trade and in each out-of-equilibrium phase that follows changes in the institutional organization of international trade, happens to be locally cheaper.

The twin globalization of both product and capital markets limits the viability of this process.

3.3 THE DYNAMIC H-O MODEL WITH KNOWLEDGE AS AN INPUT

The parallel globalization of product and financial markets in place since the last decades of the XX century, however, undermined the opportunities for European countries to cope with the changes in the international division of labor by means of the introduction of new capital-intensive technologies. Once again, institutional changes affect the working of the system dynamics deepening the out-of-equilibrium conditions for firms in European economies. The globalization of financial markets plays here a central role. The new international mobility of capital both via the flows of foreign direct investment of multinational companies and the international finance managed by international banks provided large supply of capital to industrializing companies undermining the viability of their traditional search for a capital intensive bias of induced technological change. Capital was progressively losing in terms of being relatively more abundant in European economies than in industrializing ones.

The globalization of financial markets made available cheap capital to newcomers. The competitive advantage of European economies could no longer be restored by means of capital-intensive technological changes and increased specialization in capital intensive products: the system was found farther in out-of-equilibrium conditions. The introduction of radical technological changes became even more necessary. In countries where knowledge externalities were available, firms could cope with the negative effects of the entry in international product markets of new, huge, labor abundant ad low wage countries in the global economy by changing their technologies so as to increase the intensity of their production processes in the inputs that were actually abundant in local factor markets.

The search for technological congruence led to identify technological knowledge as the key abundant factor in European economies exposed to the international mobility of goods and capital. The strong collective and systemic character of technological knowledge roots it in the specific and highly idiosyncratic features of each economic system. Technological knowledge does not spill freely in the atmosphere as suggested by the extensions of the new growth theory to international economics. Knowledge abundant countries are characterized by a complex web of networks that vehicle effective knowledge interactions and make user-producer interactions possible and effective. For these reason advanced countries discovered technological knowledge as a scarce resource upon which a new competitive advantage could be built.

The relative abundance of technological knowledge in advanced countries activated the mechanisms of knowledge congruence that led to the sharp increase of the output elasticity of technological knowledge and the complementary decline of the output elasticity of both capital and low-skilled labor. The parallel globalization of product and financial markets engendered a major shift in the slope of isorevenue plane that identifies the equilibrium solution on an innovation possibility frontier with three production factors: capital, labor and technological knowledge.

The technology production function elaborated by Zvi Griliches (1979 and 1992) can be considered as an effective representation of the production process at a time characterized by the key role of knowledge as a production factor. The explicit integration of knowledge as a production factor into the production function enables to grasp the effects of the central role of the innovation process, characterized by high levels of skilled labor intensity, and its substitution to capital and standard labor, as the central production factor.

We assume that in the out-of-equilibrium phase determined by the twin globalization, in countries Z technological knowledge is more abundant than in the rest of the international economy where both capital and labor are relatively less scarce than technological knowledge. Hence the relative wages (w) and user costs of capital (r) are lower in the other economies than in countries Z, while the relative cost (t) of the new input technological knowledge (TK) is lower in countries Z than in the other economies. We can identify two cost equations for the Z countries and the other economies (o):

(14) $C_Z = r_Z K + w_Z L + t_Z TK$
(15) $C_o = r_o K + w_o L + t_o TK$

The Cobb-Douglas technology production function includes, next to the standard inputs capital (K) and labor (L), technological knowledge (TK), with their respective output elasticity C, B and E:

(16) $Y = A_{ZZZ} (K_Z)^C (L_Z)^D \square (TK_Z)^E$

The comparison of the production function (13) and (16) makes clear that: $C<A$, $D<B$, $E>0$; $A_{ZZZ} > A_{ZZ}$

In this dynamic version of the H-O model, taking into account the effects of the twin globalization and the discovery of technological knowledge as the most abundant production factors in countries Z, the latter will change the shape of the production possibility frontier and will make a more intensive use of technological knowledge, while the rest of the international economy will specialize in technologies with higher levels of capital and labor intensity. Because of technological congruence, in fact, countries Z find it convenient to increase as much as possible the intensity of the production factor that is relatively more abundant. In country Z, technological change will be biased in favor of the intensity of knowledge, the production factor that is locally more abundant (Antonelli, 2003, 2008, 2012).

After the introduction of the new directed technologies the two economies will be far more different, than before. The specialization of countries Z in the generation, use and exploitation of technological knowledge will be even stronger than before as the substitution process on the existing map of isoquants is enhanced and reinforced by the introduction of biased technologies that favor the more intensive use of technological knowledge.

The introduction of endogenous and biased technological change changes the shape, position and slope of the production possibility frontier and helps increasing the specialization of innovating –knowledge abundant- countries in the use of knowledge as both a key production factor and a key product.

Firms based in knowledge abundant countries face these relative changes in the new globalized factor markets by means of creative responses following the localized technological change approach. This occurs by means of the introduction of new knowledge intensive technologies that help them to cope with the new conditions of both product and factor international markets. The ultimate effect is the reshaping of their specialization in international product markets with the decline and exit from traditional low-tech sectors and the attempt to try and find new knowledge intensive productions that could support a new competitive advantage.

The effects on the flows of goods among trading partners are clear. Knowledge abundant countries become the specialized providers of knowledge intensive products to the rest of the world exporting both knowledge intensive tangible goods and intangible knowledge intensive business services. Knowledge abundant countries will rely more and more on the rest of the worlds for the imports of both capital and labor intensive products. Our framework accommodates in a consistent and coherent framework the large empirical evidence on the Leontieff paradox. An apparent paradox that finds its explanation in the long standing knowledge abundance of the US economy and in a theoretical explanation centered upon the endogenous direction of technological change biased towards the intensive use of locally abundant inputs.

The new pattern of growth and change reverses a long-term growth trajectory based upon the direction of technological change induced by the fast rates of accumulation of capital. A large part of the XX century has been characterized by the introduction of new capital-intensive technologies and by the secular decline of the user cost of capital due to the increasing supply of savings and the accumulation of capital. The two dynamics reinforced each other as the introduction of capital-intensive technologies was the result of an inducement mechanism engendered by the decline in the user cost of capital. The increase in the output elasticity of capital and the decline of the user cost of capital lead to increasing levels of capital intensity that in turn favored the accumulation of competence and technological knowledge in capital intensive techniques favoring the eventual reinforcement of the direction of technological change towards higher level of output elasticity of capital (Zeira, 1998).

In our approach, instead, countries did try and innovate so as to introduce new technologies directed towards the most intensive use of knowledge, i.e. the input that is more abundant in their own factor markets not only in relative terms but also in absolute ones. Advanced countries discovered that the comparative advantage in the generation of technological change could be based upon the high quality of their knowledge governance mechanisms that made it possible the exploitation of knowledge indivisibility and limited appropriability favoring its use and dissemination as a collective resource rooted in their own economic systems.

4. CONCLUSIONS

This work has elaborated a dynamic version of the H-O model based upon the hypothesis that technological change is endogenous and biased towards the most intensive use of production factors that are locally most abundant in comparative terms. In the standard H-O model, the difference in the levels of the output elasticity of inputs is assumed to be exogenous. In this dynamic version, instead, this difference is fully endogenous.

This approach rests upon the localized technological change approach that integrates the advances of the new economic of knowledge with the Schumpeterian notion of creative reaction, the analysis of induced technological change and technological congruence, the Kuznets approach to structural change. The new economics of knowledge has stresses the strong systemic and localized character of technological change. According to the Schumpeterian notion of innovation as the result of the creative reaction, firms caught in out-of-equilibrium conditions by the changing conditions of both factor and product markets might try and react by means of the introduction of biased technological changes. The analysis of technological congruence in fact suggests that, in a dynamic H-O model, technological innovations will be aimed at increasing the intensity of the production factor via the increase of its output elasticity so as to increase total factor productivity.

Building upon the analytical tradition of the induced technological change hypothesis, we have elaborated a simple analytical framework based upon the technology production function. The appreciation of the increasing role of technological knowledge both as an input into the production of other goods and an output enables to specify a production function where the output elasticity of technological knowledge keeps increasing, while the output elasticity of labor and fixed capital declines. For given levels of capital, user cost of the stock of capital and labor productivity may decline. The technology production function can be considered an effective representation of the growing intensity of technological knowledge as the central production factor.

Because of the twin globalization of both product and capital markets, technological knowledge was found to be the most abundant input in advanced economies. In such conditions, knowledge abundant countries can cope with the changed conditions of both product and factor markets by means of the introduction of knowledge-intensive innovations and radical changes in their economic structure that enabled them to substitute the traditional manufacturing base with the new knowledge economy.

The relative abundance of technological knowledge plays a twin role in this analysis. First it made it possible to firms to react creatively and introduce new technologies. Second, because of the mechanisms of technological congruence, favored a new specialization in knowledge intensive products. The two roles reinforce each other with positive feedbacks. The larger is the knowledge abundance, in fact, the more creative can be the reaction of firms and countries in international markets an the stronger will be the direction of technological change towards the most intensive use of knowledge as the key production factor upon which a new international specialization can be built.

This framework provides a new explanation of the Leontieff paradox based upon the clear evidence about the long standing knowledge abundance of the US economy and a theoretical explanation centered upon the endogenous direction of technological change biased towards the intensive use of locally abundant inputs. This framework accommodates the large empirical evidence on the Leontieff paradox.

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