# A SCHUMPETERIAN APPROACH TO ENDOGENOUS SPECIALIZATION IN INTERNATIONAL TRADE[1]

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**ABSTRACT.** This work elaborates a Schumpeterian version of the H-O model (S-H-O) 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 differences among trading partners in the levels of the output elasticity of inputs and technological change are exogenous. The (S-H-O) model rests upon the Schumpeterian notion of the creative response of firms that, 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 to the out-of-equilibrium conditions engendered by enhanced globalization reacted with the introduction of new technologies biased towards the intensive use of technological knowledge as the most abundant and specific 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 KNOWLEDGE; INDUCED TECHNOLOGICAL CHANGE; TECHNOLOGICAL CONGRUENCE; GLOBALIZATION; SCHUMPETER-HECKSHER-OHLIN.

JEL CODES: O33, F12, F43

## 1. INTRODUCTION

The standard economics of international trade assumes that the specialization of trading countries is given and exogenous. The integration of the notions of creative response elaborated by paper by Schumpeter (1947) and of technological congruence (Antonelli, 2015) makes it possible to understand it as the result of an endogenous process.

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This paper contributes the investigation of the economic determinants of the specialization of trading countries elaborating a Schumpeterian version of the Hecksher-Ohlin (H-O) model of international trade. This analysis enables to appreciating the changing international specialization of trading partners as an aspect of endogenous structural and technological change stirred by the integration into the international markets of new trading partners (Meliciani, 2002; Urraca-Ruiz, 2013). The radical changes in the specialization of both advanced and industrializing countries that has been taking place since the last decades of the XX century can be regarded as the consequence of the radical technological and structural changes introduced to cope with the globalization of product and factor markets (Freeman, 1996; Perez, 2002).

The rest of the paper is organized as it follows. Section 2 summarizes the foundations of the localized technological change approach. Section 3 elaborates its application to implement a Schumpeterian version of the H-O (S-H-O) model of international trade. The conclusions summarize the main results.

## 2. INNOVATION AS AN EMERGENT SYSTEM PROPERTY

Schumpeter[2] (1947) elaborated the notion of innovation as a creative reaction stirred by a mismatch between expected and actual product and factor markets conditions. The eventual reaction of firms can be either adaptive or creative. Reaction can be simply adaptive and consist just in traditional price/quantity technical (as opposed to technological) adjustments. The reaction is adaptive when firms are not able to generate appropriate amount of new technological knowledge and cannot actually innovate. The creative reaction of firms is, in fact, possible only when and where knowledge

[2] Schumpeter (1947) is very little cited in the literature. It seems 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).

externalities make possible the recombinant generation of new technological knowledge at costs that are below equilibrium level. Such relevant knowledge externalities are localized in economic systems where technological knowledge is the result of the active participation and interaction of a myriad of innovators.

The recent advances of the economics of knowledge that regard technological knowledge as a collective activity with strong systemic characteristics contribute the implementation of the Schumpeterian approach. This literature draws from the Arrovian analysis of the limited appropriability, cumulability, complementarity and non-exhaustibility of knowledge and explores their consequences on the generation knowledge. In this literature knowledge spillovers and in general external knowledge to each firm are indispensable to the generation of new knowledge. Because of the sticky and tacit content of knowledge, dedicated and intentional efforts and localized interactions between producers and users are necessary to use external knowledge into the generation of new knowledge. Knowledge externalities are pecuniary rather than pure. 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 makes the endogenous introduction of innovations possible (Antonelli, 2008; Antonelli and David, 2015).

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. The amount of knowledge externalities and interactions available to the firms embedded in the system, influences their capability to generate new technological knowledge and, consequently, the actual possibility to make their reaction creative as opposed to adaptive and to actually introduce technological changes (Antonelli, 2011).

Because of the Schumpeterian emphasis on the mismatches between expected and actual factor -and not only product- market conditions, the localized technological change framework accommodates the analytical core of the induced technological change literature. This literature recognizes that the rate and the direction of technological change are induced by the changing conditions of factor markets (Ruttan, 2001). The larger are the changes of the factor markets and the higher the rate of introduction of innovations. 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. The reduction of the relative cost of a production factor, such as skilled labor or technological knowledge, induces the introduction of innovations biased towards more skill-intensive, or knowledge intensive, technologies (Acemoglu, 2002; Acemoglu, Zilibotti, 2001).

The notion of technological congruence plays a central role in the localized technological change approach. 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. High levels of technological congruence lead to high levels of total factor productivity. The increase in the levels of technological congruence enables to increase the levels of total factor productivity. All changes in factor markets and in the relative costs of inputs induce new attempts to increase the technological congruence of the production process (Antonelli, 2015).

## 3. GRAFTING THE SCHUMPETERIAN CREATIVE RESPONSE ON H-O

This section provides elaborates the grafting of the innovation as an emergent system property approach based upon the Schumpeterian notion of creative response to analyze the dynamics of international trade. 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 in the last decades of the XX century by the entry of new labor abundant countries and the parallel liberalization of international capital markets. We shall analyze with special attention the consequences on the capital abundant (OECD) countries

### 3.1. GLOBALIZATION AND FACTOR MARKETS

The well-known Hecksher-Ohlin (H-O) model provides the classic 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, that reflects the reduction of the relative price of labor intensive products and the increase of the relative price of capital intensive products, and a new international division of labor with the reduction of the equilibrium output of labor intensive products manufactured in capital abundant countries and higher levels of specialization of capital abundant countries in capital intensive products. The prices of the final goods decrease sharply and the price of investment goods exhibits a minor increase.

INSERT FIGURE 1 ABOUT HERE
GLOBALIZATION AND SPECIALIZATION: THE STATIC VERSION

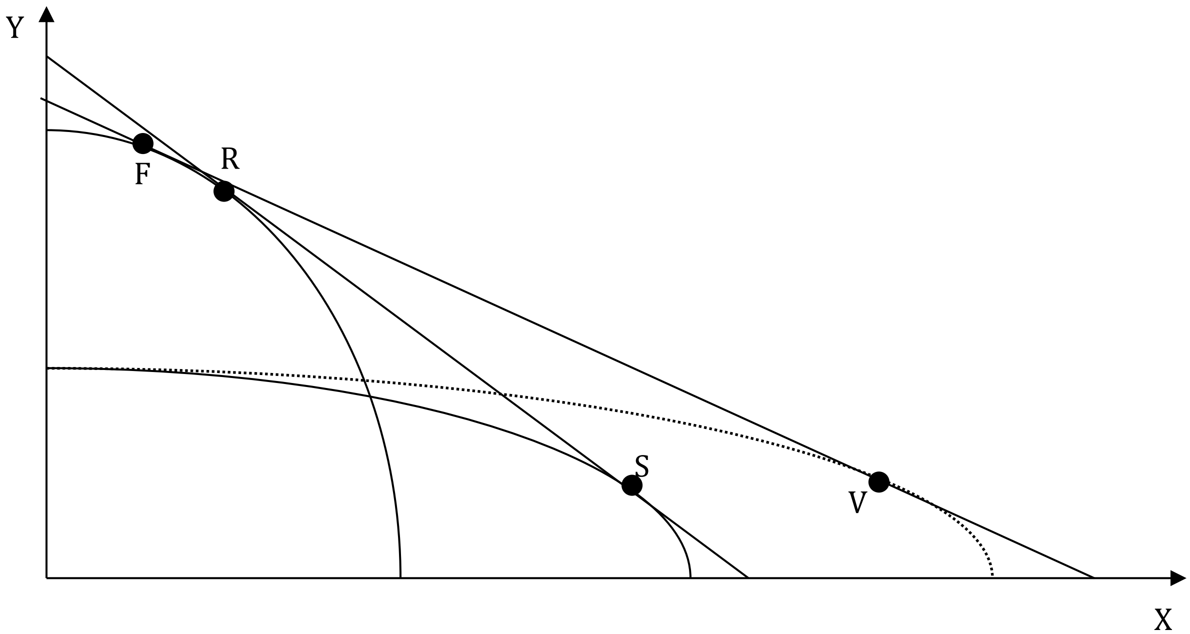



Figure 1 represents the classical overlapping of the production possibility frontiers of two trading countries or groups of countries. On the vertical axis the intercept of the production possibility frontier of capital abundant countries identifies the maximum amount of capital intensive Y goods that can be produced while the intercept on the horizontal axis identifies the maximum amount of labor intensive 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 F and V replace the old equilibrium solutions R and S, respectively in the capital and labor abundant countries.

This graphical representation 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 Z countries; the second couple identifies the frontiers of possible production of the T countries. They are characterized by their diverse endowment of capital and labor. Capital is abundant in countries Z and labor is abundant in countries T, Y represents capital goods and X final goods:

(1) $Y_Z = A_Z\ (K_Z)^{□}\ (L_Z)^{□}$ □
(2) $X_Z = A_Z\ (K_z)^{□}\ (L_z)^{□}$ □
(3) $Y_T = A_T\ (K_T)^c (L_T)^d$
(4) $X_T = A_T\ (K_t)^c$ □ $(L_t)^d$

where $Y_Z$ and $X_Z$ are respectively the output of Y and X goods in Z countries; $K_Z$ and $L_Z$ are capital and labor in countries Z engaged in the production of Y goods, $K_z$ and $L_z$ are capital and labor in countries Z engaged in the production of X goods; where $Y_T$ and $X_T$ are respectively the output of Y and X goods in T countries; $K_T$ and $L_T$ are capital and labor in countries T engaged in the production of Y goods; $K_t$ and $L_t$ are capital and labor in countries T engaged in the production of X goods; □□□□, c, d measure the output elasticity of the production factors.

$A_Z$ measures the levels of total factor productivity in the Z countries in the production of capital goods Y and final goods X; $A_T$ measures the levels of total factor productivity in the T countries in the production of capital goods Y and final goods X (for the sake of clarity we shall assume that in each country the two sectors have the same levels of total factor productivity); $A_T$ measures the levels of total factor productivity in the T countries in the production of Y and X (for the sake of clarity we shall assume that in each country the two sectors have the same levels of total factor productivity).

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 $w_Z$ measures the unit wage in countries Z and $w_T$ measures the unit wage of the T countries that interact in the globalized international product markets. For the same token $r_Z$ stand for the capital user costs in countries Z and $r_T$ for the capital user costs in the T countries.

The standard, albeit often tacit, assumptions that a>b in Z countries and c<d in T countries, makes possible the overlapping of the two different possible production frontiers so as to yield gains from trade and international specialization. Following (Maskus and Nishioka, 2009; Trefler, 1993) we take into account differentiated efficiency levels and we assume that $A_Z > A_z$, $A_T > A_t$ and $A_Z > A_t$ [3]. Actually the larger are the difference between a and b, c□ and d□ $A_Z$ and $A_T$ and □□□□□□□□□□□□□□□□the gains□□□□□□□□□□□□□□

[3] Following Solow (1957) the term A measures the levels of total factor productivity. Total factor productivity measures the residual, i.e. the amount of output that cannot be explained by the amount of inputs. A increases because of the introduction of innovations. Knowledge *may* account for the rate of technological change, but does not coincide with it. In a knowledge economy, based upon knowledge intensive services, however, the rates of total factor productivity may be zero as no innovation is introduced.

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 two 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 large 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 in real terms.

In the context, in the H-O model firms based in capital abundant countries face these relative changes in the new globalized factor (and product) 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[4].

When the Schumpeterian hypothesis of an endogenous and directed technological change induced by the mismatch between expected and actual factor markets conditions 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.

### 3.2 THE S-H-O MODEL WITH TWO INPUTS

In the S-H-O approach firms, and at the aggregate level, countries, can react to the

[4] Attempts have been made to elaborate a more inclusive 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 this version of the H-O model, however, firms are not allowed to change their technologies: technological change is exogenous (Rybczynski, 1955).

effects of globalization by means of the introduction of biased technological innovations so as to change position, slope and shape of the production possibility frontier. The S-H-O model rests upon the integration of three basic ingredients: 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 became locally more abundant and relatively cheaper.

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 S-H-O model allows 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 and relatively cheaper.

Here the appreciation of the different time horizons of the different consequences of globalization plays a crucial role. Factor cost equalization should be regarded as a secular process that displays its effects in very long term. Its implementation requires radical changes in the economic structure, the exit from labor intensive industries and the growth of capital intensive ones. This in turn requires major adjustments in labor and capital markets. The strength of trade unions causes further delays in the reduction of nominal wages. Only in the very long term, *coeteris paribus*, factor cost equalization can actually take place: wages in Z countries should fall and capital user cost increase. The changes in the relative prices of investment and final goods, instead, are instantaneous. The flows of imports from capital intensive countries of labor intensive goods have rapid effects on their relative market prices. In the short term, as a consequence, while factor costs change smoothly the price of the final goods X fall drastically and the price of capital goods Y exhibits minor increases. As a consequence, in capital abundant countries, real wages increase and real capital user costs decline.

In the very long term the new isocost and the new isorevenue should be equal, as predicted by the factor costs equalization theorem. In the short term, however, this is not the case. Because of the discrepancy between the two conflicting time horizons, a typical out-of-equilibrium condition takes place. In the short term the real isocost is different from the isorevenue: the isocost is actually steeper than the isorevenue. Formally this amounts to say that slope of the isocost in capital abundant countries, already >1 before globalization, is even steeper after globalization:

(12) $(w_Z /P_X/ r_Z /P_Y )_{t1} > (w_Z /P_X/ r_Z /P_Y )_{t0} > 1$

According to our hypothesis, because in Z countries -after globalization- real capital user costs will become relatively cheaper than real wages, and the slope of the real isocost will be steeper than before globalization, there is a major opportunity to grasp the benefits, in terms of increased total factor productivity, of an increase of technological congruence by means of the introduction of new capital intensive technologies. The Schumpeterian creative reaction and the search for technological congruence lead to the introduction of a new superior capital intensive technology represented by a new production function in Z countries with a larger capital output elasticity and higher levels of total factor productivity. 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[5]:

(13) $Y_Z = A_{Z\,Z} (K_Z)^F (L_Z)^G$

where A>a; B<b; $A_{Z\,Z} > A_Z$ . The new total factor productivity, measured by $A_{Z\,Z}$ is larger than the former $A_Z$ because of the introduction of biased technological change directed to the increase of the output elasticity of capital –F- that has become cheaper because of globalization. The new production function reflects the introduction of capital intensive technological change and hence –given the changes in factor markets brought about by the out-of-equilibrium conditions engendered by globalization- higher levels of technological congruence and higher levels of total factor productivity.

In the S-H-O model, the endogenous introduction of biased technological change directed to increase the output elasticity of capital -the production factor that because of globalization has become 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 H-O model- specialization of advanced countries in capital intensive products (Montobbio and Rampa, 2005).

As Figure 2 shows the production possibility frontier of the Z 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[6]. The changes to the production possibility frontier do have

[5] The introduction of new biased technologies can take place also in the production of $X_Z$. This, however, is not strictly necessary. The analysis of learning processes helps to 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.

[6] 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

direct effects to the 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 F and V, but in H for the Z countries and in G for the T countries.

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, change the slope of isorevenue. The new production possibility frontier of Z countries is in fact farther away from the origin and taller.

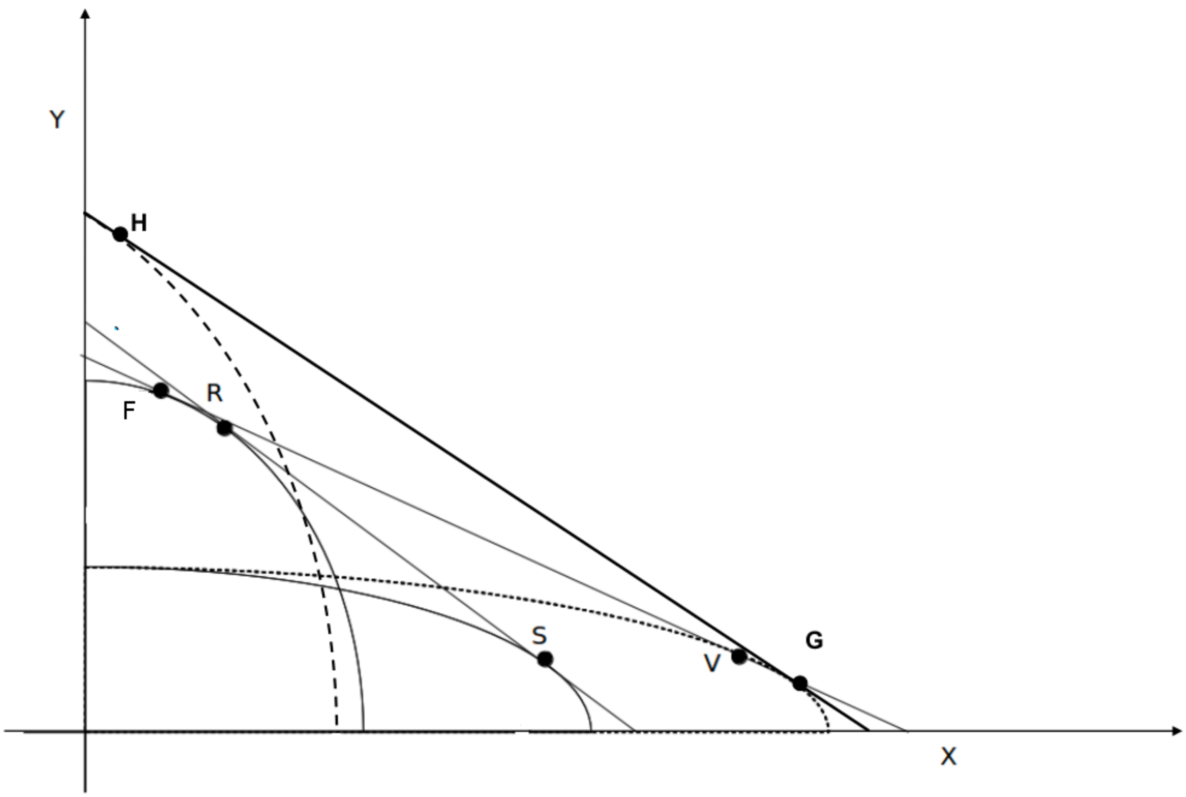
The difference between the levels of total factor productivity and of the output elasticity of the inputs in the production functions of the goods Y and X in Z and T countries, is not exogenous or random. It is, quite on the opposite, the consequence of the effects of international trade on the rate and direction of endogenous technological change in trading partners. Each country has in fact an incentive to try and increase the efficiency of the production process by means of the exploitation of the technological opportunities that are enable to change the output elasticity of the production factor that, after integration, happens to be locally and comparatively cheaper (Laursen, 1999).

The discrepancy between the time horizon into which the nominal price of goods changes in international markets and the nominal price of inputs changes in domestic markets has long-lasting consequences that make factor equalization impossible. The divergence between the changes in the nominal and real prices of both inputs and outputs, in fact, is at the origin of search for technological congruence and the consequent introduction of biased technological change. The latter in turn changes the equilibrium conditions on international markets with the final consequence that the very foundations of factor equalization disappear.

Table 1 in Appendix A shows the decline of the labor share experienced since 1990 by advanced countries. This evidence confirms that technological change in the countries most exposed to the increasing competition by labor abundant countries, has been biased in favor of the introduction of capital intensive technologies that could use the resource that was locally more abundant (Zeira, 1998; Karabarbounis and Neiman, 2014).

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.

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




**3.3 THE S-H-O MODEL WITH KNOWLEDGE AS AN INPUT**

When factor mobility is allowed, the framework elaborated so far may change. The parallel globalization of product and financial markets in place since the last decades of the XX century undermined the opportunities for Z countries to cope with the changes in the international division of labor by means of the introduction of new capital-intensive technologies. Major institutional changes affected the working of the system dynamics deepening the out-of-equilibrium conditions for firms in Z economies. The globalization of financial markets played here a central role. The new international mobility of capital via both the flows of foreign direct investment of multinational companies and the international finance managed by international banks provided industrializing companies with large capital supply, undermining the profitability of a capital intensive induced technological change of –formerly- capital abundant countries (Perez, 2002 and 2010).

The globalization of financial markets provided available and cheap capital to newcomers. The competitive advantage of Z economies could no longer be restored by means of capital-intensive technological changes and increased specialization in capital intensive products. The introduction of radical technological changes became even more necessary. In countries where knowledge externalities were available, firms could cope with the entry in international product and capital markets of new, huge, labor abundant ad low wage countries in the global economy only with a major effort to identify the input that was actually and specifically abundant in their local factor markets so as to be able to direct their new technologies and to increase its intensity of their production processes.

The search for technological congruence led to identify technological knowledge as the key abundant factor in Z economies exposed to the international mobility of goods and capital. The strong collective and systemic character of technological knowledge localizes it in the specific and highly idiosyncratic features of each economic system. Technological knowledge does not spill freely in the 'international' atmosphere as suggested by the extensions of the new growth theory to international economics, but has a strong localized content based upon its tacit and sticky content that roots it in learning countries endowed with a strong knowledge base and advanced knowledge governance mechanisms (Romer, 1994; Branstetter 2001; Montobbio and Kataishi, 2015).

Knowledge is abundant in Z countries because they are characterized by a complex web of networks that make knowledge user-producer interactions possible and effective (Breschi, Lissoni, 2001) and high quality knowledge governance mechanisms that favor the dissemination of knowledge spillovers and their actual use by third parties in the generation of new technological knowledge (Antonelli and Link, 2015). For these reasons Z countries could discover technological knowledge as a relatively abundant resource upon which a new competitive advantage could be built.

The relative abundance of technological knowledge in advanced countries activated and supported, at the same time, the mechanisms of knowledge congruence that led to the introduction of biased technological changes directed to the sharp increase of the output elasticity of technological knowledge as an input and the complementary decline of the output elasticity of low-skilled labor.

The technology production function elaborated by Zvi Griliches (1979 and 1992) is a very effective tool to analyzing 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 knowledge, characterized by high levels of skilled labor intensity, and its substitution to standard labor, as a key production factor.

We assume that in the out-of-equilibrium phase determined by the twin globalization, in countries Z technological knowledge is more abundant and cheaper than in the T economies 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 T economies than in countries Z, while the relative cost (m) of the new input technological knowledge (TK) is lower in countries Z than in the T economies.

After the introduction of the new biased technological change, the Cobb-Douglas technology production function includes on the l.h.s. capital goods Y that differ from the previous ones for their increasing intangible content and include many knowledge-intensive-business services (KIBS), on the r.h.s., next to the standard capital (K) and labor (L), the new production factor technological knowledge (TK), each with its respective output elasticity C, B and E:

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

The comparison of the production functions (13) and (14) makes clear that: C=A, D<B, E>0: we assume in fact –with constant returns to scale and hence C+D+E=1- that the new input technological knowledge -consisting primarily of intangible capital- displaces standard labor, but not fixed capital. Next, we assume that $A_{ZZZ} > A_{ZZ}$: the levels of total factor productivity in the innovating countries Z increase because of the higher levels of technological congruence made possible by the introduction of biased technological changes directed at increasing the output elasticity E of the input locally most abundant technological knowledge (TK)[7].

The introduction of TK, next to and together with the levels of total factor productivity $A_{ZZZ}$, stems from the Schumpeterian hypothesis that the amount of knowledge (TK) is a *necessary but not sufficient* condition for total factor productivity to increase. The amount of knowledge may engender knowledge externalities that may support the creative reaction of firms caught in out-of-equilibrium conditions

Now the S-H-O model can take into account the effects of the twin globalization and the discovery of technological knowledge as the most abundant production factor in countries Z, so as to explaining the introduction of induced technological change biased towards the increased output elasticity of the new input technological knowledge, as an endogenous reaction that changes the shape of the production possibility frontier.

[7] For the sake of clarity we identify the cost equation for the production of $Y_Z$ goods in Z countries:
(15) $C_Z = r_Z K + w_Z L + m_Z TK$

In order to cope with the twin globalization of the last decades of the XX century countries Z introduced a wave of biased technological changes directed towards a more intensive use of technological knowledge, while the rest of the international economy specialized in technologies with higher levels of capital output elasticity. Because of technological congruence, in fact, countries Z found it convenient to increase as much as possible the intensity of the production factor that was locally relatively more abundant (Antonelli, 2008, 2015).

The S-H-O framework elaborated so far is quite consistent with the results of Maskus and Nishioka (2009) who implement the H-O model with factor-specific productivities and factor-augmenting technological differences differentiated across countries. Their analysis suggests that factor-augmenting productivity gaps and factor abundance make the H-O framework compatible with the empirical evidence. They do not explain, however, how and why factor abundance guides the introduction of factor augmenting productivity gaps. Previously Nishioka (2005) had shown that the inclusion of knowledge as an input and output in the analysis of international trade flow helps increasing the viability of the H-O model.

The S-H-O framework implemented so far pretends to explain the process by means of which such changes take place. The S-H-O approach shows that the introduction of biased technological changes directed at increasing the output elasticity of the input locally cheaper is the result of an out-of-equilibrium condition determined by changes in international product markets. The strength of the S-H-O model consists in the endogenous account of the specialization of the trading countries. From this viewpoint the S-H-O framework differs from the Maskus-Nishioka approach as it stresses the process that underlies the endogenous definition of both the rate and the direction of technological change.

After the endogenous 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 (Abramovitz, David, 1996; Antonelli and Colombelli, 2011; Antonelli and Fassio, 2011).

In the S-H-O approach Z countries could face these relative changes in the new globalized factor markets by means of creative responses consisting in the introduction of new knowledge intensive technologies that helped them to cope with the new conditions of both product and factor international markets.

Advanced countries discovered that 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 localized in their own economic systems, could become the base of a new knowledge-intensive comparative advantage (Guerrieri and Meliciani, 2005).

The effects on the flows of goods among trading partners are clear. Knowledge abundant countries became 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 rely more and more on the rest of the worlds for the imports of both capital and labor intensive products. The introduction of the new technological system based upon new information and communication technologies was the cause and the consequence of the new specialization in the generation and exploitation of technological knowledge (Guerrieri, Luciani, Meliciani, 2011).

The ultimate effect of the endogenous technological and structural change was the reshaping of their specialization in international product markets with the decline and exit from traditional low-tech manufacturing sectors and the attempt to try and find new knowledge intensive service industries that could support a new competitive advantage. The evidence of Tables 2 and 3 in Appendixes B and C confirms the sharp decline of employment in manufacturing and the parallel increase of the share of employment in knowledge intensive business services (Evangelista, Lucchese, Meliciani, 2013; Antonelli and Fassio, 2014).

The S-H-O framework accommodates 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.

## 4. CONCLUSIONS

This work has elaborated the S-H-O, a Schumpeterian version of the H-O model based upon the hypothesis that changes in international trade interact with endogenous and directed technological change biased towards the most intensive use of production factors that are locally most abundant in comparative terms. Changes in international markets and changes in technology do interact and feed each other and shape the specialization of trading countries.

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 try and react to the changing conditions of factor and product markets brought about by globalization by means of the introduction of biased technological changes, provided they can rely upon substantial knowledge externalities. The innovation as an emergent system property approach integrates also the recent advances of the new economics of knowledge that have stressed the strong systemic and localized character of technological knowledge and the analytical tradition of the induced technological change hypothesis.

The relative abundance of technological knowledge plays a twin role in this analysis. First it makes it possible to firms to react creatively and introduce technological innovations: without a strong knowledge base their reaction could fail and be just adaptive. Second, because of the mechanisms of technological congruence, the very same strong knowledge base 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, and 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.

The S-H-O approach integrates the H-O model with endogenous technological change and shows that the levels of both total factor productivity and output elasticity of production factors are endogenous to the system. In the standard H-O model, the difference between trading countries in the levels of the output elasticity of inputs and total factor productivity is assumed to be exogenous and factor costs equalization leads to the end of international trade and specialization. In the S-H-O the technological specialization of each country and specifically the mix of output elasticity of production factor is not accidental: it reflects the search for technological congruence and the introduction of biased technological innovations directed at increasing the output elasticity of the inputs that are locally cheaper. While in the standard H-O approach trade takes place between countries because of their exogenous specialization, in the S-H-O, trade is the result of the intentional introduction of directed technological changes in countries that have differentiated factor markets. In the S-H-O approach international specialization, structural and technological change are but ingredients of a single on-going out-of-equilibrium process of transformation of economic systems.

Historically, this implies that knowledge abundant countries could cope with the changed conditions of both product and factor markets brought about by the globalization of the late decades of the XX century by means of the introduction of knowledge-intensive innovations and radical changes in their economic structure that enabled them to complement the decline of the traditional manufacturing base with the specialization in the new knowledge economy.

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APPENDIX A

TABLE 1: DECLINE OF LABOR SHARE 1990-2009

| | France | Germany | Italy | Japan | Netherlands | United Kingdom | United States |
|---|---|---|---|---|---|---|---|
| 1990 | 0.718 | 0.707 | 0.770 | 0.616 | 0.695 | 0.724 | 0.696 |
| 1991 | 0.718 | 0.714 | 0.782 | 0.617 | 0.699 | 0.737 | 0.703 |
| 1992 | 0.724 | 0.735 | 0.789 | 0.619 | 0.718 | 0.734 | 0.708 |
| 1993 | 0.734 | 0.742 | 0.768 | 0.630 | 0.719 | 0.712 | 0.699 |
| 1994 | 0.726 | 0.733 | 0.745 | 0.637 | 0.708 | 0.692 | 0.686 |
| 1995 | 0.721 | 0.736 | 0.727 | 0.636 | 0.697 | 0.691 | 0.681 |
| 1996 | 0.722 | 0.742 | 0.723 | 0.631 | 0.701 | 0.670 | 0.682 |
| 1997 | 0.711 | 0.729 | 0.726 | 0.628 | 0.695 | 0.668 | 0.679 |
| 1998 | 0.704 | 0.723 | 0.703 | 0.630 | 0.699 | 0.685 | 0.699 |
| 1999 | 0.707 | 0.729 | 0.711 | 0.621 | 0.698 | 0.694 | 0.699 |
| 2000 | 0.701 | 0.742 | 0.689 | 0.618 | 0.684 | 0.707 | 0.711 |
| 2001 | 0.701 | 0.742 | 0.680 | 0.617 | 0.684 | 0.718 | 0.710 |
| 2002 | 0.705 | 0.736 | 0.686 | 0.606 | 0.686 | 0.707 | 0.693 |
| 2003 | 0.704 | 0.734 | 0.697 | 0.591 | 0.686 | 0.705 | 0.681 |
| 2004 | 0.706 | 0.717 | 0.690 | 0.572 | 0.683 | 0.700 | 0.678 |
| 2005 | 0.705 | 0.708 | 0.702 | 0.560 | 0.661 | 0.698 | 0.667 |
| 2006 | 0.708 | 0.690 | 0.706 | 0.562 | 0.657 | 0.693 | 0.672 |
| 2007 | 0.700 | 0.681 | 0.705 | 0.558 | 0.655 | 0.699 | 0.680 |
| 2008 | 0.702 | 0.693 | 0.714 | 0.581 | 0.656 | 0.685 | 0.686 |
| 2009 | N.A. | 0.739 | 0.728 | 0.584 | 0.705 | 0.722 | 0.679 |
| 2010 | N.A. | 0.713 | 0.729 | 0.566 | 0.676 | 0.721 | 0.668 |

SOURCE: OECD data base STAN

APPENDIX B

TABLE 2: SHARE OF EMPLOYMENT IN MANUFACTURING INDUSTRY 1990-2009

| | France | Germany | Italy | Japan | Netherlands | United Kingdom | United States |
|---|---|---|---|---|---|---|---|
| Time | | | | | | | |
| 1993 | 17.0% | 24.3% | 23.2% | 22.4% | 15.4% | 16.5% | 14.4% |
| 1994 | 16.5% | 23.1% | 23.3% | 21.6% | 14.7% | 16.4% | 14.2% |
| 1995 | 16.4% | 22.5% | 23.2% | 20.8% | 14.4% | 16.5% | 14.1% |
| 1996 | 16.1% | 21.9% | 22.8% | 20.5% | 13.8% | 16.6% | 13.8% |
| 1997 | 15.9% | 21.6% | 22.6% | 20.3% | 13.6% | 16.4% | 13.7% |
| 1998 | 15.6% | 21.4% | 22.8% | 19.7% | 13.3% | 16.4% | 13.6% |
| 1999 | 15.3% | 20.9% | 22.4% | 19.4% | 13.0% | 15.6% | 13.2% |
| 2000 | 15.0% | 20.7% | 21.8% | 19.1% | 12.8% | 14.9% | 13.0% |
| 2001 | 14.9% | 20.7% | 21.3% | 18.8% | 12.5% | 14.2% | 12.4% |
| 2002 | 14.5% | 20.4% | 21.2% | 18.1% | 12.1% | 13.4% | 11.6% |
| 2003 | 14.2% | 20.0% | 21.0% | 17.8% | 11.8% | 12.6% | 11.1% |
| 2004 | 13.8% | 19.6% | 20.7% | 17.4% | 11.5% | 11.9% | 10.8% |
| 2005 | 13.4% | 19.4% | 20.5% | 17.2% | 11.3% | 11.3% | 10.1% |
| 2006 | 13.0% | 19.1% | 20.2% | 17.4% | 11.0% | 10.9% | 9.9% |
| 2007 | 12.7% | 19.0% | 20.1% | 17.4% | 10.7% | 10.6% | 9.7% |
| 2008 | 12.4% | 19.0% | 19.9% | 17.1% | 10.7% | 9.8% | 9.6% |
| 2009 | N.A. | 18.5% | 19.3% | 16.3% | 10.5% | N.A. | 8.9% |

SOURCE: OECD data base STAN

TABLE 3: SHARE OF EMPLOYMENT IN KNOWLEDGE INTENSIVE BUSINESS SERVICES 1990-2009

| | France | Germany | Italy | Japan | Netherlands | United Kingdom | United States |
|---|---|---|---|---|---|---|---|
| Time | | | | | | | |
| 1990 | 9.8% | 27.7% | 6.2% | 6.2% | 11.3% | 4.1% | 9.9% |
| 1991 | 10.0% | 27.4% | 6.4% | 6.6% | 11.4% | 4.1% | 9.9% |
| 1992 | 10.2% | 25.6% | 6.7% | 6.6% | 11.5% | 4.5% | 10.0% |
| 1993 | 10.3% | 24.3% | 6.7% | 6.6% | 11.7% | 4.4% | 10.3% |
| 1994 | 10.7% | 23.1% | 6.8% | 6.6% | 12.4% | 4.4% | 10.7% |
| 1995 | 10.8% | 22.5% | 7.2% | 7.1% | 13.3% | 4.7% | 11.0% |
| 1996 | 10.9% | 21.9% | 7.7% | 7.5% | 14.4% | 4.8% | 11.4% |
| 1997 | 11.4% | 21.6% | 8.2% | 7.7% | 15.1% | 4.8% | 11.8% |
| 1998 | 12.0% | 21.4% | 8.7% | 8.0% | 15.7% | 4.9% | 12.2% |
| 1999 | 12.5% | 20.9% | 9.2% | 8.1% | 15.9% | 4.9% | 12.5% |
| 2000 | 13.2% | 20.7% | 9.9% | 8.6% | 16.0% | 5.1% | 12.4% |
| 2001 | 13.6% | 20.7% | 10.3% | 9.2% | 16.0% | 5.3% | 12.1% |
| 2002 | 13.6% | 20.4% | 10.8% | 9.5% | 15.7% | 5.2% | 11.8% |
| 2003 | 13.4% | 20.0% | 11.0% | 9.7% | 15.4% | 5.3% | 11.8% |
| 2004 | 13.5% | 19.6% | 11.2% | 10.1% | 15.5% | 5.1% | 12.0% |
| 2005 | 13.7% | 19.4% | 11.4% | 10.6% | 16.1% | 5.2% | 13.2% |
| 2006 | 13.9% | 19.1% | 11.5% | 10.9% | 17.0% | 5.0% | 13.4% |
| 2007 | 14.2% | 19.0% | 11.8% | 10.5% | 17.7% | 5.5% | 13.5% |
| 2008 | 14.7% | 13.3% | 12.0% | 10.8% | 17.9% | N.A. | 13.4% |
| 2009 | N.A. | N.A. | 11.9% | N.A. | 17.2% | N.A. | 13.1% |

SOURCE: OECD data base STAN