**A SCHUMPETERIAN GROWTH MODEL: WEALTH AND DIRECTED TECHNOLOGICAL CHANGE[[1]](#footnote-1)**

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**ABSTRACT.** This paper explores the effects of the accumulation of savings on the creative reaction of firms, the search for technological congruence and the direction of technological change with a Schumpeterian model of endogenous growth. The model shows how the accumulation of wealth accounts for the reduction of the relative user cost of capital and activates, with proper levels of knowledge governance, the creative reaction of firms, search for higher levels of technological congruence and the introduction of directed technological change with higher levels of capital intensity. The dynamics of accumulation of wealth and induced technological change accounts the self-sustained increase of total factor productivity.

KEY WORDS: WEALTH ACCUMULATION; TECHNOLOGICAL CONGRUENCE; DIRECTED TECHNOLOGICAL CHANGE.

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**1. INTRODUCTION**

The debate on contribution of Thomas Picketty (2014) to the analysis of the effects of capital accumulation has raised new interest on the study of processes of the creation of stocks. Too often economics assumes that all the relevant variables are just flows. Quite surprisingly, little attention has been paid to appreciating the role of capital accumulation on technological change. The assessment of the effects of the accumulation of the capital stock on the rate and the direction of technological change is likely to yield important results. Results that highlight the positive effects of Picketty’s stimulation to take into account the stock dimension of relevant variables, but do not confirm the results of his analysis.

The empirical evidence shows that the direction of technological change is far from neutral. On the opposite, it exhibits a clear trend towards the introduction of capital intensive technologies. The seminal paper by Solow (1957) documents that the share of property on income in the US economy was 0.335 in 1909. Confirming Solow’s skepticism about the stability of factor shares, the share of property on income more than doubled in 60 years, reaching the pick of 0.720 in 1970 (Solow, 1958).

The paper traces the causes of the increase in the capital share in the changes in the cost of capital, stemming from the accumulation of wealth. The changing relative cost of the main production factors, capital and labor, moves the system towards the search of the new technological congruence (Antonelli, 2012). The latter is at the origins of the biased technological change, directed towards the increasing intensity of capital. The evidence shows that the direction of technological change does affect the rates of change of total factor productivity (Antonelli and Quatraro, 2013).

On such a basis, the paper elaborates an endogenous model of induced technological change and economic growth that accounts for the secular trend of introduction of technological changes directed towards capital intensive technologies. The appreciation of the crucial role of the accumulation of wealth enables to better understand the actual dynamics of the supply of resources for investment.

The model identifies the key determinants of the early phases of industrialization process of advanced countries and the current ones of late developing countries, as well as the causes of its limits.

Figure 1. Income share of capital in private economy (business sectors excl. agriculture, NACE codes C-K), averaged for 18 OECD countries.

Note: Income share calculated as alfa=1-beta, where beta=share of total labor cost over total nominal output Countries included are: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan Korea, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, United Kingdom, United States.

Source: OECD.stat

The model shows that there is a constraint to the self-sustained process of growth that stems from the dynamic balance between the effects of the derived demand of capital and the effects of automatic accumulation of wealth. The accumulation of wealth causes a reduction of capital user costs. This provides the opportunity for the creative reaction of firms that –with good knowledge governance mechanisms at work- can try and take advantage of the changes in factor markets with the introduction of capital intensive technologies. The appreciation of the positive effects on total factor productivity of the introduction of new biased technologies directed at increasing the levels of technological congruence accounts for endogenous growth.

The endogenous growth process slows down when the supply of additional capital declines because of the reduction of saving rates determined by the increase of revenue and the fall of the levels of perceived risks about the future. The growth path is interrupted when the ‘negative effects’ of the accumulation of wealth on the cost of capital are smaller than the ‘positive effects’ of the shift of the derived demand for capital.

The identification of the constraints of this process and the understanding of the role of knowledge governance mechanisms paves the way to specify policy interventions finalized to keep the system in motion on the growth path and to avoid to falling into the trap of equilibrium with no growth.

The rest of the paper is structured as it follows. Section 2 provides the key ingredients of the theoretical framework. Section 3 presents a Schumpeterian model of endogenous growth based upon the interplay between the increasing supply of resources available for investment determined by the sum of the yearly savings and the stock of cumulated wealth, the reduction of the relative user costs of capital, the creative reaction of firms, the search for higher levels of technological congruence and the consequent induced introduction of capital intensive technological change that account for total factor productivity growth. The conclusions articulate the implications for both economic analysis and economic policy.

**2. WEALTH AND THE SEARCH FOR CAPITAL INTENSIVE TECHNOLOGICAL CHANGE**

The Schumpeterian framework of innovation as a –possible- creative reaction that may take place when the amount of knowledge externalities available in a system is large enough to support the reaction of firms that try and cope with changes in factor and product markets, provide the context to grasp the endogenous determinants of both the rate and the direction of technological change (Schumpeter, 1947a and b, Antonelli, 2008 and 2011).

The innovation-as-a-creative-response framework elaborated by the late Schumpeter provides a broad analytical framework, that, next to the traditional emphasis on product markets, accommodates the analysis of the role of factor markets. This framework can include the induced technological change approach that shows that the introduction of technological change is biased, i.e. directed at increasing and saving the intensity of specific inputs according to the specific conditions of factor markets (Ruttan, 2001). Recent contributions to the induced technological change approach have stressed the role of the relative abundance of production factors as a powerful inducement mechanism. Specifically Acemoglu (1998) has elaborated the hypothesis that the new skill bias of technological change can be regarded as a direct consequence of the large increase of the supply of qualified manpower that has characterized the advanced economies in the last decades of the XX century.

In the technological congruence approach all changes in the cost of production factors are likely to activate the creative reaction of firms and the search for higher levels of technological congruence that induce the introduction of biased technological change directed at increasing the output elasticity of the input that became relatively cheaper. Specifically, all reductions in capital user costs are likely to activate a search for higher levels of technological congruence that should induce the introduction of more capital intensive technologies. The introduction of new –directed- technologies has positive effects on total factor productivity that stem both from the changing slope of the new map of isoquants i.e. the bias effects generated by the increased levels of technological congruence and from the inward movements of the mew map of isoquants i.e. the shift effects of the introduction of superior technologies (Antonelli, 2012).

The quality of knowledge governance mechanisms that define the actual amount of knowledge externalities available to firms to support their reaction and make it creative is the third ingredient. With low quality knowledge governance mechanisms, in fact, the reaction of firms, to the changing conditions of factor markets, will be adaptive, instead of creative and the search for higher levels of technological congruence will not take place. In the recombinant generation of technological knowledge the cost of a key, complementary and indispensable input such as external knowledge is so high that the introduction of technological innovations is not viable. Firms will adapt to the factor market conditions simply by means of movements on the existing map of isoquants.

The fourth key ingredient consists in the appreciation of the actual dynamics of cumulated savings. The role of savings in economic growth has received much attention in the Keynesian literature, ever since the classical models of Harrod (1948) and Domar (1941). This literature identifies the levels of the saving rates that are compatible with economic growth. Harrod and Domar however do not explain why should growth take place, neither articulate a causal relationship between saving and growth. In the neoclassical theory of growth it is possible to benefit from the natural rate of growth, determined by exogenous technological change, when saving rates match capital/output ratios (Solow, 1956). Again, as in the Keynesian approach, appropriate saving rates make growth possible, but do not explain how. Saving does not play a role in explaining economic growth in mainstream economics because it is determined exclusively by interest rates with no possible consequences on the exogenous determinants of growth and even less in Keynesian economics because the ratio capital/labor is assumed to be constant (Solow, 1958).

The literature has concentrated its attention on the role of savings as a conditional resource strictly necessary to allowing the full exploitation of the potentialities of exogenous economic growth (Houthakker, 1965). The literature has little explored the role of savings as a cause of technological change. Yet, where, when and if saving rates are high, the supply of capital would be larger and capital user costs lower. This in turn would activate the search for technological congruence with inducement mechanisms towards the introduction of more capital-intensive technologies. If the increase of savings rates is an exogenous shock, this causal relationship can take place only once. As soon as the mix of output elasticity has reached the maximum level of technological congruence there is no reason for the dynamics to take place. If the technological search and the related introduction of the new directed technology take place instantaneously, the adjustment is punctual and no dynamic process can take place (Antonelli, 2013).

If the dynamics of cumulated savings engenders a reduction of capital user costs and the quality of knowledge governance mechanisms at work in a system is high, firms can react in a creative way and introduce new biased technological changes directed at increasing the levels of technological congruence with new technologies characterized by a clear capital-intensive direction. New savings will add to the existing stock of wealth and the dynamics of a self sustained growth process is set in motion. The accumulation of wealth is at the heart of the dynamics (Antonelli and Quatraro, 2010 and 2014).

So far, very little attention has been paid to the accumulation of wealth. The recent book by Thomas Picketty (2014) has brought back to the attention of economics the central role of the stock of accumulated wealth. The supply of resources available for investment, at each point in time, depends not only on the yearly amount of savings, but also, on the amount of wealth accumulated at that time. As a consequence, the amount of resources available for capital investment within a system with savings rates larger than 0 increases ‘automatically’. At each point in time, in fact, current savings add to the existing stock of wealth. The notion of cumulated savings –i.e. the total supply of resources to fund investment- should substitute the notion of savings.

When the notions of technological congruence and creative reaction are taken into account, the implications of the notion of cumulated savings is most important to understanding the actual dynamics of the supply of capital and its consequences on the direction of technological change. Because non-zero savings add on, every year, to the levels of accumulated wealth, it is clear that, in a system characterized by high quality knowledge governance mechanisms that are crucial to support the creative reaction of firms, a self sustained growth process, characterized by directed technological change biased towards the introduction of more capital intensive technologies with the consequent enhancement of total factor productivity levels and hence output, can take place.

The dynamics of cumulated saving increase the total amount of the supply of capital and affects the interest rates that keep, at each point in time, financial markets in equilibrium. The reduction of interest rates, in turn, changes the relative cost of production factors. User capital costs decline with respect to wages. The changes in the relative cost of production factor stirs the reaction of firms and the search for higher levels of technological congruence. With the support of good knowledge governance mechanisms the creative reaction of firms can take place with the introduction of biased technological change directed to increase the output elasticity of the production factor capital that is becoming cheaper. The successful introduction of new directed capital-intensive technologies and of innovations at large accounts for the increase of output and total factor productivity. The former accounts for the increase of revenue that in turn feeds the further increase of the quantity of wealth-cum-saving in the system, the supply of capital, the new reduction of interest rates, in relative terms, and the eventual introduction of new capital intensive technologies and further innovations.

When and where the quality of knowledge governance is low, the changes in factor markets do stir the reaction of firms that, however, cannot be creative, but just adaptive. Firms will substitute the –now- cheaper capital to the more expensive labor, moving on the existing map of isoquants. Output will increase and unit costs decline with positive effects on the system. No increase of total factor productivity, however, can take place. The derived demand of capital will shift to the right for the increase of output. A process of technical –as opposed to technological- change will take place, until the increase of the total amount of resources for investments –yearly savings plus accumulated wealth- and hence the shift of the supply of capital will be able to compensate the shift of the derived demand for capital stemming from the increased levels of output.

When and if the reduction of capital user costs takes place in a system that is able to support the creative reaction of firms and hence the introduction of more capital intensive technologies aimed at increasing the levels of technological congruence, the system experience much a faster positive growth. The increases of the output elasticity of capital now matches the reduction of its costs with positive effects on total factor productivity that add on to the positive effects of the sheer reduction of capital user costs on output. Output increases much more.

A self-sustained process of endogenous directed technological change and economic growth sustained by the continual increase of total factor productivity can take place until the endogenous forces at work produce a continuative increase of the levels of supply of capital that is larger than the increase of its derived demand.

The dynamics of the system face an important constraint. The introduction of capital intensive technologies has in fact the effect to increasing the derived demand for capital. Assuming that, in the short term, the supply of capital has a positive slope, the shift of the derived demand can exert a positive effect on the interest rates. Such an effect may be strong enough to compensate for the negative effects stemming from the increased supply of resources for investment that stem from the sum of savings and the stock of wealth. In such a case the search for technological congruence would stop and the system would fall in the trap of equilibrium. The system can keep growing as long as it is able to compensate the effects of the increased derived demand for capital with the effects on the increased levels of the total supply of resources to investments.

The dynamics of increasing capital-intensity stemming from the increase of the amount of wealth-cum-saving and the relative decline of interest rates that stirs the introduction of capital intensive technological changes and the growth of output and total factor productivity seems able to grasp the contemporary process of industrialization of developing countries as well as the early stages of industrialization of advanced countries. This growth process is bounded by a dynamic constraint for which it is necessary that the shift of the demand for capital stemming from the increase of its output elasticity and of output affects interest rates less than the effects of the automatic increase of the total amount of resources available for investment determined by the addition of new savings to the stock of cumulated wealth. If the shift of the demand yields an increase of interest rates because of the insufficient increase of the supply of wealth-cum-saving, the dynamics of the process stops and the system falls into the equilibrium trap and is unable to grow.

**3. The model**

Let us consider a standard Cobb-Douglas production function with two factors: capital (K) and labour (L). Their elasticity to the output is respectively  and :

(1) 

where *  =* 1.

Denoting with *r* and *w* the price of factors K and L, the total cost equation is:

(2) C = rK + wL

We assume that, because of the search for technological congruence, the output elasticity of production factors depends on their relative cost. Firms, in fact, have a clear incentive to innovate and change their technology so that when the ratio *r/w* lowers, *α* should increase. Hence according to equation (3):

(3) 

Where , so that equation (3) implies that .

Denoting with *p* the output price, profits ** are equal to:

(4) *pY – rK – wL*



from which

From (1), we derive the marginal rate of technical substitution between K and L:



(5)

Firms select the equilibrium mix of inputs by imposing the ratio between the input marginal costs equal to the slope of isoquants. The equilibrium conditions for the couple of factors K-L is thus obtained by imposing (5) equal to the ratio of the marginal prices of factors:



(6)

From (6), in equilibrium it must be:



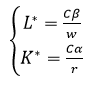
(7)

The optimal mix of productive factors that would entail total costs equal to *C* can be obtained as the solution of the following system:



(9)

The solution of (9) gives:



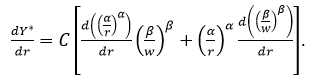
(10)

Substituting (10) in (1), we can express the level of output that can be achieved at the cost :

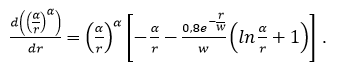


(11)

To show the effect of *r*****on the level of production let us derive (11) with respect to *r*

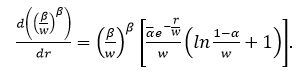


To obtain d[(r)]/dr, we apply the differentiation rule D((f(x)g(x))= f(x)g(x)[g’(x)lnf(x)+g(x)f’(x)/f(x)] where x=r, f(x)= r, g(x)=  and  expressed by (3). We thus obtain:





Similarly,



(14)

Substituting (13) and (14) into (12), we obtain:



(15) 

By using (7), the previous expression can be rewritten as:



(16) 

or, in more general terms, as



(17)

From the previous expression, we have that



(18)

Condition (18) is the necessary and sufficient condition for *dY\*/dr* < 0. However, note that, being *d/dr* < 0, for *dY\*/dr* to be negative, it is sufficient that *K\* > L\**. In other words, if *K\* > L\**, a decrease of *r* induces an increase of *Y*, keeping constant the production cost.

The demand for capital, at each point in time, from (10) it is expressed by



(19)

From expression (19), the instantaneous demand of capital is a decreasing function of *r* and increasing with *α*. Note that when r decreases, Y increases even without technological change.

Extending the result to a macroeconomic level, being *α1* > *α0*, with , it must be for all *r*.

On the side of supply, cumulated savings CS), including current savings and past savings cumulated into wealth, are assumed to be an increasing function of *r* and past savings (S):

(20) CS(r; S) = S +(sY + λr) with s, λ > 0.

The equilibrium interest rate in the capital market is found by balancing the demand for capital (from (19) with its supply (from (20):



(21)

Let us now introduce a further assumption: that the unit cost of financing r is negatively correlated with the amount of current and past savings:

K\*(Y1,1)

CS(Y0)

CS(Y1)

(22) dr/d(CS) < 0.

In Figure 1 we show the variation of the equilibrium interest rate when *α* increases from *α0* to *α1*.

K\*(Y0,0)

r

r0

r1

K, CS

Figure 1. Equilibrium in the capital market

The accumulation of savings over time induces, by (22), a decrease of r from *r0* to *r1*. The reduction of r causes a right shift of the derived demand of capital. This shift will take place both with an adaptive reaction and a creative one. In the latter case it will be stronger. Let us explore the matter in detail.

The derived demand for capital shifts to the right, because of the positive effects on Y of the decline of r, even if firms –because of the low quality of knowledge governance mechanisms at work in their economic system, are not able to implement a creative reaction and introduce biased technological changes aimed at increasing the output elasticity of capital *α*. Their adaptive reaction will consist just in changes of the production techniques on the existing map of isoquants. Yet the decline of r will yield and increase of Y and hence a positive, albeit smaller, shift of the derived demand for capital.

When, instead, the quality of knowledge governance mechanisms is high, firm will be able to take advantage of the reduction of r with a creative reaction and the consequent introduction of biased technological innovations. In this case the right shift of the derived demand of capital is much larger because of the twin effects of the increase of *α* and the larger increase of Y caused by not only the reduction of r but also by the increase of total factor productivity.

As represented in Figure 1, when the reaction is adaptive the demand for capital shifts slightly to the right because of the increase of Y. When, instead, the creative reaction takes place, the initial decrease of *r* causes by (3) an increase of  from *0*, to *1*. This produces, by (19), an augmented increase of the demand for capital, that together with the effects of the increasing levels of Y, shifts the relative function to . If initially *K\* > L\**, this implies also an increase of CS the supply of capital.

*If r2* < *r1*: the initial decrease of *r0* sets in motion an endogenous decrease of the interest rates, leading to a process directed toward a more capital intensive production mix (by means of an increase of K/L) and technological-oriented production function (by means of an increase of ) with the consequent increase of output and total factor productivity.

**4. CONCLUSIONS**

The paper has articulated a Schumpeterian model of endogenous growth based upon the effects of the changing conditions of factor markets on the creative reaction of firms and the search for technological congruence on the dynamics of induced technological change and innovation with the consequent growth of output and total factor productivity. The basic intuition is that the price of production factors may change over time for endogenous determinants that are fully accounted by the standard dynamics of supply and demand so as to engender the reaction of firms to the new conditions of factor markets. When and where the quality of knowledge governance mechanisms is larger, firms can make their reaction creative and actually search for higher levels of technological congruence, and introduce innovations and biased capital-intensive technological changes that yield an increase of total factor productivity and account for a self sustained process of economic growth[[2]](#footnote-2). When and where the quality of knowledge governance mechanisms is lower, firms will only be able to substitute cheaper capital to more expensive labor with positive effects on output, yet much lower with respect to the outcome of creative reactions.

The paper has applied this analytical framework to understanding the effects on economic growth of the secular decline of capital user costs associated to the secular increase of accumulated wealth that adds on to the amount of yearly savings to determining the actual amount of the supply of resources for investment.

The increasing amount of the stock of wealth determined by yearly saving causes the secular increase of the total amount of resources available for investment. This in turn engenders a reduction in the relative cost of capital with respect to labor. The change in relative factor costs stirs the creative reaction of firms supported by high quality knowledge governance mechanisms at work within their systems and the search for technological congruence that induces the introduction of capital intensive technologies. The successful introduction of innovations and specifically of new technologies biased by the higher output elasticity of the input that has become cheaper accounts for an increase of output and total factor productivity. The process is likely to last as long as the increased derived demand for capital affects the equilibrium level of interest rates more than the effects of the cumulated supply of saving-cum-wealth.

Historically it seems that this dynamics is bound to a limit that becomes evident when the increasing levels of revenue in advanced economic systems leads to such a reduction of yearly savings that the shifts towards the right of the total supply of resources for investments is no longer able to compensate for the effects of the shifts towards the right of the derived demand for capital stemming from the introduction of biased technological changes directed towards the introduction of capital intensive technologies. Not surprisingly, the direction of technological change in advanced countries seems no longer directed towards the introduction of more capital intensive technologies and more and more biased in favor of skill-intensive and knowledge-intensive technologies. The shift of the bias from strongly capital-intensive to more skill- and knowledge-intensive is driven not only by the decline of the interest rates, but also by declining costs of skills and knowledge, so that the relative cost of capital to labor doesn’t change that much any more and thus the search for technological congruency is slowed down with respect to capital and enhanced with respect to technological knowledge.

Policy interventions play a major role in the framework outlined by this model: a) to improve the quality of knowledge governance mechanisms; b) to support the accumulation of capital and to favor the transformation of wealth into resource actually available for investments.

Policy interventions aimed at increasing the quality of knowledge governance mechanisms at work in the system are crucial to support and actually make the reaction of firms creative as opposed of adaptive. The access to the existing stock of knowledge and the levels of its absorption costs depend upon the institutional set up of the intellectual property right regimes with special attention to their exclusivity. Patents with strong exclusive rights and a long duration spell may reduce the actual access to the existing stock of knowledge. Intellectual property rights based towards non-exclusive property rights such as the copyright regime or compulsory licensing with royalties may help the combination of appropriate rewards to inventors and better conditions for the widespread and rapid use of the existing stock of knowledge. A strong role of the public supply of technological knowledge generated by a public research and academic system helps the dissemination of knowledge, while the central role of the private supply of technological knowledge may reduce it.

Policy interventions aimed at supporting saving rates and favoring the transformation of wealth and saving into investment can be very effective in helping the system to provide adequate rates of increase of the supply of capital so as to keep the system into the growth path. A large array of policy instruments ranging from fiscal incentives to the support to the viability and profitability –for small investors- of dedicated financial products able to convert swiftly savings to long-term allocations, including, more generally, institutional interventions finalized to make financial markets transparent and effective and to reduce intermediation costs, can be implemented to this purpose. The composition of the stock of wealth plays a major role in this context. Large shares of wealth invested in real estate privately owned by families may reduce the positive effects of the stock of wealth in terms of actual supply of resources to investments for the well-known imperfection of the property markets. To the other extreme it is also clear that the concentration of the stock of wealth into public companies is the most effective way to influence the actual supply of capital.

The dynamics of increased supply of resources for investments that induce the introduction of capital-intensive technologies seems to characterize the rapid industrialization of advanced countries in the early stages of their economic growth and of emerging countries at this time.

**5. ETHICAL STATEMENT**

The author declares that this submission is fully compliant with all the ethical requirements of the Journal of Technology Transfer.

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2. The evidence provided by Karabarbounis and Neiman (2014) fully confirms the secular decline of the share of labor on income. Note that the decline is much stronger when intangible capital is taken into account. [↑](#footnote-ref-2)