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Technological congruence and the economic complexity of technological change

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ABSTRACT

Technological congruence is an emergent system property defined by the matching between the relative size of outputs' elasticity with the relative abundance and cost of inputs in local factor markets. With given total costs, output is larger the larger is the output elasticity of the cheapest input. Technological congruence is a powerful tool that helps grasping the economic complexity of technological change with respect to the determinants of the direction of technological change and its effects in terms of growth accounting and specialization, both at the firm and the system level. Its appreciation stems directly from the advances of the economics of innovation in understanding the endogenous determinants of the introduction and diffusion of directed technological changes. Technological congruence is most relevant to influence the actual levels of total factor productivity of new technologies and – consequently – to shape the competitive advance of firms and countries.

1. Introduction

Technological congruence is an important factor in economic growth both at the firm and the aggregate level. Technological congruence is defined by the relationship between the relative size of outputs' elasticity and the relative abundance and price of production factors. The study of technological congruence is likely to provide a major analytical platform that enables to appreciate the implications of heterogeneity and variety at the microeconomic level for understanding the determinants of both the direction and the rate of technological change and their effects on the dynamics of output and structural change at the system level.

Technological congruence is a fundamental tool to understanding the economic complexity of technological change as it enables to appreciate the necessary interplay between the characteristics of the technology and the properties of the system both in assessing both the effects of technological change and its determinants. The analysis of technological congruence shows, in fact, that the economic effects of each technology depend crucially upon the characteristics of the system into which it is introduced. For the same token the properties of the system, in terms of factor endowment play a crucial role in understanding the direction of technological change (Antonelli, 2011).

Technological congruence has been little studied so far. Yet it is clear that output levels are strongly influenced by the levels of technological congruence. The output will be larger when the technology of the production process enables to use more intensively the production factors that are locally more abundant and hence cheaper. The factor intensity of the production process, in fact, is not

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determined only by the relative costs of inputs but also by the relative size of the output elasticity of each production factor. The distribution of output elasticity among inputs and the relative size of the output elasticity of each input, in turn, are key features of the economic representation of a technology (Antonelli, 2003, 2012).

Technological congruence will be larger the larger is the relative size of the output elasticity of the least expensive in local factor markets. For a given budget, the output of a firm will be larger the larger is the output elasticity of the production factor that is locally cheaper. At the system level it is clear that the output will be larger the larger the output elasticity of the production factors that are locally more abundant and hence cheaper.

The notion of technological congruence has received, so far, little attention. The analysis of its determinants and effects has been quite poor with a scarce appreciation of its relevance. The identification of its implications, however, is calling growing attention (Zuleta, 2012). This substantial neglect can be considered a direct consequence of the widespread consensus about three strong economic assumptions: (a) the stability and homogeneity of outputs elasticity; (b) the static and exogenous character of factor endowments; (c) the neutrality of technological change. Whereas major developments have been made to reconcile the last point, there is still tendency to adopt the first two.

Recent developments in the economics of growth have called attention on the problem. The empirical evidence shows that output elasticity of inputs is far from stable at the aggregate level as it varies considerably across time and countries, as well as at the disaggregate level across firms, regions and industries (Krueger, 1999; Hall and Jones, 1999; Caselli and Coleman, 2006; Caselli and Feyer, 2007). The endowment of both tangible and especially intangible inputs cannot be any longer regarded as an exogenous and static character of economic systems. The relative abundance of many if not all production factors at each point in time can be considered the direct consequence of the economic activities that have been going on (Growiec, 2012). Technological change cannot be any longer regarded as an exogenous process as it is widely recognized that economic forces play a central role in determining its characteristics including its direction that is far from being neutral (Acemoglu, 2003). The contributions that have now explored the role of economic factors in shaping the direction of technological changes have identified the effects of relationship between the levels of the output elasticity of production factors and their costs, on the output levels, introducing the notion of "Factor Saving or Factor Eliminating Innovations" but did not provided a formal analysis (Sturgill, 2012; Zuleta, 2008).

With proper analytical foundations, the notion of technological congruence can acquire much a stronger role in economics. In the rest of the paper Section 2 provides the analytical demonstration of technological congruence and Section 3 shows its effects on total factor productivity. Section 4 investigates the evolutionary complexity of the dynamics of technological congruence. Section 5 outlines its implications for both economic analysis and policy. The conclusions summarize the result of the analysis.

2. The existence of technological congruence

The standard Cobb–Douglas production function seems a suitable and effective starting point. The Cobb–Douglas specification, in fact, accommodates explicitly, with α and β, the output elasticity of the production factors and enables to analyze the effects of their changes. The standard Cobb–Douglas takes the following format:

$$Y(t) = K^{\alpha} L^{\beta} \tag{1}$$

where K denotes the amount of capital and L the amount of labor.

The cost equation is:

$$C = rK + wL \tag{2}$$

Firms select the traditional equilibrium mix of inputs according to the slope of the isocosts given by ratio of labor costs (w) and capital rental costs (r) and the slope of isoquants. The equilibrium condition is:

$$\frac{w}{r} = \left(\frac{\beta}{\alpha}\right)\left(\frac{K}{L}\right) \tag{3}$$

The substitution of the equilibrium condition into the production function, assuming that $\alpha + \beta = 1$, leads to:

$$Y = \left(\frac{w}{r}\right)^{\boldsymbol{\alpha}} \left(\frac{\boldsymbol{\alpha}}{\boldsymbol{\beta}}\right)^{\boldsymbol{\alpha}} L \tag{4}$$

At this time we have not – yet – introduced the hypotheses that: (i) the firm can change its technology so as to chose the output elasticity of the inputs, and (ii) the sheer change of the output elasticity does affect the output. If this were the case it is obvious that the profit maximizing firm should choose the α which maximizes output. This would amount to assume that technological change is not neutral and its direction is influenced by the profit opportunities stemming from the relative factor cost. The positive effects of this choice, however, have yet to be demonstrated. This is what we are going to do. To show the effect of $\boldsymbol{\alpha}$ on the production function let us derive (4) with respect to α·

To do this, we exploit the derivation formula $D(f(\alpha)g(\alpha)) = f'(\alpha)g(\alpha) + f(\alpha)g'(\alpha)$, with $f'(\cdot)$ and g' $(\cdot)$ denoting the first derivative of the function, and we adopt the following substitutions: $f(\alpha) = L(w/r)^{\alpha}$ and $g(\alpha) = [\alpha/(1-\alpha)]^{\alpha}$, thus obtaining:

$$\frac{dY(L)}{d\alpha} = L\left(\frac{w}{r}\right)^{\alpha}\left(\ln\frac{w}{r}\right)\left(\frac{\alpha}{1-\alpha}\right)^{\alpha} + L\left(\frac{w}{r}\right)^{\alpha}\frac{d\left(\left(\alpha/1-\alpha\right)^{\alpha}\right)}{d\alpha} \tag{5}$$

To obtain $d[(\alpha/1-\alpha)^{\alpha}]/d\alpha$, we apply the differentiation rule $D(f(\alpha)^{g(\alpha)}) = f(\alpha)^{g(\alpha)}\,[g'(\alpha)\ln f(\alpha) + g(\alpha)f'(\alpha)/f(\alpha)]$ where $f(\alpha) = \alpha/1-\alpha$) and $g(\alpha) = \alpha$. We thus obtain:

$$\frac{d\left(\left(\alpha/1-\alpha\right)^{\alpha}\right)}{d\alpha}$$