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## **A measure of total factor productivity with biased technological change**

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### **Abstract**

The paper elaborates a new measure of total factor productivity that accounts also the biased technological change effect. In our proposal, total factor productivity growth over the interval  $(0,t)$  is given by the ratio between the observed production at time  $t$  and the theoretical production that firms should realize by using the same technology available at time  $0$ . Using the KLEMS database of 13 OECD countries from 1973 to 2005, we show that the proposed measure captures a relevant aspect of the technological change. In addition, we observe that the direction and the effects of technological change varies considerably across time and countries.

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The paper elaborates a new measure of total factor productivity that accounts also the biased technological change effect. In our proposal, total factor productivity growth over the interval  $[0, t]$  is given by the ratio between the observed production at time  $t$  and the theoretical production that firms should realize by using the same technology available at time 0. Using the KLEMS database of 13 OECD countries from 1973 to 2005, we show that the proposed measure captures a relevant aspect of the technological change. In addition, we observe that the direction and the effects of technological change varies considerably across time and countries.

**JEL classification:** O33; D24; O40.

**Keywords:** Directed Technological Change; Isoquant Shift; Technological Congruence; Neutral Technological Change; Output Elasticity.

# 1 Introduction

Productivity is an economic measure of the level of technology. According to Acemoglu (2015, 1998), technological change is neutral, if it affects the productivity of all input factors in the same way, and biased, if it has a differentiated impact. The literature on *BTC* claims that the technological change is congruent (incongruent) if it affects positively (negatively) the cheaper input factor (Abramovitz, 1956; Antonelli, 2016).

In this paper, we modify the Solow's (1957) measure of total factor productivity (*TFP*) to account for the *BTC* effect. Following the literature on *BTC*, we split the effects that a technological change has on productivity into two parts: the neutral technological change (*NTC*) effect, and the biased technological change (*BTC*) effect. The first effect is positive (negative) if the technological change increases (decreases) the productivity of all input factors. Using a capital-labor textbook diagram, a *NTC* corresponds to a parallel shift of the isoquant. Provided that input costs do not vary, the optimal mix of input factors remains unchanged. The second effect is positive (negative) if the technological change increases the productivity of the cheaper (more expensive) input factor. Graphically, a *BTC* is a slope shift of the isoquant that affects the relative productivity of input factors, which, in turn, affects the *TFP*. In this case, when the input costs do not vary, the optimal mix of input factors changes.

We measure the *TFP* growth over the interval  $[0, t]$  as the ratio between the observed production at time  $t$  and the theoretical production that firms should realize by using the technology available at the time 0. More precisely, the theoretical production is the production function excluding the Hicks-neutral (*NTC*) and the output elasticity (*BTC*) effects. The *BTC* has both a direct effect and an indirect effect on the factor productivity (Feder, 2016). On the one hand, a variation in output elasticity directly changes the productivity. On the other hand, a variation in output elasticity changes the amount of endowment factors, which, in turn, changes the productivity.

The key aspect of our approach is to split the *TFP* growth in the two components (*NTC* and *BTC*) considering some interesting features. First, our decomposition has two notable measures of *TFP* growth as special case. In particular, if there is only the *NTC* effect, the *TFP* coincides with Solow's definition; however, if there is only the *BTC* effect, the *TFP* coincides with Acemoglu's definition. Second, the *TFP* is not affected by a modification of input costs. Finally, the intensity of the *BTC* effect does not change if it raises or lowers the productivity.

Moving from the seminal contribution of Solow (1957), there are two notable papers that measure the *BTC* effect on the *TFP*: Bernard and Jones (1996) and Antonelli (2006). In the former, the theoretical production is the production function without the Hicks-neutral and the endowment of input factors effects, i.e. they

do not consider the direct effect that a change of output elasticity has on the productivity. In the latter, the theoretical production is the production function without the Hicks-neutral and the direct output elasticity effects, i.e. he does not consider the indirect effect that a change of output elasticity has on the endowment of input factors. Both methods measure correctly the *NTC* effect but not the *BTC* effect. This implies that not all the previous properties hold (Feder, 2016). In particular, in Bernard and Jones (1996) the modification of input costs affects the *TFP*. Instead, both in Antonelli (2006) and in Bernard and Jones (1996) the intensity of the *BTC* effect changes if it raises or lowers the productivity.<sup>1</sup>

Antonelli (2016) revises his previous method to consider both the direct and the indirect effect of the *BTC* on the *TFP*. He uses a sophisticated methodology to compare the observed output per worker with the theoretical output per worker. However, remembering that the *BTC* affects also the endowment of labor, Antonelli (2016) compares the observed output per worker with the theoretical output per theoretical worker. Therefore, the comparison of two variables with different units of measurement makes inaccurate the measure of *TFP*.

Finally, we implement our measure with the KLEMS database of 13 OECD countries during the period 1973-2005. Using this balanced panel database, we measure *TFP* and we split the *TFP* into the *NTC* and *BTC* effect. We conclude that the new measure of *TFP* differs systematically from the standard one. Indeed, the *BTC* effect is a relevant aspect of the productivity of input factors. In addition, we also show that the *BTC* effect is neither stable in the time nor homogeneous across countries.

The rest of the paper is organized as follows. Section 2 presents our approach to measure *TFP*. Section 3 implements empirically the method. Section 4 concludes.

## 2 A new measure of TFP

*TFP* is a measure of the effect of technological change on the overall productivity of input factors.<sup>2</sup> Commonly, to obtain a measure of the *TFP*, it assumed a production function with the following functional form:

$$Y_t = A_t \cdot f(K, L), \quad (1)$$

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<sup>1</sup>Same critiques are applied to papers that develop the Bernard and Jones' (1996) method (Ji and Wang, 2014; Li and Ji, 2014) and the Antonelli's (2006) method (Antonelli and Quatraro, 2014; 2013; 2010).

<sup>2</sup>There are some criticisms with the interpretation of the *TFP* only as the technology change, e.g. Abramovitz (1956) and Jorgenson and Griliches (1967). However, in this paper we use the Solow's (1957) interpretation to highlight a new critical aspect of this measure.

where  $A_t$  is the (neutral) technology at time  $t$ ; and  $f(K, L)$  is the production when  $A_t = 1$ , depending on the capital,  $K$ , and labor,  $L$ , input factors. However, a change of  $A_t$  affects all input factors in the same way, i.e. equation (1) accounts for the *NTC* effect. In other words,  $f(K, L)$  is the production function in the absence of *NTC* effect.

In order to take into account for also the *BTC* effect, we define  $\tilde{f}$ ,  $\tilde{K}$  and  $\tilde{L}$ , respectively, as the functional form of  $f$  and the input factors  $K$  and  $L$  that we should have without the *BTC* (explanations follow). More specifically, we can modify (1) in the following way:

$$Y_t = A_t \cdot \frac{f(K, L)}{\tilde{f}(\tilde{K}, \tilde{L})} \cdot \tilde{f}(\tilde{K}, \tilde{L}). \quad (2)$$

Given that  $f(K, L)$  is the production function in the absence of *NTC* effect; and that  $\tilde{f}(\tilde{K}, \tilde{L})$  is the production function in the absence of *NTC* and *BTC* effect, then the (logarithmic) difference of  $\tilde{f}(\tilde{K}, \tilde{L})$  and  $f(K, L)$  is the *BTC* effect. We can rewrite (2) as:

$$Y_t = T_t \cdot \tilde{f}(\tilde{K}, \tilde{L}), \quad (3)$$

where  $T_t = A_t \cdot f(K, L) / \tilde{f}(\tilde{K}, \tilde{L})$ . Respect to (1), in (3) the multiplicative factor,  $T_t$ , simultaneously accounts for the *NTC* effect,  $A_t$ , and for the *BTC* effect,  $f(K, L) / \tilde{f}(\tilde{K}, \tilde{L})$ . In addition, when there is no *BTC*, then  $f(K, L) = \tilde{f}(\tilde{K}, \tilde{L})$ , and we go back to (1). Thus, this formulation satisfies the fact that an *NTC* is a shifter of the whole production function. On the contrary, if there is no *NTC*, then  $A_t = 1$ , and therefore the change in total productivity is caused by the relative effect of the differential change of the two input factors on the production level. Knowing that  $T_t = A_t \cdot f(K, L) / \tilde{f}(\tilde{K}, \tilde{L})$ , it is possible to split the *TFP* into the *NTC* and *BTC* effect:

$$\ln(TFP_t) = \ln(NTC_t) + \ln(BTC_t). \quad (4)$$

To apply this intuition, we can start with a graphical example that clarify how technological change, neutral and/or biased, influences productivity. Figure 1 illustrates a shift of the isoquant curve (referring to a given production level) induced by a generic technological change. Let the solid curves be the initial,  $E_0$ , and the final,  $E_1$ , equilibria, and the dotted curve the virtual isoquant corresponding to a neutral shift. Therefore,  $\tilde{E}_1$  is the virtual equilibrium with the (dashed) isoquant curve at time 1 without the *BTC* effect. Thus, the intermediate point  $\tilde{E}_1$  shows that the productivity change can be split into a parallel shift and a slope shift of the isoquant.

The previous example can be represented in mathematical terms through a Cobb-

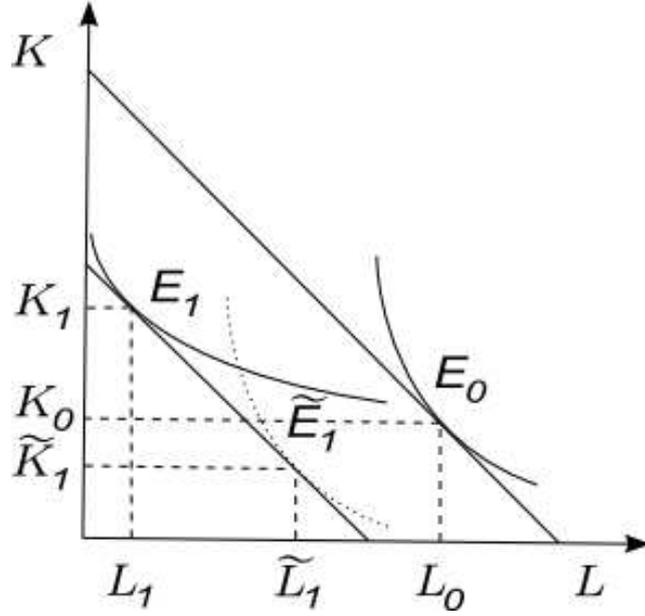


Figure 1: The effects of a technological change on the isoquant

Douglas production function with constant returns to scale. From (1) we obtain:<sup>3</sup>

$$Y_t = A_t \cdot f(K, L) = A_t K_t^{\alpha_t} L_t^{1-\alpha_t}, \quad (5)$$

where  $\alpha_t$  and  $1 - \alpha_t$  define, respectively, the output elasticity of capital and of labor at time  $t$ . Like Solow (1957), we introduce the following normalization:  $A_0 = 1$ .

In a first step, let us assume that there is only an *NTC*, i.e.  $TFP = NTC$ . Then, in order to get a measure of *TFP*, we compare the observed production at time  $t$ ,  $Y_t$ , with the theoretical production that firms should realize by using the same neutral technology available at time 0,  $A_0$ . Thus, from (5), the *NTC* at time  $t$  is given by:

$$NTC_t = \frac{Y_t}{f(K, L)} = \frac{Y_t}{K_t^{\alpha_t} L_t^{1-\alpha_t}}. \quad (6)$$

This is the same solution obtained by Solow (1957) and it measures only the neutral shift effect of technological change (Antonelli, 2006; Feder, 2015).

Now suppose a generic technological change, i.e. a change in technology that includes a *BTC* and an *NTC*. In order to provide a measure of *TFP*, we propose to rely on (3). The *BTC* alters the output elasticity of inputs, and therefore the

<sup>3</sup>As all the literature that measure the *BTC* effect on *TFP*, we assume that the production function is a Cobb-Douglas. However, (3) and the following methodology could be more general, e.g. a CES production function (Doraszelski and Jaumandreu, 2014).

technical choice. Therefore, the *TFP* at time  $t$  is given by:

$$TFP_t = \frac{Y_t}{\tilde{f}(\tilde{K}, \tilde{L})} = \frac{Y_t}{\tilde{K}_t^{\alpha_0} \tilde{L}_t^{1-\alpha_0}}, \quad (7)$$

where  $\tilde{K}_t$  and  $\tilde{L}_t$  are, respectively, the capital and labor that firms would optimally choose at time  $t$  if the output elasticity of inputs fixed at time 0. By Euler's theorem, we know that in equilibrium the value of optimal factors are:

$$K_t = \frac{\alpha_t Y_t}{r_t}, \quad (8)$$

$$L_t = \frac{(1 - \alpha_t) Y_t}{w_t}. \quad (9)$$

where  $r_t$  and  $w_t$  are, respectively, the unitary cost of capital and labor at time  $t$ . Hence, it is possible to find the value of  $\tilde{K}_t$  and  $\tilde{L}_t$ :<sup>4</sup>

$$\tilde{K}_t = \frac{\alpha_0 Y_t}{r_t}, \quad (10)$$

$$\tilde{L}_t = \frac{(1 - \alpha_0) Y_t}{w_t}. \quad (11)$$

Indeed, (10) and (11) are, respectively, the capital and labor that firms would optimally choose at time  $t$ , (8) and (9), if the output elasticity of inputs fixed at time 0,  $\alpha_0$ . Hence, putting (10) and (11) in (7) we find the *TFP*,  $T_t$ . Since  $r$  and  $w$  can change in  $t$ , the modification of input costs does not affect the *TFP* measure.

Therefore, using (6), we can compute the *NTC* effect on the productivity function, and, using (4) and (7), we can compute the logarithmic *BTC* effect, in the following way:

$$\ln(BTC_t) = \ln(TFP_t) - \ln(NTC_t). \quad (12)$$

When  $\ln(BTC)$  is above (below) zero, then the directionality of the technological change increases (decreases) the *TFP*. In other words, if the technological change affects positively (negatively) the cheaper input factor, formally, if the new output elasticity of the cheaper factor is higher (lower) than the previous one, then the output,  $Y_t$ , increases (decreases). This is exactly how *BTC* affects productivity in the literature (Acemoglu, 2007; Acemoglu and Zilibotti, 2001). From (2), we also

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<sup>4</sup>Although it is obvious that changes of output elasticity may affect the derived demand of input; we assume that there are not effects on inputs cost due to compensatory changes on the supply side.

have all the variables needed to calculate the *BTC* effect directly:

$$BTC = \frac{f(K, L)}{\tilde{f}(\tilde{K}, \tilde{L})} = \frac{K_t^{\alpha_t} L_t^{1-\alpha_t}}{\tilde{K}_t^{\alpha_0} \tilde{L}_t^{1-\alpha_0}}, \quad (13)$$

but in the literature, a logarithmic formalization is often preferred because it is considered easier to interpret.

Until now, the main measures of *TFP* with *BTC* are asymmetric, i.e. the directionality of technological change affects its intensity (Feder, 2016). Therefore, it is interesting to understand if the increases or the decreases of the output elasticity affects the intensity of the biased effect also in our method. Studying how  $\alpha_t$  affects (12), we find:

$$\frac{dBTC}{d\alpha_t} = \ln\left(\frac{K}{L}\right) \frac{K^{\alpha_t} L^{1-\alpha_t}}{\tilde{K}^{\alpha_0} \tilde{L}^{1-\alpha_0}}, \quad (14)$$

then the directionality of technological change,  $\alpha_t - \alpha_0 \lesseqgtr 0$ , does not affect the intensity of the biased effect,  $|BTC|$ . Indeed, the module of (14) is the same if  $\alpha$  increases or decreases.

Summarizing, we found a new measure of *TFP* that accounts not only the *NTC* effect but also the *BTC* effect of technology. We showed that the proposed method has some interesting properties. Firstly, if  $\alpha_t$  does not change, then *TFP* offers a measure of the *NTC* effect. Secondly, if  $A_t$  does not change, the *TFP* offers a measure of the *BTC* effect. Third, as expected, the logarithmic effect of the *BTC*, i.e.  $\ln(BTC)$ , is positive if the variation in the output elasticity is in favor of the cheaper input factor; and negative if the change in output elasticity is in favor of the more expansive input factor. Moreover, the extent of the *BTC* is symmetric: that is the direction of the technological change affects the sign of the logarithmic biased effect but not its intensity. Finally, the *BTC* and the *NTC* are not affected by a modification of input costs. To the best of our knowledge, this is the first measure of *TFP* with all of these desirable properties.

## 3 An empirical implementation

### 3.1 Methodology

The methodological extension proposed to measure the *TFP* and to split the *TFP* into the *NTC* and *BTC* effect clearly relies on the traditional growth accounting approach. For the empirical implementation, we use the KLEMS database of 13 OECD countries, i.e. Australia, Belgium, Denmark, Finland, France, Germany, Italy, Japan, Korea, Netherlands, Spain, United Kingdom and United States, during

the period 1973-2005.<sup>5</sup> This balanced panel database has the following standards variables for each country:

$$Y_t; w_t; L_t; K_t, \forall t = 0, \dots, T.$$

By Euler's theorem, under constant returns to scale, it is possible to estimate in each country:

$$\alpha_t = 1 - \frac{w_t L_t}{Y_t}, \forall t = 0, \dots, T.$$

In particular, we can also estimate the output elasticity of inputs at time 0. Thus, it is possible to calculate the *NTC* effect on the productivity, i.e.  $A_t$ , using (6) and normalizing  $A_0 = 1$ . Until now, the implementation coincides with the Solow's (1957) methodology. Hence, we need to estimate the theoretical amount of input factors that there would be if the same technology available at time 0,  $\tilde{K}_t$  and  $\tilde{L}_t$ . First of all, reusing Euler's theorem, we can also to calculate the unitary cost of capital:<sup>6</sup>

$$r_t = \frac{\alpha_t Y_t}{K_t}, \forall t = 0, \dots, T.$$

Therefore, from (10) and (11) we can measure the *TFP*. Finally, from (6), (7) and (13) it is possible to measure the *TFP* and the *BTC* effect on the productivity. To simplify the interpretation, we use the logarithmic form of *TFP*, *NTC* and *BTC* effect. Indeed, with the pure values of *TFP*, *NTC* and *BTC*, we obtain the same interpretation of values with the logarithmic form, but the threshold level is 1 (and not 0).

### 3.2 BTC, NTC and TFP

We start discussing the evolution of the output elasticity of capital of the 13 countries from 1973 to 2005. Figure 2 measures  $\alpha$  under the assumption of constant return to scale and shows that also comparing similar developed countries, the output elasticity of inputs follow divergent paths (e.g. United States versus Germany) and that its level could be different from country and/or timing (Antonelli and Quatraro, 2014, 2013, 2010; Blanchard, 1997). For example, in 2005, the United Kingdom level of output elasticity of capital is 0.35; but in the same year, the Italian level is 0.55. In addition, in Finland  $\alpha$  changes from 0.35 to 0.46 in only a decade (from 1991 to

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<sup>5</sup><http://www.euklems.net>

<sup>6</sup>Given the blurred definition of  $r_t$ , in order to calculate the output elasticity of inputs the empirical literature tends to prefer  $w_t$ . Furthermore, estimates of  $r_t$  show that this variable is lower than that assumed by the theoretical literature. However, if Euler's theorem holds to calculate the output elasticity of labor, then there is no reason why it does not hold to calculate the output elasticity of capital.

2000). In general, the range of the levels of the output elasticity of capital for these 13 OECD countries is between 0.29 and 0.66. It is also interesting to observe that since the end of the seventies the variability of  $\alpha$  is almost the same in the database. Thus, there is no convergence between the countries on a particular level of output elasticity of inputs. Finally, from a synchronically point of view, we can conclude that the order of countries, from the higher level of  $\alpha$  to the lower one, changes the own composition considerably in time.

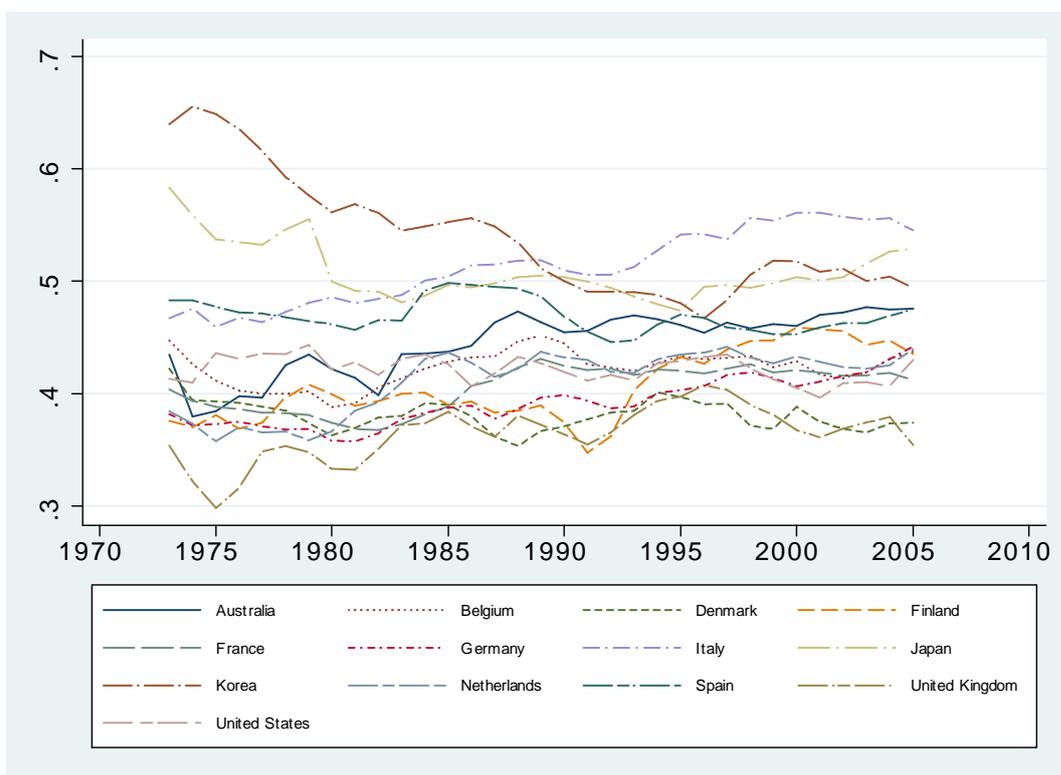


Figure 2: The evolution of  $\alpha$ . The output elasticity of capital in 13 countries from 1973 to 2005.

Therefore, we can conclude that the fix level of elasticity of outputs assumption used in the main literature on growth accounting (Cobb and Douglas, 1928; Kaldor, 1961) is not empirically supported. Scholars confirm that the output elasticity of inputs varies considerably across time and across space (Hall and Jones, 1999; Jerzmanowski, 2007; Kahn and Lim, 1998; Seater, 2005). In particular, this literature affirms that the income is one of the most important explanatory variable of the divergent levels of the output elasticity of inputs (Caselli and Coleman, 2006; Caselli and Feyer, 2007; Sturgill and Zuleta, 2014). Using this observation, all results of our paper are stronger. Indeed, independently of the results of our analysis between

similar and rich countries, adding poor countries in the database, probably the *BTC* effect and its path are still more relevant issues than the following results.

In order to show the relevance of the new approach, we confront and discuss the comparative study of the evolution of the 2 indicators, the standard ‘Solow’ and the new one, across 13 developed countries from 1973 to 2005. Figure 3 compares the Solow’s notion of *TFP* (the dashed curve), i.e. the  $\ln(NTC)$  effect, with the proposed one (the continuous curve), i.e. the  $\ln(TFP)$ . It emerges that the two measures are deeply different, thus the proposed method captures a relevant aspect of technological change on the productivity of factors. The relevance of the new definition of *TFP* depends both on the country and on the year that we analyze. For example, in Japan the *BTC* effect is always more relevant than in Spain; in the same way, in Nederland the *BTC* effect is always more relevant after than before the 1983. Finally, we observe that the *TFP* is smoother than the *NTC*; then the *BTC* has a moderating effect on the consequences of the introduction of innovations shock. In other words, this database supports the non-neutrality of the technological change and its diverging directionality conclusions.

Figure 3 also shows the relevance of the *BTC* concept. Indeed, by (4), the area between the two curves in Figure 3 measures the *BTC* effect that the technological change has on productivity. Indeed, each point on the dashed curve shows the potential amount of *TFP* that a country, in a particular time, should have if there is not directionality of the technological change and the continuous curve shows the observed amount of *TFP*, in a particular time, with both neutral and biased effects. For example, in 2005, thanks to the technological congruence with its own input factors, the Korean *TFP* is not 2.47 but 3.09; vice versa, in the same year but with an incongruent technological change, the Italian *TFP* is not 3.06 but 2.66. Therefore, we can observe four different patterns of *BTC* of these developed countries: the *BTC* effect is almost always positive (Belgium, Denmark, Japan and Korea); the *BTC* effect is almost always negative (Finland and Italy); in a first period the *BTC* effect is positive and then it is negative (Australia, France, Germany, Nederland and United Kingdom); and repeated changes of the direction of the *BTC* effect (Spain and United States).

Figure 4 summarizes all previous results. Indeed, it measures both the output elasticity of capital (the dashed curve) and the *BTC* effect in logarithmic terms (the continuous curve). However, comparing  $\alpha$  and the  $\ln(BTC)$  effect emerges that the heterogeneity of the time and the space of the *BTC* directly depends on the instability and missing homogeneity of the output elasticity of inputs. Finally, Figure 4 shows that, given the scale arrangements, the two variables evolve in a perfectly symmetric way. In particular, it emerges that an increases of the output elasticity of capital, affects negatively the *BTC* effect and then this confirms the accuracy of the new measure of *BTC* effect. Indeed, we observe that the *BTC* effect on productivity is affected only from the change of output elasticity of inputs and

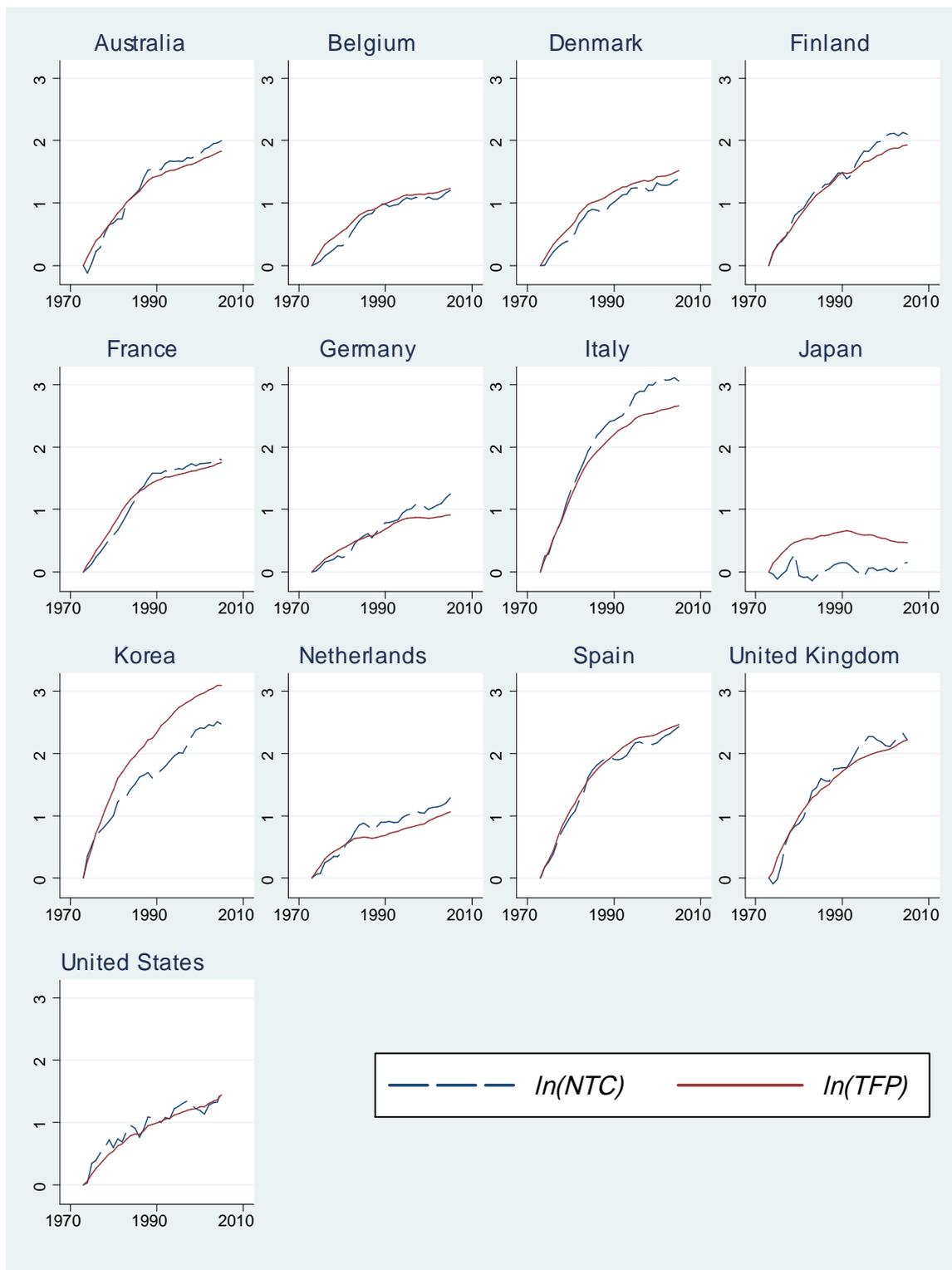


Figure 3: The evolutions of  $\ln(TFP)$  and  $\ln(NTC)$ . The values of  $TFP$  (continuous curve) and  $NTC$  (dashed curve) in logarithmic terms for each country from 1973 to 2005.

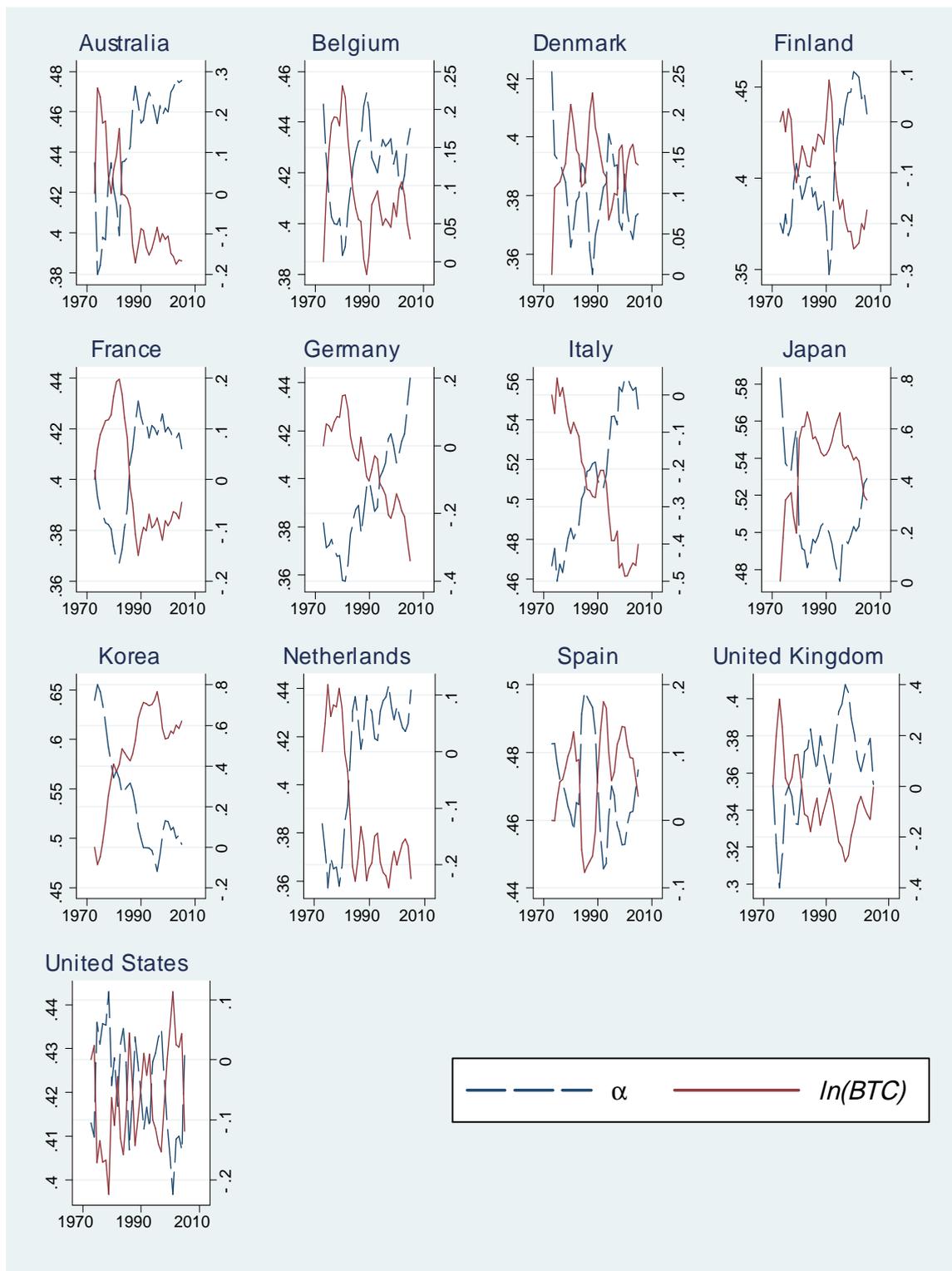


Figure 4: A comparison between  $\alpha$  and  $\ln(BTC)$ . The output elasticity of capital (dashed curve and right vertical axes) and the logarithmic values of  $BTC$  (continuous curve and left vertical axes) for each country from 1973 to 2005.

not of other variables (e.g. the price). In addition, the property of symmetry holds because the increase or the reduction of the same amount of  $\alpha$  affects only the sing of the  $\ln(BTC)$  but not its intensity.

## 4 Conclusion

Technological change modifies the productivity of an economy. To measure the technological change effects on productivity scholars often use the *TFP*. However, this measure does not take into account for the effect of biased technology described in Acemoglu (1998). The aim of this paper is to find a more inclusive measure of productivity that considers both *NTC* and *BTC* effects. Testing empirically the model with the KLEMS database of 13 OECD countries from 1973 to 2005, we show that the *BTC* is a relevant component of the technological changes and, in particular, we find that the *BTC* effect varies considerably across time and countries, also comparing similar developed country.

The next step is to use the new method to calculate more precisely the *TFP* in many and different contexts. For example, the advancements in the information and communication technologies (ICT) were responsible for a biased modification of production technology (i.e. *BTC*) in the organization of the production process, since skilled labor becomes more productive, while unskilled labor becomes less productive (Ketteni et al., 2011; Strohmaier and Rainer, 2015). In the first stage of the ICT revolution, leading economists noted that there was no significant growth in productivity so this puzzle was referred to as the ‘ICT productivity paradox’ (Brynjolfsson, 1993; Franke, 1987). In the second stage, firms started to modify the input factor mix, inducing an increase of productivity (Brynjolfsson and Hitt, 1996; Chun, 2003). This growth could be largely attributable to *BTC*.

Another application of the *BTC* concept could be found in the field of international trade (Antonelli, 2014; Zuleta and Pogorelova, 2014). Indeed, scholars uses two possible explanations for the specialization of a country: the exogenous technological differences (Di Maio, 2008; Ricardo, 1817); or the endowment of input factors (Rybczynski, 1955; Stolper and Samuelson, 1941). Using the direction of technological change to endogenize the technological differences between countries then the *BTC* approach could be connect both previous explanations.

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