Department of Economics "S. Cognetti de Martiis"

Via Po, 53 – 10124 Torino (Italy)
Tel. (+39) 011 6704917 - Fax (+39) 011 6703895
URL: http//www.de.unito.it

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Shifting the Bias: How to Disentangle Creative Adoption from Radical Innovation. Empirical Evidence from Italy and the US

Cristiano Antonelli e Francesco Quatraro

Dipartimento di Economia "S. Cognetti de Martiis"

Laboratorio di Economia dell'Innovazione "Franco Momigliano"

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Cristiano Antonelli

and

Francesco Quatraro

Laboratorio di Economia dell'Innovazione "F. Momigliano"
Dipartimento di Economia "S. Cognetti de Martiis"
Università di Torino
Via Po 53, 10124 Torino

ABSTRACT. The standard measures of total factor productivity growth assume the neutrality of technological change. When technological change is biased, the matching between the factor intensity and the relative factor prices has powerful effects on total factor productivity. This paper presents a novel methodology able to take into account the effects of biased technological change and provides empirical evidence for the Italian and the US economies in the period 1980-2000.

1. Introduction

The direction technological change has received scarce attention, despite the seminal intuitions by Hicks (1932), and the following interest by economic historians like Rosenberg (1969) and David (2004).

Many efforts have been undertaken in contexts using Malmquist productivity indexes to decompose total factor productivity in a magnitude and in a bias component (see Fare et al, 1997; Managi and Karemera, 2004). Growth accounting methodology *à la* Solow, instead, neglected the dynamics of biased technological change and its effects on total factor productivity (TFP), mainly focusing on the measure of Hicks-neutral technological change[1] (TC).

[1] The work by Bernard and Jones (1996) represents an exception in this framework. They acknowledge that the standard TFP measure is not sufficient in contexts characterized by differences also in factors' elasticities. They develop an index of total technology productivity which account for both differences in the traditional *A* term and in factors' exponents. However such an index is sensible to level of capital intensity used as a benchmark, and anyway it does not account separately for the effect of biased TC.

However, as showed in Table 1, output elasticities changed very much over time in OECD countries. Production functions hence are likely to undergo a twofold process of shift and change in their shape due to effects of TC.

INSERT TABLE 1 ABOUT HERE

In this paper we propose a methodology to compute a new TFP index able to identify these two different effects. The use of such an index has a direct bearing upon the empirical analyses of TC, in that it allows for a better understanding of innovation dynamics at stake within the new knowledge-based economies.

We call such an index *bias-TFP*, and it differs from the Solow's residual in that it allows for accounting for productivity changes due to changes in production factors' output elasticities. We calculated the index drawing on OECD data for the Italian and the US economies and we compared the dynamics of Hicks' neutral and biased TC over the period 1971-2001.

The paper is organized as follows. Section 2 offers a detailed description of the methodology, emphasizing the meaning of indexes from the viewpoint of the economics of innovation. In Section 3 we present the data, showing a practical example of calculation. The empirical analysis follows in Section 4, and finally some conclusions are drawn in Section 5.

2. Methodology

To obtain the bias-TFP index we first calculated standard TFP following a growth accounting approach (Solow, 1957; Jorgenson, 1995; OECD, 2001). The output Y of each country i at time t, is produced from aggregate factor inputs, consisting of capital services (K) and labour services (L), proxied in this analysis by total worked hours. TFP (A) is defined as the Hicks-neutral augmentation of the aggregate inputs. Such a production function has the following shape:

$$Y_{i,t} = A_{i,t} \cdot f(K_{i,t}, L_{i,t}) \tag{1}$$

Whose standard Cobb-Douglas takes the following format:

$$Y_{i,t} = A \cdot K_{i,t}^{\alpha_{i,t}} \cdot L_{i,t}^{\beta_{i,t}} \tag{2}$$

If we take logarithms of equation (2), we can write TFP as follows:

$$\ln A_{i,t} = \ln Y_{i,t} - \alpha_{i,t} \ln K_{i,t} - \beta_{i,t} \ln L_{i,t} \tag{4}$$

Where $\alpha_{i,t}$ and $\beta_{i,t}$ represent the factors' share in total factor income for each country at each year, and $\alpha + \beta = 1$.

Such a measure accounts for "any kind of shift in the production function" (Solow, 1957: 312), and it can be considered a rough proxy of technical change. By means of it Solow meant to propose a way to "segregating shifts of the production function from movements along it". But the change in the technology of the production function is made up of two elements. Besides the shift effect one should account for the bias effect, i.e. the direction of TC.

Once we get the TFP accounting for the shift in the production, we can investigate the impact of the bias effect with a few passages. First of all we get a measure of the TFP which accounts for both effects (for this reason we call it *total-TFP*), by assuming output elasticities unchanged with respect to the first year observed:

$$\ln A_{i,t}^{TOT} = \ln Y_{i,t} - \alpha_{i,t=0} \ln K_{i,t} - \beta_{i,t=0} \ln L_{i,t} \tag{5}$$

Next we get the bias effect as the difference between the two indexes we introduced above, i.e.:

$$A_{i,t}^{BIAS} = A_{i,t}^{TOT} - A_{i,t} \tag{6}$$

Under the assumption of perfect competition and constant returns to scale, standard TFP growth is derived as the growth of output minus a share weighted growth of inputs:

$$d \ln A_{i,t} / dt = d \ln Y_{i,t} / dt - \overline{\alpha}(d \ln K_{i,t} / dt) - \overline{\beta}(d \ln L_{i,t} / dt) \tag{7}$$

with a bar representing the averages of factors' share over the period considered. In the same way, the growth rate of the total-TFP can be obtained as follows:

$$d \ln A_{i,t}^{TOT} = d \ln Y_{i,t} / dt - \alpha_{i,t=0}(d \ln K_{i,t} / dt) - \beta_{i,t=0}(d \ln L_{i,t} / dt) \tag{8}$$

Where it is straightforward that we do not take averages over the period, as output elasticities remain unchanged over time. The growth rate of bias-TFP can be finally calculated by using the property of derivatives according to which the derivative of a difference equals the difference of derivatives. Hence:

$$d \ln A_{i,i}^{BIAS} / dt = d \ln A_{i,t}^{TOT} / dt - d \ln A_{i,t} / dt \tag{9}$$

3. TFP Indexes and Technological Change Patterns

The distinction between the shift effect and the bias effect TFP has an interesting meaning from the point of view of the economics of innovation. Since the seminal contributions by Schumpeter (1934 and 1942) the distinction between radical and incremental TC has had much attention in the literature. Radical innovations are very rarely introduced in the economic systemic, causing a discontinuity which is followed by a stream of sequential incremental innovations aimed at adjust the system to the new technology, and vice-versa (Mokyr, 1990).

The two different parts which the total effect TFP consists of, can be thought as the outcome of the introduction of radical and incremental TC, respectively. The shift in the production function is engendered by a radical change in the production technology, while the bias is the result of the technological manipulation of the envelope of factor complementarities. Information and communication technologies (ICT) provide to day clear evidence about the matter. On the one hand, in fact ICT are a clear case of GPT that exert a pervasive and generalized effect within the system, due to the great number of contexts they can be implemented and applied. They can be considered the result of intentional R&D efforts carried out within the boundaries of firms, taking advantage of new scientific breakthrough carried out by universities and research centres. As such, they turn out to have a strong science-based nature. The introduction of such radical and generic innovations leads to a clear shift effect such that all the map of isoquants is pushed towards the origin with no changes in the shape of each output line (Antonelli, 2003).

In the other hand, however, information and communication technologies, clearly provide the opportunity for a wave of incremental innovations that are more often the result of creative adoption and local adaptation. Economic agents try and adapt the new technology to the conditions of local factor markets, in a creative way, aiming at exploiting the locally most abundant production function. In so doing adaptive agents feed the diffusion process of the new GPT and yet change the direction of TC with respect to the intensity of use of production factors. These adjustments take place through a sequence of incremental technological innovation and rely on localised learning process and the accumulation of tacit knowledge. The idiosyncratic factors characterizing the context of utilization of the technology are likely to shape the innovation process, whose outcome hence turns out to be strongly path dependent. Such adaptation leads to the introduction of a bias, i.e. a change in the shape of the production function (Antonelli, 2006). Similar processes have been taking place through the XX century with respect to the introduction and diffusion of the gale of innovations based upon engineering.

4. Data

The data we used for the analysis are drawn by the OECD. In particular the cross-country time series of GDP (Y) at PPP of million US dollars have been drawn by the Economic Outlook, while the series on employment, worked hours, compensation of employees and fixed capital stock have been found in the OECD Stan Database. Data on capital stock (*K*) and employees' compensation (*w·L*) have been deflated by using the PPP index implicit to GDP data. The output elasticities have been calculated by assuming constant returns to scale, and focusing on labour's elasticity, which is computed as the factor share in total output:

$$\beta_{i,t} = \frac{w_{i,t} L_{i,t}}{Y_{i,t}}$$

and hence:

$$\alpha_{i,t} = 1 - \beta_{i,t}$$

Once the coefficients have been calculated, it is possible to estimate the GDP that would have been produced each year, had the marginal productivity of factors remained unchanged:

$$\hat{Y}_{i,t} = K_{i,t}^{\alpha} L_{i,t}^{\beta} \tag{9}$$

$\alpha = \alpha_{1970}$ and $\beta = \beta_{1970}$

The difference between the logarithm of actual GDP and the logarithm of the figure yielded using equation (9), gives us the index of total-TFP. As an example, the estimated *Y* of US in 1985 is 3653256 billions dollars, while the actual GDP is 6053765 billions dollars. The ratio between the two is the A_{TOT} = 0.505. Such an index consists of two components, the shift effect on the one hand and the bias on the other. The shift effect is calculated according to equation (4), i.e. as the difference between the actual GDP and the product that would have been yielded each year, had been it just the outcome of capital and labour employed. This procedure allows output elasticities to change over time. In so doing, we get is the standard measure of TFP which represents Hicks-neutral shifts of production function. In the case of the US the new estimated product *Y'* in 1985 is 3792182 billions dollars, so that the index A_{SHIFT} = 0.468. Hence in 1985 the A_{BIAS} = 0.505 – 0.468 = 0.037 in the US. In Table 2 we report the two estimations of GDP, as compared with actual GDP.

INSERT TABLE 2 ABOUT HERE

5. TFP Indexes Calculations for Italy and the US

Tables 2 and 3 report the results of our calculations concerning the US and Italy. In the first three columns of each table the dynamics of the indexes for each country are expressed with respect to 1971. It must be noted that by normalizing the time series at the 1971, the additive principle no longer holds, due to the different value each index gets at the first year. Accordingly, the figure in column (3) is not the sum of values in columns (1) and (2). For this reason, besides these series, we also show the annual growth rates of each index for both countries. In this case the value in column (6) is the sum of the values in columns (4) and (6) at each year.

Let us start from the data about the total-TFP, i.e. the index accounting for both the bias and the shift effect. In the case of the US (see also Figure 1) the index grows very slowly during the 1970s and the 1980s, while it starts accelerating in the early 1990s. It grows of about 16.6% over the whole period (about 0.54% per year on average). We turn now to decompose the index. The figures about the standard TFP (i.e. the shift effect) are characterized by a declining trend over until the late 1990s, when it starts increasing. The growth rate 2001-1971 is about 15.6% (about 0.50% per year). The bias-TFP instead increases until 1997 (when the index is 5.28), and then it is characterized by a generic decreasing trend (1.83 in 2001; 2.67% per year). This evidence is consistent with the analyses by Jorgenson (2001) and Jorgenson et al. (2006) on the contribution of ICT to productivity growth in the US. They show that in the 1980s the increase in the productivity of ICT sectors has been the main responsible of US growth, while during the 1990s the diffusion of ICTs in user sectors became the leading factor.

INSERT TABLE 3 AND FIGURE 1 ABOUT HERE

The data about Italy are interesting as well (see also Figure 2). The total-TFP index is characterized by a moderate increase until the 1991, followed by a steep growth in the following two years (it increases from 1.39 to 1.57), and then by a stationary trend. When we decompose the index, the shift effect appears to be the main source of productivity growth until the 1990s (the highest growth rate is 7.6% in 1993), and then it declines monotonically. The bias-TFP begins to increase in the early 1980s, the growth rate accelerating during the 1990s.

This aggregate evidence reflects the dynamics of a TC mainly based upon creative adoption. Italian firms excel in the adoption of new technologies, introduced abroad and in their eventual adaptation to the local factor markets. The small size of Italian firms prevented the implementation of systematic intramuros R&D and the weak scientific and technological infrastructure reduced the chances to generate radical innovations. As a consequence the Italian economy is very much based upon traditional industrial sectors while new high-tech industries have much a smaller weight than in the US economy (Quatraro, 2007).

INSERT TABLE 4 AND FIGURE 2 ABOUT HERE

The systematic efforts to adapt the new technologies to the local conditions, however, have been successful. It has made possible the introduction of a systematic bias towards the introduction of capital intensive technologies that take advantage of the low use costs of capital both in absolute and relative terms, when confronted with the relative high costs of skilled labor with high levels of trained education. The growth of traditional industries was based upon a specific form of national innovation system that made it possible for firms active in traditional industries, to introduce process innovations with high levels of capital intensity based upon systematic efforts of adoption and adaptation of new radical technologies.

The evidence (see Table 1) shows that the capital intensity of the technology used in Italy, far higher that the US capital intensity, has been able to engender a huge increase in TFP levels. The new methodology applied in this paper reveals that the rates of total-TFP of the Italian economy have been increasing in the late 1990s mainly because of the bias effects, while the shift effects was lagging behind.

6. Summary and Conclusions

The direction of TC matters as much as the rate. TC is not neutral, as it is often assumed. The matching between the bias of TC and the local endowments and hence the relative price of production factors, has important consequences on TFP growth. The methodology elaborated in this paper provides an accurate account of the performances yielding from the systematic adoption and adaptation of new process technologies with high levels of capital intensity experienced in Italian economy in the last decade of the XX century, far more successful than the traditional TFP measures are able to identify.

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Table 1 - Dynamics of Labour Share in US and Italy

	UNITED STATES	ITALY
1970	0.601	0.461
1971	0.591	0.486
1972	0.591	0.495
1973	0.591	0.493
1974	0.598	0.486
1975	0.583	0.513
1976	0.584	0.501
1977	0.585	0.503
1978	0.586	0.495
1979	0.589	0.491
1980	0.595	0.485
1981	0.587	0.492
1982	0.595	0.486
1983	0.581	0.479
1984	0.577	0.467
1985	0.578	0.465
1986	0.580	0.454
1987	0.585	0.451
1988	0.586	0.445
1989	0.578	0.444
1990	0.580	0.449
1991	0.580	0.450
1992	0.579	0.449
1993	0.576	0.446
1994	0.570	0.431
1995	0.572	0.415
1996	0.566	0.416
1997	0.566	0.417
1998	0.578	0.399
1999	0.582	0.400
2000	0.593	0.398
2001	0.590	0.400
2002	0.585	0.402
2003	0.580	0.407

Source: Elaboration on OECD data.

Table 2 – Comparison among actual and predicted GDP in Italy and in the US

	US			Italy		
	Y_{ACTUAL}	Y_{SHIFT}	Y_{TOTAL}	Y_{ACTUAL}	Y_{SHIFT}	Y_{TOTAL}
1971	3898660	2536141	2536141	733272.7	849948.5	849948.5
1972	4104910	2635027	2598920	745318.4	813000.7	846173.8
1973	4341411	2799013	2758710	769188.3	804248.2	850751.5
1974	4319511	2944908	2903375	823271.5	835974.9	882985.7
1975	4311236	2860126	2847453	857368	855356.1	892754.1
1976	4540937	2772191	2708653	826186.8	783316.9	853990.8
1977	4750562	2915871	2850325	874696.1	798995.7	853392.7
1978	5015038	3115240	3044942	891301.3	801546.9	860825.9
1979	5173463	3334191	3258855	915241.1	815340.5	863794.7
1980	5161688	3441348	3377686	960123.9	846888.5	892521.3
1981	5291713	3322224	3295301	997683.7	895396.8	933927.8
1982	5189263	3390139	3320249	999421.2	868550.4	918266.2
1983	5423764	3233696	3207854	1002647	860266.7	897787.1
1984	5813615	3437326	3339264	1016408	862509.9	889570.6
1985	6053765	3792182	3653256	1049092	896153	905733.3
1986	6263641	3922403	3781633	1079014	903819.5	909351.8
1987	6475066	3982196	3850295	1111028	936339.1	924327.5
1988	6742667	4032012	3932781	1143854	964384.9	944615.1
1989	6981418	4136172	4039987	1192991	1020582	987952.7
1990	7112543	4312389	4159218	1234564	1046607	1010298
1991	7100543	4295750	4157328	1258688	1066404	1039396
1992	7336594	4170845	4036791	1278000	1073388	1047956
1993	7532669	4289733	4140852	1286110	1056608	1030817
1994	7835495	4481375	4302563	1274711	976556.7	947561.8
1995	8031720	4743850	4503454	1303802	998623.4	939169.4
1996	8328921	4911772	4669153	1341681	1072419	973819.5
1997	8703522	5162409	4848670	1349614	1082280	985258.9
1998	9066898	5445480	5098695	1376176	1091756	995964.6
1999	9470374	5571063	5327669	1394350	1168423	1023902
2000	9816975	5763122	5547356	1420652	1194201	1048194
2001	9890675	5836054	5738374	1474219	1255102	1092653

Source: Elaboration on OECD data.

Table 3 – Comparison of TFP Indexes for the US

	TFP Shift (1)	TFP Bias (2)	TFP Total (3)	dA_{SHIFT} / dt (4)	dA_{BIAS} / dt (5)	dA_{TOTAL} / dt (6)
1971	1	1	1			
1972	0.991	1.042	0.992	-0.0088	0.0004	-0.0085
1973	0.996	1.026	0.997	0.0045	0.0002	0.0047
1974	1.021	0.327	1.011	0.0148	-0.0001	0.0147
1975	1.051	1.775	1.061	0.0488	-0.0004	0.0484
1976	1.053	1.742	1.062	0.0002	0.0005	0.0007
1977	1.031	1.713	1.040	-0.0220	0.0008	-0.0213
1978	1.017	1.692	1.026	-0.0148	0.0007	-0.0141
1979	1.016	1.378	1.021	-0.0051	0.0002	-0.0049
1980	1.050	0.618	1.044	0.0229	-0.0002	0.0227
1981	1.055	1.598	1.062	0.0173	0.0000	0.0173
1982	1.085	0.629	1.078	0.0155	-0.0003	0.0152
1983	1.066	2.254	1.083	0.0035	0.0003	0.0038
1984	1.036	2.836	1.061	-0.0226	0.0017	-0.0210
1985	1.043	2.795	1.067	0.0050	0.0007	0.0057
1986	1.063	2.621	1.084	0.0161	0.0000	0.0161
1987	1.085	1.971	1.098	0.0123	-0.0002	0.0121
1988	1.102	1.888	1.113	0.0135	0.0001	0.0136
1989	1.094	2.900	1.119	0.0056	0.0001	0.0057
1990	1.119	2.682	1.140	0.0193	-0.0002	0.0191
1991	1.151	2.750	1.173	0.0285	-0.0006	0.0279
1992	1.156	2.991	1.181	0.0063	0.0007	0.0070
1993	1.136	3.398	1.167	-0.0131	0.0009	-0.0122
1994	1.116	4.289	1.160	-0.0077	0.0012	-0.0065
1995	1.105	4.134	1.147	-0.0126	0.0010	-0.0116
1996	1.090	5.079	1.145	-0.0037	0.0019	-0.0018
1997	1.080	5.288	1.138	-0.0082	0.0017	-0.0066
1998	1.100	3.617	1.134	-0.0052	0.0018	-0.0034
1999	1.111	3.109	1.138	0.0018	0.0010	0.0028
2000	1.137	1.393	1.140	0.0015	0.0004	0.0019
2001	1.156	1.829	1.166	0.0219	0.0000	0.0219

Source: Elaboration on OECD data.

Table 4 – Comparison of TFP Indexes for Italy

	TFP Shift (1)	TFP Bias (2)	TFP Total (3)	dA_{SHIFT}/dt (4)	dA_{BIAS}/dt (5)	dA_{TOTAL}/dt (6)
1971	1	1	1			
1972	1.043	0.999	1.026	0.028	-0.001	0.027
1973	1.074	0.999	1.059	0.033	-0.001	0.032
1974	1.093	1.000	1.090	0.030	0.000	0.030
1975	1.151	0.997	1.098	0.004	0.002	0.006
1976	1.194	0.998	1.164	0.057	0.000	0.058
1977	1.213	0.998	1.176	0.011	-0.001	0.011
1978	1.224	0.999	1.203	0.023	0.000	0.023
1979	1.237	0.999	1.221	0.017	-0.001	0.016
1980	1.215	0.999	1.213	-0.005	-0.001	-0.006
1981	1.255	0.999	1.236	0.018	0.000	0.019
1982	1.271	0.999	1.268	0.025	0.000	0.025
1983	1.285	1.000	1.297	0.023	0.000	0.023
1984	1.277	1.001	1.315	0.014	0.000	0.014
1985	1.302	1.001	1.347	0.024	0.000	0.024
1986	1.294	1.003	1.365	0.013	0.000	0.013
1987	1.294	1.003	1.375	0.007	0.001	0.008
1988	1.275	1.004	1.371	-0.004	0.001	-0.002
1989	1.287	1.004	1.387	0.011	0.001	0.012
1990	1.287	1.003	1.375	-0.009	0.001	-0.009
1991	1.299	1.003	1.385	0.007	0.000	0.007
1992	1.328	1.003	1.416	0.023	0.000	0.023
1993	1.424	1.004	1.527	0.076	-0.002	0.074
1994	1.424	1.006	1.576	0.031	0.001	0.032
1995	1.365	1.008	1.564	-0.010	0.003	-0.007
1996	1.360	1.008	1.555	-0.006	0.001	-0.006
1997	1.375	1.008	1.569	0.008	0.001	0.009
1998	1.302	1.010	1.546	-0.016	0.002	-0.014
1999	1.298	1.010	1.539	-0.006	0.002	-0.004
2000	1.281	1.011	1.532	-0.007	0.004	-0.004
2001	1.284	1.010	1.529	-0.002	0.001	-0.002

Source: Elaboration on OECD data.

Figure 1 – Comparison among the Three TFP Indexes in the US, 1971-2001

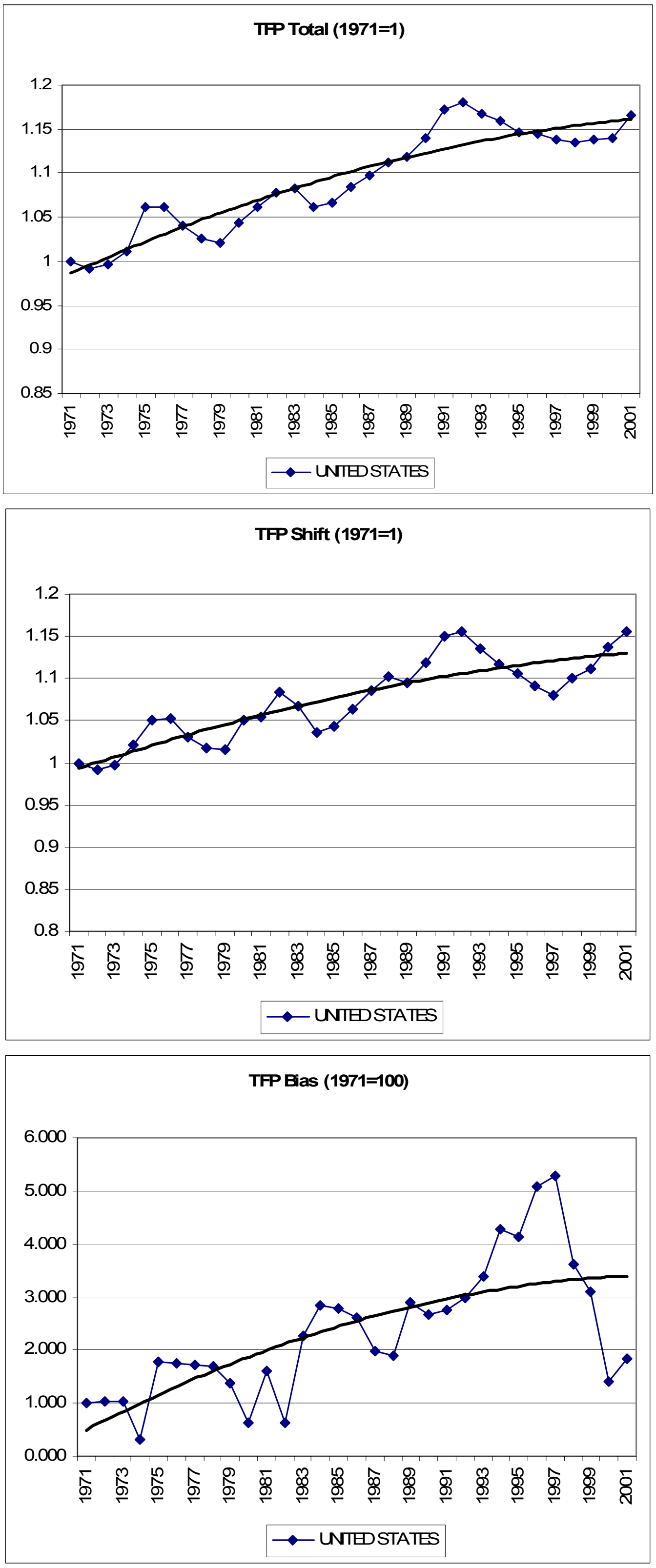

Figure 2 – Comparison among the Three TFP Indexes in Italy, 1971-2001