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Abstract

In this paper we present a non-linear model where ICT sector is endogenized. In the model there are two intermediate goods: a traditional good produced by capital and labor and the ICT good produced by innovative capital and skilled labor. The final good is obtained combining the two intermediate goods. The model is specified and estimated as continuous-time general disequilibrium framework. Our main results are the following. We find that the elasticity of substitution of the aggregate sector has a value intermediate between that of the ICT sector and that of the traditional sector, since the input complementarity is tighter in the former than in the latter. Moreover, in all the sectors elasticities are well below 1. As for the traditional sector, whose share is predominant in the production of the final good, the input complementarity helps explain most of the labour share decline of Italian economy as a consequence of the slowdown in the growth of capital intensity. In the ICT sector, technological progress, both in the form of capital augmenting and capital bias, showed a decline over the sample period with an obvious negative consequence on the global evolution of the technical progress. The results about the dynamics of the two intermediate sectors allows to interpret the "Italian paradox" of an industrial structure marked by an increasing weight of the traditional sector.

JEL classification: E22; E23; O41; C51.

Keywords: Nested CES production function; Elasticity of substitution; Endogenous technical progress and ICT technical change; Disequilibrium model; Continuous-time econometrics.

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"*...the crisis can be the occasion for our firms to carry out and extend what up to now has often been missing: a profound renewal of the mode of production in connection with the digital revolution, which can give life to new forms of enterprise and employment in new fields of activity.*" (The Governor's Concluding Remarks, Bank of Italy, May 2014)

"*Perhaps GDP does not really capture the improvements in living standards that computer-age innovation is engendering. Or perhaps this innovation is less significant than its enthusiasts believe. As it turns out, there is some truth in both perspectives.*" (Project Syndicate, Stiglitz, 2014)

1 Introduction

In previous papers (Saltari et al., 2012, 2013), we examined the role of information and communication technology (ICT) in enhancing general production in the Italian economy. Those papers assume that the ICT contribution is exogenous. In this paper, instead, we take the view that the process of innovation is complex and endogenous. The hypothesis is that the introduction and expansion of ICT increase the productivity of capital and labour so that for the same general factor inputs, output is higher, and disproportionately so, if the benefit of ICT is sufficiently strong.

Our aim here is to endogenize the ICT contribution. Two considerations lead our process of endogenization. First, we model and estimate a two-level constant elasticty of substitution (CES) aggregate production function – that nests two CES production functions into another CES function – with four inputs. Hence, we introduce a specific factor setup with two different kinds of capital and two different types of labor used in the production of the two intermediate goods (ICT and traditional). Thus, ICT enters as a factor of production through a nested CES production function allowing us to analyze the mechanisms for ICT to influence productivity growth. Second, for estimation purposes we consider ICT producing industries only. The mechanism linking technological progress in ICT to these industries is direct. Technological progress that enables the ICT producing industries to produce greater aggregate output per unit of input is a direct potential contributor to productivity dynamics. We choose to leave out ICT using industries since in this case ICT mostly affects the way to do and organize businesses. Clearly, the way ICT impacts on productivity growth is an open issue.

The model is based on the intertemporal cost minimisation of producing a given output stream taking into account a quadratic cost of adjustment of each of the factors of production. There is no assumption that the productive sectors are always in equilibrium but the model does not preclude it being so. The economic system is assumed to be non-tâtonnement so both quantities and prices may be changing simultaneously. The focus of this work is on the production side only and does not take into account any feedback from this sector onto demand or monetary and fiscal aspects of the economy.

Our main results can be presented within the multisector framework adopted. We find quite reasonably that the elasticity of substitution of the aggregate sector has a value intermediate between that of the ICT sector and that of the traditional sector, since the input complementarity is tighter in the former than in the latter. Moreover, in all the sectors elasticities are well below 1. As for the traditional sector, whose share is predominant in the production of the final good, the input complementarity helps explain most of the labour share decline of Italian economy as a consequence of the slowdown in the growth of capital intensity. In the ICT sector, technological progress, both in the form of capital augmenting and capital bias, showed a decline over the sample period with an obvious negative consequence on the global evolution of the technical progress. The results about the dynamics of the two intermediate sectors allows to interpret the "Italian paradox" of an industrial structure marked by an increasing weight of the traditional sector.

The organization of the paper is as follows. The next section describes some stylised facts of the last three decades of the Italian economy. Section 3 shortly summarizes the related literature. Sections 4 and 5 discuss the model. Estimation results are reported in section 6. The final section concludes.

2 Facts[1]

In this section we describe some important features of the Italian economy in the sample period considered (1980-2010). After more than a decade of heat debate on the existence of an economic decline, it is today generally recognized that the main cause of the insufficient Italian growth is due to the pathological behavior of both labor productivity and total factor productivity (TFP). As for the former, data are straightforward (see figure 1). Since the beginning of 80s to the mid of 90s, the yearly average growth rate was 2.3 per cent; in the following 17 years it fell to a meager 0.3 per cent. The fall of TFP was as heavy as that of labor productivity: its average growth rate was 1.3 per cent until the mid 90s; it became negative in the next subperiod. The following graph gives an illustration of the dynamics of these two variables and their tight correlation.

Figure 1 Labor productivity and TFP (average growth rate). Source: ISTAT.

[1] This section heavily draws on Ciccarone and Saltari, 2015.

Much less widespread is the consensus on the causes of this pathological behavior in productivity growth and TFP. An early explanation focused on insufficient workers' effort in both the public and the private sector, and on the misalignments between productivity and wages, which called for a comprehensive reform of the collective bargaining system. Another popular explanation of sluggish productivity growth, based on well-grounded academic literature (see, e.g., Gomez-Salvador et al., 2006) was that labor market rigidity hinders labor reallocation towards more productive firms and sectors.

We think instead that the unsatisfactory performance of labor productivity is tightly linked to capital accumulation, especially of the innovative type linked to the ICT technologies, and to the changes that occurred in the composition of the capital stock which followed changes in the legal set up of the Italian labor market. This viewpoint, which has recently found citizenship in the Italian public debate is deeply rooted in the literature. First, whereas R&D captures the technological change represented by disembodied new knowledge, investment captures the new knowledge embodied in physical capital, mainly machinery; the endowment of total capital hence affects productivity growth by capturing the embodied technological change. Second, given the total amount of capital, the diffusion of ICT plays a relevant role in affecting productivity improvements (Wilson, 2009).

Several labor market reforms were carried out since the late 90s. These reforms deregulated the utilization of fixed-term and atypical contracts, without changing the level of employment protection legislation (EPL) granted to permanent employees, hence increasing the market flexibility of labor outside the firm, rather than the flexibility of labor inside the firm, as occured in Germany, for example.

Increased labor market flexibility encouraged employment growth but, by reducing the price of labor relative to capital, favored the adoption of labor intensive production techniques leading to a reduction in the capital/labor ratio and to a slowdown in the growth of labor productivity. This interpretation can be enriched by noticing that a slow, if not negative, pace in the accumulation of innovative ICT capital also contributes to productivity growth by negatively affecting the re-organization of the workplaces requested by technical progress. In this way, the "conservative" reaction of Italian firms to national and international developments also negatively affected total factor productivity (TFP).

Summing up, the changes that characterize the Italian labor market since the beginning of the 1990s have produced negative effects on productivity through two main channels:

(i) reduced capital intensity (the capital/labor ratio);

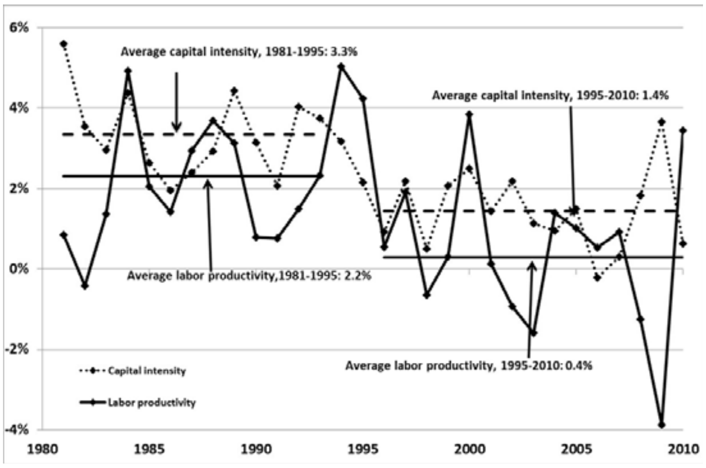
(ii) slowdown in the dynamics of innovative capital as compared to that of traditional capital which produced negative effects:

(ii.a) directly, through the behavior of the innovative capital intensity;

(ii.b) indirectly, as it hindered technical and organizational progress and, hence, TFP growth.

As for channel (i), figure 2 displays a significant sharp fall in the rate of change of the capital/labor ratio (given by the difference between the rate of change of capital and the rate of change of employment), with the average decreasing from 3.3% in 1981-1995 to 1.4% in 1995-2010. The graph shows that this fall was followed by a relevant decrease in average labor productivity, from 2.3% in 1981-1995 to 0.4% in 1995-2010. This relationship is testified by the existence of a significant correlation between the K/L ratio and labor productivity over the whole period 1981-2010.

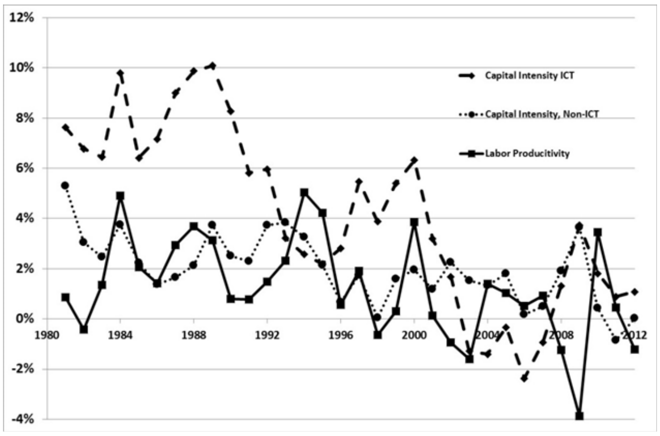
Figure 2 Labor productivity and capital intensity (Business sector, 1981-2010, yearly growth rates). Source: ISTAT.



The second channel singled out above starts from the observation that the slowdown of capital intensity was accompanied by a change in the capital composition. In particular, ICT capital represented in 1980 slightly less than 1% of total capital stock. This ratio doubled at the beginning of the 1990s, remained substantially unchanged until the end of that decade and decreased from the beginning of the 2000s.

Figure (3) depicts the rate of growth of the capital/labor ratio, with reference to both ICT and non-ICT capital. Between the end of the 1980s and 2007, the decrease of the ICT capital/labor ratio is around 12 percentage points, whereas that of non-ICT capital/labor ratio is around 4.5 points. The former ratio is at the end of the 2000s in the negative terrain, indicating a reduction, while during a crisis it is the latter that should experience a decrease. Figure (3) also shows another key feature: the high variability of the ICT capital/labor ratio closely follows that of labor productivity. Indeed, there exists a higher correlation (statistically significant at 95%) between productivity and ICT (38%) than between productivity and non-ICT (21%).

Figure 3 Labor productivity and sectoral capital intensity, ICT and non-ICT (Business sector, 1981-2012, yearly growth rates). Source: ISTAT.



The fall which occurred in the period 2000-2012 in the ratio between value added and net capital stock at constant prices (usually labelled as the "apparent" productivity of capital) in the private sector (excluding property rents) confirms our analysis. If the composition of the capital stock remained unchanged, the fall in capital productivity could be the result of an increase in capital intensity. Yet, between 2000 and 2003 ICT capital intensity decreased by around 7 percentage points (from over 6 per cent to -1 per cent) and subsequently remained in the negative terrain (indicating a reduction of the stock). Instead, the rate of growth in non-ICT capital intensity fell by around one percentage point for year, but remained positive (indicating an increase of the stock), except for 2011, the only year it was negative. Hence, the slowdown of the contribution offered by capital per worker (the worker's endowment of capital) went hand in hand with the change in its composition, in favor of capital characterized by less technological content and hence lower productivity.

Our interpretation is that the composition of the capital stock, together with the ratios between labor and different types of capital, sharply changed in this century because firms, reacting to policy stimulus and exogenous shocks, penalized the more innovative capital. This process reduced not only the apparent, but also the actual productivity.

3 Related Literature

The paper is related to the modern growth literature (e.g. Acemoglu 2008, La Grandville 2008, Aghion and Howitt, 2009) that emphasizes the power of the CES production function. In recent years, the CES production technology has returned to the center of growth theory and increasingly empirical evidence shows that the non-unity elasticity of substitution allows recognizing the existence of biased technical change (see Chirinko et al. 1999, Klump et al. 2008, León-Ledesma et al. 2010). The wider use of CES technology opens the door to a deeper understanding of the effects of variation in the elasticity of substitution on economic growth (Turnovsky, 2002). However, in a basic CES framework the production structure is limited to feature equal substitution elasticities between all inputs. To overcome this shortcoming, Sato (1967) extended the CES functional form and suggests the usage of nested CES functions. The general idea behind Sato's approach is to construct a separate CES function for each group of inputs that share the same substitution elasticity and to combine the different CES functions in different levels or nests of the overall CES function. We exploit the Sato approach to estimate substitution elasticities for a three level nested CES to deepen the relationship between the ICT innovative technology and the final good. Another strand of literature closely related to our framework is that on multisector approach to Solow growth model built as a nested CES production functions (for a synthesis, see Xue and Yip 2013).

The relevance of the elasticity of substitution and its relationship with economic growth and technical change has been established since Hicks (1932) and Solow (1957). However, it was after Arrow et al. (1961) that there was a boost on the theoretical and empirical issues involving the elasticity of substitution. More recently, La Grandville (1989) gives proof of the positive relationship between the elasticity of substitution and the output level. On the discussion about the theoretical and empirical role of the CES in the dynamic macroeconomics, see also Klump and Preissler 2000, Klump and La Grandville 2000, and La Grandville 2009.

Furthermore, the paper represents a contribution to the long tradition of continuous time disequilibrium models. Such an approach assumes non-market clearing and disequilibrium adjustment processes. This approach means that the system need not be in the long-run equilibrium nor does the long-run equilibrium need to be a steady state. Disequilibrium models for other economies are also those of Johnson, Moses and Wymer (1977) for Australia, Knight and Wymer (1978) for UK, Gandolfo and Padoan for Italy (1990), Donaghy (1993) for the USA, and Nieuwenhuis (1995) for the Netherlands.

4 The model

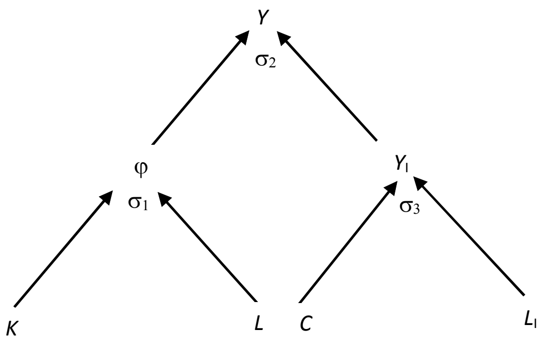
4.1 Production functions

In Saltari et al. (2012, 2013) we estimated a dynamic disequilibrium model of the Italian economy. The main argument of those papers is that the weakness of the Italian economy of the last two decades has been due to the slowdown of the total factor productivity (TFP). The modelling strategy in both papers is based on the belief that the TFP dynamics is mostly affected by ICT capital accumulation. In turn, the impact of ICT accumulation was specified as an exogenous technological factor, enhancing the efficiency of traditional capital, i.e., as a capital-augmenting technological factor.

Our aim here is to endogenize the ICT sector. To this end, we specify and estimate a two-level CES aggregate production function – that nests two CES production functions into another CES function – with four inputs. Hence, we introduce two different kinds of capital, K and C, and two different types of labor, L and L_I, used in the production of the two intermediate goods (ICT and traditional).

Following Sato (1967), the two lower level CES production functions yield two outputs that enter into the global function as intermediate inputs. The upper level production function produces the general output. One of the main contribution of this paper is that the lower level CES produces the ICT output, thus making endogenous its contribution to final output. In the following, we detail the structure of the model. Diagram 4 illustrates the nested structure of our production system.

Figure 4 The nested production function



Final output Y is obtained by a production function of labour L and capital K embedded in a CES function extended to allow for ICT goods and services, Y_I, as an additional factor input. Hence, the overall aggregate CES production function is specified as:

$$Y = f(\varphi, Y_I) = \beta_3 \left[\left(e^{\lambda_I t} \varphi \right)^{-\beta_2} + (\beta_5 Y_I)^{-\beta_2} \right]^{-\frac{1}{\beta_2}} \tag{1}$$

where φ and Y_I are the intermediate outputs of the two lower level CES functions, β_3 is a scaling factor and β_5 is the relative weight of the two sectors. The elasticity of substitution between the two intermediate goods is given by $\sigma_2 = \dfrac{1}{1+\beta_2}$. Under the assumption that ICT efficiency itself is increasing, an ICT efficiency factor $e^{\lambda_I t}$ is applied to φ, where λ_I is the rate of decrease in the amount of labour and capital required to produce a given output with the use of ICT goods and services. Although ICT is a factor input in itself, it may also act as a catalyst for change.[2]

Let λ_K and λ_C be the rates of technical progress in the use of standard capital stock K and ICT (and thus the rate of decrease in the amount of labour required to produce a given output with a given capital stock), and λ_L the rate of growth of labour. Besides that, any efficiency gains from the use of ICT determines the long-run rate of growth of

[2] As usual, φ may be written in the "distributive" form

$$\varphi = \left[\beta_4' K^{\ -\beta_1} + \left(1 - \beta_4'\right) \ \left(e^{\lambda_K t} L \right)^{-\beta_1} \right]^{-\frac{1}{\beta_1}}$$

with corresponding changes to β_3 and β_5 in (1).

output Y, which is $\mu_Y = \lambda_K + \lambda_I + \lambda_L$. This is the steady state rate of growth should it exist.

φ represents the "traditional" input produced with the non-innovative capital (K) and unskilled labour (L). Its production function is:

$$\varphi = \left[K^{-\beta_1} + \left(\beta_4 e^{\lambda_K t} L\right)^{-\beta_1}\right]^{-\frac{1}{\beta_1}}. \tag{2}$$

In (2), $e^{\lambda_K t}$ is the labour augmenting factor, while β_4 is the weight of labour relative to capital. In long-run, the rate of capital accumulation as usual must be equal to the sum the growth rate of labor efficiency (λ_K) and the growth rate of labour (λ_L). Hence, the long-run growth rate of φ is $\lambda_K + \lambda_L$. The elasticity of substitution between traditional capital and labor is $\sigma_1 = \dfrac{1}{1+\beta_1}$.

The other CES production function gives ICT output depending on ICT capital (C) and skilled labour only (L_I):

$$Y_I = f_I(C, L_I) = \beta_7 \left[C^{-\beta_6} + \left(\beta_8 e^{\lambda_C t} L_I\right)^{-\beta_6}\right]^{-\frac{1}{\beta_6}}. \tag{3}$$

Similarly to (1), β_8 is the weight of labour relative to ICT capital while β_7 is a scaling factor. The elasticity of substitution between ICT capital and skilled labor is $\sigma_3 = \dfrac{1}{1+\beta_6}$. As seen above, the long-term rate of growth of ICT output and of ICT capital C is equal to the sum of growth rates of skilled labor and technical progress, $\mu_I = \mu_C = \lambda_C + \lambda_{L_I}$.[3]

The conditions for this model to have a steady state are quite severe and include:

$$\mu_Y = \mu_\varphi + \lambda_I = \lambda_K + \lambda_L + \lambda_I$$

and

$$\mu_Y = \mu_I$$

where $\mu_I = \lambda_C + \lambda_{L_I}$.[4]

[3] To see this, assume that in the long run the variables, such as C and L_I, grow at constant rates:

$$C = C^* e^{\mu_C t},\ L_I = L_I^* e^{\lambda_{LI} t}$$

where μ_j is the generic growth rate of the endogenous variables and λ_j is the generic growth rate of the exogenous variables. Substitute these expressions in equation (3) and denote by μ_I the long run growth rate of *ICT* output. Determine this rate by taking the time derivative of the log of Y_I. The result is that stated in the main text. By definition, Y_I is the accumulation rate of the *ICT* capital stock, so that their long run growth rates are the same.

[4] The steady states may not exist but these terms may be interpreted as an indication of the expected long-run term rates of growth, providing the system is stable. The (constant) rates of growth in efficiency in the use of labour in the *ICT* production function λ_C and in the use of *ICT* on general production function λ_I need not be the same. Although the same linear function of the rate of technical progress λ_K and the *ICT* efficiency factor λ_I appears in many places in the model, the rate of technical progress appears separately in the investment function for general capital K, so the efficiency rates are identified uniquely.

The effect of the introduction of ICT into the production sector of the economy, and thus the general production function, is to change the curvature or the position of the production frontier, so allowing more efficient use of the other factors of production. It is considered that (1) the feedback of ICT on general production is perhaps better and more general representation than the one provided by our previous models.[5]

4.2 The capital inputs adjustment

What we have just described is the long run equilibrium of the system or what is usually called balanced growth path. Most of the literature imposes that in the short run the input user cost is equal to its marginal productivity. In our theoretical framework, there are imperfections and frictions that hinder the short run instantaneous adjustment. In other words, the model does not assume that input markets instantaneously clear, i.e., the economic representation of the model is one of disequilibrium dynamics.

A recent strand of literature (beginning from Solow, 1987 and Blanchard, 1997) emphasizes a medium run representation capable of explaining and reconciling protracted departures from balanced growth path. Our disequilibrium approach is not too far from this representation. Indeed, both capture deviations from balanced growth and nest balanced growth as a special case. Moreover, both account deviations introducing dynamics through factor adjustment costs. The difference resides in how these costs are modeled. In the medium run approach a variety of adjustment mechanism is introduced reflecting structural frictions. In our disequilibrium framework the adjustment costs are embedded in a system of stochastic differential equations representing partial adjustment to long run equilibrium: given a discrepancy between the long run and actual value of a variable, the latter is adjusted towards the former only gradually, according to a coefficient of reaction (indicated below by α_i).

Let us determine the marginal productivity of the traditional capital. At the current level of capital stock and for given output, $\frac{\partial \varphi}{\partial K} = \left(\frac{\varphi}{K}\right)^{1+\beta_1}$, so the marginal product of K in the general production function (1) is, assuming given aggregate demand,

$$\frac{\partial f}{\partial K} = \left(\beta_3 e^{\lambda_I t}\right)^{-\beta_2} \left(\frac{Y}{\varphi}\right)^{1+\beta_2} \left(\frac{\varphi}{K}\right)^{1+\beta_1} = \left(\beta_3 e^{\lambda_I t}\right)^{-\beta_2} Y^{1+\beta_2} \varphi^{\beta_1-\beta_2} K^{-(1+\beta_1)}. \quad (4)$$

The effect of ICT goods and services on the marginal product of capital can be seen by replacing output by the production function (1):

$$\frac{\partial f}{\partial K} = \beta_3 e^{\lambda_I t} \left[1 + \left(\frac{\beta_5 Y_I}{e^{\lambda_I t}\varphi}\right)^{-\beta_2}\right]^{-\frac{1+\beta_2}{\beta_2}} \left(\frac{\varphi}{K}\right)^{1+\beta_1}. \quad (5)$$

[5] Equation (1) may be extended to allow for other factors, for example a different representation of the interaction and effect of skilled and unskilled labour.

This expression may also be written in terms of the labour-capital ratio as:

$$\frac{\partial f}{\partial K} = \beta_3 e^{\lambda_I t} \left[1 + \left(\beta_4 e^{\lambda_K t} \frac{L}{K} \right)^{-\beta_1} \right]^{\frac{\beta_2 - \beta_1}{\beta_1}} \left\{ \left[1 + \left(\beta_4 e^{\lambda_K t} \frac{L}{K} \right)^{-\beta_1} \right]^{\frac{\beta_2}{\beta_1}} + \left(\beta_5 \frac{Y_I}{e^{\lambda_I t} K} \right)^{-\beta_2} \right\}^{-\frac{1+\beta_2}{\beta_2}} . \tag{6}$$

Thus, for a given labour-capital ratio, the marginal product of capital is an increasing function of ICT output, Y_I.

The marginal product of labour may be derived in a similar way as a function of ICT input. In both cases, differentiating with respect to Y_I shows how the curvature of these functions changes as ICT changes.

The marginal product of ICT in (1) evaluated at given K, L, and Y_I is:

$$\frac{\partial f}{\partial Y_I} = \beta_3 \beta_5 \left[\left(\frac{e^{\lambda_I t} \varphi}{\beta_5 Y_I} \right)^{-\beta_2} + 1 \right]^{-\frac{1+\beta_2}{\beta_2}} . \tag{7}$$

In our disequilibrium framework, the adjustment of the traditional capital to its short and long run equilibrium determines the investment decisions of the firm. Formally, the partial derivative with respect to capital and the real interest rate, or the marginal user cost of capital, defines the investment function in terms of the second order (time) derivative of $\ln(K)$:

$$\dot{k} = \alpha_1 \left[\alpha_2 \left(\frac{\partial f}{\partial K} - (r - D \ln(p) + \beta_{10}) \right) - (k - \mu_K) \right] , \tag{8}$$

where $k = D \ln(K)$ and $\mu_K = \lambda_K + \lambda_L$, the average long-run rate of growth of K. Owing to the effect of efficiency gains in the application of ICT to the production frontier, the long-run rate of growth of capital is not equal to that of output.

In equation (8), α_1 is the speed at which capital growth rate approximates its long-run value; in other words, α_1 can be interpreted as the speed of the accumulation process. Instead, α_2 has the nature of an investment adjustment cost to the desired capital stock. It gives a measure of the frictions and constraints found by the firms in profit maximization. The second term in parentheses in (8) is a measure of the real interest rate plus a risk premium, β_{10}. As a whole, equation (8) can be seen as the medium run adjustment process of investment.

Similarly to general capital K, ICT capital input C adjusts according to its own marginal product:

$$\dot{c} = \alpha_3 \left[\alpha_4 \left(\frac{\partial f_{Y_I}}{\partial C} - r - D \ln(p) + \beta_{11} \right) - (c - \mu_C) \right] \tag{9}$$

where $c = D \ln(C)$ and β_{11} is the risk premium for ICT capital. α_3 and α_4 can be interpreted in the same way as in the partial adjustment investment function of the traditional sector.

At the current level of ICT capital and for given ICT output, the marginal product of the ICT sector is:

$$\frac{\partial f_{Y_I}}{\partial C} = \beta_7 \left(\frac{Y_I}{\beta_7 C} \right)^{1+\beta_6}.$$

As we will see below, the production functions can be inverted to give the demand for labour in the general economy with the excess demand for labour being assumed to determine the (nominal) wage rate. Under the assumption that there is some degree of monopolistic competition in the economy, prices are determined by marginal cost with a mark-up and allowing for indirect taxes.

5 Employment, wages and prices

5.1 The aggregate sector

In the general sector, it is assumed that the demand for labour, L, is given by the inverse of the production function for Y. Hence, the amount of labour firms need in order to produce current output demand, given capital stock K, is:

$$L^d = \frac{e^{-(\lambda_K+\lambda_I)t}}{\beta_4} \left\{ \left[\left(\frac{Y}{\beta_3} \right)^{-\beta_2} - (\beta_5 Y_I)^{-\beta_2} \right]^{\frac{\beta_1}{\beta_2}} - \left(e^{\lambda_I t} K \right)^{-\beta_1} \right\}^{-\frac{1}{\beta_1}}. \tag{10}$$

Considering some stickiness in increasing employment, or reducing it, the employment equation is:

$$\dot{l} = \alpha_5 \alpha_6 \ln \left(\frac{L^d}{L} \right) - (\alpha_5 + \alpha_6)(l - \lambda_L) \tag{11}$$

where $l = D \ln (L)$, and L is actual employment deriving from the adjustment by firms towards the demand function. If demand is expected to be satisfied quickly, α_6 will be high. In this equation α_5 may be assumed to be a variable function of adjustment costs present in the labour market, as for instance firing costs proxied by the EPL index.

Wages in the general sector are determined by demand and supply. The supply function for labour L^s is

$$L^s = L_0 \left(\frac{w}{p} \right)^{\beta_{12}} e^{\lambda_L t} \tag{12}$$

The labour force is assumed to grow (or decline) at a rate λ_L and vary according to the real wage rate with elasticity β_{12}. L_0 is a parameter representing the base labour force (at $t = 0$).

The determination of wages is specified as

$$D^2 \ln (w) = \alpha_7 \ln \left(\frac{L^d}{L^s} \right) - \alpha_8 \left(D \ln \left(\frac{w}{p} \right) - \lambda_K \right) \tag{13}$$

where the numerator is the demand for labour defined as the inverse of the production function.

Although wages are defined in nominal terms in equation (13) and in units corresponding to the definition of L, the function determining wages is in real terms and such that the long-term real wage rate in efficiency units is expected to grow at a rate λ_K. Thus, prices feedback into the nominal wage determination equation but in equilibrium the real wage rate would equal the marginal product of labour.

Prices are determined according to marginal (labour) cost per unit output, $w\left(\frac{\partial L}{\partial Y}\right)$, derived from the inverse of the production function multiplied by indirect taxe rate τ, and with a mark-up γ_1 to give a partial equilibrium price $\gamma_1 \tau\ w\left(\frac{\partial L}{\partial Y}\right)$. The price dynamics of the model reflects the competitive process and the way in which prices are likely to be affected by the rates of change of real wages adjusted for increases in efficiency.

The marginal cost of labour is obtained in the usual way as the ratio between the marginal wage rate and the marginal product of labour. As the marginal product of labor is given by:

$$\frac{\partial f}{\partial L} = \left(\beta_3 e^{\lambda_I t}\right)^{-\beta_2} \left(\beta_4 e^{\lambda_K t}\right)^{-\beta_1} \left(\frac{Y}{\varphi}\right)^{1+\beta_2} \left(\frac{\varphi}{L}\right)^{1+\beta_1}, \tag{14}$$

which for given capital, labour and ICT inputs becomes

$$\frac{\partial f}{\partial L} = \beta_3 e^{\lambda_I t} \left(\beta_4 e^{\lambda_K t}\right)^{-\beta_1} \left[1 + \left(\frac{\beta_5 e^{-\lambda_I t} Y_I}{\varphi}\right)^{-\beta_2}\right]^{-\frac{1+\beta_2}{\beta_2}} \left(\frac{\varphi}{L}\right)^{1+\beta_1}. \tag{15}$$

Hence, the short term marginal cost per unit output is

$$mc\left(\frac{\partial L}{\partial Y}\right) = w\left(\beta_3 e^{\lambda_I t}\right)^{-1} \left(\beta_4 e^{\lambda_K t}\right)^{\beta_1} \left(\frac{L}{\varphi}\right)^{1+\beta_1} \left[1 + \left(\frac{\beta_5 e^{-\lambda_I t} Y_I}{\varphi}\right)^{-\beta_2}\right]^{\frac{1+\beta_2}{\beta_2}}. \tag{16}$$

The dynamics of price determination is described by a second order process in which the acceleration of prices, or the rate of change of the inflation rate, is specified as

$$\begin{aligned} D^2 \ln(p) \quad = \quad & \alpha_{13}\alpha_{14} \ln\left(\frac{\gamma_1 \cdot \tau \cdot mc\left(\frac{\partial L}{\partial Y}\right)}{p}\right) - (\alpha_{13} + \alpha_{14})\left(D\ln(p) - \mu_P\right) + \\ & + \alpha_{15}\left[D\ln\left(\frac{w}{p}\right) - \lambda_K\right] + \alpha_{16} \ln\left(\frac{vM}{pY}\right). \end{aligned} \tag{17}$$

The first two terms represent a second order adjustment of prices to short-run marginal cost, the next that prices are likely to rise faster if there is an expectation that real wages will increase faster than some long-run average, and the last term is a monetary effect that prices will be expected to rise faster if the ratio of the volume of money M to nominal output is high relative to some long-run measure of the velocity of money $\frac{1}{v}$. λ_M is the long-run rate of growth of the volume of money, adjusted for changes in velocity, and the long-run expected rate of growth of prices $\mu_P = \lambda_M - \mu_Y$.

5.2 The ICT sector

Employment in the ICT sector is defined as:

$$\dot{l}_I = \alpha_9 \left[\alpha_{10} \ln \left(\frac{\partial f_{Y_I}}{\partial L_I} / \frac{w_I}{p_I} \right) - (l_I - \lambda_{L_I}) \right] \tag{18}$$

and nominal wages are specified to allow for stickiness:

$$D^2 \ln(w_I) = \alpha_{11}\alpha_{12} \ln \left(\frac{\partial f_{Y_I}}{\partial L_I} / \frac{w_I}{p_I} \right) - (\alpha_{11} + \alpha_{12}) \left(D \ln(w_I) - D \ln(p) - \lambda_C \right). \tag{19}$$

The marginal product of labour for given output and at current levels of employment in the ICT sector is:

$$\frac{\partial f_{Y_I}}{\partial L_I} = \beta_7 \left(\beta_8 e^{\lambda_C t} \right)^{-\beta_6} \left(\frac{Y_I}{\beta_7 L_I} \right)^{1+\beta_6}.$$

At current levels of capital in the ICT sector this becomes

$$\frac{\partial f_{Y_I}}{\partial L_I} = \beta_7 \beta_8 e^{\lambda_C t} \left[1 - \left(\frac{Y_I}{\beta_7 C} \right)^{\beta_6} \right]^{\frac{1+\beta_6}{\beta_6}}. \tag{20}$$

The marginal cost of labour is given by the ratio of the wage rate to the marginal product of labour so the short term marginal cost per unit output becomes:

$$mc \left(\frac{\partial L_I}{\partial Y_I} \right) = w_I \left(\beta_7 \beta_8 e^{\lambda_C t} \right)^{-1} \left[1 - \left(\frac{Y_I}{\beta_7 C} \right)^{\beta_6} \right]^{-\frac{1+\beta_6}{\beta_6}}. \tag{21}$$

As in the general sector, it is assumed that ICT prices are determined according to marginal (labour) cost per unit output, $w_I \left(\frac{\partial L_I}{\partial Y_I} \right)$, derived from the inverse of the production function multiplied by indirect taxes τ_I and with a mark-up γ_2 to give a partial equilibrium price $\gamma_2 \tau_I w_I \left(\frac{\partial L_I}{\partial Y_I} \right)$. The price dynamics of the model reflects the competitive process and the way in which prices are likely to be affected by the rates of change of real wages adjusted for increases in efficiency. Thus, if necessary, providing the supply of labour in the ICT sector is fully elastic, so the supply of labour equals the marginal product, the model can be specified without the use of employment data and (18) becomes superfluous.

Again, the dynamics of price determination are described by a second order process in which the acceleration of ICT prices is specified as:

$$\begin{aligned} D^2 \ln(p_I) \quad &= \quad \alpha_{17}\alpha_{18} \ln \left(\frac{\gamma_2 \tau_I mc \left(\frac{\partial L_I}{\partial Y_I} \right)}{p_I} \right) - (\alpha_{17} + \alpha_{18}) \left(D \ln(p_I) - \mu_{p_I} \right) + \\ & \quad + \alpha_{19} \left[D \ln \left(\frac{w_I}{p_I} \right) - \lambda_C \right]. \end{aligned} \tag{22}$$

The long-run rate of growth of ICT prices is $\mu_{P_I} = \lambda_M - \mu_I$.[6]

In partial equilibrium, the marginal product of Y with respect to Y_I in the general production function will equal the real price of ICT inputs, or in terms of the usual equality between marginal cost and output price

$$p = \frac{p_I}{\frac{\partial f}{\partial Y_I}}.$$

Thus, it is assumed that the demand for ICT is a function of the discrepancy between the marginal product of the final good with respect to ICT input and its real price, $\frac{p_I}{p}$. The price of ICT inputs, p_I, is determined by its marginal cost plus a mark-up.

The equation which links the ICT sector with the general sector is the demand and supply of ICT goods and services which may be represented by the difference, in logarithmic terms, of the marginal product of ICT inputs in the general production function and the relative cost of those inputs. This is specified as

$$D\ln(Y_I) = \alpha_{20}\ln\left(\frac{\partial f}{\partial Y_I}/\frac{p_I}{p}\right). \tag{23}$$

6 Estimation results

Estimates of the parameters were found by a FIML Gaussian estimator of the non-linear model subject to all constraints inherent in the model using a sample from 1980/Q2 to 2010/Q4 (see Appendix B for full details and data souces). The observation period is one quarter, so all flows, such as Y, Y_I and derivatives of variables, as well as wage and interest rates are quarterly. Many of the parameters α and all λ have a quarterly interpretation, but many of the parameters β are elasticities and hence dimensionless.

Table 1 contains the parameter estimates, which on the whole appear quite satisfactory.

[6] The parameters for the rates of growth of the volume of money, the ICT labour force and for technical progress in the ICT sector are all identified, the latter from the equations for employment and wages in the ICT sector and the former from both price equations.

Table 1 Parameters Estimates

Parameters	Estimates	Asymptotic Standard Errors
β_1	0.566	0.015
$\sigma_1 = \frac{1}{1+\beta_1}$	0.639	0.035
β_2	0.793	0.063
$\sigma_2 = \frac{1}{1+\beta_2}$	0.558	0.036
β_3	0.487	0.086
β_4	74.088	17.933
β_5	398.468	138.233
β_6	1.085	0.113
$\sigma_3 = \frac{1}{1+\beta_6}$	0.480	0.026
β_7	0.430	0.064
β_8	69.277	20.168
β_9	omitted	–
β_{10}	0.020	0.011
β_{11}	0.064	0.019
β_{12}	0.289	0.098
γ_1	1.036	0.011
γ_2	1.076	0.001
λ_K	0.0038	0.0024
λ_C	0.0087	0.0033
λ_I	-0.001	0.0012
λ_L	0.0009	0.0022
λ_{L_I}	0.0033	0.0115
$\ln(L_{u0})$	2.539	0.180

6.1 The aggregate sector

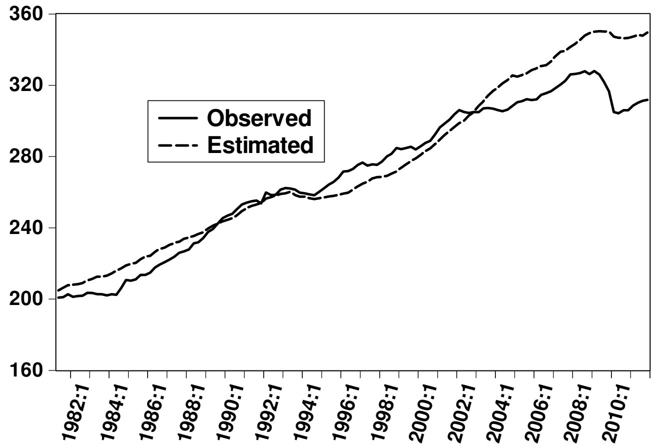
We begin our discussion with the parameters of the production functions, and in particular of their elasticities of substitution. From Table 1, we see that the elasticity of substitution in the ICT sector is $\sigma_3 = \frac{1}{1+\beta_6} = 0.48$ while that in the traditional sector is $\sigma_1 = \frac{1}{1+\beta_1} = 0.64$. As expected, the ICT sector has a lower elasticity. This result agrees with economic intuition according to which the more technological advanced sector, the ICT, should have a lower elasticity of substitution because of the tighter complementarity between capital and labour. The higher capital- skilled labor complementarity in the ICT sector implies that the substitutability between ICT capital and skilled labor is smaller than the substitutability between capital and unskilled labor in the traditional sector. These estimates imply that the inputs are complements in both sectors. As a matter of definition, this means that a fall in the wage-rental ratio leads to a lower decrease in the capital-labour (in a broad sense) ratio in the ICT sector.

It follows quite naturally that the elasticity of substitution in the general sector, $\sigma_2 = \frac{1}{1+\beta_2} = 0.56$, is between the two intermediate goods (φ and Y_I), which is midway between the two previous elasticities.

The estimated value of β_3 is an indicator of efficiency or the state of technology in the form of Hicks neutral technical progress. Technical progress is much faster in the innovative sector than in the traditional one ($\lambda_C = 0.009$, $\lambda_K = 0.004$). The growth rate of technical progress in the aggregate sector, λ_I, is not statistically significant. This result may indicate that the cost of maintaining and updating ICT reduces the benefits of the ICT to the general sector.

We will now look at the estimates of net domestic product (NDP) and restrict our attention to the analysis of the core of the model, in order to compare the dynamics of theoretical net output to the observed one. The former is determined by the production function specified in (1). This estimation procedure implies that there are no adjustment costs, or in other words, that the adjustment speeds are infinite so that this level of output can be considered "optimal". The theoretical evolution of this variable is then compared with the actual evolution of the NDP. Figure 5 reports the two NDP.

Figure 5 The dynamics of estimated and observed NDP in the Italian economy



The general production function (1) gives an estimate of average output value of € 1100 bn. per year, while the average observed NDP is € 1076 bn. for the period 1981-2011. Thus, there exists an average gap between the "optimal" and the actual value of 2 per cent over the whole period. It suggests that there are structural inefficiencies or at least long term costs, some of which are costs of adjustment. Of course, some of these will always exist but others may really be unnecessary or excessive but may have become institutionalized. These adjustment costs, be they avoidable or not, are represented in the model through the alphas. Hence, it seems that the model replicates quite well the dynamics of the Italian economy, as the high value of the correlation coefficient shows (0.96).

6.2 The traditional sector

As is well known, the traditional sector makes up a dominant part of the Italian output, roughly 90 per cent of the value added at the middle of the sample, corresponding to 1996:Q3. Actually, according to the EU KLEMS database, the weight of the total (producer and user) ICT sector value added with respect to the total value added net of public sector is about 10 percent. Thus, what happens in the traditional sector to a large extent also holds for the whole economy. By using equation (2), we can easily obtain the estimates of the traditional output; however, these cannot compared with the actual ones since the latter are not observable.

One of the main features of the Italian economy in the last three decades is the decline of the labour income share: over the sample period it falls on average by about 10 per cent. As seen above, in the same period capital intensity growth decreased. Are the two phenomena consistent? Standard macroeconomic theory suggests that the link depends on the magnitude of the elasticity of substitution.

To give a quantitative evaluation of this relationship, let us start from the definition of the elasticity of substitution for the traditional sector in the reference period (omitting the time subscript):[7]

$$\sigma_1 = \frac{d\ln\left(\frac{K}{L}\right)}{d\ln\left(\frac{\varphi_L}{\varphi_K}\right)} = \left[1 + \frac{d\ln\left(1-\pi_\varphi\right)}{d\ln\left(\frac{K}{\beta_4 L}\right)}\frac{1}{\pi_\varphi}\right]^{-1} \tag{24}$$

where $\varphi_L = \frac{\partial\varphi}{\partial L} = \left(\frac{\varphi}{L}\right)^{1+\beta_1}$, $\varphi_K = \frac{\partial\varphi}{\partial K} = \left(\frac{\varphi}{K}\right)^{1+\beta_1}$ and $\pi_\varphi = \left(\frac{\varphi}{K}\right)^{\beta_1}$ is the profit share in the traditional sector. Solving for the rate of change of capital intensity in efficiency

[7] As a useful preliminary result, note that by definition the ratio of income shares is given by:

$$\frac{\pi_\varphi}{1-\pi_\varphi} = \frac{\varphi_K}{\varphi_L}\frac{K}{\beta_4 L},$$

from which it follows that:

$$d\ln\left(\frac{\varphi_L}{\varphi_K}\right) = d\ln\left(1-\pi_\varphi\right) + d\ln\left(\frac{\frac{K}{\beta_4 L}}{\pi_\varphi}\right).$$

Hence, the elasticity of substitution can be written as:

$$\begin{aligned}
\sigma_1^{-1} &= \frac{d\ln\left(\frac{\varphi_L}{\varphi_K}\right)}{d\ln\left(\frac{K}{\beta_4 L}\right)} = \frac{d\ln\left(1-\pi_\varphi\right)}{d\ln\left(\frac{K}{\beta_4 L}\right)} + \frac{d\ln\left(\frac{K}{L}\right)}{d\ln\left(\frac{K}{\beta_4 L}\right)} + \frac{d\ln\frac{1}{\pi_\varphi}}{d\ln\left(\frac{K}{\beta_4 L}\right)} \\
&= \frac{d\ln\left(1-\pi_\varphi\right)}{d\ln\left(\frac{K}{\beta_4 L}\right)} + 1 + \frac{d\left(1-\pi_\varphi\right)}{d\left(\frac{K}{\beta_4 L}\right)}\frac{\frac{K}{L}}{\pi_\varphi}\frac{1-\pi_\varphi}{1-\pi_\varphi} \\
&= 1 + \frac{d\ln\left(1-\pi_\varphi\right)}{d\ln\left(\frac{K}{\beta_4 L}\right)}\left(1 + \frac{1-\pi_\varphi}{\pi_\varphi}\right) = 1 + \frac{d\ln\left(1-\pi_\varphi\right)}{d\ln\left(\frac{K}{\beta_4 L}\right)}\left(\frac{1}{\pi_\varphi}\right)
\end{aligned}$$

units allows to show how the elasticity of substitution connects income distribution with capital intensity:

$$d\ln\left(\frac{K}{\beta_4 L}\right) = -\frac{\sigma_1}{\sigma_1-1}\frac{1}{\pi_\varphi}d\ln(1-\pi_\varphi) \tag{25}$$
$$= -\frac{\sigma_1}{\sigma_1-1}\left(\frac{\varphi}{K}\right)^{\frac{\sigma_1-1}{\sigma_1}} d\ln(1-\pi_\varphi).$$

Our estimation of the elasticity of substitution between labour and capital in the intermediate sector is well below 1 ($\sigma_1 = 0.64$), implying inputs complementarity. In turn, complementarity implies that changes in capital intensity should positively correlated with changes in the labour income share. Specifically, using our estimates in equation (25) and assuming a decrease in labor share of $d\ln(1-\pi_\varphi) = 10$ percent, we obtain a medium-run change in capital intensity equal to:

$$d\ln\left(\frac{K}{\beta_4 L}\right) = -\frac{\sigma_1}{\sigma_1-1}\left(\frac{\varphi}{K}\right)^{\frac{\sigma_1-1}{\sigma_1}} d\ln(1-\pi_\varphi)$$

and plugging in the estimates and the values of exogenous variables in the base period, we get

$$= -\frac{0.64}{0.64-1}\left(\frac{648.1}{3294.5}\right)^{\frac{0.64-1}{0.64}}(-0.10) = -0.443,$$

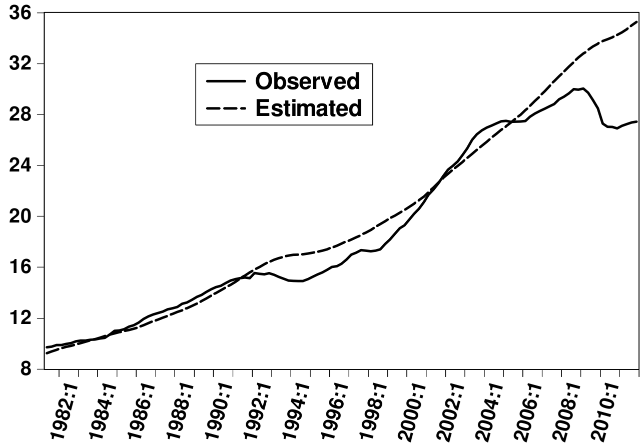
that is, over the sample period the average growth in capital deepening about halved. By and large, this is of the same order of magnitude seen in the stylized facts, where the rate of change of capital intensity decreased on average from 3.3 per cent to 1.4 per cent.

Conversely, the story, often told in the recent literature (e.g., Karabarbounis and Neiman 2014), does not seem consistent with an elasticity of substitution larger than 1. Indeed, inputs substitution entails that a decline in the labour share goes hand in hand with an increase in capital intensity. To put it differently, technological progress and/or the fall in the relative prices of investment goods have not favoured a substitution of capital for labour in the Italian economy.

6.3 The ICT sector

Figure 6 reports the levels of the ICT output. These estimates are obtained from ICT production function, equation (3). The average estimated ICT output in this case is about € 79 bn. per year, while the average observed value is € 75 bn. with an average gap between the “optimal” and the actual value of 5.3 per cent over the whole period.

Figure 6 The dynamics of estimated and observed ICT output in the Italian economy



It is worthwhile noticing that the two graphs in figure 5 and 6 follow quite similar paths. This result is consistent with the stylised facts saw above, which suggest that the stagnation of the Italian economy is due to the inability to adopt and exploit new technologies.

6.4 Technical progress

We now discuss the evolution of the TFP. The CES production function allows us to decompose the TFP by distinguishing the contributions of the different inputs in factor-augmenting technical change.

To begin with, we set the base period used for the normalization at the middle of the sample, $t_0 = 62$, corresponding to 1996:Q3. To simplify notation, we denote this period by the index 0. Normalization implies that all the variables are expressed in terms of their baseline values, that is C_0, L_{I_0} and Y_{I_0}.

We start with the ICT production function:

$$Y_I = \beta_7 \left[C^{-\beta_6} + \left(\beta_8 e^{\lambda_C (t-t_0)} L_I \right)^{-\beta_6} \right]^{-\frac{1}{\beta_6}}$$

where t_0 is the base period. The result of normalization is (see Appendix A for details):

$$\frac{Y_{I_t}}{Y_{I_0}} = \left[\pi_0 \left(\frac{C_t}{C_0} \right)^{-\beta_6} + (1-\pi_0) \left(\frac{L_{I_t} e^{\lambda_C (t-t_0)}}{L_{I_0}} \right)^{-\beta_6} \right]^{-\frac{1}{\beta_6}}. \qquad (26)$$

Before discussing factor-augmenting and factor-bias technical change, let us note that employing observed data for capital, labour and output in the ICT sector and parameter estimates in Table 1 the capital income share is:

$$\pi_0 = \left(\frac{Y_{I_0}}{\beta_7 C_0} \right)^{\beta_6} \cong 0.4.$$

The actual capital share in the ICT sector that can be derived from existing databases (such as ISTAT, EU KLEMS) is not too much different, being about 32 per cent. Therefore, in the following we adopt $\pi_0 = 0.4$ as reference value in our estimates of technical change.

6.4.1 Factor-augmenting technical change

To simplify notation, we now interpret equation (26) directly in index number form:

$$Y_{I_t} = \left[\pi_0 \left(C_t\right)^{-\beta_6} + (1-\pi_0)\left(L_{I_t} e^{\lambda_C (t-t_0)}\right)^{-\beta_6}\right]^{-\frac{1}{\beta_6}} \tag{27}$$

where the same symbols for output, labor and capital are to be intended as indexes.

The rate of growth of output is determined by the time log derivative of equation (26):

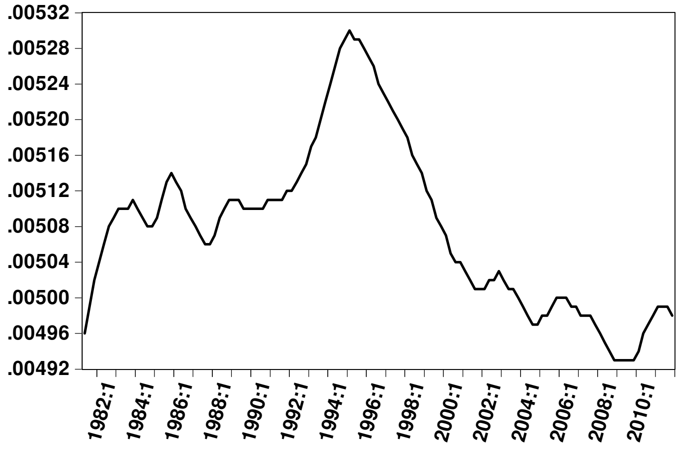
$$\begin{aligned} \frac{\dot{Y}_{I_t}}{Y_{I_t}} &= \varepsilon_{Y_I,C} \frac{\dot{C}_t}{C_t} + \varepsilon_{Y_I,LIT}\left(\frac{\dot{L}_I}{L_I} + \lambda_C\right) \\ &= \pi_0 \left(\frac{Y_{I_t}}{C_t}\right)^{\beta_6} \frac{\dot{C}_t}{C_t} + (1-\pi_0)\left(\frac{L_{I_t} e^{\lambda_C (t-t_0)}}{L_{I_t}}\right)^{\beta_6}\left(\frac{\dot{L}_{I_t}}{L_{I_t}} + \lambda_C\right) \end{aligned} \tag{28}$$

where $\varepsilon_{Y_I,C} = \frac{\partial Y_I}{Y_I} / \frac{\partial C}{C}$ and $\varepsilon_{Y_I,LIT} = \frac{\partial Y_I}{Y_I} / \frac{\partial L_I e^{\lambda_C}}{L_I e^{\lambda_C}}$ are the output elasticities with respect to the two inputs expressed in efficiency units. Generally, the contribution of each input augmenting factor to the rate of output growth is given by the sensitivity of output with respect to each input times the growth rate of technical progress. In this framework, technical change is only of the labour-augmenting type. It is given by:

$$(1-\pi_0)\left(\frac{Y_{I_t}}{L_{I_t} e^{\lambda_C (t-t_0)}}\right)^{\beta_6} \lambda_C.$$

Figure 7 displays its estimated dynamics in the sample period.

Figure 7 The dynamics of labor-augmenting technical change in the ICT sector



The graph clearly shows that the contribution of labour efficiency to technical change increases in the first part of the sample (until 1995:Q2), with an yearly peak of about 2%. Afterwards, it begins to decelerate. The capital contribution to labour efficiency was initially favoured by the diffusion of ICT, mostly through the adoption of new hardware and software. This improvement in efficiency came to a stop by the beginning of the 90s. Many factors contributed to this standstill but, in our view, it was caused mainly by the failure to adopt new forms of organisation needed to fully exploit the productivity enhancing potential.

6.4.2 Bias in the ICT sector

Taking into account the estimated value of elasticity of substitution, the result just seen is consistent with a technical change capital-biased. This is because the elasticity of substitution is less than 1, i.e. the inputs are gross complements. Indeed, the ratio of marginal productivities is

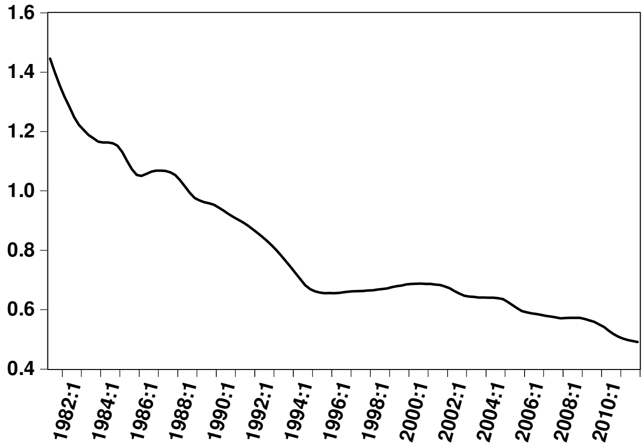
$$\begin{aligned}\frac{\partial Y_{I_t}/\partial C_t}{\partial Y_{I_t}/\partial L_{I_t}} &= \frac{\pi_0}{1-\pi_0}\left(\frac{L_{I_t}}{C_t}\right)^{1+\beta_6}\left(e^{\lambda_c(t-t_0)}\right)^{\beta_6} \\ &= \frac{\pi_0}{1-\pi_0}\left(\frac{L_{I_t}}{C_t}\right)^{\frac{1}{\sigma_3}}\left(e^{\lambda_c(t-t_0)}\right)^{\frac{1-\sigma_3}{\sigma_3}}.\end{aligned}$$

Since $\beta_6 > 0$, so that $\sigma_3 < 1$, the labour technical change, λ_C, favors the marginal product of ICT capital.[8]

Its dynamics is depicted in figure 8.

[8] Technical progress is biased toward a factor if it increases its marginal product more than the other factor's. The bias can be divided into two parts. One is the traditional substitution effect, $\left(\frac{L_{I_t}}{C_t}\right)^{\frac{1}{\sigma_3}}$, determined by the relative endowments of the two inputs, that favors the scarcer factor. The other component, that can be referred to as the technical change effect, depends on the relative weight of the factor-augmenting technical change, $\left(e^{\lambda_c(t-t_0)}\right)^{\frac{1-\sigma_3}{\sigma_3}}$, and whether the elasticity of substitution is less than, equal to or greater than 1. This second effect is obviously absent in the Cobb-Douglas case.

Figure 8 The technical change bias in the ICT sector



Though the capital bias is apparent over the whole sample, its evolution is decreasing. In our opinion, the high bias in ICT capital at the beginning can be interpreted as a new-industry advantages, i.e. as easy picking advantages, fastly running out. As Fernald (2014) argues with regards to the recent US productivity slowdown, this evidence supports the hypothesis that the contribution from the recent advances in ICT to the productivity is relatively short lived. In addition, it seems to confirm that, according to science and technology indicators (OECD 2015), Italian firms are still facing major challenges to catch up OECD leaders. Indeed, the graph shows that the marginal product of the ICT capital with respect to high skill labour reduced from 1.5 to 0.5.

6.5 The aggregate sector

The final output is produced by combining the two intermediate inputs, the traditional and innovative goods. As it is shown in Table 1, the elasticity of substitution is less than 1, so that the two goods are, not surprisingly, complements. Nevertheless, the specific weight of the two sectors is quite different. Indeed, the input share of the traditional sector is much larger than the innovative one. The traditional output share, inclusive of capital and labour income, is:[9]

$$s_\varphi = \left(\frac{\beta_3\varphi_0}{Y_0}\right)^{-\beta_2} = 0.89.$$

Thus, in our estimates the weight of traditional intermediate input is predominant. The share of ICT producing sectors in the EU KLEMS database[10] is about 5 per cent. The gap with our estimates (11 per cent), which represents an "optimum" taking into account adjustment costs, is still another signal of the scant importance of the ICT sector in the Italian economy and of its inability to fully exploit the advantages of the technological revolution of the 90s.

The profit share in the traditional sector in the base period amounts to $\left(\frac{\varphi_0}{K_0}\right)^{\beta_1} = 0.4$. As for the innovative sector, we saw above that of the income share 0.40 goes to profits. Hence, the profit share is similar in the two sectors. Although we are looking at aggregate data, the income distribution seems consistent with that observed in the Italian economy in the sample period.

Not only the weight of traditional sector has been predominant in the reference period. Over the whole sample period the evolution of technological progress seems to have favoured traditional productions. The technological bias gives us a measure of the traditional sector gain:

$$\frac{\partial Y_t/\partial\varphi_t}{\partial Y_t/\partial Y_{I_t}} = \frac{s_\varphi}{1-s_\varphi}\left(\frac{Y_{I_t}}{\varphi_t}\right)^{1+\beta_2}\left(e^{\lambda_I(t-t_0)}\right)^{\beta_2}.$$

Figure 9 displays the dynamics of the technological bias.

[9] To derive this expression, just rewrite the general production function as follows:

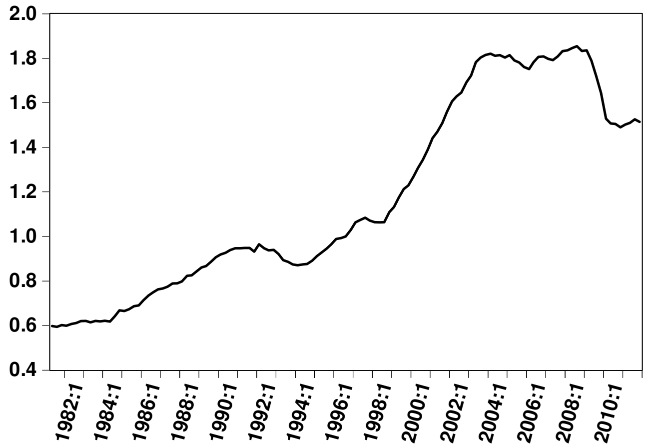
$$\left(\frac{Y_0}{\beta_3}\right)^{-\beta_2} = (\varphi_0)^{-\beta_2} + (\beta_5 Y_I)^{-\beta_2}$$

from which the share of the two intermediate sectors can be obtained:

$$1 = \left(\frac{\beta_3\varphi_0}{Y_0}\right)^{-\beta_2} + \left(\frac{\beta_3\beta_5 Y_I}{Y_0}\right)^{-\beta_2}.$$

[10] These include both manufacturing and services sectors. See the ICT taxonomy in Robinson, C. et al. (2003, p. 49).

Figure 9 The technical change bias in the aggregate sector



It is apparent from the graph that the traditional intermediate good bias has increased over the whole sample, apart from the end of the sample. To put it differently, at the start of the sample period the marginal productivity of the traditional sector was less than unity (about 60 per cent) relative to that of ICT sector; at the end, though declining during the Great Crisis, it has increased up to 1.5. It is also worth noticing that this increase is mostly due to the substitution effect since the coefficient of technological progress of ICT (λ_I), in our estimation, is not statistically different from zero. These two observations help interpret the behavior of the Italian industrial system in the last twenty years. As mentioned in the section on stylized facts, the Italian economy has seen a readjustment of its industrial structure shifting weight from the ICT sector to the traditional one. The graph shows that this reallocation is justified by the relative dynamics of marginal productivities. Moreover, the statistical insignificance of the coefficient of the ICT technological progress supports that this restructuring hampered the adoption of the new technologies and, hence, of the TFP growth.

6.6 The adjustment dynamics

We now turn to the partial adjustment processes of capital and labour markets, wages and prices. By partial, we mean that each of these variables adjusts with a distributed time lag, to its partial equilibrium value, which is a function of a subset of other variables of the model.

The model does not impose instantaneous equilibrium, but assumes the existence of a path of convergence implying lags in the adjustment to equilibrium. These distributed lag functions reflect the adjustment costs, gestation or installation lags, uncertainty or risk, and habit persistence faced by the economic agents in their intertemporal optimisation. It is that which leads to the higher order processes, formally via the Riccati equations although the derivation for a system of even very few equations can become extremely complex. The more uncertain is the future the slower will be adjustment if the costs of that adjustment are high.

The second-order functions used in the model may be interpreted as the integral of a second order distributed lag process. In formulating these models it is necessary to specify the distributed lag process in the adjustment process and there is no reason why the functions should just be first order i.e. the adjustment costs depend only on the rate of change of the adjusting variables. In fact, it is likely that the functions will be of higher order, in which case the adjustment costs depend not only on the rate of change of the adjusting variables but also on its acceleration rate. Thus if $x(t)$ is assumed to adjust to some desired or expected level $\hat{x}(t)$ with distributed lag $f(s)$,

$$x(t) = \int_0^\infty f(s)\,\hat{x}(t-s)ds.$$

It is considered that the class of exponential distributed lag functions provides a useful representation of the lag processes in the economy as they have the advantage of being simple and have the property of a density function in that $\int_0^\infty f(s)\,ds = 1$, with $f(s) > 0$ and $\lim_{s\to\infty} f(s) = 0$. These functions are smooth and differentiable to any order and can be defined to provide realistic "humped" forms with few parameters.

The standard distributed lag function corresponding to the second order process is:

$$D^2x = \alpha'\alpha''(\hat{x} - x) - (\alpha' + \alpha'')\,Dx, \qquad (29)$$

whose density is (for a derivation, see Bergstrom and Nowman, 2007)

$$f(s) = \frac{\alpha'\alpha''}{\alpha' - \alpha''}\left(e^{-\alpha'' s} - e^{\alpha' s}\right)$$

This second order process has a mean time lag (MTL), i.e. the time needed to eliminate the 63 per cent of the discrepancy between actual and partial equilibrium values, equal to

$$MTL = \int_0^\infty x(s)\,f(s)\,ds = \frac{1}{\alpha'} + \frac{1}{\alpha''} = \frac{\alpha' + \alpha''}{\alpha'\alpha''}. \qquad (30)$$

In the model, a slightly more general second order distributed lag function is sometimes used

$$D^2x = a'\left[b'(\hat{x} - x) - Dx\right] \qquad (31)$$

For instance, the traditional capital stock adjustment process, equation (8), takes the following form

$$\dot{k} = \alpha_1\left[\alpha_2\left(\frac{\partial f}{\partial K} - \text{real } r\right) - (k - \mu_K)\right]$$

where the marginal product of capital K is a function of the output/capital ratio and $k = D\ln K$. Log-linearizing about some point allows this to be written as

$$D^2x = a(\hat{x} - x) - bDx. \qquad (32)$$

Comparing (32) and (31) with (29) gives the following equivalent expressions of the MTL:

$$MTL = \frac{\alpha' + \alpha''}{\alpha'\alpha''} = \frac{a'}{a'b'} = \frac{1}{b'} = \frac{b}{a}.$$

The modal time lag (MDTL), which is the lag to the peak of the distribution, is

$$MDTL = \arg\max f(s) = \frac{\ln\left(\frac{\alpha'}{\alpha''}\right)}{\alpha' - \alpha''} = \frac{\ln\left(\frac{b+\sqrt{b^2-4a}}{b-\sqrt{b^2-4a}}\right)}{\sqrt{b^2 - 4a}}.$$

If $b^2 > 4a$ the distributed lag density function will be unimodal but otherwise it will involve complex numbers and the density function will be multi-modal.

The estimates of the means and modes of the lag distribution functions are computed in the next section from the estimated speeds of adjustment, i.e. the alphas, reported inTable 2.

Table 2 Estimated Adjustment Parameters

Parameters	Estimates	Asymptotic Standard Errors
α_1	0.079	0.015
α_2	0.172	0.063
α_3	0.198	0.030
α_4	0.207	0.030
α_5	0.027	0.012
α_6	1.003	0.203
α_7	0.082	0.035
α_8	2.370	0.840
α_9	0.029	0.023
α_{10}	0.024	0.020
α_{11}	0.375	0.081
α_{12}	0.015	0.003
α_{13}	0.039	0.019
α_{14}	1.034	0.302
α_{15}	1.656	0.443
α_{16}	0.086	0.039
α_{17}	0.013	0.005
α_{18}	0.024	0.012
α_{19}	0.031	0.013
α_{20}	0.012	0.003

If demand for output increases, firms are likely to invest more rapidly or employ more staff more quickly if the costs of making those changes are low or relatively risk free.

This form of robust control has the effect of smoothing out fluctuations in investment, employment and probably wages and prices.[11]

6.6.1 Adjustment in capital markets

The adjustment process of the aggregate capital stock, equation (8), does not assume the standard form. Indeed, a more general lag is used in (8) – where b' is α_2 – since the difference between the desired and actual values is implicitly defined in terms of the marginal product of capital. Log-linearizing about the sample mean, we get a coefficient for $\ln(K)$, say $\alpha_K = 0.046$,[12] which multiplied by α_2 gives the MTL for traditional capital adjustment

$$MTL_K = \frac{1}{b'} = \frac{1}{\alpha_2 \cdot \alpha_K} \simeq 126$$

that is over thirty years. This time length must be interpreted as the MTL needed for changes in investment to bring the marginal product of capital into line with the real interest rate. (This arises from the implicit nature of this measure). As for the modal time lag, we have

$$MDTL_K = \frac{\ln\left(\frac{\alpha_1+\sqrt{\alpha_1^2-4\alpha_1\alpha_2\alpha_K}}{\alpha_1-\sqrt{\alpha_1^2-4\alpha_1\alpha_2\alpha_K}}\right)}{\sqrt{\alpha_1^2-4\alpha_1\alpha_2\alpha_K}} \simeq 34$$

MTLs not too much different are obtained for the UK economy (Bergstrom and Nowman, 2007). These values suggest that the speed at which firms adjust the existing capital stock to its desired level is very low.

Similarly, considering the adjustment of ICT capital stock, equation (9), we follow the same procedure obtaining a MTL of more than 6 years since:

$$MTL_C = \frac{1}{\alpha_4 \cdot \alpha_C} \simeq 24,$$

where $\alpha_C = 0.2$ is the result of log-linearizing of ICT marginal product about the sample

[11] These “parameters” may be considered functions of underlying factors (such as EPL) and those functions estimated jointly with the whole model.

[12] Log-linearizing the marginal product of capital in the traditional sector about the sample mean, we get

$$\begin{aligned}\alpha_K &= -\beta_3\left(\exp((1+\beta_2)\left(\overline{\ln Y}-\overline{\ln(\varphi)}-\ln(\beta_3)\right)+(1+\beta_1)\left(\overline{\ln(\varphi)}-\overline{\ln(K)}\right)\right)\\ &\quad\times\left(1+\beta_1-(\beta_1-\beta_2)\exp\left(\beta_1\overline{\ln(\varphi)}\right)\right)=0.0438\end{aligned}$$

where $\overline{\ln Y}$, $\overline{\ln(K)}$ are the logs of the sample means of output and capital stock, and $\overline{\ln(\varphi)}$ is defined as:

$$\overline{\ln(\varphi)} = -\frac{1}{\beta_1}\ln\left[\exp\left(-\beta_1\overline{\ln(K)}\right)+\exp\left(-\beta_1\left(\ln(\beta_4)+\overline{\ln(L)}\right)\right)\right]$$

mean.[13] Thus, perhaps not surprisingly, the capital adjustment in the ICT sector is much shorter than in the traditional good sector. Its modal time lag is

$$MDTL_C \simeq 11$$

However, a word of caution must be spent on the MTL of the accumulation process of the traditional capital: even considering that it refers to the whole economy it seems a too long period.

6.6.2 Adjustment in labor markets

Equation (11) specifies the time required by firms in the aggregate sector to adjust the actual level of employment to the desired or demanded one. The MTL in this case is given by:

$$MTL_E = \frac{1}{\alpha_5} + \frac{1}{\alpha_6} \simeq 38.$$

This means that, other things being equal, it takes about 38 quarters – more than 9 years for the labour market to close the gap. The presence of rigidities in the labor market in Italy may justify such very slow adjustment. Note, however, that the mode in the labor market is much shorter and equal to

$$MDTL_E \simeq 4$$

Following the same procedure seen above for the adjustment of capital stocks, the adjustment process in the labour market of the ICT sector, which involves the demand and supply, is given by

$$MTL_{E_I} = \frac{1}{\alpha_{10} \cdot \alpha_{L_I}} \simeq 20$$

where as above $\alpha_{L_I} = 1 + \beta_6$ is the result of log-linearizing the labor marginal product in the ICT sector about the sample mean. This period is longer than expected and seems to suggest a shortage of skilled labour in the Italian labour market.

6.6.3 Price adjustments

We now turn to the goods market. In the aggregate sector, assuming money neutrality and real wages growing at productivity rate, we have a pure second-order adjustment of prices to marginal costs, allowing for a markup and taxes. The MTL is

$$MTL_p = \frac{1}{\alpha_{13}} + \frac{1}{\alpha_{13} + \alpha_{14} + \alpha_{15}} \simeq 26.$$

[13] Log-linearizing the marginal product of capital in the ICT sector about the sample mean gives

$$\begin{aligned} \alpha_C &= -\beta_7 \left((1+\beta_6) \exp((1+\beta_6) \left(\overline{\ln Y_I} - \overline{\ln (C)} - \ln(\beta_7) \right) \right) \\ &= 0.197. \end{aligned}$$

Similarly, in the ICT sector assuming that real wages grow at the productivity rate λ_C, the MTL is:

$$MTL_{p_I} = \frac{1}{\alpha_{17}} + \frac{1}{\alpha_{17} + \alpha_{18} + \alpha_{19}} \simeq 92.$$

This can be interpreted as showing there is no relation between prices in the ICT sector and its marginal costs. It seems to point to the existence of rents.

7 Conclusions

The main objective of the paper has been to endogenize ICT production by treating it as an intermediate good. As an intermediate good, part of ICT output is transformed by the general production function and becomes general output. The other intermediate good is the output of the traditional sector. This way, we estimate not only an aggregate elasticity of substitution, but also two other inputs elasticity of substitution. In all the sectors elasticities are well below 1. Not surprisingly, the elasticity of substitution of the aggregate sector has a value intermediate between that of the ICT sector and that of the traditional sector, since the input complementarity is tighter in the former than in the latter. As for the traditional sector, whose share is predominant in the production of the final good, an elasticty of substitution lower than 1 helps explain the labour share decline of Italian economy and the slowdown in the capital intensity growth. In the ICT sector, technological progress, both in the form of capital augmenting and capital bias, showed a decline over the sample period with an obvious negative consequence on the global evolution of the technical progress. The results about the dynamics of the two intermediate sectors helps explain the "Italian paradox" of an industrial structure marked by an increasing weight of the traditional sector, the declining capital intensity in the traditional sector and the weaker and weaker contribution of the ICT sector to the general technological progress.

The consequence was a rebalancing of the Italian industrial structure towards the traditional sector. All of this helps explain the pathological behavior of both labor productivity and TFP of the Italian economy. These structural features may also explain the difficulties encountered by the Italian economy in exiting from its worst recession since the 1930s. One practical implication of these results is the need to boost the ICT investment. The questions arise as to who should finance the expenditure and the juridical nature of the financing institution, public or private. This is the next step in our research agenda.

Appendix A The normalization procedure

Under imperfect competition, factor compensation is subject to a mark-up, by hypothesis constant and denoted by γ_2, so that in any period t the following relation holds:

$$\left(r_t C_t + w_{I_t} L_{I_t}\right) \gamma_2 = Y_{I_t}$$

where r_t is the real interest rate and w_{I_t} is the wage rate in the ICT sector.

In the reference period, capital compensation is:

$$r_0 = \frac{1}{\gamma_2} \frac{\partial Y_{I_0}}{\partial C_0} = \frac{(\beta_7)^{-\beta_6}}{\gamma_2} \left(\frac{Y_{I_0}}{C_0}\right)^{1+\beta_6}$$

so that total capital compensation over total factor income, or the capital share, in the base period is

$$\pi_0 = \frac{r_0 C_0}{Y_{I_0}} \gamma_2 = \left(\frac{Y_{I_0}}{\beta_7 C_0}\right)^{\beta_6} \tag{A.1}$$

Likewise, the labor compensation in the base period is

$$w_{I_0} = \frac{1}{\gamma_2} \frac{\partial Y_{I_0}}{\partial L_{I_0}} = \frac{(\beta_7 \beta_8)^{-\beta_6}}{\gamma_2} \left(\frac{Y_{I_0}}{L_{I_0}}\right)^{1+\beta_6}$$

so the labour share in the ICT sector is

$$1 - \pi_0 = \frac{w_{I_0} L_{I_0}}{Y_{I_0}} \gamma_2 = \left(\frac{Y_{I_0}}{\beta_7 \beta_8 L_{I_0}}\right)^{\beta_6} \tag{A.2}$$

Notice that labour share expressed in efficiency units is simply $\beta_8 L_{I_0}$ since in the base period the time-dependent efficiency factor disappears.

Substituting into the production function (3), the capital share evaluated in the base period is:

$$Y_{I_t} = \left[\pi_0 \left(\frac{Y_{I_0}}{C_0}\right)^{-\beta_6} (C_t)^{-\beta_6} + \left(\beta_7 \beta_8 e^{\lambda_C \, (t-t_0)} L_{I_t}\right)^{-\beta_6}\right]^{-\frac{1}{\beta_6}}$$

Following an analogous procedure for the labor share, we have:

$$Y_{I_t} = Y_{I_0} \left[\pi_0 \left(\frac{C_t}{C_0}\right)^{-\beta_6} + (1 - \pi_0) \left(e^{\lambda_C \, (t-t_0)} \frac{L_{I_t}}{L_{I_0}}\right)^{-\beta_6}\right]^{-\frac{1}{\beta_6}} \tag{A.3}$$

Writing the function in index form, we get the equation in the main text.

Appendix B Data

The data used are of the Italian economy, quarterly from 1980/Q2 to 2010/Q4. GDP and NDP, fixed capital, and total remuneration are defined as € bn., employment in millions of employees, while variables such as interest rates, rate of time preference and rates of growth are rates per quarter. All real variables are defined with base year 2000. The stock of fixed capital is calculated from net capital formation divided by the GDP deflator and cumulated from a base stock of euro 3572.4 bn. in 2000:Q2. The ICT capital stock is calculated from annual data for gross real investment less depreciation for each of three sub-sectors (office machinery, communication devices and software), each separately interpolated to provide quarterly observations, and total net investment cumulated on a base figure of euro 80.717 bn. in 2000:Q4. The sources of the data are ISTAT, Bank of Italy, EU KLEMS, OECD, AMECO, European Commission. EU KLEMS provides the data on ICT producing sectors, classified as follows (see Robinson et al. 2003, p. 49):

1. *ICT Producing - Manufacturing*: Office machinery (30); Insulated wire (313); Electronic valves and tubes (321); Telecommunication equipment (322); Radio and television receivers (323); Scientific instruments (331).

2. *ICT Producing – Services*: Communications (64); Computer & related activities (72).

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