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The diffusion of new information technologies and productivity growth*

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Abstract. This paper investigates the effects of the rates of diffusion of the cluster of new information technologies on the growth of output and total factor productivity in the main OCED and industrializing countries in the late eighties. This diffusion approach contrasts the technology production function framework. It predicts that the rates of generation of new technologies are much less effective than the rates of diffusion and the investment efforts in determining the growth of labor productivity especially when capital-intensive technologies which command high levels of investments are considered. The results make it possible to elaborate and assess empirically the notion of key-technologies that provide positive externalities to the rest of the system.

Key words: Diffusion – Productivity growth – Information technologies

JEL-classifications: 030-L9

1. Introduction

This paper investigates the relationship between the diffusion of a key technology such as new information technology and labor productivity growth.

According to the received theory there should be an "automatic link" between the generation of technological change, the overall enhancement of efficiency in the production function and the effective increase of total factor productivity. Recent advances in the economics of innovation and new technology, however, have shown that the full introduction of technological innovations in the economic system is a lengthy process which takes a long stretch of time to be completed. More specifically

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the successful introduction of a key technological innovation into the economic system is the outcome of the combined process of (1) its selection out of a variety of competing innovations; (2) its implementation and incremental development according to the requirements of customers and the opportunities to reduce costs offered to suppliers by economies of scale, learning by doing and learning by using; (3) its imitation and further refinements by other manufacturers with further declines in market prices; (4) its adoption by a variety of potential customers which are heterogeneous both in terms of size and access to both factor and product markets.

The microeconomics of the diffusion of new capital goods incorporating process innovations has been based on the epidemic approach elaborated by Griliches (1957) and Mansfield (1961). The epidemic approach assumes a disequilibrium process where profitable innovations are adopted by firms with a delay explained by the costs of substitution of old machines (differentiated among firms because of differences in the intertemporal distribution of investments) and especially by the costs of acquiring relevant information necessary to assess the profitability of new capital goods.

Consistently, a large empirical evidence has shown that the outcome of such a complex interdependent process, well known as the *diffusion* of technological innovations, takes place along a sigmoid time path which implies strong discontinuities and non linearities in the rates of growth of the demand of the innovated product. In other words, the downward movement of the isoquant in the techniques space which represents the introduction of technological innovation in the text book microeconomics, is appropriate only at the end of diffusion process as the result of a discontinuous and dynamic process of generation, selection and adoption.

Consequently, it seems appropriate to put out the hypothesis that the productivity growth determined by the introduction of innovations should follow the sigmoid time path usually approximated by a logistic or loglogistic function. In fact it can be argued that the rate of growth of productivity should exhibit the same non-linearities and discontinuities of the rates of growth of the demand for innovated products. More generally it seems that the recent advances made in understanding the *determinants* of the dynamics underlying the diffusion of innovations, now make it possible to examine the *consequences* of the diffusion on the economic system.

This approach seems consistent with the Post-Keynesian framework of analysis. In that tradition in fact the relationship between diffusion and productivity growth receives full attention not without its own limits, i.e. overlooking the role of adoption choices and equating diffusion to the outcome of the process of capital accumulation and investment.[1]

In the Post-Keynesian approach all new investment, *for given levels* of generation of technological innovations, and given levels of adoption *ability by entrepreneurs*, is expected to have strong positive effects on labour productivity. Diffusion here

[1] As Kaldor notes: "Hence the speed at which a society can "absorb" capital (i.e. it can increase its stock of man-made equipment, relatively to labour) depends on its technical dynamism, its ability to invent and introduce new techniques of production. A society where technical change and adaptation proceed slowly, where producers are reluctant to abandon traditional methods and to adopt new techniques, is necessarily one where the rate of capital accumulation is small. The converse of this proposition is also true: the rate at which a society can absorb and exploit new techniques is limited by its ability to accumulate capital" (Kaldor 1957, p. 595).

becomes the automatic outcome of investment: the relationship between investment and labour productivity appears in the well-known "technical change function" of Kaldor to be shaped by imitation lags.[2]

Our approach seems to present some advantages in that it is likely to shed some light on the relationship between the effective introduction of technological change, investments and productivity growth. Productivity growth in fact is determined, in our approach, not only by the level of technological change and investment, but *also* by the rate of diffusion which help understanding the non-linear process that "infuse innovation into the economic system".

In this perspective it seems that some "infusion" of new microeconomics based on the assumptions of bounded rationality and imperfect knowledge is essential to grasp the essence of growth processes as depicted by the Neo-Keynesian approach and to better understand the delays in the relationship between the rate of generation of technological change, the rate of investments, and the rate of growth of productivity. When new "machines" are generated such that their use implies some discontinuity with preexisting technologies and, consequently, the need for some learning processes, diffusion lags due to bounded rationality and delayed adoption choices do matter as well as the ability to generate high levels of capital accumulation (Abramovitz 1989).

2. Diffusion investment and productivity growth

2.1. The new models of economic growth

The new models of economic growth recognize the central role of technological change as driven by research and development activities in the process of economic growth (Romer 1986; Romer 1990). The new models of economic growth, however, focus all attention on the generation of new technologies rather than on their actual introduction and diffusion in the production process. From this point of view a strong commonality can be found between the models of economic growth and the technology production function elaborated by Griliches (1979). The technology production function relates explicitly the general levels of efficiency of the production function to the levels of R&D expenditures or to the levels of patents generated (Griliches 1990).

This contrasts sharply Scott's model which instead stresses the limits of the notion of capital and net investment and focus attention on the role of gross investment. On these bases Scott (1989) specifies a simple growth equation in which the growth of output is determined by the ratio of total investments to output and the rate of growth of employment.[3] Scott stresses the role of total investments, i.e.

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[2] See Kaldor (1957): "Our TT′ curve thus reflects not only "inventiveness" in the strict sense, but the degree of technical dynamism of the economy in a broader sense – which includes not only the capacity to think of new ideas, but the readiness of those in charge of production to adopt new methods of production" (p. 596). Moreover Kaldor shapes the technical change function as a trunctated logistic characterized by an upward convexity that will become flat beyond a given point, because of some saturation effects. Kaldor does not provide any further explanation for such a shape which in a more traditionally diffusion-oriented context would be of course elaborated taking into account the recent advances in the microeconomics of diffusion.

[3] The equation specified by Scott reads as follows:

$go = a1I + a2gL$ (1), where go is the growth of output, I is the ratio of total investments to output; gL is the rate of growth of employment.

both gross and net investment, in explaining growth, arguing that it is not possible to distinguish between movements along the production functions and movements of the production functions. More specifically, Scott recalls that gross investment plays the essential role to modernize the capital equipment of the economy. Gross investments in fact embody technological changes. The standard approach that takes into account only net investments instead is unable to appreciate the positive effects on productivity growth of the substitution of obsolete capital goods with better modernized pieces of equipment. In so doing Scott's approach seems to retain the essence of the Kaldorian technical progress function and to bring it even farther when assuming that the actual rate of introduction of technological change is a function of investments.

From this point of view it seems to us that the new models of economic growth should acknowledge the Kaldorian legacy more explicitly. According to Kaldor (1957), there is a functional relationship between the growth in the capital stock and the growth of labour productivity. The "technical progress function" was conceived to bypass the distinction between the movements along a production function and the shifts of the production function.[4] Kaldor (1957) formalises the technical progress function as an equation where the rate of growth of labour productivity is an *increasing function of the rate of net investment* expressed as a proportion of the stock of capital.[5]

A later version of Kaldor's technical progress function (Kaldor-Mirrlees 1962) asserts that the growth of productivity is related to the growth rate of gross investment per worker. This second specification of the technical progress function is the outcome of the attempt made by Kaldor to appreciate the effects of total investments on productivity growth. The basic argument which lies at the core of the technical change function is the process of embodiment of innovations and, consequently, the issues of diffusion and substitution of new generations of capital goods to old ones. Without investment efforts, available innovations, embodied in new capital goods, cannot enter the production process.[6]

Cornwall (1976) makes a much stronger attempt to capture the role of the diffusion of technological innovation within the kaldorian legacy elaborating a model which stresses the central role of the international diffusion of innovations

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[4] The equation specified by Kaldor (1957) reads as follows.

$gp = a1\, I(t)/K(t)$ (2), where gp is the growth of productivity, I are the investments and K the stock of capital.

[5] Kaldor however recognizes: "Whether the increase in output would be more or less proportionate to the increase in capital will depend (···) on the speed with which capital is accumulated, relatively to the capacity to innovate and to infuse innovation into the economic system. The more "dynamic" are the people in control of production, the keener they are in search of improvements, and the readier they are to adopt new ideas and to introducing new ways of doing things, the faster production (per man) will raise, and the higher is the rate of accumulation of capital that can be maintained" (Kaldor 1961, p. 36).

[6] The original Kaldorian formulation of the technical progress function has been criticised from a neoclassical point of view as nothing more than a mispecification of the production function and, subsequently, revised by Eltis (1971) who proposed to substitute the ratio of gross investments to the stock of capital with the ratio of gross investment to income. Eltis's specification of the technical change function is:

$gp = a1(GI/Y)$ (3), where gp is the growth of labour productivity, GI is the gross investment, Y is income.

and investment in determining the rates of growth of output.[7] The model of Corwall paves the way to a long series of empirical estimates that try to appreciate the opportunities for late-comers to "catch-up" with advanced countries by taking advantage of the flow of technological knowledge that spills from advanced countries (Abramovitz 1989).

With respect to the literature so far reviewed three main criticisms should be raised.

First, the neoclassical tradition as renewed by the new models of economic growth is not able to appreciate the role of diffusion of innovations as distinct from the generation of new technologies. In the neoclassical tradition, in fact all agents are necessarily in equilibrium at any time and it is difficult to accept the notion of delays due to bounded rationality and imperfect knowledge. A major limit to the new models of economic growth consists in the lack of a proper assessment of the microeconomics behavior of potential adopters.

Second, in the Post-Keynesian tradition of economic analysis the relationship between diffusion and investment receives full attention yet not without its own limits, i.e. it overlooks the role of adoption choices and equates diffusion to the outcome of the process of capital accumulation and investment. In the Post-Keynesian approach, in fact all new investment, *for given levels of generation of technological innovations, and given levels of adoption ability by entrepreneurs*, is expected to have strong positive effects on labour productivity. The features of the diffusion process, as distinct, or not fully identical to the flow of investments are somewhat misunderstood. Not all investment necessarily brings in the system-innovated capital goods.

In the catching-up models the spillover is assumed to be an automatic outcome of the difference in labor productivity levels. No assumptions are made about the differential capability of late-comers of actually adopting the superior technologies generated by advanced countries.

The ability of entrepreneurs to choose the innovated capital goods is in fact determined by a variety of factors such as (i) the levels of the stock of new capital goods already adopted, (ii) the cognitive externalities that take into account the dynamics of *viscosity* into the preliminary phases of the adjustment of adoption choices, and the later cumulative *effects* brought in by (iii) the limited knowledge of economic agents and consequent levels and rates of change of transaction costs. A more explicit and direct consideration of actual diffusion levels and rates is thus necessary.

Third, and most important, the models so far specified impinge upon the crucial role of the diffusion of a generic notion of technological change in explaining the growth of labour productivity. No assumptions are made about the technical features of the technology being diffused and the technological change actually in place. It is thus time to turn to more specific analysis of the character of new technologies being diffused.

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[7] The model of Cornwall is synthesized in the following equation:

$go = a1I + a21/Y + a3EX + a4dP$ (4), where go is the growth of output, I is the share of manufacturing investment on value added in manufacturing and expresses the embodiment process; I/Y is the reciprocal of the per capita income and expresses the opportunities for catching-up based upon the borrowing of technological innovations; EX is the rate of growth of exports of manufactured growth, and dP is the growth of employment.

3. Understanding new information technologies

New information technologies can be considered the core of the technological change presently in place.

Much empirical and theoretical work has been done in the seventies and eighties to better understand the economic aspects of the technical specifities of the new technology. It is now a common sense to assert that the black box of technology has to be opened up. Major findings which appear relevant in our context can be summarized as follows:

— Technological change is not homogeneous and evenly distributed across sectors, products and technologies, but rather highly concentrated and localized.
— A taxonomy of technological innovations is necessary to distinguish between radical, major and incremental innovations according to their effects on the production process.
— Technological change cannot be analysed in vacuum, but must be related to both existing technologies and to complementary technological innovations.

Let us analyse more carefully these broad issues with respect to new information and communication technologies.

Technological opportunities: A large empirical evidence confirms that the case and scope of potential innovations varies conspicuously across technologies; consequently, the cost of generating and implementing a new technology is very different (Scherer, 1986). The scope for introducing incremental technological changes also differs across technologies. So far, Romer's (1986) assumptions of homogeneous (diminishing) returns in research activities seem too generic. Historically one sees that technological opportunities move across sectors so that investment efforts concentrated in well-defined technologies are likely to exhibit strong increasing returns. This seems to be to-day the case of information technologies. In information technologies *technological opportunities* are still largely open (Monk 1989).

Technological convergencies: Radical technological innovations are likely to activate processes of technological convergencies across sectors and technologies. Technological spillovers and technological opportunities are very high for pervasive or "generic" technologies which are likely to activate major technological convergencies (Freeman 1982). Once more, all empirical evidence available confirms that information technologies are highly pervasive and that major technological convergencies are under way because of the generalized application of microelectronics and informatics to a broad array of sectors and technologies. In information technologies *technological convergencies* from related technologies and scientific fields are enormous. Advanced telecommunications can be considered itself the result of technological convergences between advances in electronics, informatics, space technology, new materials. Investments in advanced telecommunications are thus likely to obtain very high returns and to generate further opportunities for highly profitable investments in related fields (Antonelli 1993).

Technological complementarities: Complementarity requirements between technological innovations may be key factors of overall levels of productivity and profitability of each technological innovation. Only when an appropriate mix of complementary innovations is available, full effects in terms of increasing returns and externalities can be achieved. Interrelatedness between new technologies and the ones embodied in existing capital stocks is a major issue in assessing the rate of effective penetration of new technologies into the economic system. (David 1985 and Frankel 1955). With low levels of interrelatedness, adoption of new technologies is faster and technology blending is easier, for piece-meal addition of new capital goods to existing capital stocks is possible. Information technologies have generally very high requirements in terms of interrelatedness and are, consequently, likely to diffuse into economic systems only when a full set of complementary and interrelated infrastructure has been installed. The levels of technological interrelatedness for advanced telecommunications are very high. Advanced telecommunications cannot be added on a piece-meal made to preexisting electromechanical switching and copper coaxial cables. The adoption of electronic switching and transmission technologies and optical fiber cables requires the scrapping of large chunks of the installed infrastructure. This is also the case of information technologies that are based upon digital telecommunications networks. The modernizations of switching and transmission equipment is a precondition to the growth of distributed informatics both in terms of hardware and software. Advanced telecommunications are likely to become the basic infrastructure for a fully modernized economic system. The availability of an advanced telecommunications infrastructure is essential to provide universal, reliable, high-quality and low-cost advanced telecommunications services upon which a full array of technological and organizational innovations such as flexible manufacturing systems, just-in-time management systems, distributed data networks, advanced services, intra- and inter-corporate information flows are based. Advanced telecommunications can be considered to be the supporting infrastructure of access to information technologies (Antonelli 1988, 1993, 1993a).

Technological spillover: The externalities generated by technological innovations vary significantly across sectors according to the appropriability conditions and the interindustrial linkages. Within each industry horizontal spillovers are important when competitors can easily imitate a new product or a new process. Vertical spillovers are relevant when innovations introduced by upstream industries affect the productivity levels of users. Both horizontal and vertical spillovers seem especially important to-day in the case of information technologies. In this context *the technical features of telecommunications networks* are relevant. Telecommunications networks are featured not only by major technical, pecuniary but also by substantial consumption externalities; in fact they supply the basic empirical evidence for the notion of network externalities. In information technologies the incremental introduction of a full array of complementary and interrelated innovations in the production process and in the organization of firms depends upon the penetration of advanced telecommunications and computers in the system. High levels of diffusion of advanced telecommunications are thus likely to spread major pecuniary and technical externalities to downstream sectors – users of telecommunications services – and potential adopters of those technological and organizational innovations based upon advanced telecommunications services.

The economic advantages an economic system can benefit from the growth and development of an advanced telecommunications network can be estimated to be much larger than actual marginal monetary revenues of each telecommunications carrier. The basic issue of network-externality in fact apply to a variety of telecommunications-based innovations. The productivity of the adoption of a single computer – as well as of a variety of computer-based products and services – is dramatically enhanced by the opportunity to networking with other computers and other firms. Networking requires an advanced telecommunication network, hence network externalities provide the basic argument to expect that diffusion of advanced telecommunications is likely to spread major beneficial effects on users of telecommunications services and, consequently, to all the economic system (Antonelli 1992).

In sum, information and communication technologies should be regarded as a new emerging technological system. A technological system is characterized by high levels of complementarity and interrelatedness among different technologies that are at the same time product innovations as well as process innovations, organizational innovations and more broadly innovations that change the production mix of firms and their markets. Such an array of technological innovations is characterized by a strong complementarity that affects productivity levels. Only when the fully articulated system is in place appropriate levels of productivity can be generated.

Yet adopters decide to adopt a new technology only when its present productivity levels are higher than those of other existing technologies. Moreover, diffusion is delayed by a variety of lags. Hence, the emergence of a technological system is a lengthy process that requires time. The positive results of its implementation will eventually become clear. Consequently, a significant scope for an industrial policy aimed at pushing the diffusion of the components of the new system is likely to make it possible for the entire system to grab faster the overall positive benefits of its implementation. Each agent in isolation is not aware, in fact, of the positive externality effects that each adoption decision is likely to spur.

The notion of technological system is emerging as a substantial advance in the economic analysis of technological change and economic growth. Technological systems are made of a variety of sub-systems and specific technologies that are able to produce at a maximum level of efficiency only when all the components of the system are in place. Hence, the dynamics of productivity growth of economic systems is deeply affected by the dynamics of technical systems (Antonelli 1993b, c).

Technological systems can be thought to have a distinctive life-cycle: they emerge slowly, are implemented and enriched, they decline and they finally superseded by new technological systems. New technical systems emerge when new technologies that are individually more effective and productive than their substitutes supply important scope for further improvements of productivity levels when associated with other technologies and even more generally with other factors such as specific skills and intermediary inputs. The introduction and adoption of these complementary technologies is itself a factor of implementation of the technological system and, consequently, a factor of further growth of productivity levels.

When a new technological system emerges a cumulative process of endogenous growth is thus likely to take place along with the introduction of new complementary technologies and their effect to overall productivity level.

In conclusion, when analysing the relations between technological change and productivity growth, it seems appropriate to focus attention on key-technologies that, because of technological opportunity, technological convergencies, technological interrelatedness and hence technological spillover, are likely to spread high levels of positive externalities to the rest of the economy. Within the cluster of new information and communication technologies, advanced telecommunications seem to have been since the late seventies such a key-technology.

4. A model of diffusion and productivity growth

4.1. The hypotheses

A model of diffusion and productivity growth can be built drawing upon the Post-Keynesian tradition and on the new models of economic growth as well as upon the technology production function elaborated by Griliches (1979). We suggest that a better indicator of the factors leading to the effective increase of efficiency and hence to the increase of the total factor productivity is given by the rates and levels of diffusion of new key-technologies. Following Scott's model of growth we rely on gross investments in order to appreciate its role in the modernization of the capital stock embodying new technologies. Previous analyses of the economics of modernization processes in fact suggest to consider explicitly the actual diffusion both in levels and in rates. All investments in fact are not necessarily able to embody the best available technologies. Moreover, relying on the large empirical evidence available we assume that the diffusion of key technological innovations – rather than the generic advance of technology – such as new information and communication technologies can lead to an effective increase of labor productivity levels (see Antonelli et al. 1992). According to the hypotheses outlined, the general efficiency of the production process as well as the partial productivity of new capital goods and more generally production factors that are part of the new information technology system are significantly affected by the extent to which other components of the system are already in place.

A simple analytical model of diffusion and productivity growth can be built drawing on the technology production function approach elaborated by Griliches (1979). With respect to the technology production function our hypotheses in fact lead to the following specification:

$$Y(t) = A(t)K^{a}(t)L^{b}(t)IK^{c}(t) \tag{I}$$

where Y = output of the Ith firm, K = capital, IK = information capital, L = labor, A = general efficiency parameter and a, b, c are the partial efficiency of respectively capital, labor and information capital. For the time being we assume that the production has constant returns to scale: $a + b + c = 1$

Because of the technological system framework we assume that the general efficiency is affected by significant externalities:

$$A = f(IKSTOCK) \tag{II}$$

where IKSTOCK is the stock of information capital already installed in each economic system.

Because of the diffusion approach we elaborate upon, we now turn to analysing the dynamics of the stock of information capital in the economic system. We know that such diffusion takes place in a time period of decades and following a logistic path that can be approximated by a differential equation such as:

$$dIKSTOCK/dt = b[IKSTOCK\ (N\text{-}IKSTOCK)] \tag{III}$$

where IKSTOCK is the adoption level of information capital in a given economic system, N is a ceiling level of IKSTOCK, t is time and b is the rate of diffusion.

By now it is clear that along with the increase of the overall levels of adoption of information capital the general efficiency of each production function shifts towards the right.

A stronger case can be made when we put forward the hypothesis that the externalities engendered by the diffusion of information capital affect both the general efficiency of the production function and the marginal efficiency of information capital. In such a case increasing returns to scale are likely to emerge along the diffusion process. Formally we have the following equation:

$$c = g(\mathrm{IKSTOCK}) \tag{IV}$$

The parameter of the marginal efficiency of information capital is in fact now functionally related to the overall levels of adoption in the system of components of the emerging technological system. It is sufficient to assume that such a parameter moves from a small value and more or less rapidly moves upward so that, added to the other partial efficiency parameters, it becomes larger than 1. Now the system is likely to react to all increase in the levels of aggregate demand with a supply curve that has a negative slope. Hence, along with demand growth the system is likely to experience a reduction in real prices and, consequently, further growth of total factor productivity.

We can now see clearly that according to our hypotheses the life cycle of a new technological system is likely to emerge as the engine of a non-linear process of growth of total factor productivity. The diffusion of information capital proceeds along the conventional logistic path and affects cumulatively the general efficiency of the economic system. Its positive effects, however, are delayed with respect to the actual introduction of each single innovation and become apparent only when the fully articulate technological system is actually in place.

On these bases our empirical model of labour productivity growth can be specified as follows:

$$glp = a1(GI/Y) + a2(DICT) + a3(1/Y) + a4(PATENT) + e \tag{1}$$

The growth of labour productivity is determined by the ratio of total investments on output (as in Eltis's specification); the rates of diffusion of new information and communication technologies (DICT) that is the effective speed of penetration of these technologies[8]; the catching-up opportunity approximated by the reciprocal of the levels of GDP per capita (as in Cornwall's specification); the technology gap approximated by the innovation generation capability as specified by Fagerberg (1987) in terms of patents.

Equation (1) should capture the cumulative essence of the Kaldorian legacy by integrating the effects of a fully endogenous technological change, as expressed by the investment efforts which are meant to take into account the qualitative and quantitative growth of the capital stock together with the positive consequences of the effective rates of diffusion of new information technology, under the control of the generic spillover of technological knowledge flowing from advanced countries towards less advanced ones and the technology-generation gap.

Our hypotheses can now be fully articulated:

[8] Digital telecommunications lines data tested the standard epidemic model of analysis of diffusion rates:

$\log(D/(1\text{-}D)) = a + b(t)$ (5), where D = the number of digital lines as a percentage of total installed telephone lines in each country. Results of the generalized least squares estimates are drawn from Antonelli (1991) but for the no diffusion cases where a 0 value has been given to the DICT variable.

i) the levels of labor productivity should be explained by the capital stock and by the effective levels of penetration of key technological innovations hence the growth of labor productivity should be explained by the growth of the capital stock – i.e. the investments – and by the rates of diffusion;
ii) the intensity of efforts in the generation of new technologies "alone" as in the technology production function tradition is not able to appreciate fully the effective penetration of innovations in the economic system because of the delays in the rates of diffusion due to bounded rationality, and imperfect knowledge of the agents.
iii) gross investment seems to provide a better estimator of the actual introduction in the production process of new technologies than net investment. Net investment in fact measure only the monetary increase in the stock of capital, but miss the changes in the qualitative composition of the capital stock because of the substitution of obsolete and less effective chunk of scrapped capital with superior, more sophisticated pieces of equipment.

4.2. The empirical estimates

Data on the average rates of growth of labor productivity (glp), GDP per capita (Y) and average investment to GDP ratios (GI/Y) are available for the years 1980–1988 for a large sample of 29 representative countries, both OECD and industrializing from Summers-Heston (1991), and are shown in table 1. More specifically all OECD countries for which reliable information were available have been considered as well a large group of newly industrializing countries. A special attention has been paid not to limit the data set to traditional industrialized countries as it often happens in empirical analyses that focus on the role of technological change. The global character of technological change and the fast rates of international diffusion of technology go well beyond the boundaries of the OECD area and suggest that in order to obtain integrity of the data set for our purposes, the inclusion of a reliable sample of newly industrializing countries is necessary.

Data on the diffusion of digital telecommunication lines have been retained as a reliable indicator of a more general process of diffusion of electronic networking and more generally of the effective penetration of information and communication technologies in economics systems. Data on the diffusion levels of digital lines on total telephone lines installed for the same countries in the years 1977 through 1988 are drawn from Antonelli (1991). Countries have been considered also when the diffusion process had not yet started. So far our distribution of data can be considered as not-trunctated.

Econometric tests of our hypotheses have been conducted on the following specification:

$$\text{glp} = \text{a1} + \text{a2(GI/Y)} + \text{a3(DICT)} + \text{e} \quad (2)$$

$$\text{glp} = \text{a1} + \text{a2(GI/Y)} + \text{a3(PATENT)} + \text{a4(1/Y)} + \text{e} \quad (3)$$

$$\text{glp} = \text{a1} + \text{a2(GI/Y)} + \text{a3(PATENT)} + \text{a4(DICT)} + \text{e} \quad (4)$$

$$\text{glp} = \text{a1} + \text{a2(GI/Y)} + \text{a3(PATENT)} + \text{e} \quad (5)$$

$$\text{glp} = \text{a1} + \text{a2(GI/Y)} + \text{a3(PATENT)} + \text{a4(DICT)} + \text{a5(1/Y)} + \text{e} \quad (6)$$

where (glp) is the growth of labor productivity as measured by the increase in the

Table 1. The data

	Countries	glp	GI/Y	DICT	1/Y	Patent
1	USA	2.100	18	.301	5.453E-5	1.780
2	Japan	2.900	29	1.060	8.191E-5	.912
3	Germany	1.200	20	474	7.934E-5	.944
4	France	.900	20	.483	8.203E-5	.368
5	UK	2.400	17	.218	8.346E-5	.377
6	Italy	1.600	21	.884	8.517E-5	.140
7	Canada	1.900	21	.203	6.146E-5	.427
8	Austria	1.300	23	0	8.699E-5	.351
9	Belgium	.600	17	.546	8.699E-5	.265
10	Denmark	1.000	18	.213	8.272E-5	.360
11	Finland	2.400	24	.979	8.091E-5	.321
12	Greece	.800	20	0	1.707E-4	.006
13	Netherlands	.200	19	0	8.720E-5	.439
14	Portugal	1.500	27	.400	1.879E-4	.003
15	Spain	1.000	20	.732	1.350E-4	.018
16	Sweden	1.900	19	.871	7.698E-5	.845
17	Switzerland	1.400	24	.974	6.190E-5	1.665
18	S. Korea	5.700	31	1.164	1.939E-4	.008
19	Malaysia	.600	28	.262	2.116E-4	.001
20	Singapore	2.800	32	.368	9.600E-5	.019
21	Brazil	−.200	16	0	2.252E-4	.002
22	Turkey	2.400	26	1.044	2.779E-4	3.905E-4
23	Thailand	3.500	25	1.148	3.473E-4	2.570E-4
24	Srilanka	4.600	27	.980	4.545E-4	6.112E-5
25	Mexico	−2.700	22	.189	2.002E-4	.004
26	Australia	1.400	25	0	1.014E-4	.175
27	New-Zealand	.100	24	1.015	1.014E-4	.166
28	Taiwan	3.600	28	.600	1.752E-4	.079
29	Philippines	−.600	24	.654	.001	.001

Table 2. Results of the econometric estimates of Eqs. 2–6

	(2)	(3)	(4)	(5)	(6)
a	−2.214	−3.249	−2.677	−3.377	−2.398
GI/Y	0.134	0.215	0.148	0.208	0.150
(t)	(2.036)	(3.307)	(2.146)	(3.247)	(2.208)
PATENT	–	0.454	0.420	0.634	1.220
(t)		(0.722)	(0.735)	(1.079)	(0.216)
1/Y	–	0.132	–	–	0.180
(t)		(0.851)			(1.242)
DICT	1.475	–	1.370	–	1.548
(t)	(2.086)		(1.890)		(2.116)
R^2	.316	.225	.304	.235	.320
F	7.467	3.717	5.070	5.294	4.296

ratio GDP/worker, as calculated in the Penn World Table (mark 5) for the years 1980–88 (Summers-Heston 1991); (GI/Y) is the average ratio of total investment to GDP for the years 1980–88 (Summers and Heston 1991); (DICT) is the parameter of the rate of diffusion of digital lines in each country as estimated by equation (10) for the years 1977–1987; (PATENT) is the ratio of total U.S. patents delivered in the years 1980–1988 to nationals of each country to total population in millions (U.S. Dept. of Commerce 1991); (1/Y) is reciprocal of the levels of real per capita income in 1985 (Summers and Heston 1991)

Equation (2) is the elementary econometric specification of our hypothesis and it contrasts the alternative specifications. Equation (3) is the standard technology-gap model and it makes possible to assess the relative effects of the effective diffusion of key-technologies with respect to the role of the catching-up variable and with respect to innovation capabilities. Equation (4) makes possible to control the effect of the diffusion of key-technologies with respect to the catching-up variable. Equation (5) makes possible to assess the relative effect of the "technology gap" variable, according to the specification of Fagerberg (1987), without the control of the specific diffusion rates of a key-technology such as advanced telecommunication. Finally Eq. (6) provides a full specification of all the variables considered.

Results of ordinary least squares estimates of Eqs. (2)–(6) are listed in Table 2. Total variance explained is good for a standard cross-country test. The significance of the F statistics is above 95%. DICT and GI/Y are strongly significant in all the alternative specifications proposed.

These results confirm that the rates of diffusion of a radical key-technology such as advanced telecommunications have generated important externalities that have been spilling through the entire economic system with strong positive advantages on the overall rates of growth of labor productivity. The estimated parameter of the contribution of the rates of diffusion of advanced telecommunications to labor productivity growth, within the control of a Post-Keynesian framework of analysis is in fact significant and relevant. According to our hypotheses, this result confirms that much of the weight given to gross investment efforts in the Post-Keynesian literature in explaining productivity growth should in fact be recognized as the actual contribution of effective diffusion of key-technologies. Investment efforts are to a large extent an imperfect proxy for the adoption capability of a country.

The contrast between the statistic performances of the investment efforts variable without the control of the diffusion of a key-technology as in Eq. (5) and under the control of the diffusion variable as in Eqs. (2), (3), (4) and (6) shows that the explanatory power as well as the quantitative size of the parameter are eroded. This would suggest that the investment effort variable is in fact able to capture some of the diffusion aspects as predicted by the Post-Keynesian approach. The strong and significant performances of the diffusion variable, however, do confirm the need of a separate and well-defined key-technology diffusion variable.

It is interesting to confront the results of DICT with those of: i) the generic catching-up opportunity variable (1/Y); ii) the innovative capability of a country as measured by PATENT.

Both the "catching-up" variable and the innovative capability variable perform very poorly in all the specifications considered. The variable (1/Y) that would measure the opportunities for positive spillover of technological know-how from more advanced countries to industrializing ones is in fact significantly associated with the innovative capability (PATENT), but neither ones are significantly associated with the labor productivity growth. More specifically, we see that PATENT is never significant: the Student's t is always below significance level in all the specifications considered. This suggests that the variable has no colinearity problems with the other technological variables considered, that affect the statistical performances. These results might suggest two considerations.

First, technological spillover is unlikely to spread quickly and freely across countries, strong investment efforts and an effective adoption capability of new technologies are necessary. Technological innovation cannot be considered as a free good. It is interesting to note that at a closer statistical analysis of these results the poor performances of PATENT are significantly influenced by the composition of the sample of countries. More specifically, the exclusion from the sample of newly industrializing countries such as Taiwan and Korea has positive effects on the statistical performances of PATENT. This seems to suggest that while productivity growth of industrialized countries is significantly influenced by the innovation capability as measured by the capacity to generate original innovations, the productivity growth of industrializing countries can take advantage of the absorption of foreign technology, provided that investment efforts are made and fast rates of diffusion are achieved. (Amsden 1989).

Second, innovative capability grows along with revenue levels but per se has little effect on the growth of labor productivity. The introduction of technological innovations to the bottom-line, that is the actual adoption, matters more than the generic capability of generating new technological knowledge in enhancing labor productivity growth. When confronting the poor results of the catching-up variable in a regression equation that test data for the eighties with results on data collected for the seventies, one might suggest that the free spillover of technological know-how has become even less easy in the recent years (Cornwall 1976).

In conclusion, these results confirm our argument that the effective diffusion rates of key-technologies associated with the intensity of gross investments, provide a much better and more reliable account of the positive dynamics of new technologies within economic systems, than the innovative capability per se and the standard indirect "dummy" of the international diffusion of new technologies usually taken into account such as the catching-up opportunities.

5. Conclusions

The original notion of innovation introduced by Schumpeter includes the introduction of new products and new processes as well as the use of new intermediary inputs, new organizational structure within firms and among firms, the entry in new markets. The notion of technological innovation currently used in the recent debate on technological change, economic growth and industrial competitiveness focusses attention mainly on product innovations and pays much less attention to the other four forms of innovation detected by Schumpeter. In fact, the introduction of new capital goods embodying technological innovations in the production process of a given company is itself an important innovation as well the choice of new intermediate inputs and new structural organizations.

The skills and requirements necessary to generate product innovations on one hand and to introduce process innovations on the other are significantly different. The former center upon high levels of research and development activities both by means of the formal development of research capacity within the firm and on the access to the scientific and technological knowledge produced by universities and science centers. The latter require high levels of search activities and tacit knowledge necessary to assess all the relevant information about the new technologies made available on the market and to choose whether they can fit into the current structure of their business. Moreover, high levels of investments are necessary for firms to adopt timely new available product innovations generated by upstream industries.[9]

The adoption of new capital goods and intermediary products embodying product innovations, however, should not be regarded as the automatic outcome of the investment process. Relevant search and information activities are to be performed by firms that look for new opportunities on the markets for new processes and new intermediate products. So far, the diffusion of new processes and new intermediary products should be considered as the outcome of an actual innovation capacity of downstream firms that specialize in products that are sold mainly to final consumers.

According to our tentative interpretation upstream firms specializing in the production of capital goods and intermediate products, embodying high levels of technological advance, generate relevant pecuniary spillovers that can be appropriated by downstream firms that use those innovated capital goods and intermediate inputs as complementary inputs in their own production process. The appropriation of the flow of pecuniary externalities is higher, the higher the competition on upstream markets is. Competition in upstream industries brought about by the entry of new imitators in fact reduces the quasi-rents associated with the introduction of product innovations and, consequently, increases the levels of pecuniary externalities for downstream users.

The appreciation of the role of the modernization process based upon the diffusion of innovations and new intermediate products in the production process is especially important to grasp the role of technological change in industrial economies characterized by small firms. The small size of manufacturing firms makes it very difficult to rely on research and development expenditures and, consequently, on the generation of product innovations as a competitive tool. The minimum efficient size for conducting efficient research and development activities is in fact very high as well as the levels of risks associated with the generation of new products. A technological change based on fast rates of diffusion, enhanced and made possible by high levels of investment is instead much more appropriated to countries with high levels of regional clustering of specialized small firms that are active in complementary products so to develop a characteristic industrial system based on high levels of industrial cooperation, fast rates of diffusion and high levels of specialization in the "advanced" production of "mature" final products.

The traditional notion of mature industries associated with these products, however, seems less and less appropriate when one takes into account the significant role of the modernization process characterized by the fast diffusion of technological and organizational innovations, consisting mainly in original applications and developments of new information technologies based on the blending of computers and telecommunication that have changed in depth the overall levels of overall efficiency of the production of final goods.

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9 The relationship between investment and adoption of innovated capital goods appears central to our approach. Such a relationship highlights a micro-macro link which has not yet been fully elaborated. More specifically, we claim that recent advances in the microeconomics of technological innovation can be integrated in a Verdoorn-Kaldor-Salter approach with evident advantage So far the Verdoon Law can be considered the result of fast rates of adoption of available innovations which occur in condition of rapid economic growth. In fact, available innovations are likely to diffuse faster within the economic system when high rates of economic growth make it possible to increase the flow of investments. Faster rates of adoption in turn contribute to increase productivity rates.

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