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Technical Change and Economic Growth: Some Lessons from Secular Patterns and Some Conjectures on the Current Impact of ICT Technology

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Technical Change and Economic Growth: Some Lessons from Secular Patterns and Some Conjectures on the Current Impact of ICT Technologies[1]

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Abstract

This paper discusses the link between patterns of technological change and economic development taking an evolutionary perspective. We argue that the modes and timing of such coupled dynamics are deeply influenced by the emergence of new techno-economic paradigms or regimes. ICT-based technologies are the drivers of the current paradigm, which, we show, is still at an early stage of diffusion, particularly for developing countries. Building from historical evidence, we argue that catching up of developing countries critically depends on their ability to master the technology behind the dominant techno-economic paradigm. We then discuss threats and opportunities related to a possible ICT-based development path.

Keywords: Technical change, Economic Growth, ICT

1 Introduction

The original mandate of this contribution was: from a broadly defined evolutionary perspective, what are the likely effects of the current ``ICT revolution'' upon growth in general and development opportunities and constraints in particular? Reflecting on that, we deemed useful to move some steps backward in order to even try to give some impressionistic hints on possible answers. Hence in the following we start by addressing two broad preliminary questions, namely:

First, what is the distinctive "evolutionary" interpretation of the processes of innovation and technological diffusion in their relation to economic growth? And second, what are the historical patterns of technological change and their apparent relations with economic growth?

Only after having set such background, we shall move to the original question and offer some pieces of evidence and conjectures on the properties of a possible ICT-driven growth regime, and its implications for development.

[1] This paper draws upon Cimoli and Dosi (1995) and Castaldi, Cimoli, Correa and Dosi (2004). The paper was prepared for the seminar ``Growth, Productivity and ICT'', ECLAC, Santiago de Chile, March 2007.

2 A telegraphic summary of the results stemming from the efforts aimed at opening up the ``black box'' of technological activities

A good deal of evolutionary inspired literature on the economics of innovation and technical change has indeed advanced a lot in recent years our understanding of what one finds inside the `black box of technology' (``Inside the black box'' is also the title of the influential book of one of the pioneers of the emerging discipline of the economics of innovation and technological change, Nathan Rosenberg (Rosenberg (1982)). What does one find inside such a black box?

2.1 The properties of technological learning

Telegraphically, one finds quite well structured bodies of knowledge which elsewhere one of us has called technological paradigms. As discussed at greater length in Dosi (1982), Dosi (1988) and Dosi, Orsenigo and Sylos Labini (2005), each paradigm involves knowledge bases grounded in selected physical/chemical principles and entails equally specific patterns of solution of selected techno-economic problems and rules aimed at the refinement and accumulation of new knowledge. Examples of technological paradigms include the internal combustion engine, oil-based synthetic chemistry and semiconductor-based micro-electronics, among many others. In fact, a closer look at the patterns of technical change suggests the existence of ``paradigms'' with different levels of generality in most industrial activities.

In turn, the progressive realization of the opportunities of product and process innovation associated with each paradigm tends to proceed along relatively ordered technological trajectories. Let us recall some properties of such trajectories which will become useful in the remainder of the essay.

First, each particular body of knowledge (i.e. each paradigm) shapes and constrains the rates and direction of technological change irrespectively of market inducements (including fine variations in demand patterns and relative prices.

Second, as a consequence, one should be able to observe regularities and invariances in the patterns of technical change which hold under different market conditions (e.g. under different relative prices) and whose disruption is associated with radical changes in knowledge bases (that is, in paradigms).

Third, technical change is partly driven by repeated attempts to cope with technological imbalances which it itself creates.

A general property, by now widely acknowledged in the innovation literature, is that learning is local and cumulative. Local means that the exploration and development of new techniques is likely to occur in the neighbourhood of the techniques already in use. Cumulative means that current technological developments - at least at the level of individual business units - often build upon past experiences of production and innovation, and it proceeds via sequences of specific problem-solving junctures (Vincenti (1990)). Clearly, this goes very well together with the ideas of paradigmatic knowledge and the ensuing trajectories. A crucial implication, however, is that at any point in time the agents involved in a particular production activity will face relatively little scope for substitution among techniques, if by that we mean the easy availability of blueprints different from those actually in use, which could be put efficiently into operation according to relative input prices (on the contrary attempts at inter-factoral substitution are in fact indistinguishable from efforts to innovate).

A paradigm-based theory of technology and of production yields the following predictions:

a) In general, there is at any point in time one or very few best practice techniques which dominate the others irrespectively of relative prices.
b) Different agents are characterized by persistently diverse (better and worse) techniques and products.
c) Over time the observed aggregate dynamics of technical coefficients in each particular activity is the joint outcome of the process of imitation/diffusion of existing best-practice techniques, of the search for new ones, and of market selection amongst heterogeneous agents.
Together, note that in the evolutionary view of economic change firms are crucial, although not exclusive, repositories of knowledge, embedded in operational routines and organizational capabilities (in fact a whole field of literature has opened up under this heading). Hence, technical change and organizational change are highly intertwined: technologies and organizational structures and behaviours tend to co-evolve.
A great deal of the evolutionary interpretation of technological change also acknowledges that micro-processes of technological and organizational change are embedded in broader institutional frameworks at the national and/or the regional level. In the historical interpretation of Freeman (1995), national institutions have powerfully influenced the relative rates of technological change of different countries. The notion of 'national systems of innovation' has captured the importance of the national institutional context motivating economic actors and shaping incentives for innovation (Lundvall, 1992, Nelson 1993). Technological learning is very much an 'interactive' process where relations between different participants to the innovation process (suppliers, producers, users, universities) may be affected by existing institutional structures. The related literature has also crucially stressed the continuing institutional variety of countries, with different national institutional settings and policies co-existing worldwide. At the regional level, the local nature of technological learning implies that the innovative performance of a region will be highly influenced by the characteristics of local networks of production in terms of, for instance, the extent of knowledge externalities and the level of mutual trust. In line with the claims in Freeman (1995), we will also argue at different points in this paper that national systems of innovation and production become even more important in a globalized world where countries wish to become attractive locations within global networks of trade and production.

2.2 The evolutionary path of technological learning in economic development

Given the evolutionary representation of technological learning sketched in the previous section, what are the implications in terms of the international distribution of technological capabilities and of patterns of economic development? (see Cimoli and Dosi (1995) for a broader discussion).
First, evolutionary interpretations are comfortable with the observation of persistent asymmetries among countries in the production processes which they are able to master (this of course also shows up in terms of different inputs efficiencies: see Dosi, Pavitt and Soete (1990)). Thus, one can draw two major testable conjectures: (i) different countries might well be unequivocally ranked according to the efficiencies of their average techniques of production and, in the product space, of the (price-weighted) performance characteristics of their outputs, irrespectively of relative prices, and (ii) the absence of any significant relationship between these gaps and international differences in the capital/output ratios. Wide differences apply also to the capabilities of developing new products and to different time lags in producing them after they have been introduced into the world economy. Indeed, the international distribution of innovative capabilities regarding new products is at least as uneven as that regarding production processes.

Second, the process of development and industrialization are strictly linked to the inter- and intra-national diffusion of "superior" techniques. Relatedly, as already mentioned, at any point in time, there is likely to be only one or, at most, very few "best practice" techniques of production which correspond to the technological frontier. In the case of developing economies, the process of industrialization is thus closely linked with the borrowing, imitation, and adaptation of established technologies and, together, with the adoption and diffusion of novel organizational forms from more advanced economies. This process of adoption and adaptation of technologies, in turn, are influenced by the specific capabilities of each economy. In this context, we suggest that evolutionary micro-theories are well apt to account for the processes by which technological gaps and national institutional diversities can jointly reproduce themselves over rather long spans of time. Conversely, in other circumstances, it might be precisely this institutional and technological diversity among countries which may foster catching-up (and, rarely leapfrogging) in innovative capabilities and the per capita incomes.
To repeat, evolutionary theories are well in tune with predictions of persistent technological gaps across firms and across countries, and equally persistent income gaps. But what is the secular evidence in this respect?

3 The long-term distribution of innovative/imitative search for new technologies and its relationship with economic growth

The basic phenomenon to start from is indeed the highly skewed international distribution of innovative activities which has emerged since the Industrial Revolution (Dosi, Pavitt and Soete (1990)) starting from previously rather homogenous conditions at least between Europe, China and the Arab World (Cipolla (1965)). It is certainly true that technological “innovativeness" is hard to measure, but irrespectively of the chosen proxy, the picture which emerges is one with innovative activities highly concentrated in a small group of countries. An illustration using patents registered in the US is presented in Table 1.
Indeed, the club of major innovators has been quite small over the whole period of around two centuries and half since British industrialization, with both restricted entry (with Japan as the only major entrant in the 20th century, and Korea and Taiwan as recent additions) and a slow pace of change in relative rankings.
At the same time, since the Industrial Revolution, one observes the explosion of diverging income patterns, starting from quite similar pre-industrial per capita level. Table 2 presents estimates showing that before the Industrial Revolution the income gap between the poorest and the richest region was probably of the order of only 1 to 2. Conversely, the dominant tendency after the Industrial Revolution is one with fast increasing differentiation among countries and overall divergence. Even in the Post World War II period, commonly regarded as an era of growing uniformity, the hypothesis of global convergence, that is convergence of the whole population of countries toward increasingly similar income levels, does not find support from the evidence (DeLong (1988), Easterly et al. (1992), Verspagen (1991), Soete and Verspagen (1993), Durlauf and Johnson (1992), Quah (1996) and Castaldi and Dosi (2007), among others). Moreover, the process of divergence in incomes has speeded up over time. Clark and Feenstra (2003) claim that: ``Per capita incomes across the world seemingly diverged by much more in 1910 than in 1800, and more in 1990 than 1910 - this despite the voluminous literature on exogenous growth that has stressed the convergence of economies, or, to be more precise, ``conditional" convergence." (op. cit., p. 277).

Table 1: US patents granted, by country of applicant and year (% of non-US recipients)

		1883	1900	1929	1958	1973	1986	1995	2004
OECD	Australia	1.11	2.33	1.96	0.60	0.89	1.14	1.00	1.19
	Austria	2.62	3.36	2.47	1.12	1.05	1.09	0.74	0.67
	Belgium	1.59	1.35	1.30	1.14	1.25	0.74	0.87	0.76
	Canada	19.94	10.54	10.25	7.99	5.95	4.01	4.61	4.22
	Denmark	0.56	0.46	0.71	0.74	0.68	0.56	0.44	0.52
	France	14.22	9.79	9.76	10.36	9.47	7.24	6.18	4.22
	Germany	18.67	30.72	32.36	25.60	24.68	20.94	14.45	13.47
	Italy	0.24	0.92	1.19	3.02	3.35	3.04	2.36	1.98
	Japan	0.16	0.03	1.40	1.93	21.82	40.35	47.64	44.18
	Netherlands	0.24	0.75	1.57	5.71	3.03	2.21	1.75	1.59
	Norway	0.32	0.49	0.71	0.61	0.37	0.25	0.28	0.30
	Sweden	0.95	1.32	3.19	4.64	3.37	2.70	1.76	1.61
	Switzerland	1.75	2.27	4.46	8.80	5.86	3.70	2.31	1.60
	UK	34.55	30.52	22.23	23.45	12.61	7.35	5.43	4.31
NICs	Israel					0.37	0.58	0.84	1.28
	Singapore					0.03	0.01	0.12	0.56
	Taiwan					0.00	0.64	3.55	7.42
	South Korea					0.02	0.14	2.54	5.53
	Hong Kong					0.07	0.09	0.19	0.39
	India					0.09	0.05	0.08	0.45
	China					0.04	0.03	0.14	0.50
Latin America	Argentina					0.12	0.05	0.07	0.06
	Brazil					0.08	0.08	0.14	0.13
	Mexico					0.19	0.11	0.09	0.11
	Venezuela					0.03	0.06	0.06	0.02

Source: elaborations on US Patent and Trademark Office (USPTO)

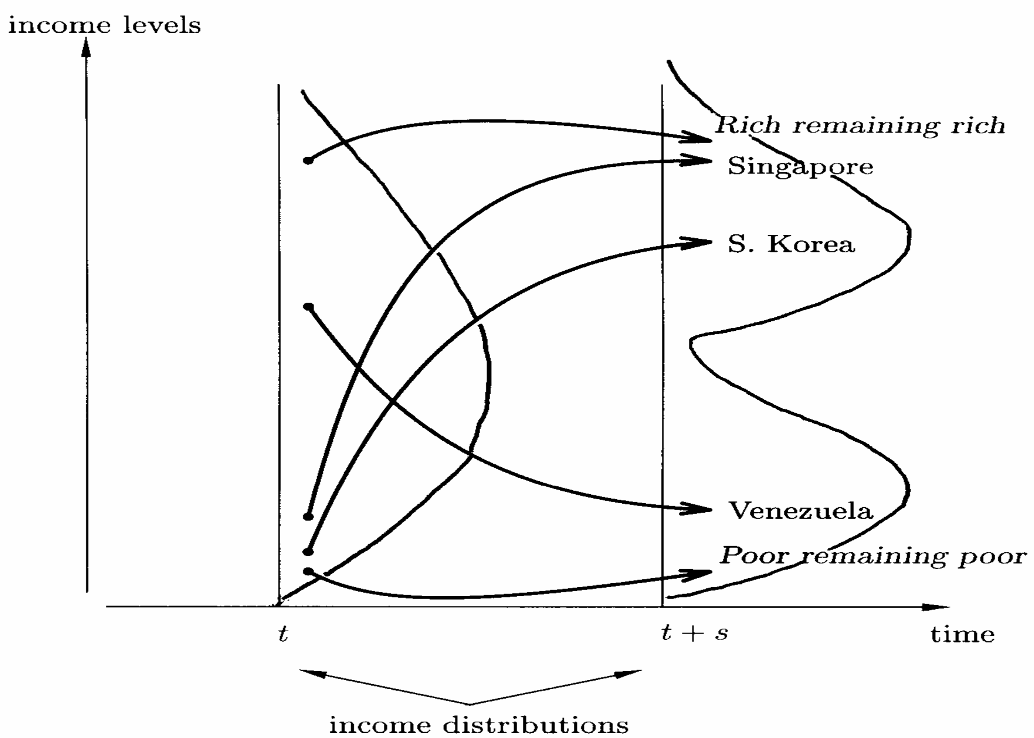
Table 2: Estimates of trends in World income: per capita GDP of regions relative to the US and Western Offshoots

Regions	1700	1820	1870	1913	1950	1973	2001
Western Europe	210	100	81	66	49	71	71
Eastern Europe	127	57	39	32	23	31	22
Former USSR	128	57	39	28	31	37	17
US and Western Offshoots	100	100	100	100	100	100	100
Latin America	111	58	28	28	27	28	22
Japan	120	56	30	27	21	71	77
Asia (excl Japan)	120	48	23	13	7	8	12
Africa	88	35	21	12	10	9	6
World	129	55	36	29	23	25	22

Source: Own elaborations on per capita GDP,1990 million international dollars, 1700-2001 from Maddison (2001).
Western Offshoots: Australia, Canada, New Zealand and the United States

Indeed, one finds some, although not overwhelming, evidence of *local* convergence, i.e. convergence within subsets of countries grouped according to some initial characteristics such as income levels (Durlauf and Johnson (1992)) or geographical locations. The typical patterns are impressionistically illustrated in Figure 1 from Durlauf and Quah (1998), showing the appearance of a two-humped distribution of countries with low (albeit positive) transition probabilities between the `poor' and `rich' clubs (and vice versa, too).

Figure 1: Evolving cross-country income distributions (Durlauf and Quah (1998))



Bimodality hints at a separating tendency between poor and rich countries, characterized by markedly different income levels. At the same time, the other part of the story, as discussed at length in Quah (1997), is that the same shape of a given distribution may conceal very different intra-distribution dynamics. Is it the case that poor countries have been converging to a common income level and rich countries to their own high level of income or the two modes are also the result of shifting in ranking between poor and rich countries? The issue at stake is the respective weight of persistence and mobility of countries inside the distribution. Quah (1997) finds evidence that the period 1960-1988 has been characterized by high persistence of relative rankings, notwithstanding some important exceptions. The main events contributing to mobility have been the `growth miracles' of countries like Hong Kong, Singapore, Japan, Korea and Taiwan and `growth disasters' including some sub-Saharan African countries, but also Venezuela which was the among the first richest countries in 1960 and has dramatically fallen in the `poor' countries club.

Recent evidence on the world income distribution has shown that population-weighted measures of inequality have decreased in the last two decades, mainly due to China and India (see the discussion in Bourguignon et al (2004)). While the finding provides indeed evidence for the convergence hypothesis, it does not shed light on the increasingly frequent episodes of `marginalization' (cf. Melchior and Telle (2001)). Authors such as Dowrick and DeLong (2003) agree on the convergence of OECD economies and also within a broader group including the East Asian economies, and with China and India too after 1980. ``However, these episodes of successful economic growth and convergence have been counterbalanced by many economies' loss of their membership in the world's convergence club.'' (op. cit., p. 193).

At the same time, across-group differences in growth performances appear to be rather persistent. Likewise, one observes persistently wide and in some cases widening (such as in a few Latin American cases) productivity gaps vis-a'-vis the international frontier (cf. Table 3 for estimates of labor productivity relative to the US). As discussed also in van Ark and McGuckin (1999) all available evidence witnesses a persistent dispersion in productivity measures. More specifically, while countries in the OECD area appeared to have moved on average closer to the US benchmark, the same cannot be said for the rest of the world.

A delicate but crucial issue concerns the relation between patterns of technical change and patterns of economic growth. Of course, technological learning involves many more elements than simply inventive discovery and patenting. Equally important activities are imitation, reverse engineering, and adoption of capital-embodied innovations, learning by doing and learning by using (Freeman (1982), Dosi (1988), Patel and Pavitt (1994)). Moreover, technological change goes often together with organizational innovation. Still, it is important to notice the existence of significant links between innovative activities (measured in a rather narrow sense, i.e. in terms of patenting and R&D activities) and GDP per capita (for the time being, we shall avoid any detailed argument on the direction of causality), which however tend to change over different historical periods.

As discussed in Dosi, Freeman and Fabiani (1994), evidence concerning OECD countries appears to suggest that the relationship between innovative activities and levels of GDP has become closer over time and is highly significant after World War II (see Table 4). Moreover, innovative dynamism, measured by the growth of patenting by different countries in the US, always appears positively correlated with per capita GDP growth, even if the relation is quite noisy and period-specific (see results from Tables 5 and 6)[2].

[2] Tables 4 and 5 are based on Pavitt and Soete (1981) for the years until 1977. Their original sample included 14 OECD countries. Results for most recent years in Tables 4 and 6 are obtained for an updated sample of 21 OECD countries (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland and United Kingdom). Our elaborations are based on data from OECD (real GDP, population and R&D spending in the business sector) and USPTO (historical series of granted patents).

The link is particularly robust between 1913 and 1970. Conversely, a sign that the regime of international growth might have changed in the 1970s, is that in this period the relation gets weaker and loses statistical significance. The link becomes again strong in the 1980s, loses significance again in the 1990s, and regains it in the most recent period: in our view, this is circumstantial evidence of a turbulent and uncertain dynamics in the “political economies" of different countries governing the coupled dynamics between technological learning, demand generation and growth.

In general, at least since World War II, the rates of growth of GDP appear to be closely correlated with: (i) domestic innovative activities, (ii) the rates of investment in capital equipment and (iii) international technological diffusion (DeLong (1988), Soete and Verspagen (1993), Meliciani (2001), Laursen (2000), among others). In particular Fagerberg (1988) finds a close correlation between the level of ‘economic development', in terms of per capita GDP, and the level of ‘technological development', measured with the R&D investment level or with patenting activity.[3] There is no strong evidence of convergence of innovative capabilities (PT and pt indicators in tables 5 and 6), but there is some continuing sign of convergence in income.

In turn, capability of innovating and quickly adopting new technologies is strongly correlated with successful trade performance (Dosi, Pavitt and Soete (1990)).

Moreover, despite technological diffusion taking place at rather high rates, at least among OECD countries, important specificities in “national innovation systems" persist, related to the characteristics of the scientific and technical infrastructure, local user-producer relationship and other institutional and policy features of each country (Lundvall (1992), Nelson (1993), Archibugi, Howells and Michie (2001)). In an historical perspective, Freeman (2002) convincingly argues how catch-up of countries has critically relied on the ability to build successful national innovation systems. This has been, in turn, the case for England, US, Japan and, most recently, the Asian tigers.

To repeat, the dominant tendency throughout the foregoing secular picture hints at long-term divergence in relative technological capabilities, production efficiencies and incomes. Together come however two more hopeful messages.

First, notwithstanding prominently divergent patterns, one has also witnessed secularly increasing average levels of technological knowledge within most countries, and together also in the levels of per capita income. Second, while it holds true that the ``innovators club" has been remarkably small and sticky in its membership, one ought to notice both the possibility of entry by a few successful latecomers (in different periods, the US, Germany and Japan being the most striking examples) and also the possibility of falling behind by very promising candidates to the club (cf. the vicissitudes of Argentina over the last century). But what about the long-term time-profile of technological change and economic growth? Can one identify some persistent features in the ways technologies and incomes are dynamically coupled?

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[3] His sample includes most world economies and covers the years 1960-1982.

Table 3: Labor productivity relative to US (real GDP in 1990 international dollars per person employed).

		1870	1913	1950	1973	1990	1998	2004
OECD	Austria	*60.6*	*56.4*	31.4	61.4	75.5	76.4	75.2
	Australia	*153.2*	*106.4*	74.2	71.7	75.7	81.1	77.3
	Belgium	*96.1*	*71.9*	58.2	75.5	91.3	89.6	85.3
	Canada	*75.7*	*86.9*	85.1	85.8	82.9	80.9	76.7
	Denmark	*69.0*	*68.6*	59.6	66.5	73.3	76.1	73.0
	Finland	*38.1*	*36.2*	34.1	53.5	69.4	75.9	74.0
	France	*60.6*	*56.0*	46.3	76.4	92.0	90.7	85.5
	Germany	*66.0*	*58.7*	42.9	72.2	71.1	73.7	70.6
	Ireland			35.0	47.9	73.9	82.3	87.6
	Italy	*45.4*	*40.6*	40.8	69.5	83.9	82.7	72.5
	Japan	*20.3*	*20.9*	18.7	56.9	76.1	71.8	69.2
	Netherlands	*107.8*	*80.4*	67.1	82.4	82.8	76.8	68.7
	Norway	*52.7*	*46.7*	51.8	63.9	78.1	84.7	83.7
	Spain		*45.0*	22.2	50.0	75.5	73.6	62.4
	Sweden	*53.9*	*50.2*	57.4	68.2	68.7	75.2	74.1
	Switzerland	*68.3*	*65.0*	75.5	82.4	75.2	69.4	63.5
	UK	*113.9*	*84.8*	65.2	65.6	72.4	75.4	73.6
	US	*100.0*	*100.0*	100.0	100.0	100.0	100.0	100.0
Latin America	Argentina			52.4	52.9	35.9	45.2	35.5
	Brazil			23.0	27.9	26.0	27.0	24.1
	Chile			48.2	40.3	38.9	47.6	44.6
	Colombia			28.5	29.3	28.5	27.5	23.8
	Mexico			34.1	45.9	36.1	31.7	29.0
	Peru			27.5	31.2	17.6	17.8	16.5
	Venezuela			97.7	92.4	53.4	46.0	37.2
NICs	Israel				61.2	65.3	64.9	55.2
	Hong Kong			87.0	43.3	75.4	78.3	85.3
	Singapore				39.5	57.7	74.5	77.4
	Korea			*10.7*	21.3	42.3	51.0	56.5
	Taiwan			*10.9*	28.7	49.6	64.2	66.5
	India			*5.8*	6.1	7.1	8.6	9.5
	China			*5.5*	4.8	6.7	9.3	13.0

Source: Total Economy Database, GGDC (2006), historical values (in italics) are from Maddison (2001).

Table 4: Correlation coefficients between levels of Innovative Activity and GDP per capita, OECD countries

	Correlation of GPD per capita with	
Year	US patents per capita	R&D per capita
1890	0.20	
1913	0.38	
1329	0.56*	
1950	0.63*	
1963	0.73**	0.79**
1967	0.72**	0.69**
1971	0.74**	0.71**
1977	0.88**	0.61**
1981	0.65**	0.62**
1985	0.61**	0.49*
1991	0.63**	0.68**
1996	0.50*	0.62**
2003	0.35	0.36

* Significance at 5% level
** Significance at 1% level *
Source: Pavitt and Soete (1981) until 1977 and own elaborations for later years

Table 5: Correlation coefficient between Innovative Activity and Output, 1890-1977, 14 OECD countries

	GDP Growth (g)	GDP per capita growth (y)	US patents per capita at t=1 (PT)	US patents per capita (pt)	GDP per capita at t=1 (Y)
1890-1913					
g	1.00	0.60*	0.60*	-0.22	-0.18
y		1.00	0.20	0.05	-0.66**
PT			1.00	-0.61*	0.22
pt				1.00	-.67**
Y					1.00
1913-1929					
g	1.00	0.76**	-0.12	0.66**	-0.41
y		1.00	-1.21	0.67**	-0.62*
PT			1.00	-0.55*	0.38
pt				1.00	-0.43
Y					1.00
1929-1950					
g	1.00	0.82**	0.31	0.66**	0.37
y		1.00	0.41	0.58*	0.40
PT			1.00	0.22	0.56*
pt				1.00	0.67**
Y					1.00
1950-1970					
g	1.00	0.75**	0.38	0.89**	-0.76**
y		1.00	0.40	0.71*	-0.76*
PT			1.00	-0.48	0.63*
pt				1.00	-0.84*
Y					1.00
1970-1977					
g	1.00	0.91**	-0.67**	0.29	-0.47
y		1.00	-0.60*	0.16	-0.48
PT			1.00	-0.28	0.66**
pt				1.00	-0.16
Y					1.00

* Significance at 5% level
** Significance at 1% level
Source: Pavitt and Soete (1981)

Table 6: Correlation coefficient between Innovative Activity and Output, 1970-2003, 21 OECD countries.

	GDP growth (g) 1	GDP per capita growth (y) 2	US patents per capita at t=1 (PT) 3	US patents per capita growth (pt) 4	GDP per capita at t=1 (Y) 5
1970-1977					
g	1.00	0.88**	-0.60**	0.37	-0.87**
y		1.00	-0.49	0.18	-0.70**
PT			1.00	-0.21	0.73**
pt				1.00	-0.14
Y					1.00
1977-1984					
g	1.00	0.88**	-0.36	0.78**	-0.76**
y		1.00	-0.25	0.82**	-0.54*
PT			1.00	-0.26	0.64**
pt				1.00	-0.63**
Y					1.00
1984-1991					
g	1.00	0.96**	-0.15	0.94**	0.94**
y		1.00	-0.13	0.89**	-0.49*
PT			1.00	-0.24	0.61**
pt				1.00	-0.58**
Y					1.00
1991-1998					
g	1.00	0.96**	-0.48*	0.37	-0.34
y		1.00	-0.46*	0.30	-0.25
PT			1.00	-0.27	0.63**
pt				1.00	-0.39
Y					1.00
1998-2003					
g	1.00	0.96**	-0.45*	0.52*	-0.44*
y		1.00	-0.40	0.51*	-0.46*
PT			1.00	-0.30	0.42*
pt				1.00	-0.17
Y					1.00

* Significance at 5% level

** Significance at 1% level

Source: Own elaborations on data from OECD and USPTO for a sample of 21 OECD countries

4 Distinct "regimes" of growth/development with distinct techno-economic paradigms and complementary organizational forms and institutions

In order to understand the evolution of the relation between technological change and economic development, it is useful to turn to the notion of "techno-economic paradigm" or "regime" (Freeman and Perez (1988))[4]. One of the very first definitions can be found in Perez (1985), p.443:

``We suggest that the behavior of the relative cost structure of all inputs to production follows more or less predictable trends for relatively long periods. This predictability becomes the basis for the construction of an 'ideal type' of producing organization, which defines the contours of the most efficient and "least cost" combinations for a given period. It thus serves as a general "rule-of-thumb" guide for investment and technological decisions. That general guiding model is the ``techno-economic paradigm''.''

Figure 2: Five successive technological revolutions, 1770 to 2000s (source: Perez (2002))

Technological revolution	***Popular name for the period***	***Core country or countries***	***Big-bang initiating the revolution***	***Year***
FIRST	The 'Industrial Revolution'	Britain	Arkwright's mill opens in Cromford	1771
SECOND	Age of Steam and Railways	Britain (spreading to Continent and USA)	Test of the 'Rocket' steam engine for the Liverpool-Manchester railway	1829
THIRD	Age of Steel, Electricity and Heavy Engineering	USA and Germany forging ahead and overtaking Britain	The Carnegie Bessemer steel plan opens in Pittsburgh, Pennsylvania	1875
FOURTH	Age of Oil, the Automobile and Mass Production	USA (with Germany at first vying for world leadership), later spreading to Europe	First Model-T comes out of the Ford plant in Detroit, Michigan	1908
FIFTH	Age of Information and Telecommunications	USA (spreading to Europe and Asia)	The Intel microprocessor is announced in Santa Clara, California	1971

Each techno-economic paradigm relies on the availability of a specific key factor that presents a set of characteristics:

``The focusing device or main organizing principle of this selective mechanism would be a particular input or set of inputs, capable of strongly influencing the behavior of the relative cost

[4] Note that the notion of "techno-economic paradigm" is essentially a *macro* notion, while the "paradigms" discussed in Section 2 address the features of individual technologies. In fact, the two notions are highly complementary, with the former being composed of interrelated constellations of the latter.

structure. Such an input, which we shall call the `key factor', is capable of playing a steering role because it fulfills the following conditions:
(1) clearly perceived low -- and descending -- relative cost,
(2) apparently unlimited supply (for all practical purposes),
(3) obvious potential for all-pervasive influence in the productive sphere, and
(4) a generally recognized capacity, based on a set of interwoven technical and organizational innovations, to reduce the costs and change the quality of capital equipment, labor and products." (op.cit. p. 444)

The work by Perez (2002) has identified five main technological revolutions in the time span from 1770 to 2000 (Table 2) and five corresponding techno-economic paradigms (Table 3). For each of them there is a clear `key factor'. Table 4 summarizes the characteristics of the underlying industries and infrastructures of the different techno-economic regimes.

There is little doubt in our view that one can talk about a new, ICT-based, techno-economic regime. ICT's share with previous regimes some distinctive features. First, the new technologies are pervasive, with a range of applications spanning all industries. Second, the new regime relies on a quasi-free crucial input: yesterday energy/electricity, today it is clearly computer power. Third, the establishment of the new regime entails painstaking ``co-evolutionary'' requirements between technological and organizational changes, which we will discuss at length in the next section and for which we will provide evidence in Section 6. Fourth, the initial phase of the new regime is characterized by bubble dynamics in the 'core economies' developing them. The recent new economy bubble following the widespread euphoria of the 1990s bears strong similarities with the panic and euphoria dynamics of the automobile boom in the US in the 1920s, as vividly recalled by Freeman (2001).

At the same time, one should also bear in mind that the emergence of an ICT based techno-economic paradigm is occurring within a regime of globalization of international economic exchanges, but not of globalization of technological capabilities (as we will argue at greater length in Section 7) so far. Not only are the capabilities of mastering new technologies deeply unevenly distributed across countries but even within technological leaders one is still in a phase of exploration of the possible application of ICT-based technologies.

5. The painstaking diffusion of the new regime

The evidence in our view largely supports the view that the `ICT revolution' is far from having expressed its full potential yet. `Technological revolutions' display long diffusion processes, because they entail co-evolution and co-adaptation of new technologies, new organizational forms, new institutions, and new consumption patterns:

``The eventual supplanting of an entrenched techno-economic regime involves profound changes whose revolutionary nature is better revealed by their eventual breadth and depth of the clusters of innovation that emerge than by the pace at which they achieve their influence. Exactly because of the breadth and depth of the changes entailed, successful elaboration of a new `general purpose' technology requires the development and coordination of a vast array of complementary tangible and intangible elements: new physical plant and equipment, new kinds of workforce skills, new organizational forms, new forms of legal property, new regulatory framework, new habits of mind and patterns of taste.'' (David (2001), p.53)

Figure 3: A different techno-economic paradigm for each technological revolution, 1770 to 2000s (source: Perez (2002))

Technological revolution ***Country of initial development***	***Techno-economic paradigm 'Common-sense' innovation principles***
FIRST *The 'Industrial Revolution'* Britain	Factory production Mechanization Productivity/time keeping and time saving Fluidity of movement (as ideal for machines with water-power and for transport through canals and other waterways) Local networks
SECOND *Age of Steam and Railways* In Britain and spreading to Continent and USA	Economics of agglomeration/Industrial cities/National markets Power centres with national networks Scale as progress Standard parts/machine-made machines Energy where needed (steam) Interdependent movement (of machines and of means of transport)
THIRD *Age of Steel, Electricity and Heavy Engineering* USA and Germany overtaking Britain	Giant structures (steel) Economies of scale of plant/vertical integration Distributed power for industry (electricity) Science as a productive force Worldwide networks and empires (including cartels) Universal standardization Cost accounting for control and efficiency Great scale for world market power/'small' is successful, if local
FOURTH *Age of Oil, the Automobile and Mass Production* In USA and spreading to Europe	Mass production/mass markets Economies of scale (product and market volume)/ horizontal integration Standardization of products Energy intensity (oil based) Synthetic materials Functional specialization/hierarchical pyramids Centralization/metropolitan centres-suburbanization National powers, world agreements and confrontations
FIFTH *Age of Information and Telecommunications* In USA and spreading to Europe and Asia	Information-intensity (microelectronics-based ICT) Decentralized integration/network structures Knowledge as capital/intangible value added Heterogeneity, diversity, adaptability Segmentation of markets/proliferation of niches Economies of scope and specialization combined with scale Globalization/interaction between the global and the local Inward and outward cooperation/clusters Instant contact and action/instant global communications

Figure 4: The industries and infrastructures of each technological revolution (source: Perez (2002))

Technological revolution	*New technologies and new or redefined industries*	*New or redefined infrastructures*
FIRST From 1771 *The 'Industrial Revolution'* Britain	Mechanized cotton industry Wrought iron Machinery	Canals and waterways Turnpike roads Water power (highly improved water wheels)
SECOND From 1829 *Age of Steam and Railways* In Britain and spreading to Continent and USA	Steam engines and machinery (made in iron; fuelled by coal) Iron and coal mining (now playing a central role in growth)* Railway construction Rolling stock production Steam power for many industries (including textiles)	Railways (Use of steam engine) Universal postal service Telegraph (mainly nationally along railway lines) Great ports, great depots and worldwide sailing ships City gas
THIRD From 1875 *Age of Steel, Electricity and Heavy Engineering* USA and Germany overtaking Britain	Cheap steel (especially Bessemer) Full development of steam engine for steel ships Heavy chemistry and civil engineering Electrical equipment industry Copper and cables Canned and bottled food Paper and packaging	Worldwide shipping in rapid steel steamships (use of Suez Canal) Worldwide railways (use of cheap steel rails and bolts in standard sizes) Great bridges and tunnels Worldwide Telegraph Telephone (mainly nationally) Electrical networks (for illumination and industrial use)
FOURTH From 1908 *Age of Oil, the Automobile and Mass Production* In USA and spreading to Europe	Mass-produced automobiles Cheap oil and oil fuels Petrochemicals (synthetics) Internal combustion engine for automobiles, transport, tractors, airplanes, war tanks and electricity Home electrical appliances Refrigerated and frozen foods	Networks of roads, highways, ports and airports Networks of oil ducts Universal electricity (industry and homes) Worldwide analog telecommunications (telephone, telex and cablegrams) wire and wireless
FIFTH From 1971 *Age of Information and Telecommunications* In USA and spreading to Europe and Asia	The information revolution Cheap microelectronics Computers, software Telecommunications Control instruments Computer-aided biotechnology and new materials	World digital telecommunications (cable, fiber optics, radio and satellite) Internet/Electronic mail and other e-services Multiple source, flexible use, electricity networks High-speed physical transport links (by land, air and water)

* These traditional industries acquire a new role and a new dynamism when serving as the material and the fuel of the world of railways and machinery

These are indeed the structural retardation factors common to both the older electricity-based techno-economic paradigm and the new ICT-based one (see David (1990) for an illuminating comparison between the fates of the `dynamo' and of the `computer').
Indeed the emergence of a new techno-economic paradigm is also associated with a profound process of structural change. On the supply side, structural change may be captured by the original Schumpeterian idea of innovation as ‘creative destruction’: new varieties of goods and new ways of producing them displace old ones and shift the structure of the economy toward new sectors (Schumpeter (1939)). On the demand side, income elasticities vary across sectors and channel growth into those sectors for which demand turns out to be higher (Pasinetti (1981)). Overall, economies enjoy a ’structural bonus’ when labor shifts to sectors with higher than average productivity (Baumol (1967)).
Note that structural change fundamentally relies on an uneven distribution of productivity increases across industries. This corresponds to what Harberger (1998) calls the ‘mushroom’ view of growth (in contrast, a ‘yeast’ process, with productivity increases uniformly spread across sectors, would not sustain any real process of structural change).
As recently emphasized by Perez (2002), in the process of establishment of new techno-economic paradigms, sheer technological factors are deeply intertwined with social ones:

``Each technological revolution, originally received as a bright new set of opportunities, is soon recognized as a threat to the established way of doing things in firms, institutions and society at large. The new techno-economic paradigm gradually takes place as a different 'common sense' for effective action in any area of endeavour. But while competitive forces, profit seeking and survival pressures help diffuse the changes in the economy, the wider social and institutional spheres where change is also needed are held back by strong inertia stemming from routine, ideology and vested interests.
[...]
It is thus that the first 20 or 30 years of diffusion of each technological revolution lead to an increasing mismatch between the economy and the social and regulatory systems." (Perez (2002), p.26)

The well-known claim by Robert Solow about seeing computers everywhere but in productivity statistics (Solow (1987)) captured the amazement of economists for not being able to immediately observe the gains from a new technological revolution. In fact, if one takes into account the existence of powerful retardation factors, then the paradox is not a paradox anymore. The way productivity gains diffuse across industries is a painstaking process that needs adaptation of economic activities to the new paradigm. If the interpretation of David (2001) is correct, we are only starting to observe the real gains from the current ICT-based techno-economic paradigm. We will discuss this point again when we turn to the empirical evidence of the impact of ICT on productivity growth.
To further illustrate the point on retardation factors, let us briefly discuss a revealing example that we analyze at greater length in another work (Castaldi, Cimoli, Correa and Dosi (2004)). E-commerce and e-business represent new forms of trade which have yet to emerge as major transaction channels. The (relatively) low diffusion of e-business is associated with two fundamental bottlenecks, namely:

1. the lack of a thorough regulatory embeddedness of such transactions (e.g. in terms of enforcement of contracts) that affects reputation mechanisms (i.e., ultimately, institutional retardation factors);
2. the need for reliable `coding technologies' which guarantee that on line transactions are safe and data are protected (i.e., sheer technological barriers).

New forms of trade such as the ones implied by e-commerce and e-finance bring in the forefront delicate institutional issues related to the `integrity' of the new markets. With the new technologies it becomes more difficult, for example, to check the identity of economic agents and to sanction deviant behaviours. The existing institutions that provide the `regulatory embeddedness' for ``old" transactions are no longer sufficient to guarantee the new forms of trade. In particular new arrangements are needed to ensure integrity and enforcement of contracts. Here as well as in other historical occurrences of new forms of trading demands the development of new institutional mechanisms aimed at providing trading processes within some governing institutions. A very old example with bearings on contemporary issues is discussed in Milgrom, North and Weingast (1990), concerning the emergence of the Law Merchant System protecting Medieval fairs. Such institutional system was able to ensure the effectiveness of reputation mechanisms even when the trade arena enlarged beyond a critical level whereby traders were not meeting the same trading partners on a regular basis. The new institution succeeded in creating incentives for merchants both to behave honestly and to sanction deviant behavior by others. And this was achieved crucially using less information than would have been needed to distribute perfect information for all agents in the system, a condition way too costly to fulfil. There is a lesson here for the ``new economy" in its needs to develop reputation mechanisms, forms of community identification and tools for contract enforcement. Take this example just as suggestive illustration of more general co-evolutionary requirements linking the diffusion of new technological paradigms and the painstaking developments of new institutional arrangements governing microeconomic interactions.

Co-evolutionary requirements concern also the mutual adaptation of new technologies and corporate organizational forms crucially affecting the impact of ICT. As evidence that most recent efforts aimed at understanding the role of ICT in the economic growth are acknowledging these co-evolutionary requirements, the contributions in Mansell et al (2007) offer a wide spectrum of studies where institutional and organizational changes are examples of complementary changes that need to accompany the technological advances in ICT. As a powerful example, recent micro-studies present a picture where productivity gains from ICT at the firm level are closely inter-related with the ability of firms to implement complementary organizational changes. Our review of the evidence on the impact of ICT shall start precisely from these studies.

5 The empirical evidence on the impact of ICT

In this section we turn to the evidence collected so far on the economic impact of ICT. The aim of both micro-, meso- and macro-studies has been to investigate the causal link between ICT and productivity growth. It is not our purpose here to review the ongoing discussion about the measurement of ICT and its contribution to productivity growth (for a recent account, see van Ark (2002)), but we should mention that measurement remains a problematic issue. In particular productivity growth measures are sensitive to the methods used to account for decline in prices and quality changes, but also to the definition of ICT used. Also note that most studies rely on US or European data. In this section we will focus more on the implications of the available stylized facts for our evolutionary interpretation. We start by discussing the evidence found at the level of firms and we then move to more aggregate studies.

5.1 The micro-evidence

A recent literature has started to use micro-data in order to illuminate the impact of ICT technologies at the firm or even at the worker level. Brynjolfsson and Hitt (2000) review the two main strands of these micro-studies.
First, a case-based literature provides evidence that the impact of ICT at the firm level goes together with changes in organizational practices, such as changes in authority relationships, decentralization of the local decision, shifts in task content and/or changes in reward schemes. Many of these studies (for instance Brynjolfsson, Reinshaw, and van Alstyne (1997)) show that

in the face of changes in organizational practice, many workers still remain trapped in old work practices. Inertial forces are at work, which explain the inability of firms to instantaneously exploit the potential of new technologies.
Second, an econometric literature has also emerged, using large scale data recently becoming available from official sources. Pilat (2004) provides an overview of these studies, available now for many countries. Let us briefly summarize the main results:

1. Most of them find a positive relation between level of ICT and firm productivity. (Note that this is a correlation, more work needs to be done in understanding causality linkages).

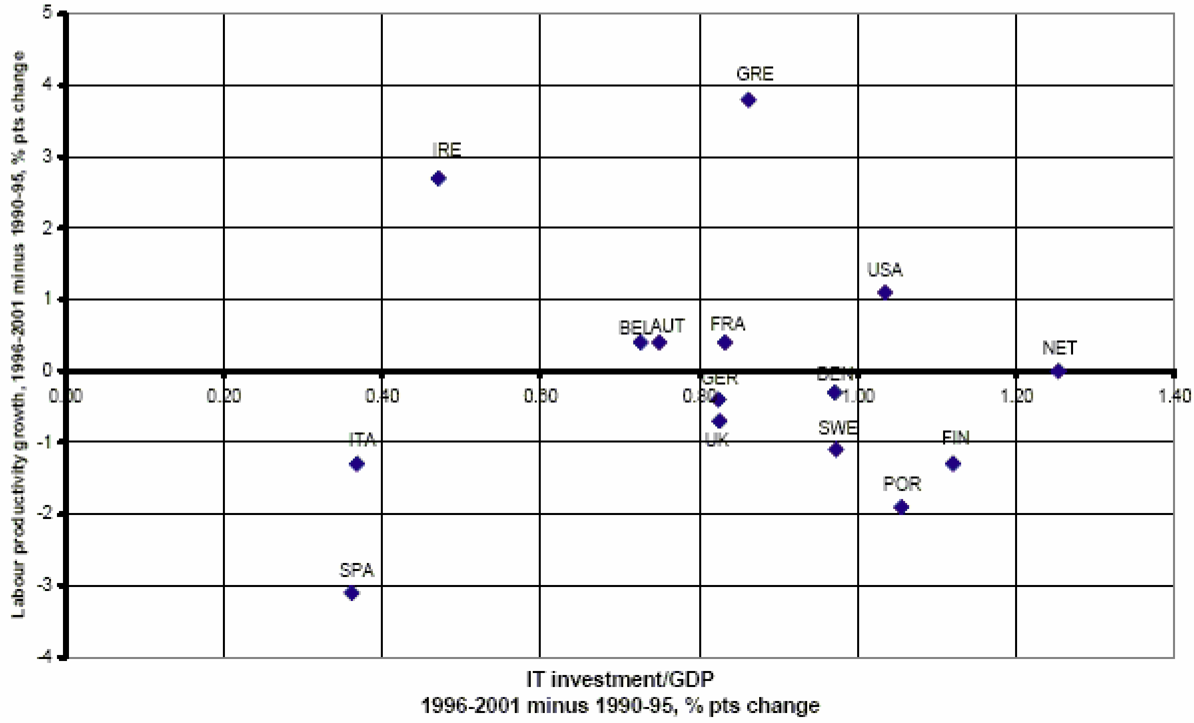
2. The evidence points at different factors moderating the impact of ICT at firm level, including the co-occurrence of matching skills of the workforce, appropriate organizational practice and other forms of technological innovation. Moreover, the size and age of the firm seem to influence the effect of ICT adoption upon productivity.

3. While improvements in IT technology tend to be quickly available throughout the economy, the complementary organizational changes at the firm level rely on a process of 'co-invention' by individual firms (Bresnahan and Greenstein, 1997) suggesting co-evolutionary processes combining 1) the adoption of information technology, 2) complementary organizational changes, and 3) innovation in the form of new products and services, (Bresnahan, Brynjolfsson and Hitt (2002)). Conversely there is some evidence that the sheer adoption of ICT without corresponding changes in organizational practices might be simply detrimental for the company. It is the combination of the three changes mentioned above that can drive productivity gains.

4. Some econometric works (cf. Brynjolfsson and Hitt (2000) for US and Greenan, Mairesse and Topiol-Bensaid (2001) for France) have used fixed effects models to estimate the impact of ICT on productivity in order to capture firm-specific determinants. The estimates controlling for fixed effects are substantially lower and indicate that much of the ability of firms to exploit gains from ICT relates to intrinsic organizational somewhat pre-existent capabilities.

Bartelsman and Doms (2000) also discuss insights coming from micro studies on the relationship between productivity and advanced technology. Use of the latest technology turns out to be highly correlated with other variables (such as human capital). A study by Doms, Dunne and Troske (1997) shows that plants that had above average productivity because of ICT, also had the same before the introduction of ICT because they consistently were the ones choosing the most advanced technologies. In this sense, also under an ICT-centered regime of technological change asymmetries across firms are the rule: some firms show a much higher performance and persistently so. In turn, this can easily be interpreted as an evolutionary story of path-dependence and persistent performance differentials among firms.

Figure 5: The IT productivity paradox in Europe (source: Daveri (2002))



5.2 The aggregate evidence on the impact of ICT

A puzzling result in the empirical literature on the impact of ICT is the fact that more aggregate studies do not find the foregoing positive relation between ICT and productivity often revealed by micro-studies (cf. also the review in Draca et al (2007)). Figure 5 from Daveri (2002) illustrates this puzzle for Europe: labor productivity growth does not have any significant relationship with IT investment. In some ways the Solow paradox still seems to hold at a macro level. In this respect, further insights can be gained by using an industry-level perspective. In fact, the sectors display striking variance in productivity performances. ICT producing industries show strong and robust productivity gains, while the evidence is much weaker for ICT using industries (van Ark et al. (2002)), see also Figure 6).

For the US, Oliner and Sichel (2000) identify ICT investment as the main driver of the recent productivity revival.[5]

Note also that, most of the productivity gap between the United States and Europe can in fact be attributed to ICT using industries (van Ark et al. (2002)). Indeed it might well be that the appearance of a `Solow paradox' in Europe might be especially due to a slower diffusion of ICT in ICT using sectors like wholesale trade and security trading. In any case, these are the sectors which make the essential difference between the US and Europe in terms of productivity differentials.

To summarize, industry-level studies strongly point at the uneven inter-sectoral diffusion of ICT-based technologies and their equally uneven impact upon productivity growth.

Given the foregoing features of the new ICT-based regime and the evidence on its impact on productivity growth, how has this new cluster of technologies influenced the international patterns of innovation, innovation diffusion and growth?

Figure 6: Productivity growth and GDP shares of ICT using and non-ICT industries in the EU and the US (source: van Ark et al. (2002)).

	Productivity growth				**GDP share**	
	1990-1995		**1995-2000**		**2000**	
	EU[6]	**US**	**EU[a]**	**US**	**EU[a]**	**US**
Total Economy	1.9	1.1	1.4	2.5	100.0	100.0
ICT Producing Industries	6.7	8.1	8.7	10.1	5.9	7.3
ICT Producing Manufacturing	11.1	15.1	13.8	23.7	1.6	2.6
ICT Producing Services	4.4	3.1	6.5	1.8	4.3	4.7
ICT Using Industries[7]	1.7	1.5	1.6	4.7	27.0	30.6
ICT Using Manufacturing	3.1	-0.3	2.1	1.2	5.9	4.3
ICT Using Services	1.1	1.9	1.4	5.4	21.1	26.3
Non-ICT Industries	1.6	0.2	0.7	0.5	67.1	62.1
Non-ICT Manufacturing	3.8	3.0	1.5	1.4	11.9	9.3
Non-ICT Services	0.6	-0.4	0.2	0.4	44.7	43.0
Non-ICT Other	2.7	0.7	1.9	0.6	10.5	9.8
Pro memoria: with national deflators						
Total Economy	1.9	1.1	1.4	2.5		
ICT Producing Manufacturing	7.8	15.1	10.1	23.7		

Source: van Ark, Inklaar and McGuckin (2002, 2003a)

[5] However their results have been questioned by Gordon (2003), who argues that their growth accounting methodology actually over-estimates the contribution of ICT investment.

First, their methodology assumes that productivity gains from ICT capital happen instantaneously. But retardation factors imply a necessary time lag for economic actors to enjoy the benefits of a new technology.

Second, most of the aggregate productivity growth is given by the productivity revival in the retail sector, but there is evidence that the latter can in fact be fully explained by non-ICT related factors. A study by Foster et al (2002) has convincingly shown that the productivity revival in the retail sector can be attributed solely to the displacement of less productive establishments with more productive ones.

[6] EU includes Austria, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Spain, Sweden and the United Kingdom, which represent over 90% of EU GDP. Notes: Productivity is defined as value added per person employed

[7] excluding ICT producine

6 The contemporary processes of generation and diffusion of innovations, skills and organizational capabilities: the international picture

One has already mentioned the continuing concentration of innovative activities, notwithstanding remarkable new entrants such as Finland, Korea, Taiwan and to a lower extent Brazil and India. Not surprisingly, such patterns in innovative outputs are matched by persistent international differences in the share of resources devoted to formal technological learning (also revealed by privately financed R&D). So, while Korea has overtaken quite a while ago ``developed '' countries like Italy, most LDCs continue to display negligible levels of private investments in R&D (cf. Figure 7).

Figure 7: Intensity of firm level R&D. Source: own elaborations on data from Main Science and Technology Indicators, OECD (2005b).

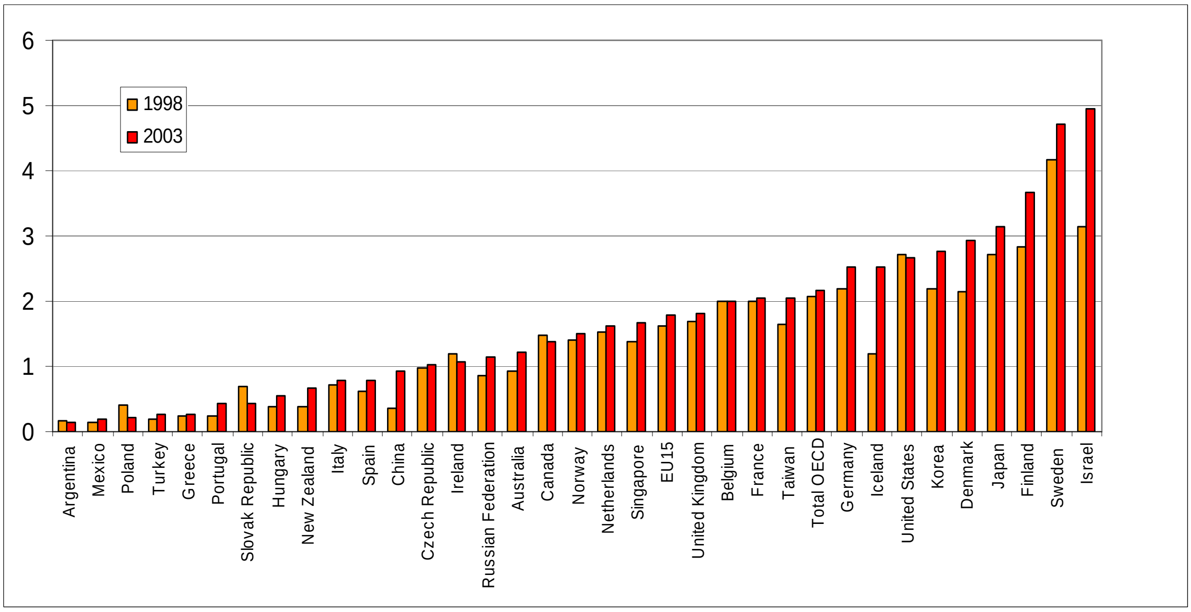
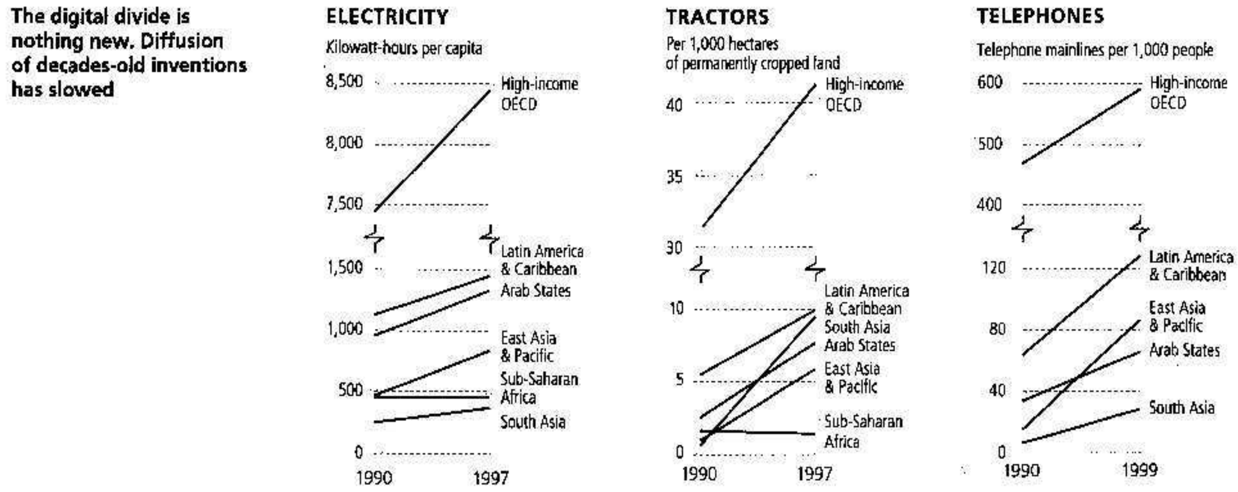


Figure 8: Diffusion of ``old" technologies, Source: United Nations, Human Development Report (2001).



Certainly, ICT technologies have determined easier diffusion of information. However, there is hardly any evidence of a generalized acceleration in the rates of adoption of both ``new" (e.g. ICT-related) and ``old" technologies (from telephones to tractors). Let us begin with the latter. Even in this case there is hardly any evidence of generalized patterns of convergence in their use at world level: see Figure 8.

At the same time levels of education and number of graduates remain very different across countries, accounting in some cases for rather low levels of human capital (see the evidence in Tables 7 and 8): in turn, other things being equal, uneven educational attainments imply deeply uneven national *absorptive capacities* for new technologies.

As for new technologies, diffusion of the new ICT technologies is occurring in highly asymmetric fashions across countries. This applies to OECD countries and, even more so, to the universe of countries in the world economy. Most of the data available refer to developed countries. But, if gaps are found for those economies, even larger gaps are to be expected for developing ones.

It is useful to start by distinguishing the relative impact on production and consumption.

As for production, there has been an increasing investment in ICT capital for the last 30 years and a rising factory automation, all the way from mechanical engineering to continuous cycle processes. At the same time, the evidence reinforces the view – discussed above – that we are still in an initial phase of the diffusion of ICT technologies, certainly with a consistent unexpressed potential. And. again, this applies even more so to developing countries. So, even in the United States ICT investment represents less than 30% of total investment and the share reduces considerably for European countries (see Daveri (2002)).

Relatedly, the degree of automation in production has greatly increased, but one is still very far from saturating levels. As an illustrative example, Table 9 provides the number of robotic units and mechanical arms installed for a sample of countries. After some normalization via national value added in manufacturing, one gets an estimate of the relative rates of diffusion of robotics. Japan is the leader, followed by the European countries and Korea, and finally by the US, at great distance.

Table 7: Number of researchers (per thousand labour force).

	1991	1994	1997	2000	2003
EU15	4.4	4.75	5	5.5	5.9
Finland	5.5	6.4	10.6	13.4	15.9
France	5.2	5.9	6	6.5	7.1
Germany	6.1	5.95	5.9	6.5	6.8
Ireland	3.8	3.7	4.6	4.9	5.4
Italy	3.1	3.3	2.8	2.8	3
Sweden	5.8	7.2	8.4	9.7	10.6
UK	4.4	4.8	5.2		
US	7.6	7.7	8.4	9	9.1
Japan	7.5	8.1	9.2	9.6	10.1
Argentina	0.97	0.75	0.5	1.7	1.5
Brazil	1.92	1.7			
Chile	1.17	1.17	1.19	1.3	
Mexico	2.28	1.48	0.6	0.6	
Venezuela	1.75	1.82	2.13		
Singapore		3.9	5.2	7.6	9.3
Taiwan			5	5.7	6.7
South Korea			4.7	4.9	6.6
China	0.7	0.8	0.8	1	1.1

Source: Own elaborations on Main Science and Technology Indicators, OECD (2005b). Data for Latin America are from Ricyt (2000)

Table 8: Mean years of schooling.

		1970	1980	1990	2000
OECD	Australia	10.2	10.3	10.4	10.9
	Austria	7.4	7.3	7.8	8.4
	Belgium	8.8	8.2	8.9	9.3
	Canada	9.1	10.3	11.0	11.6
	Denmark	8.8	9.0	9.6	9.7
	Finland	6.1	7.2	9.4	10.0
	France	5.7	6.7	7.0	7.9
	Germany			9.9	10.2
	Ireland	6.8	7.5	8.8	9.4
	Italy	5.5	5.9	6.5	7.2
	Japan	7.5	8.5	9.0	9.5
	Netherlands	7.8	8.2	8.8	9.4
	New Zealand	9.7	11.5	11.3	11.7
	Norway	7.2	8.2	11.6	11.9
	Portugal	2.6	3.8	4.9	5.9
	Spain	4.8	6.0	6.4	7.3
	Sweden	8.0	9.7	9.5	11.4
	Switzerland	8.5	10.4	10.1	10.5
	UK	7.7	8.3	8.8	9.4
	US	9.5	11.9	11.7	12.0
NICs	Israel	8.1	9.4	9.4	9.6
	Singapore	5.1	5.5	6.0	7.1
	South Korea	4.9	7.9	9.9	10.8
	Hong Kong	6.3	8.0	9.2	9.4
Latin America	Argentina	6.2	7.0	8.1	8.8
	Brazil	3.3	3.1	4.0	4.9
	Chile	5.7	6.4	7.0	7.6
	Mexico	3.7	4.8	6.7	7.2
	Venezuela	3.2	5.5	5.0	6.6
	India	2.3	3.3	4.1	5.1
	China		4.8	5.9	6.4
World	Mean	4.2	4.9	5.8	6.4
	Coeff. of variation	1.6	1.8	2.0	2.3

Source: Own elaborations on data from UN (2001).

A complementary but different picture comes out from data on expenditure for Information Technology which can be taken as a proxy for the overall automation of the economy. The percentages remain quite small in size (Table 10). Moreover the comparison of the two previous tables uncovers the puzzling position of the United States. The evidence indicates that Japan and Europe lag behind the US in terms of total automation (as proxied by the level of ICT investment), while on the contrary the US lag behind in terms of factory automation (the same circumstantial evidence was already pointed out in Arcangeli, Dosi and Moggi (1991), see also Freeman (2001) for a discussion of the US national innovation system).
As for consumption, the evidence again points to a diffusion of new technologies that is highly uneven across countries, even within the OECD. Table 11 reports on the strength of the IT infrastructure in a sample of countries. The ranking of countries now changes. US is far ahead in the `informatization' of its society and the other developed countries follow at considerable distance (the only relevant exception comes from mobile phones). Note also, interestingly, that there is also evidence of a 'digital divide' within the United States (Greenstein and Prince (2007)), with non-urban areas lagging behind in terms of high-speed Internet connection as the better alternative to low-speed/dial-up connection.

Table 9: Number of robotic units and mechanical arms installed, 2000.

Country	Number of units	Ratio to Industry Value Added
Japan	389.000	378
Germany	91.184	139
US	89.880	37
Italy	47.621	113
Korea	37.987	122

Source: Own elaborations on data from UCIMU (2001) and OECD.

Table 11 adds further evidence on the uneven diffusion of ICT technologies. Note the impressive international differences in the diffusion of ICT technologies: compare for example Finland with Poland or East Asia with Latin America.

Table 10: IT expenditure (Information Technology, excluding Communication), as a percentage of GDP

Country	1992	1996	2001
US	4.45	4.93	5.30
Japan	3.83	3.60	4.00
EU15	3.03	3.17	4.17
Sweden	4.37	4.73	6.77
UK	4.43	4.9	5.62
Netherlands	3.96	3.84	5.19
Denmark	3.94	4.1	4.99
France	3.59	3.74	4.75
Belgium	3.38	3.34	4.48
Finland	2.93	3.36	4.38
Germany	2.94	2.96	4.22
Austria	2.73	2.8	3.78
Norway	3.24	3.26	3.66
Italy	1.8	1.78	2.48
Ireland	2.35	2.18	2.25
Spain	1.62	1.56	1.94
Portugal	1.24	1.48	1.93
Greece	0.71	0.90	1.20

Source: Elaborations of Eurostat data

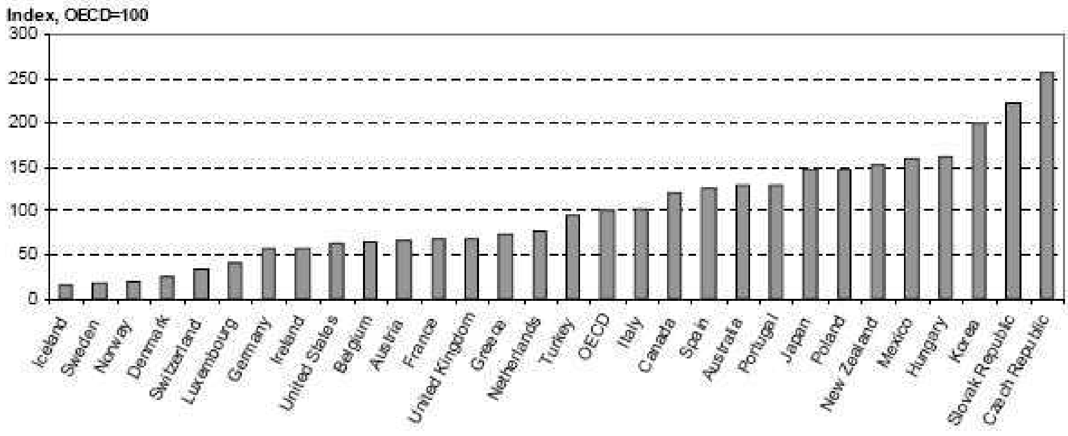
Table 11: Indexes of ICT diffusion, per 100 population

		Telephone lines and cellular subscribers			Internet users			Personal computers		
		1990	1998	2003	1990	1998	2003	1990	1998	2003
OECD	Austria	42.9	78.9	136.0	0.1	15.4	46.2	6.5	23.8	*37.4*
	Australia	46.7	77.2	126.2	0.6	22.4	56.7	15.0	36.8	60.2
	Belgium	39.7	66.7	128.2	0.0	7.8	38.6	8.8	21.5	31.8
	Canada	58.7	84.2	107.0	0.4	25.6	*48.4*	10.7	32.1	*48.7*
	Denmark	59.6	102.4	155.3	0.1	22.6	54.1	11.5	37.7	*57.7*
	Finland	58.6	110.2	140.2	0.21	25.4	53.4	10.0	34.9	44.2
	France	50.0	77.6	126.2	0.1	6.3	36.6	7.1	23.2	34.7
	Germany	44.5	73.7	144.3	0.1	9.9	47.3	9.0	27.9	48.5
	Ireland	28.8	69.6	137.1	0.0	8.1	31.7	8.6	27.3	*42.1*
	Italy	39.2	81.0	150.2	0.0	4.5	33.7	3.6	13.3	*23.1*
	Japan	44.8	86.8	115.1	0.0	13.4	48.3	6.0	23.7	*38.2*
	Netherlands	47.0	80.5	138.2	0.3	22.2	52.2	9.4	32.4	46.7
	Norway	54.8	113.4	162.2	0.7	36.0	34.6	12.1	40.5	*52.8*
	Spain	31.7	57.7	134.5	0.0	4.4	23.9	2.8	10.9	19.6
	Sweden	73.5	118.6	*162.5*	0.6	33.4	*57.3*	10.5	39.5	*62.1*
	UK	46.0	80.5	*143.1*	0.1	13.5	*42.3*	10.8	26.8	*40.6*
	US	56.9	90.7	117.0	0.8	30.8	55.6	21.8	45.2	*66.0*
	Russian Fed.	13.99	20.36	50.2	0	0.81	*4.09*	0.34	3.46	*8.87*
	Hungary	9.62	44.09	111.74	0	3.92	23.22	0.96	6.48	*10.84*
	Poland	8.64	27.74	76.96	0	4.08	23.24	0.79	4.91	14.2
Latin America	Argentina	9.3	28.1	*39.6*	0.0	0.9	*11.2*	0.7	5.5	*8.2*
	Brazil	6.5	16.5	48.7	0.0	1.5	*8.2*	0.3	3.0	*7.5*
	Chile	6.7	27.1	73.2	0.0	1.7	27.2	0.9	6.3	*11.9*
	Colombia	6.9	20.0	32.1	0.0	1.1	5.3		3.2	*4.9*
	Mexico	6.6	13.9	45.4	0.0	1.3	12.0	0.8	3.7	*8.3*
	Peru	2.6	9.3	17.3	0.0	1.2	10.4		3.0	*4.3*
	Venezuela	7.7	19.8	38.4	0.0	1.4	6.0	1.0	3.9	*6.1*
NICs	Israel	34.6	82.8	141.9	0.1	10.0	*30.1*	6.3	20.1	*24.3*
	Hong Kong	47.5	105.5	163.8	0.0	14.5	47.2	4.7	26.0	*42.2*
	Singapore	36.3	73.2	130.3	0.0	19.1	50.9	6.6	37.0	*62.2*
	Korea	30.8	75.1	123.9	0.0	6.8	61.0	3.7	18.2	55.8
	India	0.6	2.3	7.1	0.0	0.1	1.8	0.0	0.3	0.7
	China	0.6	8.9	42.4	0.0	0.2	6.3	0.0	0.9	*2.8*
World	Average	14.9	28.2	*46.7*	0.0	3.7	*13.1*	3.4	8.0	*12.8*
	Coeff Variation	1.2	1.1	*1.0*	4.6	1.9	*1.3*	1.4	1.4	*1.3*

Source: Elaborations on United Nations Millennium indicators. Values in italics refer to 2002

At the same time communication costs still remain a barrier to ICT use in a number of OECD countries (see Fig. 9).

Figure 9: The costs of communication in OECD countries: price basket for national leased line charges, August 2002.



Source: OECD, *Communications Outlook 2003*, based on OECD and Teligen.

The most recent evidence about the participation of developing countries to the ICT-based regime shows that East Asian countries such as Malaysia, Philippines and Korea have the highest share of employment and value added of the ICT sector (both manufacturing and services). Korea has in fact stopped since a couple of decades to be a developing country and has joined the quite exclusive club of innovators. Conversely, most Latin American countries and a few Eastern European ones remain at the bottom of the list (UNCTAD (2006), Chart 1.15).
The OECD Information Technology Outlook 2006 reports the geographical distribution of the top 250 ICT firms. While 116 of these are US firms, followed by 39 Japanese firms, the newcomers are also represented (11 for Taiwan, 6 for Korea, 3 for Hong Kong and for India). Mexico is the only Latin American country included (with 2 top ICT firms).

Another strong trend of the last 10 years has been the increasing outsourcing of activities by manufacturing firms in developed economies. The very properties of ICT technologies have enabled the dislocation of non-core activities and services to other regions of the world (cf. Miozzo and Soete (2001)). Within this trend, a number of countries have been able to reap the benefits of attracting foreign firms to their sites or simply directly exporting services. In fact, developing economies are playing an increasingly large role in ICT-enabled services, with success stories including Singapore for financial services and India for software. As discussed by Cantwell and Janne (1999), the recent emergence of more global chains of production has made it more important for firms to take strategic decisions not only on which activities to outsource abroad but also on which countries to select as host countries. In this respect the availability of cheap labour is attractive for foreign firms only if it is accompanied by good local infrastructures, high quality labour and, also, tax advantages.

At the same time, the internationalization of innovative activities by MNCs beyond the home countries has somewhat increased, but one is still talking about rather low proportions. Most studies indicate that patenting by MNCs originating in countries different from that of their own origin is of the order of 10-15% of their total patenting, roughly comparable to their share in the total patenting of the guest countries. Moreover, most of these foreign search activities occur within OECD countries (for discussion of the evidence cf. Patel and Pavitt (1997) and (1999), Cantwell (1992) and Archibugi and Pietrobelli (2003)).

In terms of outsourcing of R&D activities, multinational companies have been much more reluctant to transfer key research labs to developing countries. One of the reasons for firms to decentralize R&D activities is to relocate in the neighbourhood of technological centers of excellence in order to enjoy agglomeration economies and spillovers of new knowledge concentrating in that area (Dunning, 1993). But most key geographical technological clusters are still found in the developed world. As shown in Table 12, the great majority of R&D foreign affiliates are still located in developed countries and only about 10% in developing countries, of which 8% in Asian countries. Note that, also in this case, the growth figures may be impressive but the levels are not.
There is also evidence that until recently R&D facilities located abroad were mostly responsible for adapting existing products to local needs and tastes, while most fundamental and strategic R&D efforts were maintained in-house in the home countries (Pearce (1989)). 'Support laboratories' (in the definition of Pearce (1999)) are simply responsible for short-term technology transfer and facilitate the assimilation of the technologies for local affiliates. Long term goals may only be achieved if multinationals move from 'support laboratories' to 'locally integrated laboratories' and even 'international independent laboratories'.

Table 12: Geographical distribution of R&D foreign affiliates, 2004

Region/economy		Number
Total world		**2584**
Developed countries		**2185**
of which	Western Europe	1387
	United States	552
	Japan	29
Developing countries		**264**
of which	Africa	4
	Latin America and the Caribbean	40
	Asia	216
	South, East and South East Asia	207

Source: UNCTAD, based on the Who Owns Whom database of Dun and Bradstreet.
The data are based on a sample of 2284 majority-owned foreign affiliates identified in the db as engaged in either:

- commercial, physical and educational research (SIC code 8731)
- commercial economics and biological research (SIC code 8732)
- non-commercial research (SIC code 8733)
- testing laboratories (SIC code 8734)

7 Some concluding remarks and policy implications

We have led the reader through a long tour building on an evolutionary interpretation of the patterns of technological change and their (close) links with economic development. The modes and timing of such coupled dynamics, we have argued, is deeply influenced by the (relatively rare) emergence of new techno-economic paradigms or regimes, driven by constellations of complementary, thoroughly pervasive, micro technological paradigms (which in the mostly US-originated literature subsequent to Freeman and Perez (1988) and related contributions have become known under the heading of "general purpose technologies", cf. Bresnahan and Trajtenberg (1995)).

ICT-based technologies are the drivers of one of such changes in techno-economic regimes, which we suggested, is still just at an early stage of diffusion in general, and in particular with respect to developing countries. In that, the new techno-economic paradigm represents both an opportunity and a threat for developing countries. It is certainly the case that the pervasiveness of the new technologies makes their adoption a developmental necessity, independently from the precise patterns of `comparative advantage'. Even more strongly, from an historical perspective, countries that have successfully overtaken technological leaders have done so by mastering the technology behind the dominant techno-economic paradigm (see also the discussion in Freeman (1995)). That has been the case for Britain and the steam engine, Germany and the US for chemicals and Fordist mass production, Japan and Korea for electronics and most recently China and India for ICT-based products and services. Thus, catch-up of technological followers crucially depends on getting to the frontier of technological advances of the dominant techno-economic paradigm.

Given this, we would like to offer a few thoughts about a possible ICT-based development path.

First, the availability of natural resources and its utilization is an issue totally uncorrelated with the necessity of long-term ICT diffusion. Natural advantages have never been a sufficient reason for a country or region to catch-up. Instead, created advantages have been the source of sustained advantages (see Freeman (2002) for an historical perspective).

Second, catching-up in ICT investment is crucial for developing countries to build their `national absorptive capacity', also for foreign-generated knowledge (Bell and Pavitt (1993)). While late-comers have the potential to achieve the highest growth rates, the potential may be realized only if local firms are able to recognize, exploit and internalize the knowledge underlying the new technologies. ICT infrastructures play a crucial role in the latter process.

Third, developing countries need to nurture their corporate organizations that are able to exploit the opportunities associated with ICT. The role of such type of governmental policies for catch-up in general has been stressed already in the work of institutional economists like Amsden (1989).

The evidence persuasively shows that the current ICT-based techno-economic regime is emerging under the `political economy' of globalization of international economic exchanges, but not of globalization of technological capabilities so far. At the same time a globalized world is one in which local and national systems of innovation come to play an even greater role. As Freeman (1995) puts it: `` national and regional systems of innovation remain an essential domain of economic analysis. Their importance derives from the networks of relationships which are necessary for any firm to innovate. Whilst external international connections are certainly of growing importance, the influence of the national education system, industrial relations, technical and scientific institutions, government policies, cultural traditions and many other national institutions is fundamental."(op. cit. p. 5) This is also the point made by Porter (1990) in its work on the competitive advantage of nations.
More in general, while there seem to be no invariant recipes for successful economic growth, yet one can identify some fundamental policy ingredients and processes derived from the past, but valid for the future as well (see for a broader discussion Dosi, Freeman and Fabiani (1994) and Cimoli, Dosi, Nelson and Stiglitz (2006)).

First, policies aimed at increasing the opportunities for scientific and technological innovation have mostly started by ensuring a rapid expansion of the number of qualified engineers and in general strive to strengthen graduate education (see for instance the evidence in Lazonick (2007)). Broader education and training policies also help to build socially distributed learning and technological capabilities. Together with a strengthened education system, the development of technical and scientific institutions, increasingly networked with the private sector also plays a key role. The 'congruence' between science, technology, culture and entrepreneurships as 'sub-systems' within national innovation systems has also been emphasized (Freeman (2002)).

Second, most success stories also show rather sophisticated policy efforts aimed at fostering technological learning and at penalizing rent-seeking behaviours even under regimes of partial protection of the domestic market: incentive alignment measures favouring export-oriented strategies is a major case to the point. In general, targeted industrial support measures, for instance affecting the ownership structure of firms or targeting `national champions', prove to be quite effective tools for boosting technological activities at the firm level. These have to be combined with carefully chosen selection mechanisms affecting competition, entry and bankruptcy, price regulations and allocation of finance. As a general trade-off, nurturing capability-building has to be matched by mechanisms stifling inertia and rent-seeking.

Third, the patterns of information distributions and interaction across economic actors have also been subject to policy intervention. One has observed quite diverse `political economies' and `social pacts', displaying nonetheless some common features of generalized consensus building. In the case of the Far East these measures were apparently based on a variety of combinations among authoritarian politics, corporate paternalism and the ability to widely distribute the benefits from fast growth.

Fourth, at the firm level effective ingredients for productivity growth have been high rates of physical and intangible investment and the progressive integration of production design, marketing and research activities.

Fifth, in terms of international specialization patterns, success stories have shown a commodity composition of production and trade increasingly centred on technologies and products featuring high innovative opportunities and high income elasticities.

The historical experience shows a great variety of country- and sector specific combinations between the foregoing types of policies, highlighting also the subtle tradeoffs that we have discussed above. The comparison between the experience of Far Eastern countries and Latin American ones is a particularly revealing one. In a nutshell, Korea -as well as other far eastern economies - has been able to `twist around' absolute and relative prices and channel the resources stemming from `static' comparative advantages toward the development of activities characterized by higher learning opportunities and demand elasticities (Amsden (1989)). And they did that in ways which penalized rent-seeking behaviours by private firms. In fact the major actors in technological learning have been large business groups - the chaebols- which were able at a very early stage of development to internalize skills for the selection of technologies acquired from abroad, their efficient use and their adaptation and, not much later, were able to grow impressive engineering capabilities (Kim (1993)).

This process has been further supported by a set of institutions and networks for improving human resources. All this sharply contrasts with the Latin American experience, where the arrangement between the State and the private sector has often been more indulgent over inefficiencies and rent-accumulation, and less attentive to the accumulation of socially diffused technological capabilities and skills. Thus, ultimately success or failure appears to depend on the combinations of different institutional arrangements and policies, in so far as they affect learning processes by individuals and organizations, on the one hand, and selection processes, including of course market competition, on the other.
A similar reasoning applies to the opportunities and threats offered by ICT technologies. Policy making will need to carefully balance these trade-offs and complementarities to promote a virtuous ICT-based growth path for developing countries.

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