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The Contribution of ICT Investment to Economic Growth and Labor Productivity in Poland 1995-2000

Marcin Piatkowski

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Lecturer and Research Director, TIGER (Transformation, Integration, and Globalization Economic Research), Leon Koźmiński Academy of Entrepreneurship and Management, ul. Jagiellońska 59, 03-301 Warsaw, Poland. E-mail: mpiatek@tiger.edu.pl; homepage: http://www.tiger.edu.pl

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The Contribution of ICT Investment to Economic Growth and Labor Productivity in Poland 1995 - 2000[1]

Summary

There is large evidence on a positive impact of information and communication technologies (ICT) on economic growth and productivity in a number of developed countries in the 1990's. There are however no studies, which would estimate the contribution of ICT to growth and productivity in post-communist, transition economies. Data availability, consistency, and trustworthiness have been so far the main obstacles.

This paper makes a first attempt, based on an extended growth accounting framework, at estimating the contribution of investment in ICT to output growth and labor productivity in Poland, the largest post-communist economy in Central and Eastern Europe and a prospective member of the EU (2004). The paper discusses the challenges of using available data and its impact on the choice of specific methodologies.

The paper shows that ICT investment contributed on average 0.47 of a percentage point or 8.9% of GDP growth and 12.7% or 0.65 of a percentage point contribution to labor productivity between 1995-2000. This relatively large impact of ICT capital is due to an extraordinary acceleration in ICT investments between 1993-2001 induced by – one the one hand – rapidly falling prices of ICT products and services and – on the other hand – large demand for ICT fueled by high economic growth in the 1990's and substantial pent-up demand due to infrastructural underinvestment in ICT.

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1. Introduction

In spite of the recent worldwide economic gloom, the rapid pace of technological progress has not been arrested. The technological revolution in particularly information and communication technologies (ICT), which has contributed to the extraordinary performance of the US economy in the late 1990's (Jorgenson and Stiroh 2001, Oliner and Sichel 2000, Stiroh 2002), has not slowed down. The computing power of microchips, which underlies the rapid progress in productivity of ICT, has kept on doubling every 18-24 months, as Moore's Law has rightly predicted since 1965. The pace of progress in capacity of microchips has accelerated after 1995 as the product cycle for semiconductors - due to increased market competition - shortened from three to two years, which led to a decline in prices of semiconductors of some 90 percent per year (Jorgenson 2001). The rapidly falling prices of ICT products and services along with their increasing efficiency and quality kept on enticing businesses to spend on ICT, although the pace of investment has markedly slowed down after March 2001.

The erstwhile notion of a 'new economy' understood as a superior economic structure displaying sustainable and extraordinary increase in growth and productivity growth fueled by the ICT and coupled with low inflation and unemployment has been discarded. It was replaced with a notion of a 'new economy' understood as a host of new economic phenomena resulting from the two concurrent processes: on the one hand globalization, that is on-going deregulation, integration of the global markets for capital, goods, labor, and increased competition, and on the other hand, technological revolution based mostly on general-purpose ICT, which -- while impacting all sectors of the economy -- accelerate productivity and economic growth[2].

This paper will utilize a more narrow definition, where the 'new economy' is defined as an economy characterized by high growth rates in output and productivity fueled by production and use of ICT products and services.

Aside from the USA, the use and/or production of ICT have contributed to an increase in the rate of productivity and economic growth in a number of developed and developing countries in the late 1990's. Among the former, Australia, Sweden, Finland, and Ireland seem to have tapped the 'new economy' to the largest extent (OECD 2001a, Jalava and Pohjola 2002, Daveri 2002). Among the developing countries, Malaysia, Philippines, Thailand, South Korea, and Taiwan benefited from the production of ICT (IMF 2001).

Yet, there is no evidence that other countries, both developed and developing, were able to take advantage of ICT in order to accelerate their rates of growth and productivity. The lack of macroeconomic impact of the use of ICT on developing countries was confirmed by the results of a comprehensive cross-country empirical study on the returns of IT investment in developed and developing countries (Dewan and Kraemer 2000). The study showed that returns on IT investment are 'positive and significant for developed countries, but not statistically significant for developing countries' (as quoted in Kraemer and Dedrick 2001, p. 262). The estimate of IT output elasticity is 0.057 (positive and significant) for developed countries, but statistically indistinguishable from 0 for developing countries. Pohjola (2000) shows that the relative contribution of IT to GDP growth in developing countries between 1980 and 1995 was less than 2 per cent (China, India, Argentina, Chile, Brazil, Thailand, Venezuela) compared to more than 10 per cent in the US, Finland, Canada, Sweden, and UK. No other studies have found any sizeable contribution of ICT to growth in developing countries. There are no studies that would

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2 For similar definitions see Stiroh (2002b), Pohjola (2001) and De Masi (2001).

estimate the impact of the ICT revolution on output growth and productivity in post-communist, transition economies i.e. transforming from a command economy to a market economy.

Hence, this paper makes a first attempt at estimating the contribution of ICT investment to growth and labor productivity in Poland, the largest post-communist economy in Central and Eastern Europe and soon a member of the EU. The study covers the period of 1995-2000. The paper utilizes the extended growth accounting methodology. Data for ICT spending between 1992 and 2001 is obtained from WITSA (2000, 2002), which in turn is provided by International Data Corporation (IDC). All the other data is from the Poland's Central Statistical Office (2002).

The structure of the paper is as follows: Section 2 discusses the methodology of accounting for the overall economic impact of ICT based on the extended growth accounting methodology. Section 3 applies the methodology to measure the contribution of ICT investment to output and labor productivity growth in Poland. It also discusses challenges posed by the availability of data. Section 4 presents results of the study and compares them with those obtained for developed countries. Section 5 concludes the paper.

2. Accounting for the economic impact of ICT

The methodology of measuring the contribution of ICT to growth and productivity is based on original work by Solow (1957) and Jorgenson and Griliches (1968) and later extended by inter alia Oliner and Sichel (2000) and Jorgenson and Stiroh (2000). Since ICT products and services are both outputs from the ICT industries and inputs into ICT-using industries, ICT can impact economic growth through four major channels (Jalava, Pohjola 2002):

(i) production of ICT goods and services, which directly contributes to the aggregate value added generated in an economy;

(ii) increase in productivity of production in ICT sector, which contributes to overall productivity in an economy (TFP);

(iii) use of ICT capital as in input in the production of other goods and services;

(iv) contribution to economy-wide TFP from increase in productivity in non-ICT producing sectors induced by the production and use of ICT (spillover effects);

To measure the overall impact of ICT on growth, it is best to express the aggregate production function in the following form:

$$Y_t = Y(Y_t^{ICT}, Y_t^0) = A_t F(C_t, K_t, L_t) \tag{1}$$

where, at any given time *t*, aggregate value added *Y* is assumed to consist of ICT goods and services ICT – $Y^{ICT}{}_{t,}$ as well as of other production $Y^0{}_t$. These outputs are produced from aggregate inputs consisting of ICT capital $C_{t,}$, other (i.e. non-ICT) physical capital $K_{t,}$, and labor L_t. TFP (total factor productivity) is here represented in the Hicks neutral or output augmenting form by parameter A.

Assuming that constant returns to scale prevail in production and that all production factors are paid their marginal products, equation (1) can be expressed in the following form:

$$\hat{Y} = w_{ICT}\hat{Y}^{ICT} + w_0\hat{Y}^0 = v_{ICT}\hat{C}_t + v_0\hat{K}_0 + v_L\hat{L} + \hat{A} \tag{2}$$

where symbol ^ indicates the rate of change and the time index t has been suppressed for the simplicity of exposition. The weights w_{ICT} and w_0 denote the nominal output shares of ICT and non-ICT production, respectively. The weights sum to one similarly as the weights v_{ICT}, v_0, and v_L, which represent the nominal shares of ICT capital, non-ICT capital, and labor, respectively[3]. Denoting the total employment by *H(t)* and labour productivity by *Y(t)/H(t)*, the equation (2) can then be re-arranged to measure the contribution of ICT investment to growth in labour productivity

$$\hat{Y} - \hat{H} = v_{ICT}\,(\hat{C}_t - \hat{H}) + v_0(\hat{K}_0 - \hat{H}) + \hat{A} \qquad (3)$$

As shown in the above equation, there are three sources of growth in labor productivity: ICT capital deepening, i.e. increase in ICT capital services per employed person, non-ICT capital deepening, and total factor productivity.[4]
Due to limited scope of the paper, the paper will focus on only one channel through which ICT impacts growth that is through the contribution of ICT capital to output growth.[5]

3. Accounting for contribution of ICT investment to output growth

As on the right hand-side of the equation (2) the contribution of ICT investment to output growth can be defined as a sum of contributions from ICT capital ($\hat{C}_t$), non-ICT capital ($\hat{K}_0$) and labor ($\hat{L}$), where weights v_{ICT}, v_0, and v_L represent the nominal shares of ICT capital, non-ICT capital, and labor, respectively, and sum to one. Total factor productivity (TFP) is represented in the Hicks neutral or output-augmenting form by parameter A. Symbol ^ indicates the rate of change.

$$\hat{Y} = v_{ICT}\,\hat{C}_t + v_0\hat{K}_0 + v_L\hat{L} + \hat{A} \qquad (4)$$

So far the efforts to calculate the impact of ICT investment on growth in transition economies have failed due to the lack of data on:
(i) ICT investment and capital stock,
(ii) ICT income shares in total income.

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3 Please note that this study does not correct TFP for changes in labor quality. Hence, given anecdotal evidence pointing to the increase in quality of human capital, the results produced in this study are likely to overestimate the true increase in TFP in Poland.

4 Again, due to lack of data, the study does not take into account the improvement in labor quality. For the same reason, the study does not measure the ICT contribution to labor productivity through productivity growth in the ICT-producing sector, which impacts TFP. Moreover, any estimates of spillover effects of ICT production and use, which could impact TFP, will not be discussed here.

5 Due to poor availability of data it is quite challenging to estimate the impact of ICT on growth in Poland and other post-communist countries through the remaining three channels - direct contribution of ICT production to GDP (i), an increase in productivity of production in ICT (ii) and spillover effects of the ICT use (iv). At this point it is only possible to make a rough estimate of the contribution of ICT production to output growth in three countries - Czech Republic, Hungary and Slovak Republic – for which the data on ICT-producing sector share in total business sector value added is available from the OECD (2002) for the period of 1995-2000. According to rough estimates of the author based on the above and estimated growth rates of value added in ICT production, its contribution to output growth between 1995-2000 for Hungary (1995-1999), Czech Republic and Slovakia amounted to 1.0, 0.73 and 0.29 percentage points, respectively. For Poland it is estimated that ICT sector produces roughly 1-2% of total GDP. Based on a comparison of the size of the ICT sector in Poland and the other three countries mentioned above, the contribution of ICT production in Poland is likely not to exceed 0.1 of a percentage point of growth. Thus, ICT use rather than production will be the main driver of ICT impact on output growth in Poland.

Yet these shortcomings in data can be overcome. The following two subsections present the specific data problems together with methodologies and assumptions, which were used to arrive at final estimates of ICT capital contribution to growth and labor productivity in Poland between 1995 and 2000.

Accounting for ICT stock

Poland's Central Statistical Office (GUS), as most statistical offices in postsocialist countries, does not provide information about investment in ICT assets[6]. It does not provide hedonic (i.e. constant-quality) price indices for ICT stock and depreciation rates on ICT assets, either. Nonetheless, the lack of data from national statistics on ICT can be mitigated by a use of alternative sources of data and a utilization of a number of assumptions.

ICT investment

The data on ICT spending can be obtained from a private source - WITSA Digital Planet report (2002), which relies on data provided by International Data Corporation (IDC)[7]. WITSA provides consistent information on total spending on hardware, software and communication equipment between 1992 and 2001 in 51 countries representing 98% of the total global spending. The series include data on eight transition economies: Bulgaria, Czech Republic, Hungary, Poland, Romania, Russia, Slovak Republic, and Slovenia.

ICT spending as a share of GDP in Poland and seven other transition countries based on WITSA (2002) between 1993-2001 is displayed in Table 1.

Table 1. ICT spending in eight transition countries 1993-2001, as % of GDP

Country	1993	1994	1995	1996	1997	1998	1999	2000	2001
Bulgaria	2.23	2.88	2.32	2.71	2.97	3.11	3.60	4.12	4.17
Czech Republic	5.56	5.34	5.95	5.80	6.44	6.56	7.85	9.10	8.73
Hungary	4.17	4.32	3.88	4.28	4.46	7.50	8.23	8.93	10.02
Poland	**2.06**	**2.08**	**2.16**	**2.28**	**2.57**	**4.59**	**5.43**	**6.06**	**5.95**
Romania	1.07	1.09	0.93	1.03	1.28	1.39	2.09	2.32	2.41
Russia	4.01	3.18	1.83	1.71	1.97	2.66	4.11	3.52	3.20
Slovakia	4.23	4.18	4.04	4.02	3.89	5.55	6.78	8.12	8.78
Slovenia	3.02	3.03	2.92	3.08	3.39	3.72	4.42	5.26	4.72
Average	4.45	4.45	4.46	4.69	4.98	5.64	6.22	6.81	7.27

Source: WITSA (2002)

The ICT spending in Poland as a ratio of GDP has been steadily increasing since 1993 from 2.06% to 5.95% in 2001. Despite the increase, the ICT spending in Czech Republic, Hungary

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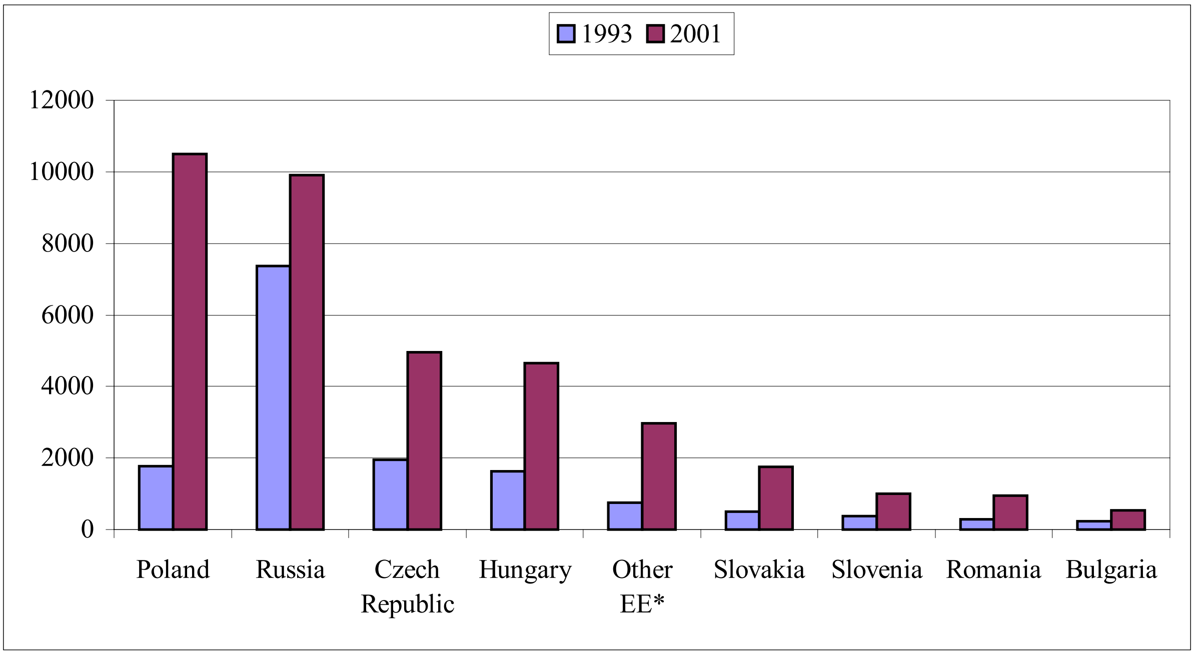
6 It is projected that GUS will produce first estimates of the ICT investment in Poland in the end of 2004. Slovenia is the only postsocialist country so far, which has published actual data for IT investment between 1996 and 2001, and total ICT investment for 2001 (Stare *et al.* 2003).

7 ICT spending by WITSA (2002) includes computer hardware, software, internal services, other office products, and telecommunications equipment and services. No data is provided on embedded ICT in non-ICT products and on ICT expenditure of non-incorporated entreprises. Moreover, WITSA (2002) data definitions of ICT do not exactly conform to those of either OECD or national accounting. WITSA data is also subject to a few measurement biases, yet their combined effects are hard to measure (for more detailed discussion of other WITSA data caveats see Daveri 2002).

and Slovakia in relative terms in 2001 was higher than in Poland. In the whole WITSA sample of 51 countries, which is biased towards developed countries, Poland's average spending on ICT in the period was almost two percentage points lower than the overall average. Nonetheless, the gap has been on a decrease throughout the period: in 2001 the difference in spending narrowed to 1.3 of a percentage point.

In nominal terms, Poland experienced a phenomenal six-fold increase in annual ICT spending from USD 1,772 million in 1993 to USD 10,489 million in 2001. This result puts Poland in the forefront of ICT spending among the transition economies (Figure 1).

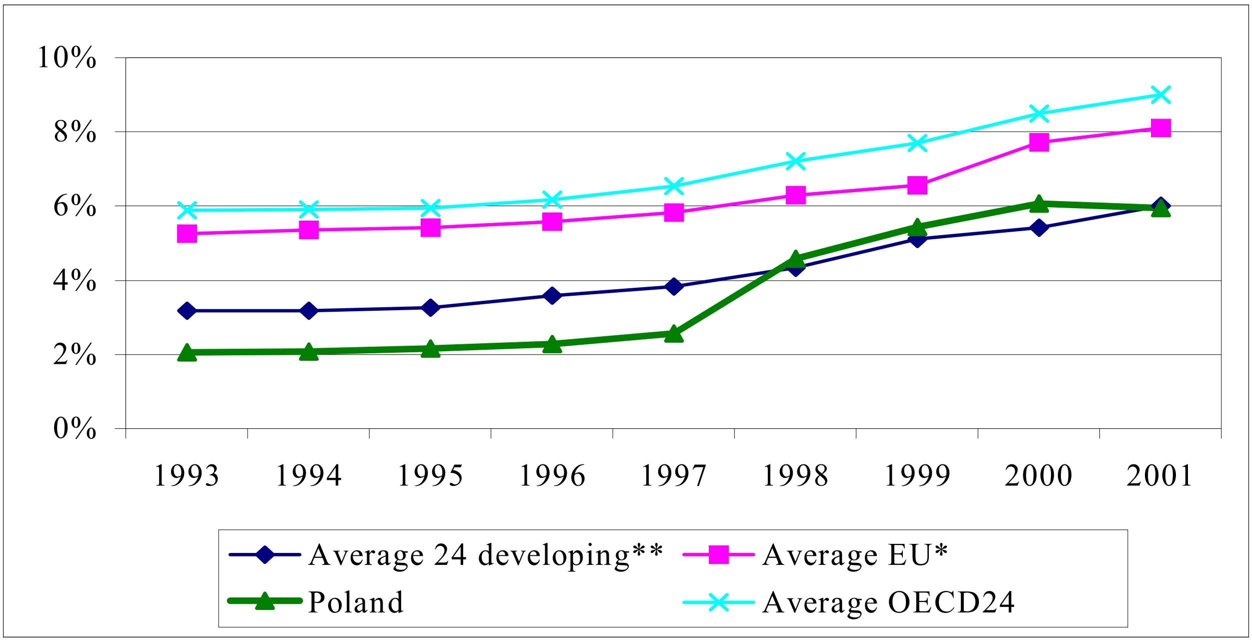
Figure 1. Total ICT spending in transition economies in 1993 and 2001 (USD million)



* Other EE – other Eastern European countries: Albania, Belarus, Bosnia and Herzegovina, Croatia, Estonia, Latvia, Lithuania, Macedonia, Moldova, Ukraine, Serbia and Montenegro.
Source: WITSA (2002)

Trends in ICT spending in Poland should also be displayed against the background of the EU, OECD, and developing countries (Figure 2).

Figure 2: ICT spending in the EU, OECD, developing countries and Poland (as % of GDP)



* Excludes Luxembourg; ** Argentina, Brazil, Chile, China, Colombia, Egypt, Hong Kong, India, Indonesia, Malaysia, Mexico, Philippines, Saudi Arabia, South Africa, Taiwan, Thailand, Turkey, Venezuela, Vietnam. Note: non-weighted arithmetic averages.
Source: WITSA (2002)

Between 1993 and 2001 Poland's relative position in ICT spending has been improving compared to all groups of countries. In 2001 the share of ICT spending in GDP caught up with the average ICT spending in the group of 24 middle and lower income developing countries. The possible explanation for this fast catch-up is the substantial pent-up demand for ICT products and services resulting from substantial underinvestment in ICT infrastructure before 1989[8]. This, together with high rates of economic growth in the 1990's, created opportunities for higher-than-normal returns on ICT investment, which induced firms to spend on ICT.

Dataset from WITSA (2002) on ICT spending does not delineate the expenditure shares of enterprises, government and households. Neither does it divide the spending between investment and services. Since spending by households and spending on services should not be regarded as ICT investment, their share in total spending has to be estimated and deducted from the total.
Schreyer (2000) and Jalava and Pohjola (2002) estimate, based on a comparison between an actual investment data from the US Bureau of Economic Analysis (BEA) and WITSA data on the ICT spending in the US, that the share of telecommunication investment in total spending reported by WITSA equals 30%. Contrary to this approach, although based on the same BEA - WITSA comparison, Daveri (2002) breaks up the whole IDC data into investment shares and household expenditure, applying 59% share of investment in hardware expenditure, 33% for telecommunications spending and 205% for software (Daveri's investment shares are for business sector only – he excludes government spending).

8 For example, Poland's fixed line telephone penetration increased from 12 lines per 100 inhabitants in 1990 to roughly 30 in 2002. Likewise, mobile phone penetration increased from zero in 1990 to approx. 33 as of the end of 2002.

For Poland it was assumed that the share of telecommunication investment in total telecommunication spending amounted to 30% in the 1992-2001 period. The share of investment in IT hardware in total IT hardware spending in the 1992-2001 period, based on actual data from IDC for Poland for 2001 (IDC 2002), was set to amount to 93.0% Under an assumption - based on estimates of the local IDC office - that the data on software spending does not take into account internally developed, custom made software, what BEA calls 'own account software', the value of software investment in Poland was projected to amount to 120% of the software spending reported by WITSA (2002)[9]. The data on 'other office equipment' is aggregated with IT hardware under the assumption that the former fits into the definition of ICT.

Based on the above assumption, the real value of investment in ICT in Poland is much lower than ICT spending reported by WITSA (2002) (see Table 2)

Table 2. Investments in ICT in Poland, 1992-2001 (current prices, USD million)

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
IT hardware	545.0	569.2	646.4	819.3	980.2	1119.7	1330.8	1428.5	1539.2	1650.8
Software	96	104.4	127.2	138	216	274.8	321.6	370.8	536.4	613.2
Telecom. equipment	155.1	176.1	200.1	323.7	360.3	395.1	1315.2	1609.2	1780.5	1937.4
Total ICT	796.1	849.7	973.7	1281.0	1556.5	1789.6	2967.6	3408.5	3856.1	4201.4
Share of ICT in total GFCF (in%)	5.5	6.2	6.6	6.5	6.4	6.5	9.2	10.8	12.4	14.2

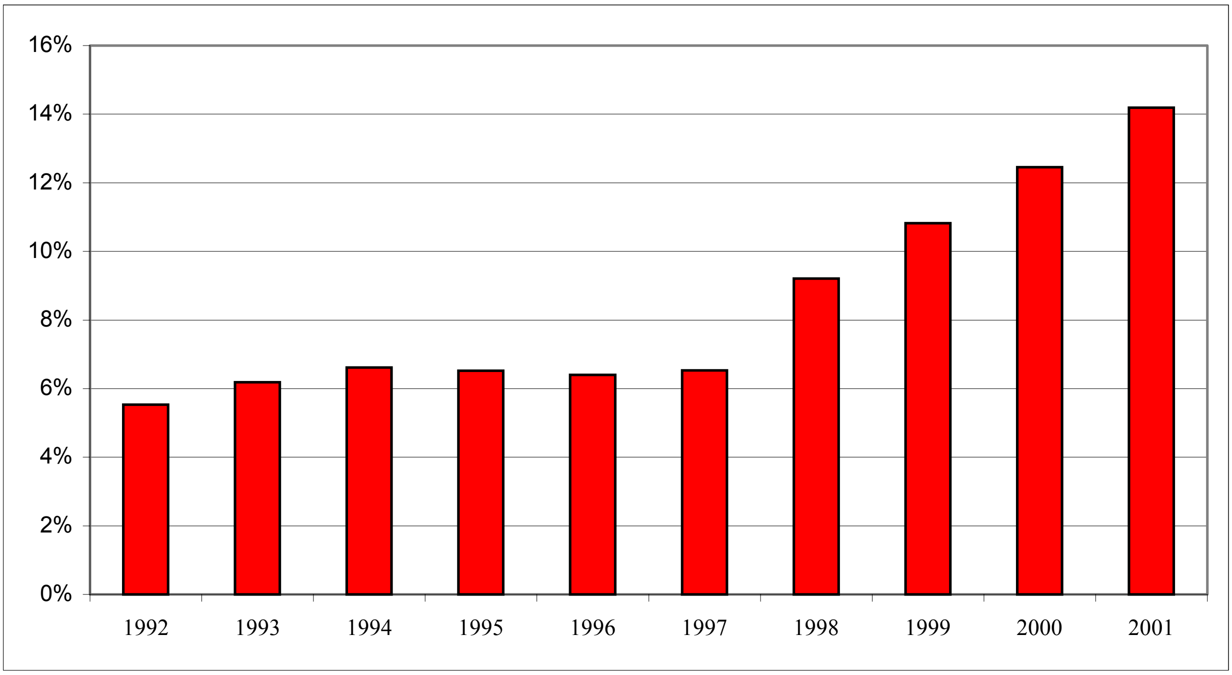
Source: own estimates based on WITSA (2000, 2002)

Share of ICT investments in total GFCF between 1992-96 has been quite stable at roughly 5.5% and 6.6%. After 1996, the ICT share has started to quickly increase and reached 12.4% in 2000 and 14.2% in 2001 (Table 2 and Figure 2). In spite of the significant increase, the ICT share in total GFCF in Poland in 2000 was still substantially lower than in the EU and the US, where it amounted to 17.1% and 29.6%, respectively (van Ark *et al*. 2002)[10].

9 The author's ratio for software of 1.2 is lower than the 2.05 multiplier used by Daveri (2002) in his study on the EU countries and the US. Van Ark *et al*. (2002) study based on actual data from EU national statistical offices found that Daveri's ratio for software investment is likely to be significantly exaggerated.

10 Van Ark et al. (2002) reports total nonresidential GFCF only, excluding non-residential buildings. Since Poland's GFCF includes residential investment, the gap in ICT investment as share of total GFCF between Poland and the EU is even larger.

Figure 3. Percentage share of ICT investment in total GFCF in Poland, in current prices, 1992-2001



Source: own estimates based on WITSA (2000, 2002)

ICT price indices

To arrive at ICT investments in the local currency, the data series were converted from US dollars into local currency by an annual average exchange rate based on EBRD (2002).
Since a dollar today buys much more computing power than in the previous years, the data on ICT investments in current prices needs to be deflated to arrive at constant-quality prices. Otherwise, the use of traditional non-hedonic price indices would significantly understate the significance of investment in ICT as non-hedonic deflators do not take into account the rapid decrease in quality-adjusted prices of ICT (for example, the quality-adjusted price of a computer bought for $1,000 in 1995 amounts to $272 in 2001; the use of non-hedonic price deflator would however value the same computer at $1,068 in 2001 – based on Jorgenson *et al*. 2002 dataset for the US).

Since no quality-adjusted deflators are available from national statistics in transition countries, the paper uses “price index harmonization” methodology developed by Schreyer (2000) and then used by Colecchia and Schreyer (2001), van Ark *et al*. (2002) and others[11]. According to this methodology, the ratio of the US hedonic deflators 1990-2001 for ICT investment in computers, software, and communication equipment relative to deflators for non-computers, non-software and non-communication equipment (all data based on Jorgenson *et al*. 2002, who relies on the the US Bureau of Economic Analysis[12]) was applied to the aggregate investment deflator for

[11] Only US, France, Denmark, Sweden and Canada report quality-adjusted, so-called hedonic prices for ICT equipment. National statistics offices in postsocialist countries do not report ICT separately, as it most often lumped together under “high-technology” products and services. Domestic hedonic price indexes have not been developed yet, either. For discussion of methodology of hedonic pricing, see OECD (2000) and Mulligen (2002).

[12] Jorgenson *et al.* (2002) constant quality price index is based on BEA deflators for the private sector, government and households. Alternative approach is to use BEA deflators for the private sector only available from BEA

Poland for the same period to obtain three separate ICT price harmonized deflators for Poland. This approach is based on an assumption that the ratio of prices of ICT to the overall investment prices in Poland follows the same ratio of prices for the US, which seems to be a plausible assumption given high tradability of ICT products and negligible size of the local ICT production. Hence, the US price level is directly converted into the local currency after being corrected for the general level of inflation. Although undoubtedly the above approach has a number of shortcomings, including the fact that it assumes that there are no differences in composition of ICT investment between Poland and the US and that price indices of ICT products imported to Poland and those domestically produced in the US behave in the same way, the "price index harmonization" method seems to be the most appropriate for constructing the ICT deflators in the face of lack of deflators from the national statistics. The most important thing here is to reflect to the largest possible extent the true decline in ICT prices.

Table 3 in the Appendix shows harmonized ICT price indices for the US and Poland for the period of 1990-2001. The price of computers (IT hardware) in Poland in that period declined by on average 7% annually. Since 1995 the price declines have accelerated to 16.5% annually, which is likely to be due to the increase in the rate of technological progress in capacity of semiconductors (shift from a 3-year to a 2-year production cycle). Unlike in the US, because of relatively high inflation rate in Poland embodied in the total investment deflator, the prices of software and communication equipment have been rising in the period by 13.1% and 11.0% annually, respectively. The inflation in both assets after 1995 has however substantially declined to 6.7% and 3.2% annually, reflecting much slower overall inflation in the total investment price index and relatively faster decline in quality-adjusted prices.

ICT capital stock

To arrive at a measure of the ICT stock, the real ICT investment series obtained above need to be depreciated using perpetual inventory method (PIM). In PIM method, capital stock is defined as a weighted sum of past investments with weights given by the relative efficiencies of capital goods at different ages[13]:

$$K_{i,T} = \sum_{t=0}^{\infty} \partial_{i,t} I_{i,T-t} \qquad (5)$$

with $K_{i,T}$ the capital stock (for a particular asset type i) at time T, $\partial_{i,t}$ the efficiency of a capital good i of age t relative to the efficiency of a new capital good, and $I_{i,T-t}$ the investments in period T-t.[14] A geometric depreciation pattern is applied, which – as argued by Fraumeni (1997) - better reflects the pattern of stock aging (faster at the beginning of the utilization period, slower towards the end of efficient life) than a straight-line depreciation method. Hence, with a given constant rate of depreciation ∂_i different for each asset type, $\partial_{i,t}$ is given by $\partial_{i,t} = (1-\partial_i)^{t-1}$, so that:

(2002). In this paper, Jorgenson *et al* (ibid.) dataset's base year 1996 has been changed to 1995 to be consistent with the data on GDP and fixed capital stock obtained from the national statistical office.

13 This section is largely based on van Ark *et al*. (2002).

14 As remarked by van Ark *et al*. (ibid), various equations of that kind make an implicit assumption that services of assets of various vintages are perfect substitutes for each other.

$$K_{i,T} = \sum_{t=0}^{\infty}(1-\partial_i)^t I_{i,T-t} = K_{i,T-1}(1-\partial_i) + I_{i,T} \quad (6)$$

Because of the lack of data on ICT investments before 1992 and in order to arrive at a sufficiently long series of ICT stock, the investment stock series were extrapolated back to 1985 by applying a geometric average of growth rates in ICT real investment for the three types of assets in local currency between 1992-2001. ICT stock in 1985 was assumed to equal zero[15]. While this is surely an improbable assumption, given high depreciation rates for ICT, most of the early ICT stock from before 1992 depreciates to less than 10 per cent of the value of ICT stock in 1995 and to almost zero by 2000. Nonetheless, to limit the impact of the assumptions on ICT investments, the contribution of ICT investment to growth will cover the period starting from 1995 only.

Alternative method of obtaining sufficiently long series of ICT investment, as reported by van Ark *et al.* (2002), is to derive the ICT investment for the period 1985-93 from a share of ICT investment in aggregate investment in a period for which the relevant data exists. Yet, this approach can be quite misleading since there is no compelling reason to believe that the share of ICT investment in mid-1990's was comparable to that in 1985. It is particularly true in transition economies, which in 1985 were operating under totally different economic system of a command, communist economy.

Van Ark *et al*. (ibid.) in their study apply a commodity flow method to arrive at long series of ICT investment, yet given the lack of detailed data on input-output tables from national statistical offices, its use in measuring ICT investment in postsocialist countries is not possible.

Geometric depreciation rate for IT hardware is based on van Ark e*t al*. (ibid.) and is set at 0.295. Depreciation rates for telecommunications equipment and software, obtained from Jorgenson and Stiroh (2000) and Oulton (2001), were set at 0.115 and 0.315, respectively.

The real investments in ICT in Poland between 1995 and 2000 have been growing at an average annual rate of 50.9% (Table 4), which was a much faster rate than in the EU and the US. Investments in communication equipment were particularly robust in comparison to the EU and the US as they were increasing in the period by 65.7% annually. This is likely to be due to substantial pent up demand for communication services and fast catching up in communication infrastructure from low levels of telephone penetration.

Table 4. Growth rates in real ICT investment in Poland and selected countries, arithmetic average for 1995-2000

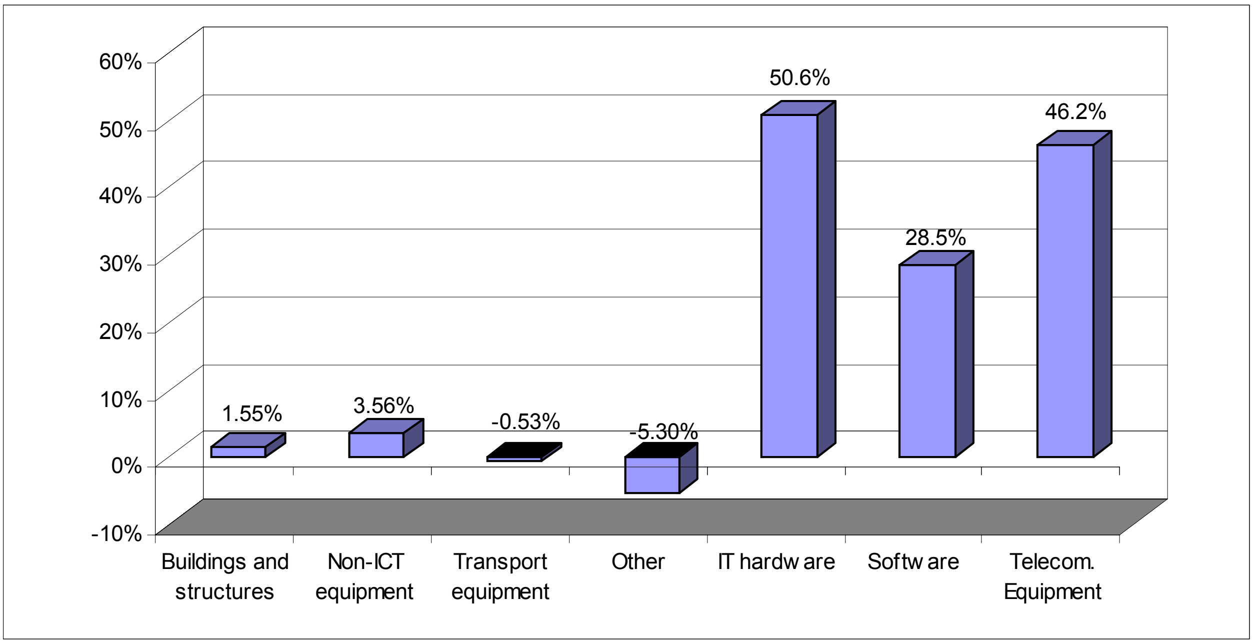
	Poland	EU	USA
IT hardware	52.7%	31.6%	27.0%
Software	32.7%	12.3%	16.0%
Communication equipment	65.7%	11.9%	15.7%
Total ICT	50.9%	18.5%	19.3%

Source: Van Ark *et al.* (2002) for the EU and the US, own estimates for Poland

15 Alternatively, one can assume the value of ICT capital stock to equal zero in 1992. Yet, since some ICT stock surely existed in 1992, it seems methodologically more appropriate to extrapolate the data back to 1985 as the starting point of ICT stock accumulation.

In the end the author arrived at a measure of the end-year real ICT capital stock 1985-2001. These were adjusted from end-year to mid-year. Between 1995 and 2000 on the back of large ICT investments the real stock for three types of ICT assets have been quickly growing, particularly in comparison to other, non-ICT capital (Figure 4)

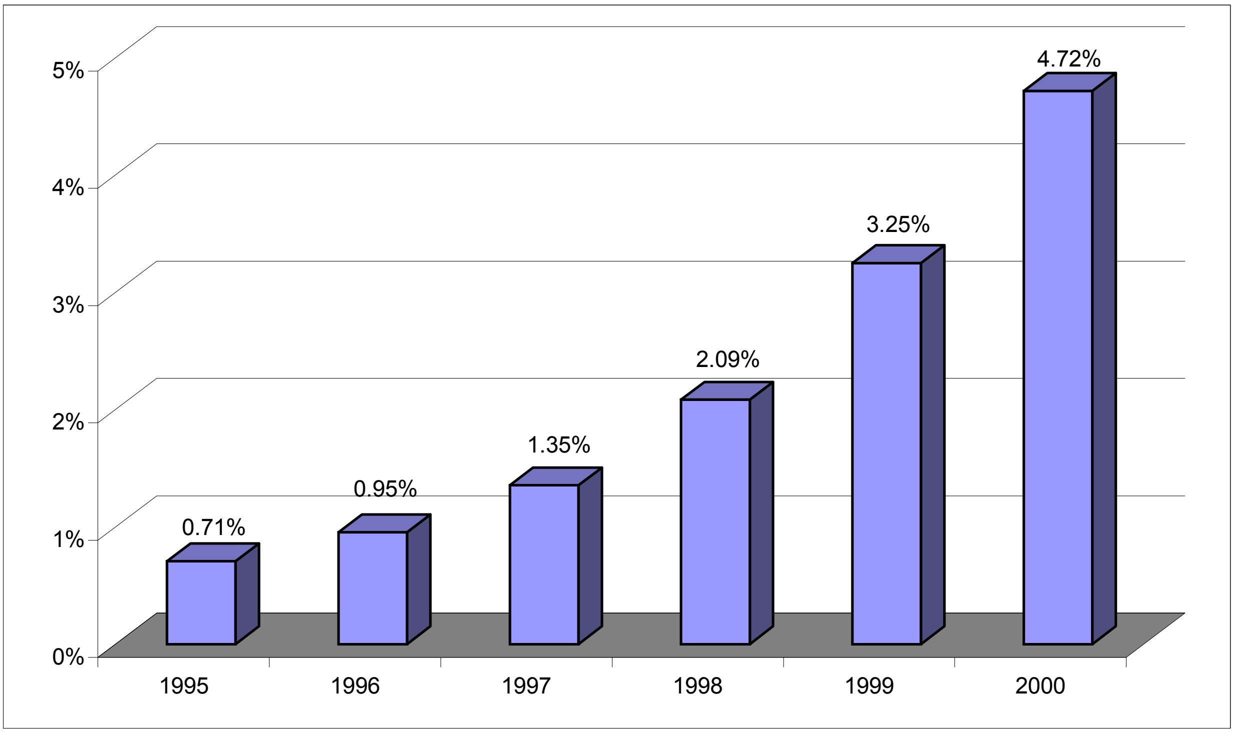
Figure 4. Average annual growth rates in real mid-year ICT and non-ICT capital stock, 1995-2000 (in fixed prices 1995)



Source: own estimates

As a consequence of the rapid growth in real ICT stock, its share in gross total capital stock substantially increased from 0.71% in 1995 to 4.72% in 2000 (Figure 5).

Figure 5: ICT real mid-year capital stock as a percentage of a total gross mid-year capital stock in Poland, 1995-2000 (in fixed prices 1995)



Source: own estimates

Accounting for non-ICT capital stock

In order to sustain consistency, the methodology applied to constructing the ICT capital stock from ICT investments is also applied to construct the non-ICT capital stock for four non-ICT asset types for the years 1995-2000.[16] Data on total investments in total gross fixed capital for all four categories in both fixed and current prices was available from the Central Statistical Office (2002)[17]. Investment deflators for each category of non-ICT assets were constructed on the basis of data available from the above.

Due to unavailability of long-run GFCF series (consistent GFCF series start only from 1990), the non-ICT capital stock was calculated based on 1995 constant prices for four non-ICT categories. Data on investment for years 1995-2000 for all four categories were depreciated using the same PIM method as for the ICT stock (as in equation 6). Since Central Statistical Office does not report geometric depreciation rates for investment flows for the above aggregate categories, the study uses rates based on van Ark *et al*. (2002) (Table 5).[18]

Table 5. Depreciation rates for non-ICT capital

Buildings and structures*	0.028
Non-ICT equipment	0.132
Transport equipment	0.191
Other fixed assets**	0.10

*** Van Ark et al. (ibid) reports rates for "Non-residential buildings and structures" only, while available data aggregates residential and non-residential investment. Assumption is then made that the depreciation rate for both is the same; *As reported by Central Statistical Office: "Long term plantings, detailed meliorations and livestock (basic herd). Depreciation rate based on own estimate. The value of other fixed assets does not exceed 2% of the total stock in the period, so the impact of the estimate is negligible.*

Source: Van Ark *et al*. (2002)

Accounting for ICT income share

Having arrived at the estimates of ICT capital stock, the annual capital service flows from the stocks have to be estimated in order to measure the contribution of ICT capital to ouput growth. Capital service flows, representing the user costs for each type of asset, for ICT capital are much higher than for non-ICT capital due to high rates of depreciation for ICT assets and relatively large capital loss due to fast decrease in ICT prices. In other words, a dollar spent on new ICT equipment should provide higher services flows than alternative investment in non-ICT equipment. The difference between growth in capital services and capital stock represents the

16 The use of actual data from Poland's Central Statistical Office, which is based on a straight-line depreciation pattern, would create inconsistency in methodological approach and result in incomparable results.

17 Investments in "non-ICT equipment" were obtained by deducting current price investments in IT hardware and telecommunication equipment from data series on investment in "machinery, technical equipment and tools". Investments on software were not deducted since they are not part of the national accounts.

18 This is arguably a very rough estimate. Yet, there is no reason why actual depreciation rates in Poland would have to be substantially different than those reported by van Ark et al. Nonetheless, any changes in depreciation rates would have a negligible impact on the final results of the study.

improvement in capital quality, which reflects the substitution towards assets from higher marginal products. Since ICT capital has relatively high marginal product, then a shift towards ICT increases the overall quality of capital. Estimates based on capital stock only rather than on capital services does not take into account this increase in quality of capital and hence underestimates the contribution of ICT capital to output growth (Jorgenson 2001).

Similarly to van Ark *et al*. (2002), the author measures the contribution of ICT capital to output growth on the basis of the services flows from three separate ICT assets (IT hardware, software and telecommunication equipment) and four non-ICT assets (buildings and structures, non-ICT equipment, transport equipment, and other non-ICT capital). Estimation of rental prices for each of the assets provides their weights in total income.

Based on an assumption that the flow of capital services from ICT capital (K^c) and non-ICT capital (K^n) is proportional to the mid-year capital stock (average of $K_{i,T}$ and $K_{i,T-1}$), the capital services for each type of asset will be obtained as

$$CS_i = r_i K_{i,T} / p_y Y \tag{7}$$

where r_i represents user costs of each specific asset, $K_{i,T}$ real capital stock of a specific asset at time T, and p_y the output price. User cost of each specific asset will be denoted as

$$r_i = p_{i,T}(r_T + \partial_i - \pi_{i,T}) \tag{8}$$

where $p_{i,T}$ represents the acquisition price of a new asset, r_T represents the nominal rate of return, ∂_i the depreciation rate of asset type *I*, and $\pi_{i,T}$, the rate of inflation in the price of asset type *I,* which can be calculated from the appropriate price deflators. The expression in the brackets represents the rental price, which measures the price of an asset good at which the investor is indifferent between buying or renting the capital good cost of capital. The rental price represents the cost of capital, which is an annualisation factor that transforms the acquisition price of investment goods into the price of capital input.

As shown in equations (2), (7) and (8) the size of the contribution of ICT capital to output growth will depend on the rate of capital accumulation, gross rate of return, and capital-ouput ratio.

Depreciation rates for each asset type and rate of inflation in the price of each asset are already available. The nominal rate of return on the total stock in the economy has to be however estimated in order to calculate the user costs for each type of asset. The methodology for obtaining the nominal rate of return was developed by Jorgenson *et al*. (1987). The methodology applies an ex-post approach to measure the nominal rate of return based on the following assumptions:

a) there is perfect competition and zero profits in each market sector
b) the nominal rate of return is equal for all assets in a particular market sector
c) the sum of rental payments for all assets is equal to total capital compensation, that is share of capital in total income.

Based on the above assumptions and given that the capital revenue (CR)

$$CR^T = \sum_i p_{i,T} K_{i,T} \quad (9)$$

where p_i represents the rental price of capital services from asset type i and that for each asset type

$$p_{i,T} = r_T + \partial_i - \pi_{i,T} \quad (10)$$

where r_T represents the nominal internal rate of return, ∂_i the depreciation rate and $\pi_{i,T}$ the rate of inflation, the pre-tax nominal rate of return r_T can be obtained by combining (8) and (9)

$$CR^T = r_T \sum_i K_{i,T} + \sum_i (\partial_i - \pi_{i,T}) K_{i,T} \quad (11)$$

and finally solving for r_T [19]

$$r_T = \frac{CR^T - \sum_i (\partial_i - \pi_{i,T}) K_{i,T}}{\sum_i K_{i,T}} \quad (12)$$

Poland's average nominal rate of return for 1995-2000 amounted to 0.246. This compares with the EU and the US average of 0.14 and 0.15 for that period (van Ark *et al*. ibid.). In the same study, out of all the EU countries, Ireland had the highest rate of return at 0.38 followed by Portugal, the UK, and Italy, at 0.19, 0.18 and 0.17, respectively[20]. Similar study by Oliner and Sichel (2000) came up with the estimated rate of return on non-residential equipment and structures for the US for 1970-92 of 0.12 on average. High nominal rate of return for Poland is due to large increases in capital revenue relative to capital stock.[21]

Combining nominal rate of return with a depreciation rate for each asset and the rate of inflation in the price of asset type yields a total gross rate of return on asset type. Average gross rate of return for IT hardware, software and telecommunication equipment between 1995-2000 amounted to 69.5%, 48.2%, and 31.1%, respectively.

Having obtained an estimate of the nominal rate of return for 1995-2000 and total user costs for each type of equipment, the income share of ICT capital in total GDP can be estimated (Table 6).

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19 Due to lack of data on tax expenditure, it was not possible to estimate the after tax rate of return. For a methodology of after-tax measurement of rate of return, refer to Jorgenson and Stiroh (2000). In this study, the capital revenu CR was estimated as a capital share in total income in current prices.

20 Van Ark *et al*. (ibid) study is for non-residential capital only, while this study computed the nominal rate of return for the capital stock including residential stock. Exclusion of the residential capital, if suitable data were available, would further increase the rate of return for Poland relative to international comparisons.

21 The sensitivity analysis of the pre-tax nominal rate of return shows that the estimates of the contribution of ICT capital to output growth are quite sensitive to changes in the rate of return: a one tenth of percentage point change in the rate of return alters the contribution of ICT capital to growth by almost exactly the same one tenth of a percentage point. As the nominal rate of return in this study seems to be on a high side (also because the rate is calculated as pre-tax) any other estimates of the rate of return would most likely decrease the impact of ICT capital on growth.

Table 6. Average shares of ICT capital, non-ICT capital and labor compensation in GDP in Poland, EU, and USA, 1995-2000, (in %)

	Poland	EU	USA
IT hardware	0.9	1.0	1.8
Software	0.2	1.0	1.8
Telecom. Equipment	0.4	1.0	1.8
TOTAL ICT	1.50	3.0	5.4
Buildings and structures*	27.1	19.5	15.0
Non-ICT equipment	10.5	8.3	7.8
Transport equipment	4.2	2.8	2.8
Other	0.8	n.a.	n.a.
TOTAL non-ICT	42.6	30.8	25.9
Total capital	44.1	33.8	31.3
Total labor	55.9	66.2	68.7

Source: own estimates for Poland, van Ark *et al*. (ibid) for the UE and the US. * Van Ark *et al*. for non-residential buildings only.

Poland's ICT capital compensation shares are much lower than in the EU and the US. This particularly applies to software and telecommunication equipment, which reflects still low stock of both types of ICT assets.

4. The contribution of ICT investment to output growth and labor productivity in Poland

Given availability of estimates of ICT capital stock and income share of ICT capital in the 1995-2000 period, it is now possible to measure the contribution of ICT investment to GDP growth in that period. All remaining data is obtained from the Poland's Central Statistical Office (2002).[22]

Using the methodology presented in Section 3, the average contribution of ICT capital to economic growth in Poland between 1995-2000 amounted to 0.47 percentage points or 8.9% of average output growth of 5.31% in that period. Table 7 presents the detailed results.

Table 7. Contributions of ICT capital to real output growth in Poland 1995-2000 (in percentage points and in %)

		In percentage points	In %
ICT capital	IT hardware	0.33	6.23
	Software	0.04	0.74
	Telecommunication equipment	0.10	1.94
Total ICT capital		0.47	8.90
Non-ICT capital		0.66	12.40
Labor (employment)		0.26	4.82
TFP		3.67	69.09
Total output growth		5.31	100.00

22 Labor force measured as total employment. No data is available on hours worked.

The above results can be compared with estimates for the contribution of ICT capital to growth in the OECD countries in the same period obtained by van Ark *et al.* (2002), the study largely based on actual data from national statistics, and Daveri (2002), who used the WITSA dataset for ICT spending, the same as in this study (Table 8).

Table 8. Percentage point contribution of ICT capital to real output growth in the EU countries and Poland, 1995-2000

	Van Ark *et al.* 2002	Rank	Daveri 2002*	Rank
USA	0.86	1	1.45	1
Ireland	0.80	2	0.96	3
UK	0.69	3	1.17	2
Netherlands	0.68	4	0.72	6
Denmark	0.61	5	0.65	7
Sweden	0.53	6	0.85	4
Poland	**0.47**	**7**	**0.47**	**8**
Italy	0.41	8	0.35	13
Finland	0.37	9	0.74	5
Germany	0.37	10	0.45	10
Austria	0.36	11	0.43	12
France	0.35	12	0.44	11
Portugal	0.34	13	0.49	8
Spain	0.27	14	0.34	14

* 1996-99 only.
Source: van Ark *et al*. (2002), Daveri (2002) and own estimates for Poland

Poland ranks almost exactly in the middle of the sampled countries: 7th in van Ark's study and 8th in Daveri's study, *ex aequo* with Portugal. Poland's high position relative to its GDP per capita, which for 2000 hovered around 45% of the EU average, owes to extraordinary rates of growth in real ICT investment (50% annually between 1995 and 2000) as profit-maximizing firms in response to rapidly falling prices of ICT have massively substituted investment in ICT capital for non-ICT capital. The additional incentive for large ICT investments seems to have been the opportunity to reap extraordinary rates of return on investments in ICT due to substantial pent-up demand for ICT products and services resulting from low level of penetration of IT and telecommunications infrastructure, a legacy of underinvestment and technological retardation under the communist system.

Relative contribution (in per cent) of ICT capital to output growth in Poland between 1995-2000 amounted to 8.9%. It compared with the EU and the US average of 17% and 20%, respectively (van Ark *et al*. 2002). The low relative contribution of ICT to GDP in Poland results mostly from high GDP growth in that period, which averaged 5.31% annually.

Labor productivity growth in Poland in the second part of the 1990's amounted to a very high average of 5.07% annually. This fast growth was mostly due to substantial increase in TFP (78% of total growth), which have reflected structural changes in the economy, accelerated microeconomic restructuring, changing composition of labor force, and rising quality of human capital. Capital deepening contributed the remaining 22% of the growth (Table 9).

ICT capital had a larger impact on growth in labor productivity (12.7%) than its contribution to economic growth in the period (8.9%). Contribution of ICT capital was also higher than that of the non-ICT equipment.

Table 9. Sources of labor productivity growth in Poland, 1995-2000

	Labor productivity growth	Capital deepening						TFP
		Total capital	Total non-ICT	Total ICT	IT hardware	Software	Telecom. equipment	
1995	6.07	0.63	0.35	0.28	0.22	0.02	0.05	5.40
1996	1.11	-1.45	-0.76	0.31	0.24	0.02	0.05	2.54
1997	7.19	0.94	0.43	0.51	0.38	0.06	0.07	6.22
1998	2.68	0.52	-0.22	0.74	0.44	0.06	0.25	2.13
1999	7.00	3.26	2.20	1.06	0.52	0.07	0.47	3.78
2000	6.37	2.88	1.91	0.97	0.46	0.09	0.42	3.56
Average 1995-2000	**5.07**	**1.13**	**0.48**	**0.65**	**0.38**	**0.05**	**0.22**	**3.94**
In % of LP growth		22.29	9.55	12.74	7.42	1.05	4.27	77.71

Source: own estimates

According to van Ark *et al*. study, ICT capital was responsible for 34% and 28% of labor productivity growth in the USA and the EU in the same period, respectively (LP measured per person hour worked rather than per employed person as in this study). ICT contribution to LP in Poland was substantially smaller owing to much lower ICT income share in total income.

5 Conclusions

This paper makes a first attempt at estimating a contribution of ICT capital to output growth and labor productivity in Poland between 1995-2000 based on an extended growth accounting framework and private-source data on ICT spending from WITSA (2000, 2002). The paper shows that the contribution of investment in IT hardware, software and telecommunication equipment represented some 8.9% of an average GDP growth in the period or 0.47 of a percentage point out of 5.31% average output growth in that period. This result places Poland in the middle of the ranking of the contribution of ICT capital to growth in the EU countries and the US, well above Poland's position based on GDP per capita. ICT capital deepening has also contributed 0.65 of a percentage point or 12.74% of labor productivity growth in the same period.

The relatively large contribution of ICT capital to output growth is based on an extraordinary acceleration in real ICT investments, which were growing between 1995-2000 at an average cumulative rate of 50.9% a year. Consequently, by 2001 Poland has caught up with other middle and lower income countries in terms of ICT spending per GDP. Among transition economies, Poland is fourth in terms of ICT spending as per cent of GDP, but number one in nominal terms of total spending on ICT.

Large investments in ICT seem to have been induced by falling prices of ICT products and services, which enticed companies to substitute ICT for non-ICT capital. Polish companies substantially increased outlays on ICT also in order to satisfy pent-up demand for ICT products

and services. This pent-up demand for ICT resulted in turn from a need to upgrade poor ICT infrastructure, which was a legacy of decapitalization and technological gap existing before 1989. Fast economic growth, which accelerated from 3.8% in 1993 to 6.8% in 1997 and more than 4% in 2000-01, further contributed to an increase in demand for ICT.
One can plausibly assume that given a small size of ICT-producing sector in Poland, which is roughly estimated to have represented some 1% to 2% of GDP in 2002, its impact on ouput growth and productivity would not be significant. For the same reason, the contribution of TFP growth in ICT-producing industry to economy-wide TFP is likely to be marginal. As for the spillover effects of ICT use and production, it is too early to estimate them, yet given small size of the ICT producing sector and relatively low penetration of ICT networks, any potential effects are poised to be negligible. Hence, the overall impact of ICT on output growth seems to be predominantly dependent on ICT capital, whose contribution to GDP growth is presented in this paper.

One can speculate that given continuation of growth in ICT investment above the growth rates for non-ICT capital, as reported by various local data sources, the contribution of ICT capital to growth is likely to gradually increase. Future research, aside from estimating the ICT capital impact on growth in the remaining post-communist economies along the lines presented in this paper, should focus on measuring the contribution of ICT production to output growth and an economy-wide TFP growth in Poland and other post-communist countries.

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Appendix

Table 3. Price indices for ICT stock

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Computers US	2.2002	1.9586	1.6411	1.3717	1.2088	1.00	0.7496	0.5655	0.4073	0.3045	0.2584	0.2046
Non-computers US	0.8918	0.9115	0.9288	0.9419	0.9754	1.00	1.0273	1.0479	1.0528	1.0618	1.0822	1.0981
Investment deflator Poland	0.3063	0.4656	0.5537	0.6636	0.8412	1.00	1.1677	1.3169	1.4248	1.5021	1.5661	1.5600
Computers Poland	**0.7557**	**1.0005**	**0.9785**	**0.9664**	**1.0424**	**1.00**	**0.8520**	**0.7107**	**0.5512**	**0.4308**	**0.3740**	**0.2906**
Software US	1.0861	1.0921	1.0287	1.0258	1.0025	1.00	0.9676	0.9338	0.9046	0.9085	0.9209	0.9351
Non-software US	0.8968	0.9158	0.9325	0.9443	0.9772	1.00	1.0246	1.0423	1.0437	1.0486	1.0665	1.0791
Software Poland	**0.3709**	**0.5552**	**0.6109**	**0.7209**	**0.8629**	**1.00**	**1.1027**	**1.1799**	**1.2350**	**1.3014**	**1.3524**	**1.3518**
Communication equipment US	1.1056	1.0935	1.0799	1.0623	1.0366	1.00	0.9667	0.9437	0.8997	0.8513	0.8067	0.7626
Non-communication US	0.8965	0.9158	0.9320	0.9439	0.9768	1.00	1.0245	1.0419	1.0433	1.0492	1.0682	1.0822
Communication equipment Poland	**0.3777**	**0.5560**	**0.6416**	**0.7469**	**0.8926**	**1.00**	**1.1019**	**1.1928**	**1.2286**	**1.2188**	**1.1827**	**1.0993**

Note: "IT hardware" represents "Computers" in the paper. Similalrly, "Telecommunication equipment" stands for "Communication Equipment".