Innovation and information technology in services

G E O R G L I C H T and D I E T M A R M O C H
Zentrum für Europäische Wirtschaftsforschung, Mannheim (ZEW)
(Centre for European Economic Research)

1. Introduction

Research on the impacts of IT usually starts with the basic assumption that computers enhance productivity.[1] The available evidence is mixed. Brynjolfsson and Hitt (1996), Siegel and Griliches (1992), Greenan and Mairesse (1996) and Lichtenberg (1995) present evidence supporting a positive productivity impact of IT. Landauer (1995) argues the evidence in favour of productivity effects is weak and that existing studies suffer from severe measurement problems.

Yet, information technology has become an important field of corporate investment in all sectors. For example, the German IT market was valued at about 37 billion ECU in 1994 or about 4.5 percent of Germany's GDP. Most of these goods and services are demanded by firms. The fact that companies continue to invest in IT suggests that there must be positive impacts.

In Germany, investment in IT is especially important in the service sector, as it is in other countries too. This observation is supported by the sector-specific absolute amounts of money invested as well as the shares of IT-investment relative to other investment. In the most dynamic service industries, investment in IT is said to be larger than in manufacturing. Looking at the total IT-investment in the economy, service industries are responsible for the largest and ever growing share of total expenditure on IT in the economy. Yet, productivity growth seems to be slower in these service industries. Landauer (1995, p. xii) states that "for the jobs most people do in service enterprises, most computer applications make work only a little more efficient." Some scholars such as Gordon (1996) argue that the structural shift towards service industries is at least partly responsible for our inability to measure positive productivity effects of IT. Quality aspects of technical change are hard to assess, especially in services. Based on new data for Germany we try to show that this is a significant problem for empirical research on the effects of IT.

We use new data to assess the importance of certain problems concerning the measurement of IT productivity effects. This is the first study on this topic using German data. Our data set has the usual deficiencies associated with output

Canadian Journal of Economics Revue canadienne d'Economique, Vol. 32, No. 2
April / avril 1999. Printed in Canada Imprimé au Canada

mismeasurement, input mismeasurement of IT, and the endogeneity of computer capital and other inputs. Nevertheless we are able to offer some interesting stylized facts. Also, we demonstrate that it is important to distinguish between different types of IT investment. Considering the enormous variety of computer equipment ranging from personal computers to mainframe computers, one should not be surprised to find that aggregation of computer capital matters.

We proceed as follows. In section 2 we briefly describe the theoretical background of productivity analysis in the service sector. In section 3 we assess the impact of IT on innovation in services using data from the Mannheim Innovation Panel for the Service Sector (MIP-S). Section 4 analyzes the impact of the structure of IT investment on labour productivity using data from International Data Corporation Deutschland (IDC). We present regression results of a Cobb-Douglas model that allows for the IT-structure. Section 5 summarizes the empirical results from both data sets and draws conclusions.

2. A short survey of the recent empirical literature

The problem of measuring productivity in the service sector has received considerable attention recently (see, for instance, Griliches 1992). Therefore we only provide a brief summary of related literature.

One possible way to analyze these effects is to separate computer-capital from non-computer capital as Brynjolfsson and Hitt (1996) did. They found that computer capital shows a higher rate of return. Constructing a capital stock in computers as they did, however, assumes that the utility derived from an investment only depends on the nominal value. We would expect that there are differences in the productivity impact of various *types* of IT equipment.

There have been other approaches to trying to explain the productivity paradox that have focused on the importance of correct price index series for the inputs and outputs. One possibility is that the productivity paradox is due to the use of deflators that do not truly capture quality changes. During the last decades, the capacity and performance of computer hardware and software have dramatically improved. At the same time, nominal prices have either decreased slightly or just maintained their level. Recent studies on the decline of quality-controlled prices for personal computers (PCs) (e.g. Gordon 1990, Berndt and Griliches 1993, Nelson, Tanguay, and Patterson 1994, and Berndt, Griliches and Rappaport 1995) have found quality-adjusted prices for PCs declined on average by 25-30 percent per year in recent years. The growth of nominal investment in the presence of a decrease in quality-adjusted prices allowed the acquisition of large IT related capital-stocks in many firms. We should expect to find stronger positive impacts of this recent IT investment on productivity in the present, since users now can get the same utility at considerably lower prices.

Moreover, modern IT equipment can be more easily combined with other assets of a firm since computer skills have become more widespread. This has made modern IT-equipment more of a general purpose technology.[2] If this is important, more recent data should show stronger IT-effects than analyses that use data of the eigthies. However, IT-effects of this sort would also reflect complementary assets. Moreover, the compatibility of software and hardware has been increasing since personal computers became the leading IT-technology. This is confirmed by a recent study of Harhoff and Moch (1996). This too suggests that there should be larger IT-productivity gains today than in the past.

3. Impacts of IT in services - some assessments using data on innovation activities in services

3.1 Data on innovation in the service sector

The first part of our empirical analysis draws on the Mannheim Innovation Panel for the Service Sector (MIP-S). These data stem from a mail survey on the innovation behaviour in the service sector carried out in 1995-1996.[3] The first author was responsible for the design and implementation of the survey. Summary statistics for the MIP-S data set are given in appendix 1.

The MIP-S extends the concept of innovation surveys in manufacturing as summarized in OECD's Oslo-Manual (1997) to the service sector. Topics covered in the questionnaire include (1) general information about the firm (size, industry, sales, number of employees, labour costs, exports, strategic management objectives, customers and product characteristics), (2) the human capital of the firm, and (3) investment in new physical assets and in information technologies. Special attention was paid to the innovative activities of firms with questions on R&D personnel, the acquisition of knowledge, co-operative innovation activities, linkages to public R&D institutions, the importance of various new technologies and the impacts of innovation. Firm investments in IT are seen as a by-product of innovation and not a main focus of this survey.

The survey covers all service sector firms with more than four employees contained in the records of CREDITREFORM, Germany's largest credit-rating agency.[4] This source provides data on the number of employees, industry and the addresses of firms. This information was used to stratify the sample by sector and firm size as well as former West-Germany and East-Germany. The MIP-S is restricted to marketed services and, therefore, only includes firms from wholesale and retail trade, transport, traffic, banking, insurance, software, technical consultancy, marketing and other business services.

About 2,800 firms participated in this voluntary survey. The overall response rate was about 26%, which is in line with the response rates for other voluntary mail surveys in Germany. The response rate was above average for the firms in the banking sector and for the firms in technological services and software firms (around 30%), and it was below average for the firms in wholesale and retail trade (around 24%). Participation slightly increased with firm size.[5]

Before considering the role of IT in service innovation we examined some basic results on innovation activities in the service sector. In particular, we examined the weighted[6] shares of firms with five or more employees that reported product, process or organizational innovations. *Product innovations* are defined as new or improved services which are offered to customers. *Process innovation* refers to improvements in the 'production process' applied internally in the firm. *Organizational innovation* encompasses significant changes in the organizational structure (for example, changes in the number of hierarchical layers) or in basic organizational patterns (such as in the introduction of total quality management procedures).

Product innovations were found to dominate. However, in many cases innovations cannot be clearly categorized as product or process. This problem is illustrated by the introduction of 24 hour-cash-dispensers. The lengthening of access to banking services can be regarded as a product innovation, although the actual banking product being dispensed through the machine, the transfer of money, remains unaltered. On the other hand, since this service is not rendered through personal contact at the counter but rather by customer self service, this could also be viewed as a process innovation. We refrain from using the self-assessed differentiations for product and process innovations.

Further problems arise from the definition and interpretation of research and development (R&D). What this is for service sector firms is not always compatible with the definition of R&D in official R&D statistics. Nevertheless, we use R&D expenditure as an indicator of a knowledge-intensive input.

3.2 Impact of innovation in services

Our inability to measure productivity changes in services owing to the use of new technologies in service sectors may be due to the fact that, unlike the manufacturing case, innovation in services often is neither represented by new services nor by process improvements which increase output or decrease inputs. *Innovation in service is often more closely connected to the way products are delivered*. For example, technical change is often associated with the number of hours during which a service can be delivered or with improvements in the spatial dimension of the services (e.g. home banking).[7] Measuring innovation outputs by sales shares for new products, as is often done in manufacturing, is not adequate to capture product innovation in services.

As a first step to evaluate the impact of technical change in services, we use a qualitative, multidimensional approach. Firms were asked to rate different dimensions of the impact of innovations on a 5-point scale ranging from 'not at all important' (=1) to 'very important' (=5). These dimensions are given in table 1, which also shows the shares of firms by sector and firm size which evaluate these different dimensions as important (=4) or very important (=5).

Overall, most firms view 'increasing productivity' as important or very important. So, we should expect technical change to be reflected in the traditional (labour) productivity measurement. Other dimensions such as 'increasing

TABLE 1
Dimensions of the impact of technological change in services
Part I: by industry

	Overall	Wholesale Trade	Retail Trade	Transport	Banking Insurance	Financial Services	Software	Consulting	Others
Flexibility in adjusting customer needs	0.77	0.81	0.74	0.77	0.77	0.73	0.75	0.76	0.76
User friendliness	0.53	0.58	0.40	0.55	0.74	0.57	0.67	0.52	0.59
Reliability	0.71	0.80	0.66	0.73	0.62	0.65	0.77	0.65	0.70
Temporal availability	0.72	0.75	0.75	0.64	0.71	0.71	0.86	0.63	0.71
Spatial availability	0.43	0.46	0.45	0.45	0.47	0.40	0.43	0.32	0.42
Delivery speed	0.72	0.82	0.59	0.68	0.81	0.67	0.79	0.73	0.77
Fulfilling standards, regulations	0.34	0.39	0.30	0.48	0.40	0.31	0.08	0.28	0.33
Fulfilling health, ecological, safety regulations	0.16	0.24	0.16	0.12	0.11	0.03	0.09	0.16	0.11
Output level of customers	0.40	0.48	0.34	0.37	0.32	0.38	0.71	0.39	0.33
Well-being of customers	0.35	0.29	0.52	0.26	0.18	0.23	0.18	0.24	0.31
Productivity of customers	0.37	0.57	0.25	0.27	0.20	0.20	0.78	0.37	0.28
Maintenance or recycling properties	0.22	0.34	0.15	0.14	0.05	0.06	0.53	0.29	0.16
Motivation of employees	0.66	0.69	0.68	0.60	0.66	0.72	0.59	0.73	0.64
Productivity	0.77	0.79	0.72	0.71	0.86	0.83	0.76	0.82	0.81

TABLE 1(continued)
Dimensions of the impact of technological change in services
Part II: by firm size

	5-19 employees	20-49 employees	50-249 employees	>=250 employees
Flexibility in adjusting product to customer needs	0.76	0.81	0.78	0.75
User friendliness	0.51	0.55	0.57	0.56
Reliability	0.72	0.73	0.67	0.65
Temporal availability	0.74	0.71	0.68	0.67
Spatial availability	0.45	0.37	0.45	0.44
Delivery speed	0.7	0.77	0.76	0.63
Fulfilling standards, regulations	0.29	0.42	0.47	0.36
Fulfilling health care, ecological, safety regulations	0.12	0.24	0.20	0.28
Output level of customers	0.39	0.42	0.39	0.43
Well-being of customers	0.37	0.27	0.33	0.27
Productivity of customers	0.36	0.41	0.39	0.27
Maintenance, recycling properties	0.23	0.24	0.21	0.17
Motivation of employees	0.68	0.67	0.62	0.65
Productivity	0.77	0.80	0.75	0.79

flexibility', 'increasing availability in the time dimension', 'increasing availability in the space dimension' as well as 'increasing delivery speed' are found to be nearly as important in the judgement of the respondents.

Items reflecting customer benefits such as 'enhancing productivity of customers' or 'well-being of customers' are important for about 40% of the firms. Only a minority view 'regulation aspects' (concerning health care, safety, ecology, etc.) and 'increasing product life-time' (e.g. improving maintenance properties) as important impacts of their innovative activities.

Moreover, it can be seen from table 1 that inter-industry differences seem to be more important than firm size differences. For instance, the majority of firms in the software industry expect their innovative activities to have huge productivity impacts on their customers which will also strengthen the customers' ability to increase their output. This kind of effect is not evident from the firm size distribution. Moreover, if this is the case, the productivity effect of innovations in the software industry should be expected not within the software industry but rather in their downstream industries.

We consider four dimensions of innovation based on a factor analysis of the qualitative assessments reported in table 2. These are: (1) innovations that enhance the quality and the scope of service sector products by increasing delivery speed or the temporal or spatial availability of a service, (2) innovations that increase the productivity of the customers of service firms, (3) technical changes that induce productivity changes within service firms, and (4) innovations that are made to fulfill regulations or standards.

TABLE 2
Factor analysis of various dimensions of impacts of technical change in services

			Factor loadings (varimax-rotation)			
Variable	Mean	Std. Dev.	Factor 1	Factor 2	Factor 3	Factor 4
Flexibility in adjusting product to customer needs	4.07	1.02	***0.3745***	0.2525	0.2459	0.0071
User friendliness	3.51	1.29	***0.3795***	0.2412	0.1681	0.1875
Reliability	3.80	1.16	***0.5449***	0.2004	0.2113	0.2194
Temporal availability	3.78	1.21	***0.6935***	0.0795	0.2049	0.2194
Spatial availability	3.00	1.44	*0.5612*	0.1622	0.1284	0.1823
Delivery speed	3.92	1.13	***0.5057***	0.2017	0.2739	-0.0462
Fulfilling standards, regulations	2.85	1.43	0.2792	0.1709	0.1215	***0.4869***
Fulfilling health, ecological or safety regulations	2.03	1.25	0.068	0.2228	0.1094	***0.5319***
Output level of customers	2.97	1.40	0.1451	***0.6675***	0.1244	0.1547
Well-being of customers	2.44	1.42	0.099	0.2116	0.2743	***0.3204***
Productivity of customers	2.70	1.45	0.1499	***0.6804***	0.0988	0.0993
Maintenance, recycling properties	2.09	1.39	0.1253	0.3027	0.0788	***0.3501***
Motivation of employees	3.73	1.02	0.1845	0.0942	***0.7169***	0.1294
Productivity	4.04	0.94	0.1775	0.0990	***0.7088***	0.0184
Eigenvalue			3.6699	0.8526	0.6073	0.4330
Scale Reliability: Cronbach's Alpha	0.823					
Number of firms:	1869					

NOTE: The largest factor loading of each row is bold and italics.

Each of the four components covers a different aspect of service innovation and entails different measurement problems with respect to traditional approaches to measuring productivity enhancing technical change in services. For instance, if IT-use enables a firm (and the firm's competitors) to run a 24-hour-service, the volume of sales and its cost of production might be unchanged but customer choice would be expended. Traditional productivity measurement would not reflect these sorts of impacts. Measurement problems may also arise with the elements of dimension (2) which reflect increases in service that enhance the productivity or output levels of customers. Increased competition in the software market and the steep decline of software prices, which is hardly reflected in price indices, will cause measurement problems for this dimension too. Only dimension (3) is easy to assess. Increased productivity of the service generation process and motivation of employees will immediately affect traditional productivity measurements. Dimension (4) is harder to evaluate since fulfilling new legal standards or work place safety regulations will usually not be reflected in increases in sales or lower factor input requirements.

These arguments imply that relating labour (or total) productivity numbers to factor inputs in services is not likely to fully reflect the effect of technological change in services. Rather, productivity effects of physical capital investment and/or knowledge input uncovered by this kind of analysis will represent a lower bound to the total effects of technological change in services.

3.3 Assessing the impact of innovation inputs on innovation outputs

As shown by MIP-S, IT technologies represent the most important technologies for the overwhelming majority of firms. Nearly all firms that introduced product, process or organizational improvements view IT as a key instrument for innovative activities (see table 3). So, we should expect that the impacts of innovative activities are related to the investment of firms in IT. However, based on the above assessment, it seems reasonable to argue that the missing productivity effect of information technology can be partly explained by 'hidden' output dimensions (see e.g. Griliches 1994).

To assess the hypothesis of unmeasured output generated by IT, we use the qualitative assessment of the impact of innovative activities and relate these output indicators to input factors. Given the way the question is posed in the questionnaire we have interpreted these qualitative assessments as an indicator of a change in output characteristics rather than in the level of output. We relate this change in output to the change in inputs which is given by the investment in physical capital, investment in information technologies, R&D expenditure, and also investment in the capabilities of employees ('training'). We normalize these different types of input by the number of employees and use additional controls for the level of human capital, industry, firm size, and region.[8] Therefore, our empirical model is given by

$$D_i = \alpha_i I + \beta_i IT + \delta_i R\&D + \gamma_i E + \sum_{j=1}^{3} \lambda_{j,i} S + \sum_{j=1}^{7} \kappa_{j,i} Z + \mu_i G + \varepsilon_i$$

where the symbols are defined by:

D_i	i-th dimension of output of innovation activities in 1993-1995
I	investment in non-IT physical capital per employee 1994
IT	investment in information technologies per employee in 1994
R&D	share of R&D employees in total employment in 1994
E	1994, per employee training and professional education expenditures
S	firm size dummies[9]
Z	industry dummies[10]
G	East-German firm.

If most of the output of information technology for service industries is unmeasurable, then we might expect to find only a weak correlation, or no correlation, between the dimension of innovation output which refers to the productivity of a firm and IT-investment.

TABLE 3
Importance of new technologies in services, by industry (percentage shares)

	Wholesale Trade	Retail Trade	Transport	Banking Insurance	Financial Services	Software	Technical Consultancy
Software	84	82	72	96	92	91	93
Computer hardware, etc.	83	85	84	96	96	90	95
High-speed communication networks (ISDN)	36	42	41	61	46	75	46
Media-, publishing and printing technologies	18	22	11	35	22	39	38
Transport technologies, logistics	38	37	80	4	8	7	14
Measurement, control technologies	24	27	10	9	0	16	32
Medical technologies	7	10	2	1	1	8	5
Biotechnology	10	6	2	1	0	1	2
Environmental technologies	31	27	33	5	7	13	37
New materials	28	12	12	1	4	3	21

NOTE: The table gives the percentage shares of innovative firms which state that these technologies are important for their innovative activities. The list of these technologies was given in the questionnaire.

TABLE 4
Relating factor inputs to qualitative assessments of innovation impacts in services: ordered probit regressions*

	Investment (excl. IT) per employee	IT-Investment per employee	R&D-Intensity	Training expenses per employee	No. of firms/ chi2(16) -test
Flexibility in adjusting to customer needs	0.0077	0.0142	0.0034	0.0275	1196
	(5.35)	(2.05)	(0.73)	(1.55)	71.2
User friendliness	0.0032	0.0187	0.0065	0.0133	1186
	(2.50)	(3.00)	(1.48)	(0.84)	73.06
Reliability	0.0027	-0.0002	0.0186	0.0143	1189
	(2.08)	(-0.04)	(3.96)	(0.87)	65.42
Temporal availability	0.0028	0.0197	0.0073	0.0670	1178
	(2.09)	(2.93)	(1.61)	(3.89)	99.91
Spatial availability	0.0080	0.0107	0.0001	0.0544	1190
	(6.01)	(1.67)	(0.03)	(3.37)	101.66
Delivery speed	0.0051	0.0228	0.0065	0.0323	1190
	(3.62)	(3.34)	(1.41)	(1.89)	101.66
Fulfilling standards, regulations	0.0093	0.0102	0.0130	0.0246	1178
	(7.02)	(1.60)	(3.01)	(1.55)	113.25
Fulfilling health, ecological, safety regulations	0.0089	0.0003	0.0110	0.0489	1165
	(6.71)	(0.04)	(2.48)	(2.97)	126.23
Output level of customers	0.0078	0.0015	0.0142	0.0571	1176
	(6.02)	(0.25)	(3.30)	(3.49)	156.99
Well-being of customers	0.0087	-0.0054	0.0000	0.0614	1172
	(6.64)	(-0.85)	(0.00)	(3.75)	107.6
Productivity of customers	0.008	0.0028	0.0165	0.0553	1168
	(6.29)	(0.46)	(3.74)	(3.30)	280.29
Maintenance, recycling properties	0.0037	-0.0155	0.0080	0.0280	1157
	(2.69)	(-2.13)	(1.78)	(1.68)	124.75
Motivation of employees	0.0040	0.0089	0.0164	0.0585	1190
	(2.92)	(1.35)	(3.61)	(3.50)	67.12
Productivity	0.0028	0.0093	0.0147	0.0412	1191
	(2.06)	(1.38)	(3.10)	(2.42)	52.26

* t-values are given in parentheses below the regression coefficients.
NOTE: The model also includes controls for human capital level, industry affiliation, firm size, and region. Results are not reported but are available upon request.

Given the qualitative nature of the output dimension (5-point Likert-scale), we use ordered probit models. The results are reported in table 4 where each row represents an ordered probit regression.[11]

The results of our exercise are quite robust with respect to the inclusion of additional variables. In particular, we included variables for export shares, ownership and more disaggregated industry classifications. Adding these variables left our basic conclusions unchanged.

In summary, we found significant effects of IT-investment on flexibility in adjusting products to customer needs, user-friendliness of the products, and the temporal availability of services and delivery speed, but only a weak impact of IT-investments per employee on the productivity of the firm. We even found a negative correlation between the maintenance or recycling properties and the intensity of IT-investment. Thus, we conclude that the effects of IT-investment on innovation in services are reflected mainly in product quality improvements.

On the other hand, non-IT physical investment (calculated as total investment minus IT-investment) bears a significantly positive sign when compared to the dimensions of innovation output. Strong associations are found for enhancing the flexibility in adjusting products to customer needs, fulfilling legal standards and regulation, and with respect to the productivity of customers.

Moreover, R&D efforts are relevant to several features of service innovations.[12] R&D enhances the productivity of firms as well as the customers. R&D is associated with unmeasureable components like reliability and the ability to fulfill regulatory requirements. Likewise, expenditures of firms on human capital enhance productivity and the quality of services. We further test the validity of these results by considering potential complementarities between the factor inputs and by taking into account unmeasured input dimensions which could lead to correlations between the error terms in the regression models for different output dimensions. We review these results below.

If there are complementarities between IT-investment on the one hand and non-IT-investment, R&D intensity or human capital intensity on the other hand, our model specification will fail to uncover these effects. To account for this possibility, we also ran regressions with additional interaction terms for IT-investment and the other forms of investment. Indeed, we find especially strong associations between one of these interaction terms (IT-investment * non-IT-physical investment) and the productivity impact of service innovation. There are also associations, though weaker, with respect to customer’s productivity, and to the temporal and spatial availability of service innovations. However, we failed to uncover complementarities between investment in human capital (measured by expenditures on training) and IT-investment.[13] These results highlight another measurement problem: our ability to measure the productivity effects of IT is also affected by the degree of complementarity between physical non-IT-investment and IT-investment. Hence some productivity effects of IT are probably reflected in the measured effects of non-IT-investment.

To summarize the results so far, we should keep in mind that IT-investment seems to often be associated with quality aspects of service innovations. Therefore, there is the danger that labour productivity or total factor productivity will not adequately reflect the true impact of IT. This suggests that the productivity paradox with respect to IT investments in the service sector can at least partly be attributed to measurement problems.

4. Productivity effects of information technology

4.1 Data on information technology

The second part of our empirical analysis is based on the German Information Technology Survey. This data set contains information on the different kinds of IT capital used by firms. We use only a part of the information that has been provided by International Data Corporation Germany (IDC).[14] About 3800 IT managers or managing directors of establishments from all sectors voluntarily participated in the telephone interviews in January and February 1996.

We use data from the 317 establishments[15] from the manufacturing sector and the 474 establishments from the service sector. We will make extensive use of variables representing the various kinds of computer hardware used. The data distinguish among four different types of computer terminals. There are terminals that are either connected to a mainframe[16] (e.g. IBM 3090) or to a midrange computer (e.g. IBM AS/400). There are also stand-alone UNIX workstations and personal computers that are either IBM-compatible or Apple compatible. We use the number of IT workplaces per employee that existed by the end of 1995 as a proxy for the IT-intensity of a firm. The number of terminals is a better proxy for the real use of IT than aggregations of memory or MIPS[17] installed.

The data set also contains the number of employees and sales figures. These were used to calculate labour productivity. However the original dataset did not contain information on capital stock and the materials used. We constructed firm specific values of these variables using the disaggregated national accounts data on sector specific ratios of capital stock and materials per employee for 1992.[18]

Since the IT-Survey data were collected in telephone interviews, we chose estimation techniques that are robust against outliers.

4.2 Estimating the productivity impact of IT

Our attempt to estimate the productivity impacts of IT starts from a Cobb-Douglas production function linking sales (Y) with labour (L), capital (K) and materials (M)[19]:

$$Y = A * K^{\acute{a}} * L^{\hat{a}} * M^{\tilde{a}}.$$

We impose constant returns to scale by setting ($\acute{a} + \hat{a} + \tilde{a} = 1$).[20] If the aggregation of IT capital does not distinguish between different types, the IT capital variable may not reflect the ‘true value’ of IT. Our model allows for the possibility of different productivity impacts for different types of IT.

In principle, IT investments affect the marginal productivity of all factor inputs. Moreover, expenditures related to IT are ‘hidden’ in all factor inputs. The book values of IT are included in K, the capital stock variable. The IT expenses on software and services and the leasing rates are included in M. Labour input comprises workers who are and are not able to use computers. Recent empirical work by Autor et al. (1996) points to higher wages for workers who can use computers as well as shifts in the skill structure of labour towards more computer skills. Despite these considerations, data limitations force us to follow the common practice of distinguishing IT capital and non-IT capital and neglecting IT shares in the other factors. This may lead to an overestimation of the marginal productivity of IT capital, since all differences between IT users and non-users show up in our empirical model via the capital stock.

There may also be other problems with the capital stock. First of all, it is difficult to assess the IT used by companies. If we take the book value of computers owned, we face a bias arising from different ownership concepts. A company may buy or rent a computer. This is especially a problem with mainframe computers. In the first case we would find the value of the computer in the business records and would count this in the capital variable, whereas in the second case the leasing rates would add to the materials variable as intermediate inputs. Second, we expect the choice of IT-products and IT-brands to have a strong influence on the price and thus on the capital stock figures whereas we expect the productivity of an employee to be independent from the brand chosen. Third, technical change is very fast in the IT industry. Therefore the construction of a computer capital fraction of the capital stock requires quality adjusted price indexes which are hard to obtain for different types of IT equipment. Fourth, it is - at least in Germany - not allowed to carry software and IT services as assets,[21] making it hard to track IT capital over time.

The most important problem, however, is that if it is the specific technology used that matters, a disaggregation of production functions by IT-inputs is needed. To deal with some of the problems with the capital stock variable, we also included a variable for IT-equipment: the number of workplaces equipped with access to computing services. We distinguish three types of computing devices. First, there is centralized computing with terminals that usually provide a character based display and that are either connected to a mainframe or to a midrange system. The processing is done centrally in a computing center. Second, there is localized UNIX computing with stand-alone UNIX workstations. These are high powered devices that have proprietary hardware and require administrative services. Third, there are personal computers that are either IBM-compatible or Apple systems that provide local computing power and usually a graphical user interface as well. A wide variety of inexpensive packaged software is available for PCs.

Our empirical model is given by[22]

$$LP = A + \acute{a}K + \tilde{a}M + \ddot{e}_1 TERM + \ddot{e}_2 UNIX + \ddot{e}_3 PC + \sum_{j=1}^{3} v_{j,i} S + \sum_{j=1}^{6} k_{j,i} Z + \varepsilon$$

where the symbols are:

LP labour productivity[23]
K log of physical capital per employee
M log of materials per employee

TERM log of terminals per employee
UNIX log of standalone UNIX workstations per employee
PC log of PCs per employee
S firm size dummies
Z industry dummies.[24]

In addition to the variables for which coefficient estimates are shown in table 5, all regression models include industry dummies and firm size dummies. The regression models for all firms include some zero-expenditure values. In place of the undefined log-values for those cases, we have substituted the lowest positive expenditure values in our sample and an additional dummy variable has been added that takes the value of one in those cases.

TABLE 5
Labour productivity and IT-equipment: LAD[25] regression estimates

	All Sectors		Service Sector	
log (Labour productivity)	Coef.	t-value	Coef.	t-value
log(Capital)*	0.2208	3.13	0.1780	1.98
log(Material)*	0.2564	2.65	0.3147	2.95
log(Terminals)*	0.1451	3.11	0.0507	0.81
log(UNIX workstations)*	0.0938	1.79	0.0526	0.67
log(PCs and MACs)*	0.3229	11.13	0.3260	8.48
Test Statistics				
Size dummies	F(3,773) =	3.68	F(3,459) =	2.97
Industry dummies	F(7,773) =	36.5	F(4,459) =	52.88
F-test (whole regression)	F(17,773) =	42.27	F(14,459) =	39.04

* Per employee

The proper interpretation of our regression results depends on whether there exists double-counting for IT or not. We will consider two extreme cases: a pessimistic one and an optimistic one. In the pessimistic case there does not exist any double counting. In this case, there is no IT in the capital stock variable K, and the estimated coefficients ë$_i$ must be significantly greater than á to exhibit above average productivity gains for IT against other types of capital. In the optimistic case, there is full double-counting of IT. In this case the ë$_i$ represent the additional productivity of IT compared to the average capital, and it will be sufficient for ë$_i$ to be significantly greater than zero for there to be above average productivity gains for IT.

Strikingly, in both regressions PC equipment shows very large impacts on labour productivity whereas the effect of other IT-equipment is low or zero. Looking only at service sector results, we do not find any significant impacts of terminals and UNIX workstations. So, from the optimistic point of view, we can confirm positive impacts in the service sector for only the PC technology. To explore the pessimistic case, for each type of IT we start with the hypothesis that its impact on productivity is the same as the average impact of capital. This hypothesis can be tested for each type of IT by an F-test. For mainframes, $F(1,459)=1.36$ is insignificant. We find, moreover, that the productivity impacts of mainframes are lower than for other capital. For PCs the hypothesis is also rejected, with $F(1,459)=2.15$. The results for the all sectors case point in the same direction with insignificant $F(1,773)$ values of 1.72, 2.08 and 0.83 for PCs, UNIX and terminals, respectively.

One might argue that PC investment may be so large because firms do not recognize the real cost of a PC. Usually, the establishments do not take account of the opportunity costs of time spent by their workforce maintaining their PCs. If this interpretation is true, our estimation results capture not only a PC effect but also the effect of the complementary know-how of employees.

Mainframe environments are complex systems that require big staff and long-term projects. Hence, they exhibit a very conservative influence on the development of organizations. In a world where markets and product cycles are speeding up, they do not allow their users to quickly adapt to different conditions. In contrast PC-users can react very fast to information needs. For example spreadsheets and databases allow user defined data aggregations which, in a mainframe environment, would require either tedious programming or the printing and manual processing of long lists.

Another important explanation of why the influence of PCs is so large is provided by the theory of general purpose technologies (GPT).[26] According to this approach, the knowledge embodied in the product enables productivity gains. The PC is thought to represent more of a GPT than the other types of IT equipment do. We find higher correlation of PCs with labour productivity than with any other type of IT equipment.

Finally, network effects are a very important factor in computer related productivity. Standardization processes lead to network externalities and thus to productivity effects. This hypothesis is also supported by Harhoff and Moch (1996) who find significant price premia for packaged PC database software that are positively correlated with the degree of compatibility.

5. Summary and conclusions

This study presents some evidence about the use of IT in the service sector and about the effects of IT on the quality of service sector output as well as on productivity. The MIP-S data indicate that information technology has strong impacts on the quality aspect of service innovations. We find plausible correlations between our qualitative output indicators on the one hand and capital investment, R&D, and human capital on the other hand. Contrary to these results, IT seems to affect some quality aspects of service sector products but not productivity. Although a high percentage of innovating firms claim to have realized productivity gains, managers of service firms seem to be less convinced about the productivity benefits of IT investments. In this respect, our results are consistent with pessimistic views on the productivity effects of IT.

It could be, however, that we do not find significant productivity effects using the MIP-S data because we do not consider the type of equipment. Maybe it is more important what type of IT companies use than how much they invest. This argument is supported by the IT-survey data that exhibits large differences in the correlations between each type of IT and labour productivity.

Surely, automation is expected to bring productivity gains. However, we expect much more utility from obliterating business functions. Firms just started restructuring their IT. Most firms move along traditional lines and continue revamping traditional business functions with IT. This may prohibit the industry from reaping the benefits, or might even have negative effects. As Paul David (1991) argues, the real benefits of electric power became visible after we had learned to replace central power distributed with transmission belts by locally powered devices. Therefore, we should expect that the real impacts of IT on productivity and product quality are still to come.

Notes

This paper was prepared for the conference on Service Sector Productivity that was organized by the Centre for the Study of Living Standards in Ottawa, April 12, 1997. We would like to thank the participants for stimulating discussions. We are also very grateful to Alice Nakamura for numerous suggestions that significantly improved our paper. Of course we are responsible for all remaining errors.

1 See Landauer (1995) for a comprehensive survey of studies of the productivity paradox and a collection of arguments suggesting that IT improves productivity.

2 Blechinger and Pfeiffer (1996) show that computer use in the workplace has increased sharply in the last two decades. In 1979, about 6% of employees in Germany used computers. The share of computer users amounted to 17% in 1985 and to 32% in 1991. The recent increase is mainly due to the diffusion of PCs. Black and Lynch (1996) draw similar conclusions.

3 The MIP-S was commissioned by the federal ministry of science and technology (*BMBF*). Other contributors to this project are the *Fraunhofer Institut für System- und Innovationsforschung (ISI)* and *infas*. The concept of the MIP-S and further results are presented in Licht et al. (1997).

4 This seems to be the best available data source. No official register is available for service sector enterprises. The most recent data from official sources on firm size or industry distribution of service sector firms is for 1987.

5 Another 1,000 firms participated in a short telephone survey of randomly drawn non-respondents which was conducted to reveal potential non-random selection effects depending on innovation activities. Comparing the results from the mail and the telephone survey we conclude that there seems to be only a small response bias in favour of innovative companies. There seems to be a small over-representation of product innovative firms. Firms with process innovations are slightly under-represented (cf. Licht et al. 1997).

6 Throughout the paper we use as weights the product of the inverse of the inclusion probability and the inverse of the response rate.
7 Recent studies on service sector productivity develop physical output measures (e.g. tons of kilometers for transport services) for specific service sector industries (see van Ark 1996 for further references). Mind that meaningful physical input measurement can only be derived for homogeneous output categories. Given the large heterogeneity of services, the development of physical output indicators is only possible for narrowly defined industries. Developing physical output measures for the different sectors was beyond the scope of the MIP-S. The use of the qualitative output assessment in this study should be viewed as a first step towards more refined quantitative measurement of innovation output in services.
8 Additional controls for export status and the introduction of a full set of interaction terms were added as well in preliminary work but were dropped subsequently. The basic conclusions are unaffected by this.
9 We use four different size classes: 1-19, 20-49, 50-249, 250 or more employees.
10 We distinguish 8 different industries in the service sector: wholesale trade, retail trade, transport, banking and insurance, financial services, software, and consulting.
11 To save space we only report the coefficients and t-values for the variables which are used to test our hypothesis. In additon to the results reported, we find significant inter-industry and inter-regional differences. Size class effects play a minor role.
12 Remember that the interpretation of 'R&D' by the responding firms is only partly compatible with the standardized R&D definitions as given in the FRASCATI manual. R&D should be best interpreted here as efforts on near-market product development.
13 When asked for medium term employment expectations by skill level, the respondents reply that they expect larger skill shifts if they invest more in IT. So, complementarities between IT and human capital investment are present in the long-run and with respect to general human capital. Training expenditures that are used here reflect firm-specific human capital investment.
14 We thank the International Data Corporation (IDC) for providing us with the data and helpful information. IDC is conducting market research, analysis and consulting for the information technology industry.
15 This data set provides detailed information about the IT-equipment in use and the IT related expenditures. Unfortunately only about 30% of the companies provide information on their sales. We drop all observations from other sectors and all non-profit organizations. Appendix 2 shows some descriptive statistics on the service sector firms in the IT-survey.
16 Only terminals connected to a mainframe in the establishment were considered.
17 Million Instructions Per Second (MIPS) is a measure for computing power.
18 Using capital stock of the year 1992 ensures that there is less double counting of IT-capital in the capital stock since the IT-equipment is usually replaced after 3-4 years.
19 Brynjolffson also uses a Cobb-Douglas model to estimate the productivity impacts of IT.
20 Note that the coefficients used here are different from those in the previous section.
21 Due to the prudence concept in German law, it is not allowed to show intangible goods in the balance sheet, if they are self-provided.
22 Please note that the data taken from national accounts (i.e. material and capital intensity by sector) correspond to the year 1992.
23 Labour productivity is defined as log (sales per employee). In banking we use the

balance sheet total as output and for insurance companies we use total premia income.

24 Because we have less observations than in the SIAS, we combine the SIAS groups of wholesale trade and resale trade, transport and financial services, software engineering and of consulting. The regression on all sectors includes 3 additional dummies for non-service sector industries.

25 LAD stands for Least Absolute Deviation regression.

26 See Helpman and Trajtenberg (1996).

References

Ark van, Bart (1996) ‘Issues in measurement and international comparison issues of productivity - an overview,’ in *Industry Productivity. International Comparison and Measurement Issues,* ed. OECD, OECD Proceedings (Paris)

Autor, David, and Lawrence F. Katz, and A. B. Krueger (1996) ‘Computing inequality: have computers changed the labor market?’ NBER, Working Paper 5956 (Cambridge, MA)

Berndt, R. Ernst, and Cathrine J. Morrison (1995) ‘High-tech capital formation and economic performance in U.S. manufacturing industries: an exploratory analysis,’ *Journal of Econometrics* 65, 9-43

Berndt, R. Ernst, and Cathrine J. Morrison, and Larry S. Rosenblum (1992) ‘High-tech capital formation and labor composition in U.S. manufacturing industries: an exploratory analysis,’ NBER, Working Paper 4010 (Cambridge, MA)

Berndt, R. Ernst, and Zvi Griliches (1993) ‘Price indexes for microcomputers: an exploratory study,’ in *Price Measurements and their uses*. ed. M. Foss, et al. (Chicago: The University of Chicago Press)

Berndt, R Ernst, and Zvi Griliches and Neal Rappaport (1995) ‘Econometric estimates of price indexes for personal computers in the 1990’s,’ *Journal of Econometrics* 68, 243-68

Black, E. Sandra, and Lisa M. Lynch (1996) ‘How to compete: the impact of workplace practices and information technology on productivity,’ *The American Economic Review* LXXXVI, 263-67

Blechinger, Doris, and Friedhelm Pfeiffer (1996) ‘Technological change and skill obsolescence: the case of German apprenticeship training,’ *ZEW Discussion Paper* 95-16 (Mannheim)

Brynjolfsson, Erik, and Lorin M. Hitt (1996) ‘Computers and productivity growth: firm-level evidence,’ mimeo

Computer Science and Telecommunications Board (1994) ‘Information technology in the service society: a twenty-first century lever,’ *National Academy Press* (Washington, DC)

David, Paul A. (1991) ‘Computer and dynamo: the modern productivity paradox in a not-too-distant mirror in technology and productivity: the challenge for economic policy,’ *OECD* (Paris)

Gault, Fred D. (1996) ‘Service industries in the innovation survey, background paper for the revision of the OSLO-manual,’ *OECD-Document STI/EAS/STP/NESTI (96)* 4 (Paris)

Gordon, Robert J. (1990) *The Measurement of Durable Goods Prices* (Chicago: University of Chicago Press)

)))) (1996) 'Problems in the measurement and performance of service-sector productivity in the United States,' *NBER Working Paper* 5519 (Cambridge, MA)

Greenan, Nathalie, and Jacques Mairesse (1996) 'Computers and productivity in France: some evidence,' *NBER Working Paper* 5836 (Cambridge, MA)

Griliches, Zvi, ed. (1992) *Output Measurement in the Service Sectors* (Chicago: The University of Chicago Press)

)))) (1994) 'Productivity, R&D, and the data constraint,' *American Economic Review* 84, 1-23

)))) (1995) 'Comments on measurement issues in: relating IT expenditures to productivity growth,' *Economic Innovation New Technologies* 3, 317-21

Griliches, Zvi, and Jacques Mairesse (1995) 'Computers and productivity in France: some evidence,' *NBER Working Paper* 5836 (Cambridge, MA)

Harhoff, Dietmar, and Dietmar Moch (1996) 'Price indexes for PC database software and the value of code compatibility,' *Research Policy* 26, 509-20 (Amsterdam: North-Holland)

Harhoff, Dietmar,Georg Licht Harald Stahl, Marian Beise, Johannes Felder and Eric Nerlinger (1996) 'Innovationsaktivitäten kleiner und mittlerer Unternehmen. Ergebnisse des Mannheimer Innovationspanels,' in *ZEW Schriftenreihe Bd.* 8 (Baden-Baden: Nomos)

Helpman, Elhanan, and Manuel Trajtenberg (1996) 'Diffusion of general purpose technologies,' *NBER Working Paper* 5773 (Cambridge, MA)

Höflich-Häberlein, Lisa, and Hubertus Häbler (1989) 'Diffusion neuer Technologien und ihre Auswirkungen im privaten Dienstleistungssektor,' in *Technologischer Wandel und Beschäftigung (Arbeitsmarktwirkungen moderner Technologien, 1)*, eds. R. Schettkat and M. Wagner (Berlin: Gruyter)

Landau, Ralph (1989) 'Technology and capital formation,' in *Technology and Capital Formation*, eds. W. Dale Jorgenson and Ralph Landau (MIT Press)

Landauer, Thomas K. (1995) 'The trouble with computers - usefulness, usability and productivity.' (Cambridge, MA: MIT Press)

Lehr, William and Frank R. Lichtenberg (1996) 'Computer use and productivity growth in federal government agencies 1987 to 1992,' *NBER Working Paper* 5616 (Cambridge, MA)

Licht, Georg, Christiane Hipp, Martin Kukuk, and Gunnar Münt (1997) 'Innovationen im dienstleistungssektor. empirischer befund und wirtschaftspolitische konsequenzen,' in ZEW Schriftenreihe Bd. 24 (Baden-Baden: Nomos)

Lichtenberg, Frank R. (1995) 'The output contributions of computer equipment and personnel: a firm-level analysis,' *Economic Innovation New Technologies* 3, 201-17

Miles, Ian and M. Matthews (1992) 'Information technology and the information economy,' in *Understanding Information Technology* ed. K. Robins (London)

Nelson, A. Randy, Tim L. Tanguay, and Christopher D. Patterson (1994) 'A quality adjusted price-index for personal computers,' *Journal of the American Statistical Association* 12, 12-31

OECD (1996) *Industry Productivity: International Comparison and Measurement Issues* (Paris)

)))) (1997) *Guidelines for Collecting and Interpreting Innovation Survey Data - The OSLO Manual*, second edition (Paris)
Oliner, D Stephen, and Daniel E. Sichel (1994) ‘Computers and output growth revisited: how big is the puzzle?’ *Brookings Papers on Economic Activity* 2
Siegel, Donald, and Zvi Griliches (1992) ‘Purchased services, outsourcing, computers, and productivity in manufacturing,’ in *Output Measurement in the Service Sector*, ed. Z. Griliches (Chicago: The University of Chicago Press)

Appendix 1
Summary statistics for the MIP-S data set

	Raw data		Weighted data*	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
Labour productivity**	1560.915	16440.3700	1420.5110	23799.2200
Investment (excluding IT) per employee**	14.3275	23.2332	16.1106	27.5136
IT-investment per employee**	2.9028	5.1726	2.5304	4.9201
R&D employment per employee [%]	1.5946	6.2944	1.4551	6.3107
Expenditures on professional education per employee**	1.2608	2.7117	0.9906	2.1413
Share of high-qualified employees	0.284		0.2408	
East-Germany	0.3575		0.2593	
(Base: Retail trade)				
Wholesale trade	0.1826		0.2677	
Transport	0.1452		0.1083	
Banking / Insurance	0.0898		0.0046	
Other financial services	0.0428		0.0110	
Software	0.0446		0.0321	
Technical consultancy	0.1023		0.0573	
Other business services	0.3093		0.1977	
(Base category: less than 20 employees)				
20-49 employees	0.2062		0.1515	
50-249 employees	0.2775		0.1318	
250 and more employees	0.1872		0.0242	

* Weights are the product of the inverse of a firm’s inclusion probability and the inverse of the response rate.
** In 1000s of DM.

Appendix 2

Mean values for IT-survey data variables: service sector

	Overall	Wholesale Trade	Retail Trade	Transport	Banking, Insurance	Financial Services	Software	Consulting	Others
log(labour productivity)*	12.428	13.094	12.602	12.428	14.899	12.001	12.214	11.481	12.086
log(capital)*	5.524	4.996	4.656	5.719	5.579	4.712	7.065	6.261	6.011
log(material)*	4.692	6.418	5.390	4.693	4.451	4.092	4.388	4.566	4.156
log(mainframe terminals)*	-0.017	-0.004	0	-0.073	0	-0.064	-0.125	0	-0.004
log(midrange terminals)*	-0.298	-0.249	-0.069	-0.288	-0.432	-0.182	-0.519	-0.148	-0.420
log(UNIX workstations)*	-0.320	-0.243	-0.286	-0.358	-0.509	-0.179	-0.137	-0.692	-0.324
log (PC and MACs)*	-1.410	-1.2647	-1.280	-1.768	-0.810	-1.977	-0.502	-0.505	-1.502
size class 1: 1-19 employees	0.4303	0.4545	0.6578	0.3076	0.2800	0.3265	0.3750	0.5000	0.4000
size class 2: 20-49 employees	0.2362	0.3272	0.2105	0.4102	0.2800	0.2448	0.3750	0.3636	0.1600
size class 3: 50-249 employees	0.2299	0.1636	0.1315	0.2307	0.4000	0.3673	0.2500	0.1363	0.2400
size class 4: >=250 employees	0.1033	0.0545	0	0.0512	0.0400	0.0612	0	0	0.2000
Wholesale/Trade	0.1160								
Retail/Trade	0.1603								
Transport	0.0822								
Banking/Insurance	0.0527								
Financial Services	0.1033								
Software /Consulting	0.0632								
Others	0.4219								

N = 474