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Do ICT spillovers matter

Evidence from Dutch firm-level data

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Abstract

This paper presents an empirical analysis of the contribution of Information Communication and Technology (ICT) to labour productivity growth in the 1990s, using an extensive panel of firm-level data for Dutch market services. We estimate enhanced production function models that include ICT spillovers as well as innovation as a component of TFP (growth). Additionally, we compare the results of this approach with the growth-accounting approach carried out at the firm level. Doing so, we attempt to reconcile the different pieces of empirical evidence regarding the contribution of ICT to productivity growth reported in the literature so far. It is shown that, after accounting for ICT spillovers, the relatively high estimated elasticities of own ICT capital at the firm level are substantially reduced. So, they are more consistent with findings for aggregated levels reported in growth-accounting studies. Nevertheless, the latter studies do not disentangle the causes of TFP-growth into ultimate causes like productivity growth arising from ICT spillovers. Our results underline that the contribution of those spillovers in the years of the ICT boom was probably more substantial than the contribution of ICT capital deepening.

JEL-codes: C33, D21, D24, L80, O30.
Keywords: ICT, TFP, labour productivity, spillovers,

1 Introduction[1]

This paper presents an empirical analysis of the contribution of Information Communication and Technology (ICT) to labour productivity growth in the 1990s, using an extensive panel of firm-level data for Dutch market services.

One of the most impressive 'stylized facts' of the previous decade was the economy wide acceleration of ICT investment. This ICT 'boom' has given rise to many discussions about the potentials of ICT to produce externalities and, more precisely, the role of ICT in the resurgence of (labour) productivity growth in the second half of the 1990s in some OECD countries, most notably in the US.

The debate has been mainly fuelled, amongst others, by the unclear relation between ICT use and Total Factor Productivity (TFP growth).[2] While ICT can affect labour productivity growth via different channels, growth-accounting studies mainly focus on the contribution of ICT capital deepening at the industry level. These studies have documented that ICT investment has contributed to labour productivity growth in the US and EU including the Netherlands (see, e.g. Jorgenson and Stiroh, 2000, Gordon, 2000, Van Ark et al., 2003 and Van der Wiel, 2001a).

After controlling for cyclical effects, Gordon (2000) concludes that returns on computer investment in the US are close to zero outside of durable manufacturing. This leads him to rephrase the famous Solow paradox as follows: 'how could there be such a low payoff to computer investment in most of the (US) economy where computers are located?' Several researchers have put this question to the testing by applying econometric methods to the industry-level data underlying their growth-accounting results. Surprisingly or not, these econometric studies fail to exhibit a positive impact of ICT on TFP growth (see, e.g. Stiroh, 2002, and Van der Wiel, 2001a).[3]

Nonetheless, it is often suggested that much of the acceleration of TFP growth in the second half of the previous decade came from the ICT boom. The econometric evidence based on firm-level data seems to underline the importance of ICT for boosting (labour) productivity growth.

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[2] TFP growth represents the residual output growth once the direct contribution of changes in the inputs (e.g. labour, capital) are accounted for.

[3] Similar inconclusive results for the relation between ICT and productivity were reported for the US by Berndt and Morrison (1995). The failures of econometric methods applied to aggregated data may explain why so many studies resorted to growth-accounting methods for analyzing the impact of ICT on productivity.

In many cases the econometric ICT capital deepening elasticities are much higher than seems to be 'consistent' with the (still) relatively low ICT cost shares. Moreover, evidence seems to support the assumption that the relationship between ICT and TFP is positive. Examples for the US (manufacturing and service) firms are well documented in Brynjolfsson and Hitt (1995) and Brynjolfsson and Hitt (2000). Similar findings are reported recently for other countries (see, e.g. Hempell, 2002, for Germany and Broersma et al., 2002 and Van Leeuwen and Van der Wiel, 2003 for the Netherlands).

Several explanations can be put forward why the output elasticity for ICT exceeds its (measured) input share at the firm level. The estimated output elasticity of ICT is well measured but not the related inputs due neglecting the role of unmeasured complementary investments including adjustment costs. Second, hidden assets play a considerable role in the relationship between ICT and productivity like (complementary) innovations, organisational practices and firm-specific human capital. Finally, also ICT spillovers could induce a wedge between the output elasticity of ICT and its input share.

Based on this brief overview of studies, we conclude that the effect of ICT on TFP growth is ambiguous. It depends on the level of aggregation (i.e. meso versus micro level) and the method (i.e. econometrics versus growth accounting) used as well. Therefore, which part of the recovery of labour productivity growth is channelled through TFP growth and which part is due to 'capital deepening' remains an ongoing debate.

This paper elaborates further on this issue for the Netherlands by placing the contribution of ICT to TFP on the firm level at the centre of interest. It uses both an econometric production function approach and a growth-accounting approach at the firm level. Both approaches are applied to an extensive panel data set of firms constructed with the help of accounting data for firms belonging to Dutch market services covering the period 1993-1999.

Using a production function approach, we analyse to what extent ICT spillovers matter. Similar to the well-known practice followed for the modelling of R&D spillovers (see, e.g. Jacobs et al., 2002), we construct ICT spillover capital stocks at the industry level. Subsequently, we include this (proximate) spillover indicator in an econometric production function model to capture both the impact of technology spillovers as well as a control for simultaneity or omitted variable biases.

The results of the production function approach will be compared to that of the growth accounting method. Likewise, measured TFP is regressed on the same variables as used in the production function model. This second approach is also conducted to have a comparable method at our disposal as those growth accounting studies at the industry level earlier mentioned.

The plan of the paper is as follows. Section 2 discusses the theoretical framework of this paper. Starting with a production function framework, it confronts theoretically two ways of obtaining TFP-measures: via the growth-accounting approach and by estimating a production function. Thereafter, it incorporates ICT technology spillovers and deviations from the perfect-competition case into the analysis. The next section describes the firm-level data used in the analysis. It gives a precise description of the construction of the balanced panel, the construction of data on capital inputs and the linking of innovation data to the balanced panel. Furthermore, it presents some summary statistics for several key variables. In section 4, we address some econometric issues and explain which estimation method is applied in the empirical part in the next section. Section 5 presents the main results of the production function approach and compares these results with that of the growth accounting approach at different levels of aggregation. Finally, section 6 gives a brief summary and sketches the most important conclusions.

2 Theoretical framework

2.1 Decomposition of labour productivity growth

Following the general tradition, we start with a production function framework that relates output to input. The production function is approximated by the Cobb-Douglas specification. In logarithmic form this specification reads:

$$y_{it} = a_{it} + \gamma_1 ict_{it} + \gamma_2 k_{it} + \gamma_3 l_{it}, \tag{1}$$

where y, ict, k and l are the logarithms of respectively real value added (Y), ICT capital (ICT), other capital (K) and labour inputs (L). We use value added as the measure of output as this measure is better comparable across industries than gross output. Subscripts refer to firms (i) and years (t). The variable a_{it} in (1) represents the log level of TFP. After taking first-differences, we can derive the corresponding equation for TFP growth (denoted by $dTFP$) as:

$$dTFP_{it} \equiv da_{it} = dy_{it} - \gamma_1 dict_{it} - \gamma_2 dk_{it} - \gamma_3 dl_{it}. \tag{2}$$

Equation (2) defines $dTFP$ as the growth of output (value added) minus the weighted growth of inputs and uses the production function elasticities as weights. Thus, in essence, TFP-growth is a residual (see box). The elasticities needed to implement TFP growth are not directly available and thus have to be estimated in some way. Below we discuss two alternatives: the growth-accounting decomposition and the (econometric) production function approach.

TFP-growth: a measure of our ignorance

TFP growth in the neoclassical model is assumed to represent exogenous (disembodied) technological change. This assumption disregards that growth-accounting TFP is a catch-all term. Besides exogenous technological change it also covers the contribution of other unspecified inputs, deviations from constant returns to scale and perfect competition and measurement error.

TFP growth in the growth accounting method is a residual of output growth that can not be accounted for by the (quality adjusted) traditional input factors. Here, TFP is a proximate cause for economic growth as the growth accounting method does not shed light on the ultimate causes of TFP growth.

Growth-accounting method

The growth-accounting method solves the problem of unknown elasticities by adopting the following assumptions of the standard neoclassical model:

- firms do not have market power in output and input markets (the case of perfect-competition);
- the technology is characterised by (global) constant returns to scale (CRS);
- technical change is Hicks neutral and disembodied.

After using these assumptions, the first order conditions of profit-maximising behaviour –stating that marginal costs should be equal to marginal revenue product– imply that the unknown elasticities can be set equal to the observable input shares:

$$\gamma_1 \equiv \frac{\partial Y}{\partial ICT}\frac{ICT}{Y} = \frac{w_{ICT}\,ICT}{pY} = s^{ga}_{ICT} \tag{3a}$$

$$\gamma_2 \equiv \frac{\partial Y}{\partial K}\frac{K}{Y} = \frac{w_K\,K}{pY} = s^{ga}_{K} \tag{3b}$$

$$\gamma_3 \equiv \frac{\partial Y}{\partial L}\frac{L}{Y} = \frac{w_L\,L}{pY} = s^{ga}_{L}, \tag{3c}$$

where $\{s^{ga}_{ICT}, s^{ga}_{K}, s^{ga}_{L}\}$ are respectively the cost shares of ICT capital, other capital and labour inputs, $\{w_{ICT}, w_K, w_L\}$ is a vector of factor prices for the corresponding inputs and p represents the exogenously given output price.

After using the assumption that $s^{ga}_{ICT} + s^{ga}_{K} + s^{ga}_{L} = 1$, equation (2) can be rewritten to obtain an equation for the decomposition of output growth into TFP growth and capital deepening components for ICT capital - and conventional capital inputs respectively:

$$dy_{it} = dTFP^{ga}_{it} + s^{ga}_{ICT}\,dict_{it} + s^{ga}_{K}dk_{it} + (1 - s^{ga}_{ICT} - s^{ga}_{K})dl_{it}, \tag{4a}$$

and in which $dTFP^{ga}_{it}$ represents 'measured' TFP growth according to standard growth-accounting.

Notice, that the cost shares used in equations (3a) - (3c) are taken relative to total revenue (i.e. value added) and not to total costs. It can be verified that $dTFP^{ga}_{it}$ in (4a) is consistent with a Divisia type index of TFP change (the ratio of a quantity index for one output over the Divisia input quantity index) only, if all firms are faced with perfect competition on all markets and if the technology of each firms can be described by global constant-returns-to-scale (see Balk, 2000).[4] Under these rather restrictive assumptions the cost shares relative to value added coincide with the shares relative to total costs (*TC*), where total costs are obtained by adding up labour costs and the user costs of ICT and other capital. These assumptions can be made more explicit by expressing the growth-accounting cost shares as follows:

$$s_{ICT}^{ga} = \frac{w_{ICT}\ ICT}{pY} = \frac{TC}{pY}.\frac{w_{ICT}\ ICT}{TC} \equiv \mu s_{ICT}^{c},$$

$$s_{K}^{ga} = \frac{w_K K}{pY} = \frac{TC}{pY}.\frac{w_K K}{TC} \equiv \mu s_{K}^{c},$$

$$s_{L}^{ga} = \frac{w_L\ L}{pY} = \frac{TC}{pY}.\frac{w_L\ L}{TC} = (1 - \mu s_{ICT}^{c} - \mu s_{K}^{c}),$$

where μ represents deviations from perfect-competition and s_i^c denotes the corrected cost shares. In section 2.4 we will discuss the empirical implementation of TFP corrected for deviations from the perfect-competition case in more detail.

Production function method

Another way to obtain the unknown production elasticities of (1) is by interpreting equation (4a) as the functional form of a regression model. Replacing the cost shares with the production function estimates obtained after applying some econometric method, then we obtain the *production function* equivalent of (4a) as:

$$dy_{it} = dTFP_{it}^{e} + \hat{\gamma}_1 dict_{it} + \hat{\gamma}_2 dk_{it} + \hat{\gamma}_3 dl_{it}, \qquad (4b)$$

where $dTFP_{it}^{e}$ now represents 'estimated' TFP growth based on econometric estimation, i.e. the regression residual of (4b). Notice, that (4b) is more flexible than (4a) as it does not impose scale economies and deviations from perfect competition to be absent.

[4] In principle, growth rates of output and inputs are measured by Divisia indices. However, since growth rates cannot be observed continuously, they are approximated with the help of Törnqvist weights:
$\bar{v}_{it}^{j} = [s_{it}^{j} + s_{i,t-1}^{j}]/2$

2.2 A closer look at the growth accounting approach

Equation (4a) is the empirical device that underlies the majority of growth-accounting studies that were triggered by the ICT-boom of the previous decade. Examples are given in Oulton (2001) for the UK, Pilat and Lee (2001) for OECD countries, Van der Wiel (2001a) for the Netherlands and Vijselaar and Albers (2002) for the Euro Area.

From (4a) it is clear that ICT positively contributes to labour productivity growth if the growth rate of ICT capital exceeds the growth rate of labour inputs. Consequently, the conclusion of growth-accounting studies on industry-level data that ICT investments boost labour productivity growth can be well understood as ICT capital (deepening) significantly increased at this level of aggregation in the 1990s.

As ICT is primarily an investment good for firms, firms will substitute ICT for labour or other types of capital *along* a given production function if the prices of ICT become relatively cheaper. And they became cheaper than other inputs in the 1990s. So, more and better ICT per worker has contributed to higher productivity. However, it is argued that falling ICT prices are only one part of the story. ICT also has the potential to generate TFP-growth due to externalities or excess returns. This implies that the production function of ICT-using industries shifts outward. Here, the evidence at the macro and industry level is scarce.

Growth accounting exercises are, however, principally based on the neoclassical model stating that the contribution of ICT to labour productivity is only channelled through capital-deepening. ICT induces 'normal' rate of returns. These exercises leaves no room for a direct assessment of the ICT impact on TFP growth except for the impact of ICT producing industries.[5] To do this in the growth accounting practice requires the use of a two-stage approach, testing that the impact of ICT on TFP can be isolated from capital deepening. Although, several studies at the industry level have done that without conclusive answers, a similar approach here is followed at the firm level by using the measured TFP growth as a dependent variable.

Stiroh (2002) points out that a difference between the estimated ICT output elasticity of (4b) and the ICT cost share of (4a) signals a failure of the neoclassical model to account properly for the distribution of labour productivity growth across the two sources: ICT capital deepening and TFP growth. His argument can be demonstrated by comparing (4a) and (4b). Focussing on ICT capital, this yields:

$$dTFP_{it}^{ga} - dTFP_{it}^{e} = (\hat{\gamma}_2 - s_{ICT})dict_{it} + ...$$

[5] In that respect, in the late 1990s, the contribution of the latter to TFP growth was considerably in many countries including the Netherlands.

This expression shows that a positive 'wedge' between the estimated ICT elasticity and the ICT cost share $(\hat{\gamma}_2 - s_{ICT})$ points to a positive correlation between ICT and ('measured') TFP. Furthermore, such a 'wedge' signals an upward bias of measured TFP growth. Notice, that this interpretation also rests on the assumed unbiasedness of the ICT capital elasticity. Therefore, a more neutral position would be: a 'wedge' between elasticities and cost shares might mirror two things. Firstly, the benefits of ICT for 'boosting' productivity growth show up in a different way than conjectured by capital deepening. Secondly, this 'wedge' might also be the outcome of using inappropriate model specifications or estimation methods.

Stiroh (2002) offers several economic and econometric explanations why (4a) and (4b) are able to reveal some of the apparent 'proximate' causes behind productivity growth, but at the same time (have to) remain silent on other 'ultimate' causes underlying 'true' productivity relationships (e.g. omission of factors like the contribution of ICT related spillovers, innovation and scale economies). Economic explanations focus on externalities (spillovers) in particular and the econometric 'reasons' concern measurement issues, omitted variables, simultaneity or reversed causality.

Contrary to Stiroh (2002), we elaborate on the before mentioned economic and econometric issues more explicitly along two lines. First, we address the specification problem by extending equation (1) in order to capture the impact of ICT spillovers, deviations from the perfect-competition case and the impact of other innovations on productivity (growth). Second, we apply recently developed estimation methods to the modified model in order to obtain a better control for other potential biases concerning its estimation. More details will be discussed in section 4.

2.3 ICT spillovers

The main focus of this paper is whether ICT spillover matter for TFP growth. This subsection discusses its features. There is a lengthy list of literature that emphasizes how ICT enables the creation and use of network externalities and spillovers. ICT externalities imply that social returns on investment can exceed their private returns because the benefits of computer usage increase when ICT is adopted by more users (the direct network effect).

The increased use of ICT facilitates new organisations of production and sales at the firm level as well as economy wide. At the level of individual firms ICT network externalities are expected to show up in non-pecuniary rents or production efficiency gains arising from the streamlining or upgrading of internal business processes (see, e.g. Black and Lynch, 2000 and Bresnahan et al., 2002) or improved business-to-business communications (see, e.g. OECD, 2003). Furthermore, besides being intrinsically an instance of process innovation itself, ICT may also enable innovation in a broader way, by enhancing the creation of new or better applications (the indirect spillover effects).

These typical characteristics of ICT suggest that an increasing use of ICT predominantly invokes a shift in the production frontier (at the firm level as well as at higher levels of aggregation) rather than a movement along the production frontier as conjectured by the neoclassical model (Bartelsman and Hinloopen, 2000). Moreover, following Van Ark (2002), network externalities also 'justify' why the marginal product revenue of ICT capital can exceed the marginal costs of investing in computers.

So, the potential of ICT to produce production externalities or spillovers simultaneously explains:

- why estimated ICT elasticities obtained from regressions on firm-level data can exceed the ICT cost shares used in the growth-accounting practice
- the other side of the (same) coin: the relatively low contribution of ICT capital deepening to the acceleration of labour productivity growth as extensively documented at the industry or macro level in growth-accounting studies.

Furthermore, the fact that the ICT 'boom' was an economy wide phenomenon also explains some of the problems encountered in regression analysis applied to industry-level data. The latter may have something to do with the failure of econometric studies on aggregated time series data to identify or disentangle the ICT impact from the contribution of technological change in the presence of an economy wide supply shock (e.g. world trade).[6]

2.4 Deviations from the perfect-competition case

As we use TFP (growth) based on growth-accounting at the firm level, another feature of this method deserves further attention. In section 2.1 we mentioned the 'perfect-competition case' as one of the basic assumptions underlying the 'growth-accounting' method. Our data consists for a large part of firms belonging to the (business) services sector, thereby representing a very heterogeneous collection of markets that are mostly characterised by a high degree of product differentiation (see also Kox, 2002). This empirical fact makes it hard to justify that all these markets are 'ruled' by perfect competition. It seems more reasonable to relax this assumption at least for the output markets and to allow these markets to deviate from the perfect-competition case.

Griffith (2001) shows that in case of imperfect competition on output markets the usual measures of TFP growth are likely to be 'biassed' and that the direction of the bias depends on

[6] The importance of taking into account the 'trending' behaviour of ICT has been demonstrated recently by O'Mahony and Vecchi (2002). Starting with the application of standard (panel) estimation methods to a panel of industry-level data, they could not find any significant impact of ICT on output growth. However, the application of an Error-Correction model yielded very substantial evidence for the contribution of ICT to output growth.

changes in input ratios. Following Griffith (2001) and Klette (1999), we control for this 'competition bias' by introducing 'mark-ups'. If a firm has to some extent market power in output markets and remains a price taker in input markets, then the perfect-competition price (p) in (3a) - (3c) should be replaced by marginal revenue product (r) given by:

$$r_t = p_t(1 - \frac{1}{\varepsilon_t}),$$

where ε_t is the price elasticity of demand. Perfect competition on output markets corresponds with $\varepsilon \rightarrow -\infty$ or, equivalently, $\mu = 1$. In this paper we allow for deviations from 'perfect competition' on output markets by expressing that the equality of prices and marginal cost is broken down at the market level:

$$\frac{P_t}{MC_t} = \mu_{mt} = (1 - \frac{1}{\varepsilon_{mt}})^{-1}, \text{ with } \mu_{mt} \geq 1 .$$

We define a market (indexed by m) as a group of firms belonging to the same 3-digit level of NACE. In the empirical application we approximate the 'mark-up' over variable cost with the ratio of prices over average total costs. This has been achieved by using the data on output (value added in current prices) and total costs (the sum of labour, ICT and other capital costs). Thus, we use:

$$\mu_{mt} \equiv \frac{P_{mt}Y_{mt}}{TC_{mt}} = \frac{P_{mt}}{AC_{mt}}$$

to obtain a modified set of expressions for the cost shares to be used in the TFP calculations. For input j this modification yields:

$$\hat{s}_{it}^{j} = \mu_{mt}\frac{w_{it}^{j}\, X_{it}^{j}}{p_{it}Y_{it}} > s_{it}^{j}$$

indicating that the 'measured' cost share of input j relative to value added ($\hat{s}_{it}^{j}$) can be considered as a 'disturbed' estimate of the preferred Divisia input weights (s_{it}^{j}). Stated otherwise: TFP as calculated on the basis of unadjusted cost shares does not represent 'true' technological TFP in case of imperfect competition on output markets.

Possible impact of competition on TFP growth

Using $\mu_{mt} > 1$, we can show how a TFP 'competition-bias' emerges if output markets deviate from 'perfect-competition' and if the technology can be described by global constant-returns-to-scale in all inputs. Starting from:

$$TFP_{it}^{ga} = y_{it} - \hat{s}_{it}^{ict} ict_{it} - \hat{s}_{it}^{k} k_{it} - (1 - \hat{s}_{it}^{ict} - \hat{s}_{it}^{k}) l_{it}, \tag{6a}$$

and using $\hat{s}_{it}^{ict} = \mu_{m,t}\, s_{it}^{ict}$ and $\hat{s}_{it}^{k} = \mu_{m,t}\, s_{it}^{k}$, then (6a) can be rewritten as

$$TFP_{it}^{ga} = TFP_{it}^{cga} - (\mu_{m,t} - 1) s_{it}^{k} (k_{it} - l_{it}) - (\mu_{m,t} - 1) s_{it}^{ict} (ict_{it} - l_{it}), \tag{6b}$$

where TFP_{it}^{ga} denotes TFP according to (standard) 'growth-accounting' and TFP_{it}^{cga} represents its equivalent corrected for the possible competition bias. Furthermore, equation (6b) serves as a starting point for assessing the competition bias of measured TFP growth, as the differencing of (6b) yields:

$$dTFP_{it}^{ga} = dTFP_{it}^{cga} - \bar{v}_{it}^{k} (dk_{it} - dl_{it}) - \bar{v}_{it}^{ict} (dict_{it} - dl_{it}), \tag{7a}$$

with Törnqvist weights given by:

$$\bar{v}_{it}^{k} = [(\mu_{m,t} - 1) s_{it}^{k} + (\mu_{m,t-1} - 1) s_{i,t-1}^{k}]/2, \text{ and} \tag{7b}$$

$$\bar{v}_{it}^{ict} = [(\mu_{m,t} - 1) s_{it}^{ict} + (\mu_{m,t-1} - 1) s_{i,t-1}^{ict}]/2. \tag{7c}$$

Equation (7a) shows that the direction of the bias of 'measured' TFP growth is indeterminate in general. However, taking into account the impressive record of ICT investment in the previous decade, it is likely that 'measured' TFP growth underestimated 'true' TFP growth in the period under consideration.

Wrapping and putting the pieces together, ICT spillovers and deviations from perfect competition lead to two opposing effects on measured TFP growth using the growth accounting:

- ICT spillovers could imply an upward bias of measured TFP growth;
- If markets are non-perfect this could result into an underestimated TFP growth.

Which effect is stronger, is up to empirics.

3 Data

3.1 The construction of panel data

In the empirical part of this paper we will use a balanced panel consisting of firm-level data for firms belonging to the Dutch service sector. The panel covers the period 1994-1998 and is constructed after linking the detailed accounting data collected in the yearly Production Surveys of Statistics Netherlands over time.

The accounting data cover – amongst others – the following key variables: gross output, total turnover, employment in full time equivalents (from 1995 onwards) and employed persons[7], intermediate inputs, wage costs (including social security charges), investments, depreciation costs and before-tax profits. The data enable the construction of value added as the measure of output.[8] In order to consider real outputs and inputs in our analyses, we use detailed price indices from the National Accounts to construct value added in constant (1995) prices at lower levels of aggregation.

The panel contains interesting features, but is not completely perfect. Regular issues of sampling, covering, missing variables are at stake. One of the missing variables is that at the level of the firm no prices are available. Likewise, the average size of firms in the balanced panel is considerably higher than actually measured for the total population of firms. The Dutch service sector consists of many small firms and – due to the sampling design – many of them are only occasionally covered in the Production Survey. The sampling probability increases with firm size and firms that have twenty or more persons employed are sampled every year, in principle. Nevertheless these larger firms may also disappear in the course of time because of bankruptcy, merging with other firms etc.

Despite these complications, due to a unique firm identifier one can easily construct panel data linking the yearly surveys over time.

3.2 Construction of capital inputs

Both approaches of section 2 require data on capital stocks. Unfortunately, and common for studies using firm-level data, capital stock data are not readily available and have to be constructed in some way. In this paper, we exploit the interesting feature of the Production

[7] We use persons employed as the measure of labour inputs because this variable is available in all years.

[8] As mentioned in section 2, we could also opt for gross output (or total sales) as the measure of output, but we have chosen not to do so. The reason for this is that many firms belong to wholesale and retail trade. For these branches the data on intermediate inputs consist for a very large part of purchases on trading goods and this make these data incomparable with the intermediate inputs of other branches.

Survey that investment data is collected simultaneously with the (other) accounting data.[9] Thus, we have available a consistent set of investment data at the firm level for those firms that are present in every year. This paper distinguishes two types of capital inputs: ICT and other capital. We used the data to construct real expenditures on ICT - and total investment expenditures at the firm-level. For total investment we used National Account price indices at the industry level and for ICT investment we applied the hedonic ICT price index for Germany calculated by Schreyer (2002) to deflate the nominal investment data. The hedonic deflator is used because it better represents the sharp decrease of ICT prices in the previous decade than the corresponding National Accounts price index for computers.

After this, we constructed capital stocks only if we had available at least five consecutive observations on investment in constant prices. Capital stocks for ICT and total capital inputs (including ICT) were constructed by using the perpetual inventory method and assuming constant geometric depreciation (δ_k) for capital of type *k*. Accordingly, the capital stock K_{kt} of type *k* in period *t* reads:

$$K_{kt} = (1 - \delta_k) K_{k,t-1} + I_{k,t-1}. \tag{9a}$$

Estimates for the unknown initial levels of the stocks of (9a) were obtained by using the approach of Hall and Mairesse (1995):

$$K_{k1} = \frac{I_{k1}}{g_k + \delta_k}, \tag{9b}$$

in which g_k represents the pre-sample growth rate of real investment for type *k*, and I_{k1} is real investment in the base year.

The implementation of (9a) and (9b) requires a number of assumptions concerning the pre-sample growth of investment and their depreciation. Estimates for g_k were taken from industry time series and for the depreciation schedule we used values that are close to the parameters underlying the construction of capital stock at the industry level followed by earlier CPB research (van der Wiel, 2001a). The assumed values for g_k and δ_k are summarised in table 3.1.

[9] If investment data would have been collected in a separate survey, then the linking of the two surveys would reduce the size of the panel substantially as differences in sampling designs or response rates may complicate the matching. Moreover, as it is now based on one single survey, probably the data are more consistent.

Table 3.1 Pre-sample growth of investment (g) and depreciation rates (δ)

	Pre-sample growth Total investment	ICT	Depreciation Total investment	ICT
Wholesale trade	6.0	25.0	6.5	25.0
Retail trade	6.0	27.5	6.5	25.0
Other services	7.5	20.0	6.5	25.0

Another complication concerning the implementation of (9b) refers to I_{kI}. Contrary to the observable patterns for industry-level data, investment behaviour at the firm level is more erratic. Stated otherwise: investments appear to differ markedly between firms over time. Therefore, the initial capital stock estimates may be too dependent on the probability of having invested in the first year. We circumvent this problem by replacing I_{kI} with the average (real) investment observed in 1994-1998, thereby reducing the influence of firm-specific investment cycles. This approach has been followed for total investment expenditure but not for ICT, for reason that the observed rates of ICT investment were less likely to be dominated by cyclical fluctuations in the period under consideration.[10]

Table 3.2 reports some summary statistics concerning the construction of capital inputs for the panel data used in the econometric part of this paper. The balanced panel consists of 7828 services firms for which capital stock data could be constructed and that passed through other data cleansing rules.[11] In terms of output (value added in 1996) the balanced panel represents nearly 45% of all firms in the service sector (see Van Leeuwen and Van der Wiel, 2003a, for more details on the construction of the panel). This relatively low coverage ratio is mainly due to the fact that the smallest firms have low inclusion probabilities and, thus, were not surveyed consecutively. However, their contribution to aggregate capital stocks appears to be smaller. In fact, after using the sample weights to obtain results for the whole population, the (weighted) growth rates for capital inputs are similar to those found at the industry level.[12] The table also shows that, although doubled in a short period, the shares of ICT in total capital stocks were still rather small among industries in 1998.

[10] For some firms the share of ICT investment in the first year appeared to be zero and since the econometric specification is in logarithms this raises an additional problem. Omitting these firms may lead to an overestimation of the ICT contribution to output and productivity growth. For this reason we did not exclude these firms but instead we assumed that actual ICT investment was not zero but rounded to zero by the respondents. Accordingly, we imputed for these cases the minimum of ICT investment observed for the sample.

[11] Besides applying a selection rule concerning the requirement of consecutive investment data, we also applied a data cleansing to reject firms with negative values for their value added. However, we did not apply any censoring or trimming of the data to remove firms with extreme values for value added per employee or productivity growth.

[12] The growth rates presented in table 3.2 are of the same order of magnitude as reported in Van der Wiel (2001a), if one takes into account that the latter study did not use hedonic ICT deflators.

Table 3.2 Summary statistics for ICT and total capital inputs for services

	1994	1998
	%	%
Share of ICT in total capital stock (in prices of 1995)		
Services	1.6	3.3
Wholesale trade	2.6	5.7
Retail trade	0.8	1.7
Business services	1.6	3.4
Other services	0.9	1.0
Growth of capital stocks, 1994-1998[a]		
ICT capital		25.5
Total capital		4.5

[a] Annualised growth for total services calculated on the basis of raised totals.

A related complication of the growth-accounting approach is that cost shares of capital inputs have to be constructed. With two inputs (labour and capital) this is easy as the share of capital inputs is the complement of the share of labour relative to value added. However, with two capital inputs, the allocation of non-labour income to ICT and other capital is less straightforward. The usual procedure is to distribute total capital income (value added minus the wage bill) across the two types of capital proportional to their user costs.

3.3 Approximating ICT spillovers

In spite of the attention given to ICT spillovers in explaining the value of ICT, their explicit modelling is still in its infancy. The reason for this is obvious. It is hard to imagine how ICT spillovers should be modelled taking into account that ICT has no limits by definition.

As discussed, ICT can generate social returns beyond the private returns flowing to the firms using ICT. These spillovers may show up in different ways. Usually one distinguishes between rent spillovers and technology spillovers. Rent spillovers refer to a situation where the volume of inputs related to the use of ICT capital are higher than measured, due to the fact that real prices are lower than actual prices. This definition can be extended to include the use of non-priced inputs related to ICT use. In this view ICT spillovers enter TFP as an instance of measurement error (see Jacobs et al., 2002). Technology spillovers are linked to the effect that ICT can make it easier to spread new knowledge and absorb it. ICT can induce technological and non-technological innovations.

The fact that ICT is a general purpose technology makes it difficult to implement the theoretical construct of ICT spillovers empirically. In this paper, we assume that ICT mainly generates technology spillovers which show up in better organisational practices within and outside of a firm, thereby enhancing the productivity performance of the firm. One can argue that it makes sense to account for the increased use of ICT outside of the firm as this makes the existing ICT capital stock of a firm more productive.

This output-orientation of ICT spillovers fits reasonably well into the 'primal' representation of technology that underlies the production function framework presented in section 2.1. Similar to Mun and Nadiri (2002) and Jacobs et al. (2002), we implement ICT technology spillovers in the model by constructing an indicator for ICT spillover capital. We do so by subtracting a firm's own ICT capital stock from the industry aggregate. Thus approximate ICT spillover capital for firm i belonging to industry I in year t is obtained as:

$$SICT_{it}^{I} = \sum_{j=1,\, j \neq i}^{N(I)} ICT_{jt}. \tag{5}$$

By extending the approaches with this exogenous variable we assume that ICT spillovers affect the location and the structure of the production frontier bounding the relationship between own inputs and output. Therefore, the extended approaches aim at providing a better characterisation of production possibilities than would be the case if spillovers were excluded (see Kumbhakar and Knox Lovel, 2000).

It goes without saying that this measure is only an approximation for the ICT adoption outside of the firm. In that respect, data on inter-industry dependencies are probably more suitable for the analysis of ICT spillovers. One could, however, argue that ICT spillovers predominantly materialise on the firm level. Thus, firm-level data may not be such a bad starting point for assessing their importance.

3.4 Linking innovation data

As differences in innovativeness seem to be a natural candidate for explaining differences in firm performance, we determine which part of the balanced panel was innovative during 1994-1998. This has been achieved by linking the two available waves of the Dutch Community Innovation Survey (CIS) to the balanced panel: CIS 2 covering the period 1994-1996 and CIS 2.5, covering 1996-1998.[13] This innovation panel consists of 1451 firms and includes firms that were covered in both waves of CIS.

The linking of CIS data to the accounting data described above is straightforward in principle, as the innovation surveys and the production surveys use a similar unit of observation and have the same unique identifier. Nevertheless, some shortcomings of CIS complicate an analysis of the links between innovation and firm performance in market services (see Van der Wiel, 2001b). In CIS, small firms are even more under represented and this survey also disregards just started firms. As small and starting firms are considered as an important source of (increasing)

[13] Prior to the third wave of the big and harmonised European CIS (CIS 3) Statistics Netherlands has carried out an intervening survey, called Cis 2.5.

innovativeness, the low coverage of these firms in CIS could underestimate the importance of innovation in market services. Despite these shortcomings, CIS-data remain imperative for assessing the role of innovation in explaining differences in productivity (growth).

3.5 Productivity performance of Dutch market services

Table 3.3 presents some evidence on productivity measures and inputs for both the complete panels. For the complete panel, the table shows that labour productivity growth for Dutch market services was moderate on average, with annualised growth close to 1.5% in 1994-1998.

Table 3.3 Summary statistics for key variables for Dutch market services

	Complete panel (N = 7828)		Innovation panel (N = 1451)	
	mean	stdev	mean	stdev
	%	%	%	%
Growth rate of [a]				
ICT capital	19.8	38.1	29.3	29.2
Other capital	4.3	3.5	4.0	3.2
Employed persons	3.0	12.3	3.3	13.1
Value added per employee	1.5	12.4	2.5	12.3
TFP growth-accounting	0.7	12.0	1.8	12.1
TFP 'corrected' growth-accounting	0.9	12.3	2.1	13.3
Levels				
Employment 1994	93.9	677.7	181.3	656.0
Employment 1998	111.2	821.5	206.6	753.2
Value added per employee 1994 [b]	38.1	67.9	41.4	29.5
Value added per employee 1998 [b]	43.3	69.4	51.3	63.2

[a] Annualised (unweighted) growth rates calculated over the period 1994-1998.
[b] Weighted levels in constant prices (1995) x 1000 Euro.

We also listed statistics for TFP growth based on two growth accounting measures. The first one uses formula (6a) to calculate TFP based on the standard traditional assumption. The second TFP measure uses the same formula, except that the shares are corrected for 'imperfect competition' with the help of the market-specific mark-ups. Thus, we use:

$$TFP_{it}^{cga} = y_{it} - \frac{\hat{s}_{it}^{ict}}{\hat{\mu}_{mt}} ict_{it} - \frac{\hat{s}_{it}^{k}}{\hat{\mu}_{mt}} k_{it} - \left(1 - \frac{\hat{s}_{it}^{ict}}{\hat{\mu}_{mt}} - \frac{\hat{s}_{it}^{k}}{\hat{\mu}_{mt}}\right) l_{it}, \quad (8)$$

to calculate 'corrected' growth-accounting TFP (TFP_{it}^{cga}).

Table 3.3 shows that the contribution of TFP to labour productivity growth varies between 47% and 60% for the two considered measures of TFP based on the complete panel. Furthermore, and in line with the discussion in the previous section, it is shown that TFP growth increases when deviations from 'perfect competition' are taking into account. Nevertheless, the difference between the 'mark-up' corrected measure of TFP growth and the traditionally measured contribution of TFP growth appears not to be very substantial.

Although the difference between the traditional measure of TFP growth and the corrected TFP-growth appears to be not very exiting, the measures of the mark-up are considerably greater than one (see table 3.4). Moreover, the average 'mark-ups' for services as a whole rose from about 1.23 in 1994 to about 1.27 in 1998.

Table 3.4 Mark-up results in market services, 1994 and 1998

	1994	1998
Complete panel	1.228	1.269
Innovation panel	1.238	1.272

If we compare the results between the balanced panel and the innovation panel in table 3.3, the most striking difference is that the latter consists of a collection of firms that had a remarkably better productivity performance in terms of labour productivity and TFP than their counterparts (the firms not covered in CIS). For the innovation panel average labour productivity in 1998 was nearly 20% higher than for the complete panel. Furthermore, labour productivity growth was also substantially higher for the innovation panel than the comparable figure for the complete panel (2,5% versus 1,5%). Notice further, that productivity growth and firm size seem to be correlated as the 'average firm' in the innovation panel is larger than in the complete panel. Furthermore, the better productivity performance of the innovation panel appears to arise mainly from a higher contribution of TFP growth and irrespective of the measure of TFP growth used.[14]

[14] Again, we obtain the result that correcting for a possible competition bias results in a higher TFP growth than in 'standard' growth-accounting.

4 Econometric issues

4.1 Introduction

This section discusses several econometric issues concerning the estimation of both approaches (i.e. the production function approach and the growth accounting approach). Before adding the stochastic assumptions to both approaches, we first have to be more clear about the specification of the TFP component. Therefore, section 4.2 comments on issues such as the spillover indicator, innovation, the initial ICT-intensity and unobserved firm characteristics. Section 4.3 discusses the econometric estimation method.

4.2 Specifying TFP

As mentioned before, our primary interest in this paper concerns the role of ICT production externalities in explaining differences in productivity (growth). Therefore, a first and quite natural step is to 'purify' TFP by using the proximate ICT spillover indicator given by equation (5) of section 2.3.

Although possibly important, ICT externalities may only be one of the many sources of productivity differences between firms. A notorious problem often encountered when estimating production function parameters concerns the role of unobserved firm characteristics. To give an example: one can imagine that firms differ in the skill structure employed as a consequence of ICT usage. If these differences (which typically are positively correlated with size) cannot be taken into account explicitly, then one can expect a correlation between this 'unobservable' and the included explanatory variables. Other examples of unobserved firm characteristics are differences in the (pre-existing) vintage structure of capital inputs or the quality of management.

The usual way to control for these unobserved firm characteristics is to adopt an error component structure. In the empirical application we extend the commonly applied error component model by including additional 'controls' for firm-specific initial conditions that can be implemented which firm-specific observed variables. For each firm we determine its (relative) ICT intensity at the beginning of the period and we use this ICT intensity dummy as a control for the continuous ICT variables that are correlated with initial stocks.[15]

Similarly, we control for an innovation impact on TFP if the model is applied to the innovation panel. We recall that we label a firm 'innovative' if it has applied at least one type of innovation in the period under consideration. Thus, we use an innovation dummy variable to

[15] The ICT intensity dummy variable has been constructed as follows. For each NACE 3-digit we determined the median score of the share of the ICT capital in the total capital stock for 1994. Thereafter we assigned a value of one to the ICT dummy if the firms' score was above the corresponding median value. This firm is labeled as ICT intensive firm. Low ICT-intensive firms are the reference group.

capture the contribution of innovation to TFP. We are forced to the use such a qualitative variable due to the lack of continuous and more informative variables in CIS for market services. A more precise account for innovation is not possible, because the data do not contain information on innovation output for most of the firms that implemented technological innovations. Furthermore, data on innovation costs incurred are not available for the many firms that implemented non-technological innovation only.

Summing up, this leads to the following specification for TFP in (1):

$$a_{it} = \gamma_4 sict^I_{it} + \alpha_i + \sum_{s=1}^{S} \lambda_s D_s t + \beta_1 D_{i,ICT} + \beta_2 D_{i,Inno} + \nu_{it}. \quad (10)$$

In (10) $sict^I_{it}$ is the logarithm of ICT spillover capital and α_i a firm-specific fixed effect that may be freely correlated with all the other variables of the estimating equation. The third term on the right-hand side of (10) represents the contribution of disembodied technical progress, which is assumed to vary between industries. The following common breakdown of market services is used for constructing the industry dummy variables of (10):

- Wholesale trade (reference industry, trade and repair of cars excluded, NACE-code 51);
- Retail trade (trade and repair of cars excluded, NACE-code 52);
- Business services (NACE-code 71-74);
- Wholesale -, retail trade and repair of cars (NACE-code 501-505);
- Other business services (NACE-code 55, 90).

Furthermore, $D_{i,ICT}$ and $D_{i,Inno}$ are dummy variables that are included to capture the contribution of initial conditions concerning a firms' ICT intensity and the contribution of innovation to TFP, and ν_{it} represents the remaining transitory and idiosyncratic differences in productivity.

Putting the pieces together for both approaches, after inserting (10) in (1) for *the production function approach*, it follows that:[16]

$$y_{it} = \gamma_1 ict_{it} + \gamma_2 k_{it} + \gamma_3 l_{it} + \gamma_4 sict^I_{it} + \alpha_i + \sum_{s=1}^{S} \lambda_s D_s t + \beta_1 D_{i,ICT} + \beta_2 D_{i,Inno} + \nu_{it}, \quad (11a)$$

and for the *growth accounting approach*:

$$TFP^{cga}_{it} = \tilde{\gamma}_1 ict_{it} + \tilde{\gamma}_2 k_{it} + \tilde{\gamma}_3 l_{it} + \tilde{\gamma}_4 sict^I_{it} + \tilde{\alpha}_i + \sum_{s=1}^{S} \tilde{\lambda}_s D_s t + \tilde{\beta}_1 D_{i,ICT} + \tilde{\beta}_2 D_{i,Inno} + \tilde{\nu}_{it} \quad (11b)$$

[16] Equation (10) is the most extended specification of TFP and can be applied to the innovation panel only. If we use the complete panel than the innovation dummy variables are not included in the model.

in which TFP_{it}^{cga} is calculated according equation (8).[17]

The estimation of the (enhanced) production function approach (11a) aims at minimising the risk of simultaneity or omitted variables bias for the traditional inputs in order to obtain better estimates for TFP (growth). Estimating specification 11b tests the potential **ultimate sources** using the measured (growth-accounting) TFP.

A similar approach as applied in the growth accounting approach could be followed for the production function approach by using the residual $dTFP_{it}^{e}$ obtained after applying OLS to (4b) as the starting point. However, viewed from an econometric perspective, this route is not preferable if there are reasons to assume that the TFP component of labour productivity growth is related to ICT too. Then, the estimates of (4b) may suffer from an estimation bias. In particular, the latter reason might explain why studies on the firm level obtained higher ICT elasticities than seems to be consistent in view of the (still) relatively low cost shares of ICT.

A comparison of the results of model (11a) with or without ICT spillovers enables us to judge whether the estimates of ICT capital stock elasticities are 'hiding' an ICT impact on TFP (growth).

Finally, estimating (11a) and (11b) as well also provide a benchmark for TFP-regressions carried out in growth-accounting studies at the industry level. These studies show up to be inconclusive with respect to the contribution of ICT to TFP growth (see, e.g. van der Wiel, 2001a, and Stiroh, 2002).

4.3 Estimation methods

In equations (11a) and (11b) we have included firm-specific fixed effects as separate parameters which only vary between firms. These parameters can be eliminated by estimating the models in growth rates. For production function (11a) this yields:

$$\Delta y_{it} = a + \gamma_1 \Delta ict_{it} + \gamma_2 \Delta k_{it} + \gamma_3 \Delta l_{it} + \gamma_4 \Delta sict_{it}^{I} + \sum_{s=1}^{S-1} \lambda_s D_s + \Delta \nu_{it}, \qquad (12a)$$

whereas for the growth accounting approach (11b) we use:

$$\Delta TFP_{it}^{cga} = \tilde{a} + \tilde{\gamma}_1 \Delta ict_{it} + \tilde{\gamma}_2 \Delta k_{it} + \tilde{\gamma}_3 \Delta l_{it} + \tilde{\gamma}_4 \Delta sict_{it}^{I} + \sum_{s=1}^{S-1} \tilde{\lambda}_s D_s + \Delta \tilde{\nu}_{it}. \qquad (12b)$$

However, this transition from the cross-sectional dimension to the time series dimension of the data may not solve all problems. Reversed causality and measurement errors may still cloud

[17] We add a tilde to the parameters of the TFP model in order to make a distinction between the parameters of the production function model and the TFP model.

results. If productivity shocks are anticipated before factor demands are determined, than changes in productivity shocks (Δv_{it}) remain correlated with the right-hand side variables of the equations and this may bias estimates upwards. On the other hand, we have to face the consequences that measurement problems may be exacerbated when estimating the model in first-differences, thereby giving rise to a downward estimation bias which may completely offset the positive 'causality' estimation bias. Indeed, with the data at hand and the method chosen for constructing capital inputs, errors-in-variables are very likely cause of correlations between Δv_{it} and the capital inputs.

The SYS-GMM estimator

The usual way to account for a possible correlation between the error of the models (12a) or (12b) and the explanatory variables is to use the GMM estimator (see for example Mairesse and Hall, 1996). This generalised instrumental-variables estimator uses the following orthogonality conditions [a]

$$E[\Delta v_{it} X_{i,t-s}] = 0 \text{ for } t = 3, \ldots, T \text{ and } 2 \leq s \leq t-1. \tag{13a}$$

These conditions exploit the lagged explanatory variables of the level equation (11a) as instrumental variables after the equation has been differenced to eliminate the unobserved fixed effects.

However, the resulting first-difference estimator often appeared to give unsatisfactory results (see, e.g. Blundell and Bond, 1998a). Typical examples for the production function framework showed that capital elasticities were implausibly low and often insignificant when using GMM estimation. These problems are related to the weak correlation that can exist between growth rates of the inputs and the lagged levels of these variables. For instance, since capital stocks within firms are highly persistent over time, one may expect that the correlation between the current growth rate and lagged level of the capital stock is close to zero (see Hempell, 2002, for an illustration).

Blundell and Bond (1998b) showed that the performance of GMM estimators can be improved considerably by exploiting the so-called SYS-GMM estimator of Arellano and Bover (1995). This estimation strategy uses both the equations in first-differences (e.g. (12a), instrumented with 'levels') and the equations in levels (e.g. (11a), instrumented with 'first differences') simultaneously, thereby imposing cross-equations constraints for the parameters of interest. This is achieved by extending the set of orthogonality conditions with

$$E[v_{it} \Delta X_{i,t-1}] = 0 \text{ for } t = 3, \ldots, T. \tag{13b}$$

and by stacking (13a) and (13b) to obtain a system.

[a] The vector X collects the explanatory variables of equation (11a).

SYS-GMM provides an optimal way to combine the orthogonality conditions (see box and, particularly formula (13a) and (13b)). In the empirical application we will apply this method by using the full set of conditions given by (13a). From (13b) we use the conditions that cover all valid instruments for the level equation pertaining to 1998. Thus, when estimating production function parameters, the system uses equation (12a) for 1996, 1997 and 1998 and equation (11a) for 1998.[18]

[18] Using only the level equation in 1998 is sufficient if the method is applied to balanced panel data (see Arellano and Bover, 1995). In this case $(\Delta X_{1995}, \ \ldots \ ,\Delta X_{1997})$ are valid instruments.

5 Results

5.1 Results of production function approach[19]

We begin the presentation of the estimates by first looking at the econometric estimates for the production function approach using a traditional Cobb-Douglas specification. To obtain a link with other studies based on firm-level data (e.g. Brynjolffson and Hitt, 1995) we first used (11a) and (12a) without taking into account the contribution of innovation and the impact of initial ICT adoption on TFP.

Table 5.1 SYS-GMM results for the production function approach Dutch market services [a]

	Complete panel		Innovation panel	
	A	B	C	D
N	7828	7828	1451	1451
ICT capital (γ_1)	0.077	0.029	0.046	0.025
	(0.006)	(0.007)	(0.011)	(0.009)
Other capital (γ_2)	0.122	0.144	0.119	0.177
	(0.024)	(0.046)	(0.058)	(0.051)
Labour (γ_3)	1.034	0.964	0.545	0.543
	(0.044)	(0.042)	(0.079)	(0.066)
ICT spillover capital (γ_4)	x	0.079	x	0.131
		(0.035)		(0.049)
ICT intensity (β_1)	x	0.034	0.035	0.037
		(0.046)	(0.029)	(0.055)
Innovation (β_2)	x	x	0.289	0.273
			(0.051)	(0.048)
Scale parameter [b]	[0.233]	[0.137]	[−0.290]	[−0.254]
	(0.022)	(0.031)	(0.078)	(0.071)
R^2	0.81	0.85	0.74	0.75

[a]The dependent variable is value added in constant prices (1995). All regressions control for first- and second order correlation in the error term of the models. The standard heteroscedasticity consistent standard errors of the estimates are presented in parenthesis.
Column A refers to the production function approach without ICT spillovers and the (initial) ICT intensity and innovation impact on the TFP level. Column B includes ICT spillovers and the ICT intensity dummy in the baseline model. Column C is the same model as A but now applied on the innovation panel and column D extends model C by also including the impact of innovation conditions on TFP levels.
[b] The scale parameter is derived afterwards with the help of the estimated elasticities of ICT capital, other capital and labour.

[19] The presentation of estimates will be restricted to the results of the SYS-GMM estimation method. The appendix compares this method with standard GMM and discusses the validity of the additional moment restrictions employed. This comparison shows that SYS-GMM yields more reasonable values for the estimated capital elasticities with higher precision.

Column (A) of table 5.1 presents the results for the production function approach without spillovers and initial ICT conditions using the complete panel, covering all firms in the Dutch market service sector. The table shows that all estimates (including the capital elasticities) are significantly different from zero. The outcome for the ICT capital stock elasticity is close to 0.08. Estimates of a comparable magnitude were also reported by Brynjolffson and Hitt (1995) and Hempell et al. (2002).

This result reaffirms that the ICT impact on output growth (and labour productivity growth) can be identified reasonably well when using firm-level data. The relatively high estimate for the ICT capital stock elasticity underlines the importance of ICT capital deepening for labour productivity growth. Taking into account the growth rate of ICT capital stock per employee (see table 3.4), the point estimate would even imply that (on average) all productivity growth came from ICT capital deepening.

The next phase in our analysis is to specify and break down the TFP variables, consisting of ICT spillovers, the initial conditions concerning the initial ICT intensity and innovativeness. We do this in three steps and the results of these steps are reported in table 5.1 under column B to D respectively. Again, and to enhance a better comparison, we start with the data of the complete panel. Therefore, we will not account for an innovation impact on TFP levels at this stage.

Column (B) of table 5.1 summarises the results for the full model (11a) and (12a) with ICT spillovers and the initial conditions concerning the initial ICT intensity included. The most striking result is that when ICT spillovers are taken into account more explicitly, the elasticity estimate of own ICT capital stocks is lowered substantially. As the estimate of ICT spillover capital is significant, this illustrates that a considerable part of the ICT impact on labour productivity growth is probably channelled through TFP. As a consequence, we obtain an estimate for ICT capital which is close to the average ICT cost share. This suggests that controlling for the possibility of simultaneity arising from the correlation between own ICT capital stocks and the (firstly omitted ICT spillover stocks) makes much sense. Furthermore, firms that were relatively ICT intensive in 1994, appear to have higher TFP levels in 1998 than ICT extensive firms, although this effect is not statistically significant.

The next two steps aim at controlling for productivity differences that are related to innovativeness and ICT spillovers. Being innovative can be such a condition, and for this reason we re-estimated the enhanced production function for the firms of the innovation panel. We recall, that average size for this selection of firms was larger than (average) size observed for the complete panel. Furthermore, as also shown in section 3.4, their productivity performance appeared to be slightly better than the average outcome for all firms. In view of these differences one could also expect quite different results for the production function estimates.

Columns (C) and (D) in table 5.1 show the estimation results for the innovation panel. A comparison with the estimates for the complete panel (columns (A) and (B)) reveal that the differences are minor, except for labour inputs. Again, the 'own' ICT capital stock elasticity appears to be lower after the ICT spillover indicator has been included and the elasticity estimate for ICT spillover capital remains significant, even after controlling for an innovation impact on TFP.

A notable difference between the complete panel and innovation panel concerns the scale parameter. According to the corresponding estimate, the null-hypothesis of CRS is rejected convincingly in favour of increasing-returns-to-scale for the complete panel. In contrast, the lower elasticity of labour inputs causes that the CRS-hypothesis is rejected in favour of decreasing-returns-to scale when using the innovation panel. This asymmetric result reflects the importance of scale economies for boosting labour productivity growth in the services sector (see Kox, 2002). Moreover, it suggests the existence of optimal scale sizes in the service sector (see Kox et al., 2003).

Another notable result concerns the contribution of innovation to TFP. The remarkably better productivity performance of innovative firms reported in section 3.4 clearly shows up in the estimates for the contribution of innovation to TFP. According to the estimates presented in columns (C) and (D) of table 5.1, the TFP level of innovative firms was about 28% higher than TFP for non-innovating firms.

5.2 Results of growth accounting approach

In this section we discuss the results for the growth accounting approach that use the corrected TFP as the dependent variable. Using (11b) and (12b) we can directly assess the contribution of ICT to TFP (growth) derived from the two-stage approach underlying the growth-accounting practice.

As discussed, this exercise resembles the econometric attempts to find an ICT impact on TFP of growth-accounting studies. Doing so, we attain a comparable benchmark with earlier studies at higher levels of aggregation Two differences should be kept in mind. First, here we first constructed an adjusted TFP measure (free from competition biases) and – thereafter – applied the SYS-GMM method to *explain* simultaneously differences in TFP levels and TFP growth. Second, our attempt is conducted at the level of the firm. Evidence from meso-level studies cannot be used unconditionally to extrapolate the spillover effects on lower levels of aggregation and vice versa.

Table 5.2 presents the results of this second approach. First we look at the outcome for the *complete panel* by comparing the first column of table 5.2 with column (B) of table 5.1. The most striking result is that the estimate for the own ICT capital stock elasticity of table 5.2 is very close to the spillover elasticity of table 5.1. The (very) significant elasticity of own ICT capital reflects the ICT impact on measured TFP in growth accounting practices as predicted by Stiroh (2002). On the other hand, the ICT spillover elasticity for the complete panel appears to be minor and also insignificant. These results suggest that the impact of own ICT investment shows up in different ways than in table 5.1 as a consequence of the two-stage approach adopted in the growth-accounting practice. With this we mean that the valuation of ICT capital used for the construction of TFP disregards the value of production externalities that are related to the complementarity of own ICT use and the ICT adoption outside of a firm. Similarly, we find a very significant TFP elasticity of labour inputs in table 5.2. This estimate is significantly positive, pointing to a sizable and positive scale effect on TFP, and this reflects the other side of the same coin as presented by the significant scale parameter of table 5.1.

Table 5.2 SYS-GMM results for the growth accounting approach for Dutch market services [a]

	Complete panel	Innovation panel
N	7828	1451
ICT capital (γ_1)	0.070	0.021
	(0.009)	(0.014)
Other capital (γ_2)	−0.189	−0.212
	(0.054)	(0.122)
Labour (γ_3)	0.306	0.142
	(0.052)	(0.119)
ICT spillover capital (γ_4)	0.005	0.097
	(0.040)	(0.067)
ICT intensity (β_1)	0.007	0.253
	(0.057)	(0.114)
Innovation (β_2)	x	0.703
		(0.106)
R^2	0.65	0.72

[a] The dependent variable TFP is calculated with the help of (8), thus the model uses TFP after accounting for the 'competition bias'. Otherwise, note a of table 5.1 also applies to this table.

The last column of table 5.2 presents the estimates for the TFP model for the *innovation panel*. Again, ICT appears to contribute to TFP growth, but in this model the impact of ICT spillovers is more sizable than the elasticity estimate of own ICT capital stocks. Moreover, and similar to column (D) of table 5.1, we find a very significant innovation impact on TFP. This latter result reaffirms the importance of innovation for explaining differences in TFP. However, the difference between column D of table 5.1 and the result of the last column of table 5.2. should be interpreted with care, as the estimate of table 5.2 has been obtained in a two-stage approach, thereby neglecting a possible correlation between innovation and other inputs. The two-stage approach also leads to strange results for the impact on TFP of initial ICT adoption (a significantly negative estimate for the innovation panel) and for other capital (a negative contribution for both samples).

Summing up: the evidence of tables 5.1 and 5.2 seems to underline that ICT spillovers are an important source of TFP growth. Taken on the whole, and focussing on ICT, our finding also corroborates the 'growth-accounting' studies that showed a relatively small –but positive– contribution of ICT capital deepening to labour productivity growth for ICT using industries.

Notice however, that this result has been obtained in this study after taking into account ICT spillovers more explicitly.

Viewed from an econometric angle, the production function approach yields more significant and plausible results than the growth accounting approach. It has been found that taking into account differences in levels and growth rates simultaneously, seems to pay off in terms of more reasonable and more precise estimates of the capital deepening parameters.

5.3 Decomposing labour productivity growth

In this section, we compare the decomposition of labour productivity growth following from the econometric approach with the growth-accounting calculations. In more detail, we compare TFP growth derived from the traditional' growth-accounting calculations with 'growth-accounting' TFP growth after the correction for deviations from 'perfect competition', and also the 'direct' calculations of TFP growth obtained from regression analysis of the production function approach. Using the econometric elasticity estimates of ICT and other capital and their geometric averages growth rates derived TFP growth in a similar way as is applied in the 'growth-accounting' practice. Doing so we achieve that the productivity effects of ICT externalities, scale economies and innovation are attributed to TFP (growth).

Table 5.3 shows that, after controlling for ICT externalities via the ICT spillover indicator employed, the contribution of ICT capital deepening according to the econometric approach is very similar to the results of the growth-accounting when using the complete panel. For this data set ICT capital deepening shows up to be twice as important for labour productivity growth than was other capital deepening.[20] This conclusion also applies to the selection of innovative firms (the firms that stated to have implemented innovations during the whole period considered). For both samples, we obtained a contribution of ICT capital deepening to labour productivity growth which seems to be rather robust taking into account the two rather different samples.

The most striking result is that the contribution of ICT capital deepening to labour productivity growth varies between 30% and 35% and that most of the contribution of ICT is channelled via ICT spillovers. The latter result came already apparent from the estimates of tables 5.1 and 5.2. In table 5.3 this is shown more explicitly: the contribution of ICT spillovers to TFP and labour productivity growth varies between 1.5% for all firms and 2.7% for innovators. Especially, the latter seems to be at odd. However, this relatively large contribution is fairly consistent with findings of Munn and Nadiri (2002). They analyse the importance of ICT rent spillovers at the industry-level with the help of inter-industry commodity flows to model the impact of forward and backward linkages of ICT adoption in a cost function framework. In their

[20] We recall that the decomposition of labour productivity growth for the two 'growth-accounting' variants presented in table 5.2 remains based on the (possibly invalid) assumption of constant returns to scale. Hereafter, we will return to this subject.

study they find an elasticity of total costs with respect to ICT spillovers which varied between 2% and 3% for UK market services.

Table 5.3 Decomposition of labour productivity growth using firm-level data, services 1994-1998 [a]

	'Growth-accounting' Traditional TFP	TFP corrected for 'competition bias'	'Production function'
	Annualised growth (%)		
Complete panel (N= 7828)	1.5	1.5	1.5
Contribution of:			
ICT capital deepening	0.5	0.4	0.5
Other capital deepening	0.3	0.2	0.2
TFP growth	0.7	0.9	0.8
Of which: ICT spillovers	NA	NA	1.5
Economies of scale	NA	NA	0.4
Rest	NA	NA	−1.1
Innovating firms (N = 776)	2.6	2.6	2.6
Contribution of:			
ICT capital deepening	1.0	0.7	0.8
Other capital deepening	−0.3	−0.4	0.0
TFP growth	1.9	2.3	1.8
Of which: ICT spillovers	NA	NA	2.7
Economies of scale	NA	NA	−0.6
Rest	NA	NA	−0.3

[a] Contributions calculated on the basis of geometric averages; NA= not applicable.

Table 5.3 also sheds some light on the importance of scale economies in market services. The result for the scale parameters of table 5.1 shows up in a contribution of 0.4 % (about 25% of labour productivity growth) if we use the most extended sample. However, for the selection of innovators we have a negative contribution of diseconomies of scale to labour productivity growth of the same order of magnitude. As innovating and size are positively correlated, this suggests the existence of a trade off between innovation and scale economies. As an analysis of this trade off is beyond the scope of this research, this result opens opportunities for further research.

6 Conclusions and further research issues

This paper presents an in-depth analysis of the ICT contribution to labour productivity growth in Dutch ICT using industries at the firm level covering the period 1993-1999. It disentangles the impact of ICT on productivity labour productivity growth into a capital deepening effect and a spillover effect by using an ICT-spillover indicator. Additionally, the impact of innovation is accounted for in an innovation panel.

The paper primarily focusses on the impact of ICT usage in Dutch market services. We constructed a balanced panel of firm-level data pertaining to the Dutch service sector in order to investigate the importance for boosting productivity growth of own investment in ICT in a period that was characterised by an economy wide acceleration of ICT investment. It is shown that the boosting of ICT investment at the firm level in response to an economy wide supply shock raises difficulties for the assessment of the contribution of own ICT to the contribution of labour productivity growth.

By using a production function approach, we have found that ICT spillovers can be an important source of TFP growth in ICT-*using* industries and that controlling for ICT spillovers lowers the elasticities of ICT capital. A further decomposition of TFP growth shows that the ICT spillovers as well as scale economies were probably important sources of labour productivity growth in the period considered. Our results suggest that neglecting ICT spillovers at the firm level entails the risk of an inappropriate allocation of ICT impacts across 'capital deepening' and TFP. This conclusion is reaffirmed if we control for the possibility of an innovation bias in the estimates (that is by re-estimating the models for the innovation panel) and after allowing for deviations from the 'perfect-competition' case.

Our results indicate that, after controlling for ICT externalities via an approximate ICT spillover indicator, the contribution of ICT capital deepening according to the production function approach is very similar to the results of the growth-accounting practice. Nevertheless, the latter approach is not able to disentangle the causes of TFP-growth into ultimate causes like productivity growth arising from ICT spillovers. On average about one third of labour productivity growth in Dutch market services can be attributed to own ICT capital deepening. However, this contribution appears to be less important than the more indirect contribution of ICT spillovers to productivity growth.

We conclude by mentioning two topics for further research. First, in this paper we have tried to account for the importance of deviations from perfect competition, innovation and economies of scale for the explanation of differences in productivity growth. Each of these determinants is capable of explaining (some of the) differences in productivity performance. However, they may not be independent causes. Ample research suggests that innovation and size are positively correlated. However, the relation between innovation and competition is less clear. Future CPB-research will try to shed more light on the relation between competition, innovation and productivity.

The second topic for further research concerns the ICT spillover indicator. Here, we have made an attempt to construct and quantify the effect of ICT spillovers at the firm level for the Netherlands and the results seem to be very promising. As far as we know, this is a novelty at this level of aggregation. However, two comments should be considered. First, due to a lack of data availability, the applied spillover indicator is only an approximation. Further research is needed whether an extension of the approximation is achievable and to check whether the presented firm-level results are robust on higher levels of aggregation. Second, besides the main topics of this contribution – ICT and innovation – human capital is an important source of labour productivity. Investments in education and training lead to the accumulation of knowledge and skills. Therefore, an increase of human capital positively affects labour productivity growth. As human capital, ICT and innovation are strongly interrelated, neglecting one of these productivity determinants could lead up to an overestimation of the effect of the included determinants in a regression. Unfortunately, Statistics Netherlands hardly collects any measure of human capital at the firm level.

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Appendix Validity of SYS-GMM model

Short introduction

Here, we test the validity of using the SYS-GMM-model in this paper. In the GMM method the first differenced equations of the model are 'instrumented' with the help of (lagged) levels of the explanatory variables. The extended GMM-method (i.e. SYS-GMM also uses the level equations of the model and use first differences of the same explanatory variables as the instrumental variables. This extension of the traditional GMM method aims at exploiting also the information contained in the cross-sectional differences of levels of the variables included in the model.

In both cases the GMM-method exploits the panel data structure by making use of the additional moment restrictions that become feasible in the course of time. Contrary to the standard IV-estimator, GMM-methods allow the projections on the instruments to be different for every year. In principle, this yields better predictions for the endogenous explanatory variables in finite samples and hence smaller standard errors for the estimated coefficients. However, in spite of this advantage, the inclusion of longer lags of explanatory variables as additional instrumental variables may not yield additional efficiency gains (more precise estimates) by definition when the additional instruments are highly correlated with the instrumental variables already included.[21]

Testing for the validity of additional moment restrictions

The usual way to investigate the validity of (additional) moment restrictions is by using the Sargan/Hansen test. In the sequel we will employ the so-called 'incremental' version of this testing procedure. Under the null hypothesis that all additional moment restrictions hold, the 'incremental Sargan' test statistics is chi-squared distributed with degrees of freedom (DF) equal to the number of the additional moment restrictions employed.[22]

This testing procedure has been applied to the production function models estimated for the innovation panel (columns C and D of table 5.1 of the main text). The results are summarised in table A1.

[21] In Mairesse and Hall (1996) it is shown that GMM methods still (can) perform better than the standard IV method in this case, because of the different sets of instrumental variables applied for different equations and not because of using more instrumental variables as such.

[22] If we have k parameters to estimate and use J_1 ($J_1 > k$) moment restrictions, then the standard Sargan test procedure checks the validity of the $J_1 - k$ over identifying moment restrictions. In the baseline model - GMM(-2) - the null hypothesis of the validity of the $J_1 - k$ over identifying restrictions is not rejected. The 'incremental Sargan' test compares the Sargan statistics for a baseline model with the results for the same model that uses $J_2 - k$ moment restrictions, where $J_2 > J_1$.

Table A1 Results of using different instrumental variables; innovation panel (N = 1451)		
	Estimate	SEE
A) GMM(-2)		
ICT capital	−0.008	0.012
Other capital	0.189	0.123
Labour	0.467	0.069
ICT spillover capital	0.125	0.047
B) GMM (-1)		
ICT capital	0.005	0.010
Other capital	0.198	0.102
Labour	0.329	0.056
ICT spillover capital	0.100	0.043
Incremental Sargan (B - A)	29.2	
Degrees of freedom	12	
Chi2 (0.01)	26.2	
C) SYS-GMM (-2, -2)		
ICT capital	0.017	0.011
Other capital	0.182	0.085
Labour	0.542	0.068
ICT spillover capital	0.139	0.050
Impact ICT initial ICT-intensity on productivity	0.050	0.073
Impact innovation on productivity	0.286	0.065
Incremental Sargan (C - A)	14.9	
Degrees of freedom	6	
Chi2 (0.01)	16.8	
D) SYS-GMM (-2, -1)		
ICT capital	0.025	0.009
Other capital	0.177	0.051
Labour	0.543	0.066
ICT spillover capital	0.131	0.049
Impact ICT initial ICT-intensity on productivity	0.037	0.055
Impact innovation on productivity	0.273	0.048
Incremental Sargan (D - C)	5.1	
Degrees of freedom	3	
Chi2 (0.01)	11.3	

The baseline model (A) – labelled GMM(-2) – uses lag two and earlier levels of the explanatory variables as instrumental variables. This specification allows for simultaneity of the three capital stocks (own ICT capital, own stocks of other capital inputs and ICT spillover capital) at the beginning of each period by dropping the instrumental variables contained in x_{t-1}.

Next, we re-estimated this model after including x_{t-1} as additional instrumental variables (see entry B of table A1). It can be seen that the 'incremental Sargan' test rejects the validity of the additional set of instrumental variables.[23] With the exception of the estimate of labour inputs the estimated coefficients of the two models appear to be very similar, as are there standard errors. The low estimate for labour inputs signals that the measurement-error bias seems to exceed the counteracting simultaneity bias when also (invalidity) using lag one instruments.

The next step is to compare the results of the GMM- and the SYS-GMM estimator. This is achieved by extending the GMM(-2) model towards a model (SYS-GMM (-2,-2)) that also accounts for the cross-sectional differences in levels, thereby using a comparable instrumental variable setting as in the baseline model GMM(-2).[24] The results of this exercise are given in entry (C) of table A1. Looking at the estimates it can be verified that also using the cross-sectional differences in levels (in addition to the cross-sectional differences in growth rates), yields more plausible estimates for the parameters of interest. Furthermore, the use of additional moment restrictions cannot be rejected at the chosen significance level for the 'incremental Sargan' test.

The last entry of table A1 builds on model (C) by extending the set of instrumental variables to include Δx_{t-1} in addition to Δx_{t-2} as instrumental variables. This extension yields the reference model as presented in the main text of the paper. For this variant (labelled model (D)) we arrive at the conclusion that including Δx_{t-1} in addition to Δx_{t-2} and earlier growth rates makes sense as the precision of all estimates improves considerably due to the use of the additional instrumental variables concerned. Furthermore, the 'incremental Sargan' test statistics validates the use of Δx_{t-1} as additional instrumental variables.

To sum up, applying the SYS-GMM method seems to pays off in terms of more precise estimates for the parameters of interest. This can be understood as consecutive growth rates show much lower correlations than consecutive level variables in the standard GMM method.[25]

[23] Because we have available a relatively large data set, we adopted a significance level of 0.01.

[24] The similarity of SYS-GMM(-2,-2) and GMM(-2) estimates refers to the inclusion of Δx_{t-2} and earlier growth rates in the SYS-GMM method.

[25] We recall that in our implementation we only use the level-equation for 1998. This allows us to use different (lagged) growth rates as instrumental variables.