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Disentangling the impact of ICT capital deepening and ICT spillovers on labour productivity growth

Evidence from Dutch firm-level data

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Abstract

This paper presents an empirical analysis of the contribution of ICT to labour productivity growth, using an extensive panel of accounting data for Dutch market services. We estimated enhanced production function models that include ICT spillovers as well as innovation as a component of TFP (growth) with the help of recently developed econometric methods. We compare the results of the production function approach with growth-accounting 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. It is shown that, after accounting for ICT spillovers, the relatively high elasticities of own ICT capital stocks of production function models estimated on firm-level data are consistent with the contribution of ICT capital deepening to labour productivity growth reported in growth-accounting studies. Our results underline that the contribution of ICT spillovers to productivity growth in the years of the ICT boom was more substantial than the contribution of ICT capital deepening as suggested by the standard neo-classical model of firm behaviour.

JEL-codes: C33, D21, D24, L80, O30.

1 Introduction[1]

One of the most impressive 'stilized 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 production externalities and the role of ICT in the resurgence of productivity in the second halve of the previous decade (see e.g. Jorgenson and Stiroh, 2000, and Gordon, 2000). The debate has been fuelled, amongst others, by the unclear relation between ICT use and TFP (growth). While ICT can affect labour productivity growth via different channels, growth-accounting studies mainly focussed on the contribution of ICT capital deepening. This paper attempts to extend these studies by also looking at the contribution of ICT to TFP (growth) and by comparing a 'production function approach' with the results of 'growth-accounting' carried out at the firm level.

After controlling for cyclical effects, Gordon (2000) concluded that returns on computer investment in US were 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 conclusion to the testing by applying econometric methods to the industry level data underlying their growth-accounting results. Surprisingly or not, these econometric studies failed to exhibit a positive impact of ICT on labour productivity growth as well as on TFP growth (see e.g. Stiroh, 2002, and Van der Wiel, 2001a).[2]

Nonetheless, it is often claimed that much of the acceleration of the TFP component of labour productivity growth in the second halve of the previous decade came from the ICT boom. As opposed to this claim, the econometric evidence based on firm-level data seems to underline the importance of ICT capital deepening for boosting labour productivity growth. In many cases the econometric ICT elasticities found when using firm level data showed up to be very significant and, moreover, much higher than seems to be 'consistent' with the (still) relatively

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[2] 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.

low ICT cost shares. Examples for US (manufacturing and service) firms are well documented in Brynjolfsson and Hitt (1995) and Brynjolfsson and Hitt (2000). Similar findings were 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). Therefore, which part of the recovery of labour productivity growth is channelled through TFP growth and which part is due to 'capital deepening' remains open to debate.

This paper elaborates further on this issue by placing the contribution of ICT to TFP on the firm level at the centre of interest. We argue that growth-accounting studies are less able to appraise this indirect contribution of ICT to labour productivity growth for two reasons: 1) TFP-growth in growth-accounting is a residual constructed without taking into account that ICT use may invoke technology or rent spillovers, thereby increasing the productivity of all inputs and 2) such spillovers may predominantly materialize at the firm-level, in particular for ICT using industries.

We analyse to what extent the before mentioned result arises from the omission of indicators representing ICT spillovers in the functional form of the model. 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 and use these (proximate) spillover indicators to capture the impact of technology spillovers and as a control for 'simultaneity' or 'omitted variable biases' in the econometric model. Furthermore, we aim at purifying TFP (growth) further by controlling for (dis)economies of scale, the contribution of innovation to TFP and for a possible underestimation of TFP growth resulting from deviations from perfect-competition. As to the latter, we will adjust the 'growth-accounting' cost shares by applying the mark-up correction suggested by Griffith (2001). These modifications of the basic framework are applied in order to account for the fact that TFP (growth) is a catch-all term, which preferably should be specified as much as possible. The models are applied to an extensive panel data set constructed with the help of accounting data for firms belonging to Dutch market services.

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 econometric approach and compares these results with that of the growth accounting approach. Finally, section 6 gives a 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. The production function is approximated by the Cobb-Douglas specification. In logarithmic form this specification reads:

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

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 have chosen to 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 level of Total Factor Productivity (TFP). After taking first-differences, we can derive the corresponding equation for TFP growth (denoted by $dTFP$) as

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

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 technical change. This assumption disregards that 'growth-accounting' TFP is a catch-all term. Besides exogenous technical change it also covers the contribution of other unspecified inputs, deviations from constant returns to scale and perfect competition and measurement error. More specifically, TFP is assumed to be related to innovation. Innovation may affect TFP (growth) along various lines. Product innovation by definition leads to new products and the emergence of new products raises difficulties for constructing appropriate deflators. TFP (growth) may also be affected more directly by various types of process innovation or non-technological innovations. An example of the latter are organisational changes. This type of innovation may not be independent form ICT.

Growth-accounting decomposition of labour productivity growth

The ‘growth-accounting’ method solves the problem of unkown elasticities by adopting the following assumptions of the standard Neoclassical model:

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

After using these assumptions, the first order conditions of profit maximizing 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:

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

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

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

where $\{s_{ICT}^{ga},\ s_K^{ga},\ s_L^{ga}\}$ are 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 $s_{ICT}^{ga} + s_K^{ga} + s_L^{ga} = 1$, then 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:

$$dy_{it} = dTFP_{it}^{ga} + s_{ICT}^{ga}\ dict_{it} + s_K^{ga} dk_{it} + (1 - s_{ICT}^{ga} - s_K^{ga}) dl_{it}, \tag{4a}$$

and in which $dTFP_{it}^{ga}$ represents ‘measured’ TFP growth according to ‘standard’ growth-accounting.[3]

Notice, that the cost shares used in eqations (3a) - (3c) are taken relative to total revenue (value added) and not to total costs. It can be verified that $dTFP_{it}^{ga}$ 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

[3] The cost shares in (4a) are averaged across adjacent time periods.

the technology of each firms can be described by global constant-returns-to-scale (see Balk, 2000). Under these rather restrictive assumptions the cost shares relative to value added coincide with the shares relative to total costs (*TC*), where total costs is 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:

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

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

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

and in which μ represents deviations from 'perfect-competition'. In section 2.4 we will discuss the empirical implementation of TFP corrected for deviations from the perfect-competition case.

Production function approach

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, i.e. the regression residual of (4b). Notice, that (4b) is more flexible than (4a) as it does not impose scale (dis)economies to be absent.

2.2 A closer look at the two approaches

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) we can easily verify that ICT positively contributes to labour productivity growth if the growth rate of ICT capital exceeds the growth rate of labour inputs. In this case, a positive contribution of ICT to labour productivity growth seems to arise naturally from the growth-accounting method as the cost share of ICT capital (however measured) is positive by construction. Consequently, the conclusion of 'growth-accounting' studies on industry-level data that ICT is able to boost labour productivity growth can be well understood.

A more important question can be phrased as follows: which part of labour productivity growth can be attributed to ICT capital deepening and which part is due to an ICT impact on TFP (growth)? The Neoclassical model underlines that the contribution of ICT to labour productivity is channelled through capital-deepening and this leaves no room for an assessment of the ICT impact on TFP growth. Notwithstanding that TFP (growth) might have something to do with ICT, an analysis of the contribution of ICT to TFP (growth) in the 'growth-accounting' practice requires the use of a two-stage approach, testifying that the impact of ICT on TFP can be isolated from capital deepening.[4]

A similar approach could be followed by using the residual $dTFP_{it}^{e}$ obtained after applying OLS to (4b) as the starting point for analysing the ICT impact on TFP growth. 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 share of ICT.

Stiroh (2002) pointed out that a difference between the estimated ICT 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:

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

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 unbiasdness of the ICT capital elasticity. Therefore, a

[4] A related complication of the 'growth-accounting' method 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.

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 standard economic theory. 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 will elaborate on the before mentioned 'economic' and 'econometric' issues more explicitly along two lines. Firstly, we shall address the specification problem by extending model (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). Secondly, we apply recently developed estimation methods to the modified model in order to obtain a better control for other potential biases concerning its estimation.

2.3 ICT spillovers

Stating that ICT is about information technology embodied in computers is tantamount to saying that one often used interpretation of TFP should be questioned from the outset: TFP growth cannot be attributed exclusively to Hicks neutral disembodied technical change. There is a lengthy list of literature that emphasizes how ICT enables the creation and use of network externalities. 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 usage of ICT facilitates new organizations 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 usage of ICT predominantly invokes a shift in the production frontier (at the firm level as well as in the aggregate) 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.

Summing up: the potential of ICT to produce production externalities or spillovers simultaneously explain 1) why estimated ICT elasticities obtained from regressions on firm-level data can exceed the ICT cost shares used in the 'growth-accounting' practice and 2) 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 phenomena 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 the ICT impact from the contribution of technical change in the presence of an economy wide supply shock.[5]

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 information technology has no limits by definition. 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 ICTcapital 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).

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 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 make sense to account for the increased usage 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

[5] 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.

into the 'primal' representation of technology that underlies the production function framework given 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.[6] 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:

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

It goes without saying that this measures cannot be more than an approximation for the ICT adoption outside of the firm. By extending the model with this exogenous variable we assume that ICT spillovers affect the location and the structure of the production frontier bouding the relationship between own inputs and output. Therefore, the extended model aims at providing a better characterization of production possibilities than would be the case if spillovers were exluded (see Kumbhakar and Knox Lovel, 2000.

2.4 Deviations from the perfect-competition case

As we intend to use TFP (growth) at the firm-level, another feature of standard 'growth-accounting' 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 characterized 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 for the output markets and to allow these markets to deviate from the perfect-competition case.

Griffith (2001) showed that in case of imperfect competition on output markets the usual measures of TFP growth are likely to be 'biased' and that the direction of the bias depends on changes in input ratios. Following Griffith (2000) and Klette (1999), we will control for this 'competition bias' by introducing 'mark-ups'. If firms have some market power in output markets and remain price taker in input markets, then the perfect-competition price (p) in (3a) - (3c) should be replaced by marginal revenue product (r) given by:

[6] In defence of the argument that data on inter-industry dependencies are more suitable for the analysis of ICT spillovers, one could argue that ICT spillovers predominantly materialize on the firm level. Thus firm-level data may not be such a bad starting point for assessing their importance.

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

where ε_t is the price elasticity of demand.[7] In this study 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:

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

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

$$\mu_{mt} \equiv \frac{P_{mt}}{AC_{mt}}$$

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 (CRS) in all inputs. Starting from:

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

[7] Perfect competition on output markets corresponds with $\varepsilon \rightarrow -\infty$ or, equivalently, $\mu = 1$.

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.

3 Data

3.1 The construction of panel data

In the empirical application 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 average size of firms in the balanced panel is considerably higher than in the total population of firms. The Dutch service sector consists of many small firms and - due to the sampling design - many of them are covered in the Production Survey occasionally. 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 an unique firm identifier one can easily construct panel data from this data source by linking the yearly surveys in time.

The accounting data cover - amongst others - the following variables: gross output, total turnover, employment in full time equivalents (from 1995 onwards) and employed persons[8], 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.[9] 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.

3.2 Construction of data on capital inputs

The models of section 2 also require data on capital stocks. Unfortunately, and not uncommon for studies that use 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

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

[9] 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 are collected simultaneously with the (other) accounting data.[10] Thus, we have available a consistent set of investment data at the firm level for those firms that are present in every year. We used these 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. We used this hedonic deflator 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 CPB. The assumed values for g_k and δ_k are summarized in table 3.1.

[10] 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.

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

	Pre-sample growth		Depreciation	
	Total investment	ICT	Total investment	ICT
Wholesale	6.0	25.0	6.5	25.0
Retail sales	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: investment cycles appear to differ markedly between firms. 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.[11]

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

	1994	1998
	%	%
Share of ICT in total capital stock		
Services	1.6	3.3
Wholesale	2.6	5.7
Retail sales	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] Annualized growth for total services calculated on the basis of raised totals.

[11] 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.

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 firms for which capital stock data could be constructed and that passed through other data cleansing rules.[12] 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, 2003, 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 appear to be smaller. After raising the firm-level data we obtained (weighted) growth rates for capital inputs that are similar to those found on industry-level data.[13] The table also shows that, although doubled in a short period, the share of ICT in total capital stocks was still rather small in 1998.

3.3 Linking innovation data

As differences in innovativeness seem to be a natural candidate for explaining differences in firm performance, we determined 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.[14]

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 severely (see Van der Wiel. 2001b). In CIS, small firms are under represented and this survey also disregards just started firms. As small and starting firms are considered as an important source of increasing innovativeness, the low coverage of these firms in CIS could underestimate the importance of innovation in services. Despite these shortcomings, CIS-data remain imperative for assessing the role of innovation in explaining differences in productivity (growth).

[12] 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.

[13] 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.

[14] Prior to the third wave of the big and harmonized European CIS (CIS 3) Statistics Netherlands has carried out an intervening survey, called Cis 2..5.

Table 3.3	**Innovation activities and types, 1994-1998** [a]				
	Innovation only technological	only non technological	both types	None	Total
	% of firms				
Services	5	28	54	13	100
Manufacturing	8	9	77	6	100

[a] Based on innovation panel services (n=1451) and manufacturing (n= 1091).

The Dutch CIS makes a distinction between technological and non-technological innovation. Technological innovation is defined as the introduction of new or improved products (product innovation) or means of production (process innovation). Non-technological innovation covers a broad range of other types of innovation.[15]

Table 3.3. shows that many Dutch firms have innovated in some way in the period 1994-1998. More than 50 percent of all firms in services implemented both a technological and a non-technological innovation. Non-technical innovations are more likely to be applied solely in services than in manufacturing. More than one out of four firms in services appears to have implemented non-technological innovations only.

3.4 The productivity performance of Dutch market services in 1994 -1998

Table 3.4 presents some evidence on different productivity measures for the complete panel. The table shows that labour productivity growth for Dutch market services was moderate on average, with annualized growth close to 1.5% in 1994-1998.

We also listed statistics for TFP growth based on two growth accounting measures. The first one uses formula (6a) to calculate 'growth-accounting' 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:

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

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

[15] The Dutch questionnaire distinguishes between four classes of non-technological innovations: changes in strategy, marketing, organizational changes and management.

In table 3.4 it can be seen the contribution of TFP to labour productivity growth varies between 47% and 60% for the two considered measures of TFP. Furthermore, and in line with the discussion of section 2.4.1, 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.

Table 3.4 Summary statistics for key variables Dutch market services

	All firms (N = 7828)	
	mean	stdev
	%	%
Growth rate of [a]		
ICT capital	19.8	38.1
Other capital	4.3	3.5
Employed persons	3.0	12.3
Value added per employee	1.5	12.4
TFP 'traditional' growth-accounting	0.7	12.0
TFP 'corrected' growth-accounting	0.9	12.3
Levels		
Employment 1994	93.9	677.7
Employment 1998	111.2	821.5
Value added per employee 1994 [b]	38.1	67.9
Value added per employee 1998 [b]	43.3	69.4

[a] Annualized growth calculated over the period 1994 - 1998.
[b] In constant prices x 1000 Euro.

Although the difference between the traditionally 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 3.5). Moreover, the average 'mark-ups' for services as a whole rose from about 1.23 in 1994 to about 1.27 in 1998.

Table 3.5 Mark-up results in market services, 1994 and 1998

	1994	1998
All firms (complete balanced panel)	1.228	1.269
Innovation panel	1.238	1.272

Next we look at the summary statistics for the innovation panel (see table 3.6). This panel consists of 1451 firms. It is derived from the balanced panel and includes firms that were also covered in the two waves of CIS.

Table 3.6 Summary statistics for key variables for Dutch market services

	Innovation panel (N = 1451)		Innovating firms (N = 776)	
	mean	stdev	mean	stdev
	%	%	%	%
Growth rate of [a]				
ICT capital	29.3	29.2	34.1	43.3
Other capital	4.0	3.2	3.7	3.1
Employed persons	3.3	13.1	3.9	12.0
Value added per employee	2.5	12.3	2.6	11.2
TFP growth-accounting	1.8	12.1	1.9	11.4
TFP 'corrected' growth-accounting	2.1	13.3	2.3	13.7
Levels				
Employment 1994	181.3	656.0	229.7	829.1
Employment 1998	206.6	753.2	261.6	954.1
Value added per employee 1994 [b]	41.4	29.5	45.7	28.7
Value added per employee 1998 [b]	51.3	63.2	54.9	53.5

[a] Annualized growth calculated over the period 1994 - 1998.
[b] In constant prices x 1000 Euro.

If we compare table 3.4 and 3.6, then the most striking difference between the balanced panel and the innovation panel is that the innovation panel consists of a collection of firms that had a remarkably better productivity performance 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 firms-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.[16]

However, these results are not decisive for answering the question as to whether innovativeness really is important for boosting labour productivity growth. The reason for this is

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

that not all of the firms of the innovation panel actually implemented innovations during 1994-1998. Which part of this panel was really innovative in this period depends on the chosen definition of innovativeness. In this paper, we label a firm as 'innovative' if it has implemented at least one type of innovation (technological or non-technological innovations) in each of the two periods considered in CIS. According to this definition we obtain 776 firms that were innovative during 1994-1998.[17]

With respect to these innovating firms, it can be seen in table 3.6 that the differences with the outcome for the innovational panel as a whole are relatively small. Nevertheless, a comparison with the complete panel reveals that innovation seems to pay off in terms of labour productivity growth and that most of the productivity growth came from TFP. Notice further, that innovating firms also showed a higher increase of ICT capital stocks than observed for the complete panel. This signals that ICT and innovation seem to be positively correlated.

[17] It is worth mentioning that the class of 'non-innovating' firms also covers a considerable number of firms that implemented technological or non-technological innovations 'only' once, either in 1994-1996 or in 1996-1998.

4 Econometric issues

4.1 Specifying the TFP component

In this section we discuss several econometric issues concerning the estimation of the models of section 2. Before adding the stochastic assumptions to the econometric models, we first have to be more clear about the specification of the TFP component of the production function (1).

As mentioned before, our primary interest 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.[18] 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 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

[18] 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 ICT intensive. ICT extensive firms are the reference group.

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):

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

In (10) is $sict_{it}^I$ 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 (reference industry, trade and repair of cars excluded, NACE-code 51);
- Retail Sale (trade and repair of cars excluded, NACE-code 52);
- Business services (NACE-code 71 - 74);
- Wholesale and retail sales 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.

After inserting (10) in (1), the enhanced production function reads:[19]

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

whereas, after changing the dependent variable in TFP, we can use as the TFP model:

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

and in which TFP_{it}^{cga} is calculated according equation (8).[20]

The estimation of the enhanced production function (11a) aims at minimizing the risk of a simultaneity or omitted variables bias for the traditional inputs in order to obtain better estimates

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

[20] 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.

for TFP (growth) following from the production function approach.[21] We can compare these estimates with TFP calculated according to the 'growth-accounting' method, either by using (6a) for the 'standard' calculation of 'growth-accounting' TFP or (8) for TFP corrected for the 'competition bias'.

Another, and more interesting, comparison concerns the explanation of 'growth-accounting' TFP. This will be achieved by using (11b) instead of (11a). Doing so, we can test more directly to what extent the ICT impact on productivity was channelled through TFP. Estimating (11a) and (11b) also provides a benchmark for TFP-regressions carried on industry-level data in growth-accounting studies and which showed up to be inconclusive with respect to the contribution of ICT to labour productivity and TFP growth (see e.g. van der Wiel, 2001a, and Stiroh, 2002). Furthermore, a comparison of the results for model (11b) with estimates for model (11a) and model (11a) with ICT spillovers excluded, also enables us to judge whether the estimates of ICT capital stock elasticities obtained from the results of production function models that exclude ICT spillovers are 'hiding' an ICT impact on TFP
(growth).

4.2 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 'TFP model' (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 results even more. If productivity shocks are anticipated before factor demands are determined,

[21] Although the estimation of the enhanced production function model directly yields information on the specified sources of TFP (growth), we could plug in the production function estimates in (4b), thereby obtaining an 'econometrically' based estimate of TFP (growth).

than changes in productivity shocks ($\Delta\nu_{it}$) 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 $\Delta\nu_{it}$ 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 generalized instrumental-variables estimator uses the following orthogonality conditions [a]

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

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 quite 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

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

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) and 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.[22]

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

5 Results

5.1 Production function models

We begin the presentation of the estimates by first looking at the econometric estimates for the '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 initital ICT adotion on TFP. This specification resembles a standard production funtion.model.

Table 5.1 SYS-GMM results for the production function models Dutch service sector [a]

	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. 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 baseline model (the production function model 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 baseline model for the innovation panel and column D extends model C by including the impact of initial ICT and innovation conditions on TFP levels.
[b] The scale parameter is derived with the help of the estimated elasticities of ICT capital, other capital and labour.

Column (A) of table 5.1 presents the results for this baseline model after using the complete panel, covering all firms in the 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 re-affirms 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.

Another interesting result concerns the scale parameter of the model. According to the corresponding estimate, the null-hypothesis of CRS is rejected convincingly in favour of increasing-returns-to-scale. This outcome corroborates the conclusion of an earlier Dutch study that pointed to the importance of scale economies for boosting labour productivity growth in the services sector (see Kox, 2002).

The next phase in our analysis is to add the TFP variables – consisting of ICT spillovers, the initial conditions concerning the initial ICT intensity and innovativeness – to the baseline production function specification. 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 summarizes the results for the full model (11a) and (12a) with the innovation dummy excluded. 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 channelled through TFP. As a consequence, we obtain an estimate 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 initial conditions. 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 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 concerns the scale parameter. 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 asymmetrical result reflects the different size distribution of the innovation panel (compare tables 3.4 table 3.6) and also 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 paragraph 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 TFP models

In this section we discuss the results for the models that use TFP as the dependent variable. By replacing (11a) and (12a) with (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. Thus, this exercise resembles the econometric attempts to find an ICT impact on TFP of ‘growth-accounting’ studies. The difference is that we first contructed 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 at the firm level.

Table 5.2 presents the SYS-GMM results. 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 capital elasticity of table 5.1.The (very) significant elasticity of own ICT capital reflects the ICT impact on ‘growth-accounting’ TFP 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 two things. Firstly, ICT spillovers are an important source of TFP growth and - secondly - 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 TFP models [a]

	All firms	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 re-affirms 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 columns 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 findings 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.

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 form the 'traditional' growth-accounting calculations with 'growth-accounting' TFP growth after the correction for deviations from 'perfect competition' has been applied, and also the 'direct' calculations of TFP growth obtained from regression analysis. Using, the econometric elasticity estimates of ICT and other capital stocks we derived TFP growth in a similar way as is applied in the 'growth-accounting' practice. Doing so we achieve - similar to the ('traditional') growth-accounting practice - 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' are 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, a picture which seems to be reasonably consistent with the growth-accounting results reported for industry-level data.[23] 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

[23] We recall that the decomposition of labour productivity growth for the two 'growth-accounting' variants presented in table 3.4 remain based on the (possibly invalid) assumption of constant returns to scale. In the next section we will return to this subject.

channelled via ICT spillovers. The latter result came already apparent from the estimates of tables 5.1 and 5.2. In table 3 this is shown more explicitly: the indirect contribution of ICT spillovers to labour productivity growth varies between 1,5% for all firms and was with 2,7% even more substantial for innovators. This relatively large contribution is fairly consistent with the outcome of the Munn and Nadiri (2002) study, which analysed 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 study they found an elasticity of total costs with respect to ICT spillovers which varied between 2% and 3% for market services.

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 postitively correlated, this suggest the existence of a trade-off between innovation an scale economies. As an analysis of this trade-off was beyond the scope of this reserach, this results opens opportunities for futher research.

Table 5.3	Decomposition of labour productivity growth using firm-level data, services 1994-1998 [a]		
	'Growth-accounting'		'Production function'
	Traditional TFP	TFP corrected for 'competition bias'	
	Annualized 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
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

[a] Contributions calculated on the basis of geometric averages (NA: not available).

6 Conclusions

This paper presents an in-depth analysis of the ICT contribution to labour productivity growth in Dutch ICT using industries at the firm level. 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 and innovation data.

The paper primarily focusses on the impact of ICT usage in Dutch 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 characterized 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 an econometric approach, we have found that ICT spillovers are an important source of TFP growth in ICT *using* industries and that controlling for ICT spillovers lowers the elasticities of ICT capital. A further decompostion of TFP growth following from the production function approach shows that the ICT spillovers as well as scale economies were 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 re-affirmed 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 'econometric approach' are 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 productivty growth arising from ICT spillovers. On average about one third of labour productivity growth 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 a topic for further research. 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. In future research will try to shed more light on the relation between competition, innovation and productivity.

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