Working Paper

Inter- and Intra-Firm Diffusion of Technology: The Example of E-commerce. An Analysis based on Swiss Firm-level Data an analysis based on Swiss firm-level data

Author(s):
Hollenstein, Heinz; Wörter, Martin

Publication Date:
2007-03

Permanent Link:
https://doi.org/10.3929/ethz-a-005381939 →

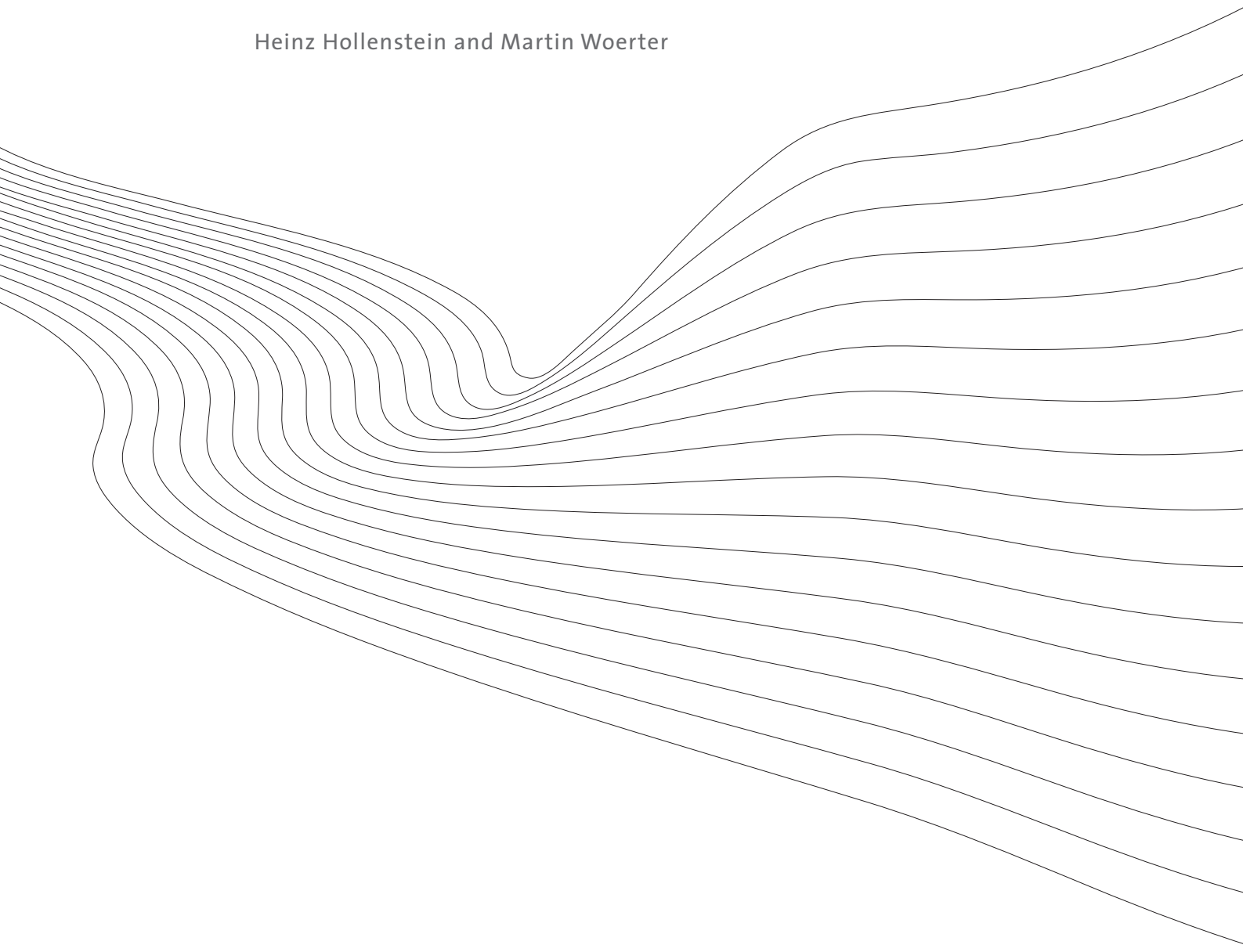
KOF

KOF Working Papers

Inter- and Intra-Firm Diffusion of Technology:
the Example of E-commerce

An Analysis based on Swiss Firm-level Data

Heinz Hollenstein and Martin Woerter



No. 157
March 2007

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

KOF

ETH Zurich
KOF Swiss Economic Institute
WEH D 4
Weinbergstrasse 35
8092 Zurich
Switzerland

Phone +41 44 632 42 39
Fax +41 44 632 12 18
www.kof.ethz.ch
kof@kof.ethz.ch

Inter- and Intra-Firm Diffusion of Technology: the Example of E-commerce

An Analysis based on Swiss Firm-level Data

Heinz Hollenstein and Martin Woerter

KOF Swiss Economic Institute, ETH Zurich
Weinbergstrasse 35, WEH D 4
CH-8092 Zurich, Switzerland
woerter@kof.ethz.ch

Abstract

The paper aims at a joint analysis of inter-firm and intra-firm diffusion of technology, taking as an example E-selling and E-purchasing. The analysis is based on an encompassing model of diffusion, drawn from the literature, which is extended by considering technology-specific obstacles and benefits of adoption. As hypothesised, we find, firstly, that the determinants of inter-firm and intra-firm diffusion differ in case of both types of E-commerce; secondly, that the drivers of the diffusion of E-selling and E-purchasing are not the same, and, finally, that uncertainties and adjustment costs, mostly neglected in previous work, are important factors in explaining technology diffusion.

Keywords: Technology diffusion; Inter-firm and Intra-firm diffusion; E-commerce; E-selling, E-purchasing

JEL Classification: O3

Correspondence to

Dr. Heinz Hollenstein
KOF Swiss Economic Institute
ETH Zurich
Weinbergstrasse 35, WEH D 4
CH-8092 Zurich, Switzerland
E-mail: hollenstein@kof.ethz.ch, Tel.: +41-44-632-5329; Fax: +41-44-632-1352

1. Introduction

The economy-wide degree of diffusion of a technology can be decomposed into two elements, that is inter-firm diffusion (adoption, i.e. first use of a new technology) and intra-firm diffusion (intensity of use by firms having already adopted a new technology). Whereas there is a rich literature on the first type of diffusion, empirical work on the second one, with the seminal paper of Mansfield (1963) as an exception, has become available only recently and empirical evidence is still limited (see, among others, Arvanitis and Hollenstein, 2001; Astebro, 2004; Battisti and Stoneman, 2005; Fuentelsaz et al., 2003; Hollenstein, 2004). Rare are studies that jointly deal with inter- and intra-firm diffusion; exceptions are Battisti and Stoneman (2003) on the diffusion of CNC as well as Battisti et al. (2004, 2007) and Hollenstein (2004) on Internet and E-commerce.

A second observation refers to the analysis of the diffusion of E-commerce as a specific application of "Information and Communication Technology" (ICT). To our knowledge, there is no (econometric) study attempting to separately explain the two sides of E-commerce, i.e. E-purchasing and E-selling, based on information from the same set of firms. This is quite surprising as the degree of diffusion of the two types of E-commerce strongly differs (see Section 2).

Against this background, the paper attempts to contribute to the literature on the joint analysis of inter- and intra-firm diffusion of a new technology, taking E-commerce[1] as an example. By distinguishing the two sides of E-commerce we aim at deepening and differentiating our understanding of the determinants of diffusion of E-commerce, which still is quite a recent development in the field of ICT. We hypothesise, firstly, that inter- and intra-firm diffusion are driven by different factors (and expect this proposition to hold true for both forms of E-commerce). Secondly, we posit that the determinants of the diffusion of E-selling and E-purchasing are not the same, or, if they would be the same, that they do not influence the two sides of E-commerce to the same extent.

In this study, we only consider *Internet-based* E-commerce, whereas electronic transactions realised by use of other types of networks (e.g. older vintages of EDI systems that are not based on an Internet platform) are not taken into account. Whereas E-purchasing of firms, by nature, is B2B trading (Business to Business), E-selling also captures B2C transactions (Business to Consumer).

The empirical analysis is based on the encompassing diffusion model proposed by Battisti et al. (2004), which is an extension of Battisti (2000) and Battisti and Stoneman (2003). This model assumes that rank-, epidemic, stock and order effects, which have been shown to drive inter-firm diffusion (see Karshenas and Stoneman, 1995), will determine intra-firm diffusion as well. By using (more or less) the same categories of explanatory variables and the same dataset in all model equations it is possible to identify the common and the different drivers of the two types of diffusion as well as the two forms of E-commerce. The model specification takes into account the hypotheses

---

[1] E-commerce is defined as transactions conducted over Internet Protocol-based (IP) networks or over other computer-mediated networks (e.g. EDI if not carried out via IP). The products are ordered over such networks, but payment and/or delivery of the products may be made on or off-line. Note that orders received via non-interactive systems (for example manually typed e-mails) are not counted as electronic commerce (for this definition, see Eurostat, 2004).

and previous findings of the literature on technology diffusion as well as those on the use of E-commerce.

As an additional element (and in contrast to most previous empirical studies), our approach explicitly takes into account technological, economic and institutional uncertainties as well as adjustment costs.[2] Moreover, it considers anticipated benefits from using a *specific* new technology such as E-commerce as these may not fully be captured through the more general model specification based on rank, epidemic, stock and order effects (example: "linking the elements of internal ICT infrastructure" as a specific benefit from adopting E-commerce). This broad-based approach of modelling has been successfully applied in some earlier work (Arvanitis and Hollenstein, 2001; Hollenstein, 2004).

In order to identify the determinants of inter- and intra-firm diffusion of E-selling and E-purchasing respectively, we estimated models allowing for a potential selection bias in the equation explaining intra-firm diffusion (Heckman selection model).[3]

The data used in this paper was collected by means of two surveys conducted in the Swiss business sector based on the same sample of firms. The principal source is a survey dealing with the use of ICT and E-commerce carried out in 2002. The second source is an innovation survey also conducted in 2002. The model estimates are based on the dataset we got from matching the observations of the two surveys (1472 observations).

The paper is structured as follows: Section 2 provides information on the database and the degree of inter- and intra-firm diffusion of E-selling and E-purchasing in the Swiss economy. Section 3 describes the conceptual framework and the empirical model. In Section 4, the estimation procedure is discussed and the empirical results are presented. Finally, we summarise and assess the main findings of the paper.

2. Database and pattern of diffusion

2.1 Data

The data underlying the econometric analysis was collected by means of two surveys conducted in 2002, the one dealing with innovation activities of Swiss firms, the other with the use of ICT (the two questionnaires can be downloaded from www.kof.ethz.ch). Both surveys were based on a sample (firms with 5 or more employees) stratified by 28 manufacturing, construction and service industries and three industry-specific firm size classes (full coverage of large firms). We got valid information from 2583 firms (innovation survey, response rate 40%) and 3377 companies (ICT survey; response rate 56%). A non-response analysis did not indicate any serious selectivity bias in the two surveys. "Item" non-response is another problem of survey data. The usual procedure of deleting observations with incomplete data may produce biased estimates. Therefore we substituted imputed for missing

---

2 See Stoneman (1990) for a theoretical treatment of adjustment costs as well as Battisti and Stoneman (2005) for an attempt to take account of technological and economic uncertainty.

3 We also estimated a bivariate probit model jointly explaining whether a firm, at the same time, adopts E-selling and E-purchasing, in order to check whether the Heckman procedure yields reliable results (see subsection 4.1).

values using the "multiple imputation" procedure proposed by Rubin (1987). The estimates presented in this paper are based on the dataset we got from matching the observations of the two surveys and excluding the firms that do not use the Internet. The final dataset used for model estimates contains 1472 observations.[4]

2.2 Diffusion of E-commerce in the Swiss economy

Table 1 contains some information on inter- and intra-firm diffusion of E-selling and E-purchasing in the Swiss economy. The first two columns of Table 1 show that inter-firm diffusion (adoption) of E-purchasing is much higher than that of E-selling both in the economy as a whole (44% vs. 16%) and in all sectors. Diffusion of E-purchasing is highest in knowledge-intensive services and high-tech manufacturing; in case of E-selling, the proportion of users is higher in manufacturing than in services. Columns 3 to 6 show the level of intra-firm diffusion (intensity of use) of E-purchasing and E-selling (only firms having adopted the corresponding practice). It turns out that transaction values, though strongly increasing, were still low in 2002, that is 3.8% of purchases of intermediate inputs and 2.0% of total sales. Intra-firm diffusion of E-purchasing is about the same in manufacturing and services; in case of E-selling, the intensity of use is highest in the high-tech manufacturing sector. By combining inter- and intra-firm diffusion, we find that, in 2002, only 1.7% of purchases of intermediate inputs and 0.3% of total sales were traded through the Internet.

Table 1

Table 2 shows an international comparison of the diffusion of E-purchasing and E-selling. In this respect, Switzerland is among the leading European countries. In case of E-purchasing it is ranked second behind Sweden and exhibits a higher penetration rate than other smaller countries like Austria, Denmark or Finland. With regard to E-selling the position of Switzerland is somewhat weaker (rank 5); but diffusion is only slightly lower than in Norway, Ireland, Austria and Denmark, but much higher than in countries like Finland or Sweden, which, in general, belong to the most advanced users of ICT.[5]

Table 2

3. Conceptual framework and model specification

3.1 Conceptual framework

The empirical analysis is based on an encompassing model of diffusion proposed by Battisti et al. (2004),[6] which is an extension of Karshenas and Stoneman (1995) and subsequent work of Battisti (2000) and Battisti and Stoneman (2003). The model integrates different strands in the (inter-firm) diffusion literature and investigate empirically whether these strands are empirically relevant for

4 We had to exclude 9 observations in the model explaining E-purchasing because of inconsistent data.

5 No comparable data is available for the USA and most of the other non-European countries.

6 The same approach is used in Battisti et al. (2007, in press).

intra-firm diffusion as well. In both cases, the model is designed to reflect equilibrium models (i.e. rank, stock, order effects) and disequilibrium approaches (i.e. epidemic effects).

According to Battisti et al. (2004), the first use (adoption) of a new technology and the extent of its usage in time t by firm i in industry j, $\mathbf{D_i}(t)$, are determined by four categories of variables:

1. a vector of characteristics of a firm, $\mathbf{R_i}(t)$, and its environment/industry, $\mathbf{R_j}(t)$, reflecting rank effects that may be positive or negative.
2. the extent of industry usage of the new technology, to capture between-firm stock and order effects $\mathbf{SO_j(t)}$. The signs of these effects depend on the behaviour of the competitors that influences a firm's return from introducing the new technology: a) low vs. high degree of diffusion in the industry giving rise to positive and negative stock effects respectively; b) first mover advantages vs. late comer disadvantages implying positive and negative order effects respectively. In general, these effects are expected to be negative, unless network effects are particularly strong (what, indeed, might be true in case of E-commerce).
3. two dimensions of a firm's experience and learning, reflecting (positive) epidemic effects: the firm's own experience gained from using a predecessor technology, $\mathbf{E_i}(t)$, and the knowledge gained from observing other users of the new technology, $\mathbf{E_j}(t)$.
4. the costs a firm expects to incur by adopting or extending the use of the new technology $\mathbf{P_i}(t)$.

We therefore arrive at the following equation that we use for estimating models of inter- and intra-firm diffusion of E-selling and E-purchasing respectively (for a detailed derivation of the equation, see Battisti et al., 2004):

(1) $$\mathbf{D_i}(t) = f \{ \mathbf{R_i}(t), \mathbf{R_j}(t), \mathbf{SO_j}(t), \mathbf{E_i}(t), \mathbf{E_j}(t), \mathbf{P_i}(t) \}$$

Diffusion essentially is a dynamic process reflecting the spread of new technology across and within firms. However, since we have at our disposal only data for a single cross-section, i.e. the year 2002 (with some variables lagged by one year), we are not able to uncover the dynamics of technology diffusion. Instead we shall use the model to predict the factors that should be considered as determinants of inter- and intra-firm usage in the year 2002. The deficiency involved by using a single cross-section is common to almost all econometric studies dealing with intra-firm diffusion (a rare exception, however not pertaining to E-commerce, is Fuentelsaz et al., 2003), whereas investigations on inter-firm diffusion usually are based on time series information.

Using equation (1) we specify and estimate four models that explain inter-firm diffusion (i.e. adoption) and intra-firm diffusion (i.e. intensity of use) of E-commerce differentiated by E-selling and E-purchasing. We thus get two dependent variables related to inter-firm diffusion (adoption of E-selling yes/no: variable *ESALE*; adoption of E-purchasing yes/no: variable *EBUY*) based on information for all firms using the Internet. Another two dependent variables measure the degree of intra-firm diffusion of E-selling (share of E-sales as a percentage of total sales: variable *ESALEPCT*)

and E-purchasing (share of E-purchases as a percentage of total purchases of goods and services: variable *EBUYPCT*) for firms having adopted the corresponding type of E-commerce. The precise definition of the four dependent variables is given in Table 3.

Table 3

We hypothesise, firstly, that inter- and intra-firm diffusion are driven by different factors and expect this proposition to hold true for both forms of E-commerce. Secondly, we posit that the determinants of the diffusion of E-selling and E-purchasing are not the same in case of inter-firm as well as intra-firm diffusion.

In order to test these propositions, one would like to use the same vector of explanatory variables in all four models. Although, we do not fully attain this goal (partly on theoretical grounds, partly due to data restrictions), the four specifications are sufficiently similar, so that we are able to assess the validity of these hypotheses.

3.2 Specification of the explanatory part of the model

We specify the explanatory part of the model drawing, firstly, on the theoretical literature on technology diffusion as well as the empirical evidence (which primarily deals with inter-firm diffusion, i.e. adoption). Secondly, as far as possible, we also take account of previous (empirical) work specifically related to E-commerce. Table 4 gives an overview of the specification of the variables used in model estimation.

Table 4

We consider ***firm-specific rank effects,*** $\mathbf{R_i}(t)$, by using the following variables:

a) *Firm size*, measured by five dummy variables (*L5-19, ..., L200-499*) representing firm size classes based on the number (full-time equivalents) of employees in 2001 (with large firms as reference group). Many previous studies suggest that large firms are more likely to adopt new technologies (e.g. Davies, 1979; Mansfield, 1968; for a summary of the evidence, see Karshenas and Stoneman, 1995). In case of E-commerce, Bertschek and Fryges (2002) and Hollenstein (2004) also report a positive relationship between firm size and adoption. We therefore expect the size of the firm to exert a positive impact on inter-firm diffusion of both types of E-commerce (*negative* sign of the five dummies, with very large firms as reference group). In case of intra-firm diffusion, the influence of firm size is more controversial. Some studies find that small firms, once they have adopted a new technology, tend to use it more intensively than large ones (see Mansfield, 1963, and more recently: Battisti et al., 2004; Fuentelsaz et al., 2003). In contrast, Battisti and Stoneman (2005) detected a positive size effect in case of intra-firm diffusion of CNC machine tools. No significant impact of firm size on the extent of usage of new technology was found by Astebro (2004) in case of CNC and CAD technology. According to Hollenstein (2004), the effect of firm size on intra-firm diffusion differs among specific elements of ICT. Against this background, in contrast to adoption, we expect a *positive* sign of the firm size dummies (with the largest firms as

reference group) in case of intra-firm diffusion of E-selling and E-purchasing, but the effect may not necessarily be significant.[7]

b) *Technical prerequisites for adopting and extending the usage of new technology*, measured by the number of ICT elements (e.g. PC, Internet, Intranet, etc.) a firm had installed in 2001 (variable *ICTINFRA*; value range 1 to 9; for details see Table 4). It is assumed that a firm is more likely to introduce and to use intensively E-selling and E-purchasing the more it already has developed its ICT infrastructure. In case of E-purchasing, we control, additionally, for downstream capacity of data transmission, which is captured by two dummy variables representing the firm's use (yes/no in 2002) of specific high speed Internet connections, with firms using low speed connections (analogue, ISDN) as reference group; *DSL* depicts the use of Digital Subscriber Line (ADSL, HDSL, SDSL, etc.), and *HSPOTHER* represents firms using other high-speed connection techniques (satellite, TV cable, WLAN, etc.).

c) *Absorptive capacity*, represented by *INNO*, a dichotomous variable that indicates whether a firm introduced product or process innovations in the period 2000-2002. We have used this variable, following Cohen and Levinthal (1989) and many empirical studies, on the grounds that innovative firms may have a greater capacity to absorb new technologies (for evidence in the case of E-commerce, see e.g. Bertschek and Fryges, 2002, or Hollenstein, 2004). In addition to this overall indicator of absorptive capacity, we use a measure specifically oriented towards ICT (proportion of employees regularly using the Internet; variable *NETUSER*), expecting that a high proportion of this type of personnel facilitates adoption and intensive usage of the two types of E-commerce. Consequently, we expect both variables to exert a positive impact on inter- and intra-firm diffusion. The effect might be larger in case of E-selling since its adoption is more demanding than that of E-purchasing.

d) *Potential of application*, captured by a measure of the extent to which a firm's product(s) are suited for E-selling (variable *POTENTIAL*; assessment of the firms themselves on a three-point scale). Goods which, in advance to selling, need to be examined or tried by the buyer (e.g. consumer goods such as shoes; see Liang and Huang, 1998), or investment goods that are developed specifically according to a buyer's specifications are hardly suited for E-selling. Similar arguments apply to services requiring face-to-face contacts. In case of multi-product firms, the potential for using the Internet as selling channel may strongly differ among the individual products. Therefore, the potential for intensifying the usage of E-selling may be an important determinant of intra-firm diffusion as well. Consequently, this variable is expected to be positively related to the adoption and the extent of usage of E-selling.

e) *Foreign-owned company*, measured by a dummy variable (*FOREIGN*) indicating whether a firm is controlled by a foreign parent company. We include this variable, which has not been considered in previous studies of technology diffusion, on the grounds of some evidence that

---

7 Firm size may also be interpreted, to some extent, as a control variable as it captures the impact of some variables not specified in the model. In this sense, firm size may correct a (potential) omitted variable bias in a similar way as the industry dummies we explicitly use as control variables.

foreign parent companies often transfer new technology to domestic affiliates (e.g. Erdilek and Wolf, 1997); see also the literature dealing with technology flows within multinational firms). We expect that foreign ownership is positively related to the adoption and extent of usage of both types of E-commerce.

In order to control for ***environmental and industry-specific rank effects,*** $\mathbf{R_j}(t)$, we include the following variables:

f) Intensity of competition on a firm's product markets, measured by the two variables *CHANGE* and *ENTRY*, which reflect the outcome of a principal component factor analysis of the importance of five dimensions of a firm's market environment (as assessed by the firms themselves on a five-point scale). The quality of the factor solution is satisfactory as the two factors we extracted account for 60% of total variance and show a convincing pattern (for details, see Table A1 in the appendix). *CHANGE* indicates rapidly changing production technologies and short product cycles, while *ENTRY* stands for low entry barriers and high market uncertainty. As competition may be an important driver of innovative activity, we also expect that the two competition variables are positively correlated with inter- and intra-firm diffusion of the two types of E-commerce. So far, evidence with regard to the impact of competition on the diffusion of E-commerce is not conclusive. Whereas Bertschek and Fryges (2002) found a positive impact of competitive pressure (measured by the degree of international exposure of firms), Hollenstein (2004) could not detect such an effect.

g) *Market distance*, measured by two dummy variables indicating whether the firm primarily is active on local/regional or national markets (variables *LOCAL* and *NATIONAL*), with firms serving international markets as reference group. The evidence with respect to the impact of market distance is ambiguous. On the one hand, Freund and Weinhold (2004) found that the diffusion of E-selling is fostered by lower cross-border transaction costs due ICT. On the other hand, Adelaar et al. (2004) could not detect any ICT-related change of the geographical extension of markets. Moreover, Steinfield et al. (1999) showed that successful strategies of B2C are mostly accompanied by local physical presence as a means to increase trust and reduce consumer risk. Considering these arguments, we expect that orientation towards local and national markets is positively correlated with the diffusion of E-selling, but the effect may not necessarily be significant.

h) *Industry dummies*, (16 industries, as defined in Table 4, with "energy/water/construction" as reference category, are used to control for unobserved heterogeneity and "omitted variable bias. It is left to empirics to determine sign and magnitude of such industry effects.

Next we deal with ***epidemic effects*** which reflect both learning from own experience (within-firm epidemic effect) and learning from the experience of other firms (between-firm epidemic effects).

Within-firm learning, $\mathbf{E_i}(t)$, which we expect, with some reservations (see below, paragraph j), to favour early adoption and an intensive usage of both types of E-commerce (positive sign), is specified as follows:

i) *Experience with a predecessor technology*, measured by the dummy variable *EDI*, indicating whether a firm used (non IP-based) "Electronic Data Interchange" in 2001. This specification implies a one-year lag between EDI, the old technology, and the adoption and usage of the new technology, i.e. Internet-based E-commerce , in the year 2002. Given the data at hand, it was not possible to apply a longer time-lag. We expect EDI to exert a positive effect on inter- and intra-firm diffusion of the two types of (IP-based) E-commerce, although the costs of switching from old to new technologies work in the opposite direction. The available evidence points to a positive (net) effect in case of E-commerce (Bertschek and Fryges, 2002; Dholakia and Kshetri, 2004; Hollenstein, 2004) and some other technologies (see, among others, Arvanitis and Hollenstein, 2001; Colombo and Mosconi, 1995; McWilliams and Zilberman, 1996).

j) *Complementarity/substitution of old and new technology* also is related to the within-firm experience effect; it is proxied by the share of EDI-based sales/purchases as a percentage of total sales/purchases in 2001 (implying a one year lag; variables *EDISELLPCT* and *EDIBUYPCT*). A positive sign would point to a complementary relationship between old and new technology, at least in the short run (old and new technologies co-exist), whereas a negative sign could reflect economies of scale that may be gained by sticking to the old technology. In this way, complementarity supports positive experience effects, whereas substitution refers to the switching costs mentioned above.

Between-firm learning, $\mathbf{E_j}(t)$, which is expected to foster the adoption and the extent of usage of the two types of E-commerce (positive sign), is specified according to standard practice:

k) *Learning from firms having adopted E-commerce*, measured by the share of firms having adopted E-commerce in the industry to which the firm belongs (variables *EPIDINTERSELL* and *EPIDINTERBUY*).

l) *Learning from firms intensively using E-commerce*, measured as an industry's mean share of E-sales/E-purchases in total sales/purchases (variables *EPIDINTRASELL* and *EPIDINTRABUY*).

In a cross-section analysis, between-firm epidemic effects $\mathbf{E_j(t)}$ are measured in the same way as between-firm stock and order effects $\mathbf{SO_j}(t)$, i.e. the industry usage of the new technology. Since $\mathbf{E_j(t)}$ and $\mathbf{SO_j}(t)$ work in the opposite direction, we are not able to separate out the positive impact of between-firm learning and the negative influence of the stock and order effects.[8] Therefore, the empirical estimates only show the net effect which may be positive (dominance of the epidemic effect), negative (dominance of stock and order effects) or insignificant (the two opposite effects offset each other, or, none of the two effects is strong enough to "produce" a significant positive or negative sign).

The evidence from time series analyses shows that between-firm epidemic effects are powerful drivers of *inter*-firm diffusion of new technology (for a review of a set of papers, see Canepa and Stoneman, 2003). The results with respect to *intra*-firm diffusion are not so conclusive, although they also point to positive effects. However, with one exception (Fuentelsaz et al., 2003), the evidence is

8 In case of E-commerce, negative stock/order effects are alleviated by positive network effects (see Easton and Araujo, 2003).

based on cross-section studies (for the case of E-commerce see Battisti et al., 2004; Hollenstein, 2004). On the grounds of these pieces of evidence as well as of theory we may expect that epidemic effects play an important role in explaining not only inter-firm diffusion of E-selling and E-purchasing but intra-firm diffusion as well.

We also take into account the ***costs of adopting or extending the usage of E-commerce***, $\mathbf{P_i}(t)$. In contrast to most studies (for some previous work see Battisti and Stoneman, 2005; Stoneman, 1990), we apply a broad concept of adoption costs as we capture, in addition to the costs of investing in the new technology (in the narrow sense), several aspects of adjustment costs and of costs reflecting uncertainties. Adjustment costs may be substantial and a multiple of the price of the technology (see Brynjolfsson and Hitt, 2000). These broadly-defined costs of adopting E-commerce are represented by seven variables we identified by performing a principal component factor analysis of the importance of 18 (potential) obstacles to E-commerce as assessed on a three-point scale by the firms themselves (see Table A2 in the appendix). The quality of the factor solution is high: the seven factors we extracted account for 76% of total variance and cover the most important components of the costs of adopting E-selling as proposed and reported in the literature:

m) Costs of technology use, $\mathbf{P_i}(t)$, are represented by the following seven variables: *TECHCOST* captures the "traditional" element of adoption costs, i.e. the investment and current costs of new technology (Canepa and Stoneman, 2005). *ORG* refers to costs arising from the need to re-organise production processes and to overcome problems of compatibility with existing ICT infrastructure (for the case of E-commerce, see Kaefer and Bendoly, 2004; OECD, 2000). *TECH* and *ECON* capture technological and economic uncertainties respectively, which are highly important in case of E-commerce (Eurostat, 2004; Hollenstein et al., 2003). The variable *KNOWHOW* covers costs arising from information problems and a lack of qualified ICT-related personnel (see, among many others, Chapman et al., 2000; Lange et al., 2000). *SECURITY* stands for costs caused by problems concerning data protection or insufficient reliability of online payment that are stressed, for example, in OECD (2000). Finally, *RESIST* captures costs generated by resistance to the new technology within the firm (e.g. resistance of salesmen in case of E-selling) and insufficient attention paid to E-commerce by the management (see Chang et al., 2003).[9] We expect these cost variables to exert a negative influence on the diffusion of E-commerce. However, it cannot be excluded that we also find some insignificant or even positive signs, particularly in case of intra-firm diffusion, since certain obstacles may become relevant only beyond a certain level of technology use. We only can determine the influence of costs of inter- and intra-firm diffusion in case of E-selling, since we do not have at our disposal data reflecting barriers to E-purchasing.

Finally, we include a set of variables representing the most important dimensions of **anticipated benefits** accruing to a firm from **using a *specific* new technology** such as E-selling or E-purchasing. We hypothesise that rank, epidemic and stock/order effects reflect a concept of explanation that is too

[9] Resistance from the management side, to a certain extent, reflects some subjective obstacles that are not captured by the other six (objective) impediments to E-commerce.

general to fully capture *technology-specific* benefits (for example, benefits from "linking the elements of internal ICT infrastructure"). The fact that these variables are only very weakly correlated with those capturing rank and epidemic effects supports the usefulness of this approach that has been successfully applied in Arvanitis and Hollenstein (2001) and Hollenstein (2004).

Since the benefits to be gained from using E-selling and E-purchasing respectively are different, we include two separate sets of variables. These are identified by performing two factor analyses, based on twelve (potential) types of benefits in case of E-selling, and on eight items as far as E-purchasing is concerned. For both types of E-commerce the factor analysis yielded satisfactory results: the four factors we extracted for E-selling account for 66% of total variance, for E-purchasing the two factors representing the optimal solution capture 53% of total variance (for details see Table A3 and A4 in the appendix). The following dimensions of anticipated benefits of E-selling and E-purchasing were included in the empirical model:

n) Four components of benefits of E-selling: The variable *MARKET* refers to anticipated benefits from E-selling on the revenue side; it captures benefits resulting from developing new markets and launching new products. *COSTSALE* stands for expected cost reductions in general as well as in marketing. *PROCESS* depicts advantages to be gained from improving internal processes (speeding-up business processes, linking ICT elements) and optimising the interface to users (e.g. customer orientation). Finally, *COMPET* stands for anticipated benefits from (technologically) keeping up to competitors and improving market appearance and image.

o) Two components of benefits of E-purchasing: The variable *SUPPCOST* refers to anticipated benefits accruing from higher transparency of the input market, easier access to suppliers, lower purchasing costs as well as cost-savings resulting from improved internal processes (lower inventory requirements, more rapid business processes). *SUPPLINK* reflects improved backward and forward linking of the ICT elements relevant for E-purchasing as well as a better market presence (image and appearance, (technologically) keeping up with competitors).

These two sets of variables capture the most important benefits from the usage of E-commerce reported in the literature (see, for example, Garicano and Kaplan, 2000; Lucking-Reiley and Spulber, 2001; Pires and Aisbett, 2003; and, in much detail, OECD, 2000). With regard to savings of labour input, we refer to the vast literature on skill-biased technical change (specifically for ICT, see e.g. Bresnahan et al., 2002). We expect these variables representing anticipated benefits from E-selling and E-purchasing respectively to exert a positive influence on adoption and intra-firm diffusion of the two types of E-commerce.

4. Estimation procedure and empirical results

4.1 Estimation procedure and methodological problems

In order to model the extent of diffusion of the two types of E-commerce in 2002 we used the Heckman (1976) selection model (maximum likelihood estimator),[10] where the selection equation captures *inter*-firm diffusion (adoption yes/no (1, 0): *ESALE*, *EBUY*; sample: all Internet users) and the second equation ("intensity equation") represents *intra*-firm diffusion (extent of within-firm usage of E-selling and E-purchasing: *ESALEPCT*, *EBUYPCT*; sample: firms engaged in E-selling and E-purchasing respectively). The extent to which the inter- and the intra-firm diffusion equations are related (sample selection) is measured by parameter ρ (i.e. the correlation between the residuals of the two equations), which in case of dependence of the two equations significantly differs from zero. In such conditions, separate estimation of the intensity equation would yield biased parameter estimates. However, as can be seen from the results reported in the last row of Table 5, the Wald test of independence of the two equations ($\rho = 0$) cannot be rejected at any reasonable level of significance both for E-selling and E-purchasing.[11] This result is in line with the findings of Battisti and Stoneman (2003, 2005) suggesting that to be an adopter does not necessarily mean being an extensive user of the new technology. Although we did not find a statistically significant dependence of the two equations, we present in this paper the results we got from estimating the Heckman model.[12]

Before proceeding to the results we deal with some methodological problems. Firstly, one may object that the decision of using E-selling and E-purchasing is not taken independently. Joint decision-making, however, would ask for simultaneous modelling, what is a difficult task in this case as it would involve a combination of two Heckman selection models. Nevertheless, in order to get some insight into a (potential) dependence of the two decisions, we performed for the adoption part of the model, a bivariate probit estimation; and, indeed, the Wald test of ($\rho = 0$) shows a significant sign indicating some dependence. However, as the results of this exercise hardly differ from those we got from applying the Heckman selection model, we only present the estimates of the latter procedure.

A second problem to be discussed is endogeneity. The majority of the explanatory variable refers to 2002, that is the same year as the dependent variables, and the innovation variable INNO is measured for the period 2000-2002. We define the former as "potentially endogenous", while the latter is "potentially weakly endogenous".[13] We tested for endogeneity by instrumenting the innovation

---

[10] Astebro (2004) and Battisti and Stoneman (2003) applied a similar approach in modelling technology diffusion, that is Heckman's two-stage estimation procedure (Heckman, 1979).

[11] We notice that, in our model, the adoption and the "intensity" equation slightly differ as one variable (ICTINFRA) deliberately has been dropped in the intensity equation in order to get unbiased parameter estimates (see Wooldridge, 2006). In the present case, however, the differences are larger, as information on anticipated benefits is available only in case of the intensity equation. In order to test the independence of the two equations in a way that is fully in line with panel econometrics (i.e. all variable, except one, should be common in both equations), we estimated a modified Heckman model where the "benefit variables" were excluded from the intensity equation. The results of this exercise fully confirm the previous findings: the decisions to adopt and to extend the usage of E-selling (E-purchasing) are independent.

[12] Independent estimation of an adoption equation (probit) and the "intensity" equation (OLS) yielded practically the same results.

[13] A different case are the anticipated benefits of technology use which, as measured in this paper, refer to assessments made at the time the data were collected (i.e. the year 2002). Consequently, diffusion having occurred before that period, in a strict interpretation, is explained by expectations formed later on. Therefore, we have to assume that anticipations have been relatively

variable, which is most suspicious to be endogeneous; however, the Rivers-Vuong (1998) test did not point to an endogeneity bias. In addition, we re-estimated the model omitting the potentially endogeneous variables. We found that this procedure hardly affected the other parameter estimates. In view of these results, we are quite comfortable that the parameter estimates of our model are unbiased.

Finally, multicollinearity could be an issue, particularly in view of the large number of explanatory variables. However, it turns out that correlations between the covariates, with only few exceptions, are very low, in case of E-selling, and even more so for E-purchasing. We conclude that multicollinearity is not a (serious) problem.[14]

4.2 Empirical results

4.2.1 General assessment

The core elements of the encompassing model of diffusion underlying the analysis are confirmed. Rank and epidemic (*net of* stock/order) effects are very important determinants of inter- and intra-firm diffusion of both types of E-commerce. Furthermore, the costs and anticipated benefits of the usage of E-commerce technologies play an influential role. The estimates show that it is sensible to use a broad concept of costs that accommodates for uncertainty, adjustment costs, etc., as well as to take account of *technology-specific* benefits (in addition to the general benefits captured by rank, epidemic and stock/order effects).

In the following we evaluate the two basic hypotheses of this paper, that is: a) inter- and intra-firm diffusion are driven by different factors in case of both types of E-commerce, and b) the determinants of the diffusion of E-selling and E-purchasing are not the same (neither in case of adoption nor in case of the intensity of use). In so doing, we shall discuss the most important results we got for the different (categories of) explanatory variables.

Table 5

4.2.2 Inter-firm vs. intra-firm diffusion

E-selling

The differences between inter-firm diffusion (adoption) and intra-firm diffusion (intensity of use) of E-selling are only moderate and pertain, primarily, to epidemic effects and some components of the costs of technology use (see column 1 and 3 of Table 5). There are only minor discrepancies with regard to rank effects. A comparison of anticipated benefits is not feasible given the data at hand; therefore differences between inter- and intra-firm diffusion of this type of E-commerce may be somewhat underestimated.

---

stable over time. Since the diffusion of E-commerce, at least in 2002, was still a very recent phenomenon, in particular in terms of transaction values (see Table 1), this assumption may be not as restrictive as it looks at first glance.

14 As the correlation matrices for the two types of E-commerce are very large, we do not include them in this paper. The reader may get them from the authors.

Among the *rank effects*, absorptive capacity and the potential for application are important drivers of both types of diffusion (the impact is stronger in the intensity equation), whereas we do not find any influence of competition and market distance. The same holds for firm size what is not in line with most previous work (in case of intra-firm diffusion, we find the expected positive sign for the smallest size categories but it is statistically not significant). Technological prerequisites play an important role for adoption; this variable has not been used in the intensity equations for econometric reasons (see footnote 11). *Epidemic effects* are highly relevant in the process of diffusion of E-selling, although in case of adoption E-selling solely is fostered by information spillovers from other adopters (between-firm learning: inter-effect). Epidemic effects are more broad-based in case of intra-firm diffusion, as firms having experience with older technologies of E-selling (within-firm learning from EDI) as well as those having good access to knowledge from experienced users (between-firm learning: intra-effect) are more likely to increase the extent of usage of this form of E-commerce. *High costs* of using E-selling technology hamper inter- and intra-firm diffusion, but there are clear differences in terms of the relevance of specific cost components: security problems are the most important obstacle in case of adoption, whereas economic uncertainty is the most relevant barrier of a more intensive usage of E-selling. We also observe a (statistically not significant) tendency for organisational adjustment costs to hamper the two types of diffusion. Finally, an increase of the efficiency of internal processes and a better design of the interface with customers are the most relevant *benefits* expected from a more intensive usage of E-selling (no data for adoption).

E-purchasing

In this case the differences between the two kinds of diffusion are large, pertaining to rank as well as to epidemic effects (see column 5 and 7 of Table 5).

As far as *rank effects* are concerned, we find significant differences among the two types of diffusion for most variables. The intensity of competition, and, to some extent, technological prerequisites are the only ones that have an influence in both cases (positive sign, as expected). Small firms use E-purchasing more intensively than larger companies (as hypothesised), whereas in case of adoption, in contrast to most previous studies on diffusion, we did not find a statistically significant size effect. Absorptive capacity and foreign ownership (interpreted as advantages from intra-group knowledge flows) are statistically significant only in case of adoption. *Epidemic effects* influence the intensity of use of E-purchasing (between- and within-firm learning) but not the adoption of this technology. Finally, anticipated *benefits* due to a reduction of procurement costs, both directly (lower prices and transaction costs) and indirectly (lower inventory requirements, faster business processes) is a highly important incentive for intensifying the use of E-selling (no data for adoption).

4.2.3 E-selling vs. E-purchasing

Inter-firm diffusion

The differences between inter-firm diffusion (adoption) of E-selling and E-purchasing are moderate (see column 1 and 5 of Table 5). They primarily pertain to epidemic effects, whereas we do not find many differences with regard to rank effects, at least as we concentrate on the core variables.

However, since data on the application potential as well as the costs of adoption are available only in case of E-selling, and information on anticipated benefits are missing altogether, we are quite sure that the differences between the two kinds of E-commerce are significantly underestimated.

Among the *rank effects*, absorptive capacity and technological prerequisites, as hypothesised, are important drivers of adoption in case of E-selling as well as E-purchasing, whereas firm size, quite surprisingly, does not influence the adoption of the two types of E-commerce. In line with our expectations, the adoption of E-purchasing is fostered by a competitive environment, but the same does not hold true for E-selling. Foreign-ownership (group-internal knowledge flows) is statistically significant, but it works in different directions for the two types of E-commerce. *Epidemic effects* favour the adoption of E-selling (between-firm learning), but are irrelevant in case of the introduction of E-purchasing.

Intra-firm diffusion

The differences between the explanation of the intensity of use of E-selling and E-purchasing are quite modest. They pertain to the rank effects, whereas we can hardly detect any differences with respect to epidemic effects and the anticipated benefits of technology use (see column 3 and 7 of Table 5). Since we have no comparable information for some important variables, such as the potential of application and the costs of technology use (only data for E-selling) as well as the technological prerequisites (only data for E-purchasing), the differences between the two types of E-commerce might be underestimated.

Rank effects quite significantly differ between the two types of E-commerce. Small firms use E-purchasing more intensively than large firms, whereas firm size is statistically not significant in case of E-selling. Absorptive capacity is an important driver of intra-firm diffusion of E-selling but not of E-purchasing. It is the other way round in case of the intensity of competition (i.e. only relevant for E-purchasing). With respect to *epidemic effects*, the differences are very small. Within- as well as between-firm learning foster the extent of usage of both types of E-commerce. We also find pretty small differences with respect to the anticipated *benefits*, which in both cases are primarily efficiency- and/or cost-oriented (E-selling: improving internal business processes and customer-related interfaces; E-purchasing: cost reduction and improving supplier-related interfaces).

5. Conclusions

Based on an encompassing model of technology diffusion (Battisti et al., 2004), we jointly analysed inter- and intra-firm diffusion of ICT, taking as an example E-commerce differentiated by E-selling and E-purchasing. The model reflects rank, epidemic, stock and order effects, and has been extended in this paper in two respects. Firstly, we used a concept of costs of technology that is broader than in most empirical studies as we included adjustment costs as well as economic, technological and institutional uncertainties. Secondly, we considered some technology-specific benefits firms expect to obtain from using E-selling and E-purchasing respectively, which may not be fully captured by the more general model specification reflecting rank, epidemic, stock and order effects.

Overall the model estimates are satisfactory for inter- and intra-firm-diffusion of the two types of E-commerce. The results for the most important categories of explanatory variables are consistent with theory, although not all covariates are significant. This assessment particularly holds true for the core components of rank and epidemic effects. Moreover, we find that adjustment costs, uncertainties and technology-specific benefits play an important role in explaining diffusion (although incomplete data hampered the estimation of the impact of some of the variables representing this part of the model). Since these factors are neglected in most previous studies, research could profit a lot from including them in theoretical and empirical models of technology diffusion.

Stock/order effects are attenuated by positive network effects that might be quite substantial as the attractiveness of E-commerce significantly increases with the number of trading partners. Nevertheless, on balance, there still may remain some negative stock/order effects, which work in the opposite direction than positive between-firm epidemic effects. Unfortunately, we are not able to disentangle these countervailing forces, because the empirical analysis is based on a single cross-section. Therefore, the estimated between-firm epidemic effect, in fact, is a *net* effect where (positive) epidemic and (negative) stock/order effects are balanced out. As this net effect is found to be significantly positive, this holds true all the more for the "pure" epidemic effect.

The two basic hypotheses investigated in this paper are confirmed, although not to the same extent. Firstly, in line with our expectations, it turns out that inter- and intra-firm diffusion are driven by different forces. This implies that to be an adopter of E-selling (E-purchasing) does not necessarily mean being an extensive user; in other words, the two decisions are independent. This result is in line with the findings of Battisti et al. (2004, 2007). The differences between inter- and intra-firm diffusion are large in case of E-purchasing, but moderate in case of E-selling.

Secondly, the diffusion of E-selling and E-purchasing is determined by different factors, but not to the extent we expected. The discrepancies between the two types of E-commerce only are moderate in case of inter-firm diffusion, and quite modest in case of intra-firm diffusion. However, due to missing information on some important groups of variables, these differences might be significantly underestimated in case of inter-firm diffusion and, to a lesser extent, with regard to intra-firm diffusion as well. Therefore, we conclude that it is necessary to distinguish between E-selling and E-purchasing in future work dealing with the diffusion of E-commerce.

The most important limitation of the paper is the cross-section nature of the analysis. As a consequence, we are not able to uncover the dynamics of the diffusion process. Therefore, an extension towards an analysis of longitudinal data (panel estimation), provided suitable data will become available, would be highly desirable.[15] Moreover, in a panel setting it would be possible to separate stock and order effects from epidemic effects. A second shortcoming is the incomplete information with respect to the (broadly defined) technology costs and the technology-specific anticipated benefits from adopting and intensively using E-commerce. This deficiency has been an

15 Fuentelsaz et al. (2003) used longitudinal data but they only analysed the intra-firm element of diffusion.

obstacle to fully identify and compare the drivers of the inter- and intra-firm diffusion of the two types of E-commerce.

References

Adelaar, T., Bouwman, H., Steinfield, C., 2004. Enhancing Customer Value Through Click-and-Mortar E-commerce: Implications for Geographical Market Reach and Customer Type. Telematics and Informatics 21, 167-182.

Arvanitis, S., Hollenstein, H., 2001. The Determinants of the Adoption of Advanced Manufacturing Technology. Economics of Innovation and New Technology 10, 377-714.

Astebro, T., 2004. Sunk Costs and the Depth and Probability of Technology Adoption. Journal of Industrial Economics 52, 381-399.

Battisti, G., 2000. The Intra-firm Diffusion of New Technologies, PhD Thesis, Warwick University.

Battisti, G., Canepa, A., Stoneman, P., 2004. Profitability, Externalities and Policy in the Inter and Intra Firm Adoption of New Technology: The Example of E-Business Activities in the UK. Paper Presented at the 8th Conference of the European Network on Industrial Policy (EUNIP), Birmingham, 13-15 December.

Battisti, G., Hollenstein, H., Stoneman, P., Woerter, M, 2007. Inter and Intra firm Diffusion of ICT in the United Kingdom (UK) and Switzerland (CH). An Internationally Comparative Study Based on Firm-level Data, Economics of Innovation and New Technology 16, in press.

Battisti, G., Stoneman, P., 2003. Inter- and Intra-firm Effects in the Diffusion of New Process Technology. Research Policy 32, 1641-1655.

Battisti, G., Stoneman, P., 2005. The Intra-firm Diffusion of New Process Technologies, International Journal of Industrial Organisation 23, 1-22.

Bertschek, I., Fryges, H., 2002. The Adoption of Business-to-Business E-Commerce: Empirical Evidence for German Companies. ZEW Discussion Paper No. 02-05, Centre for European Economic Research, Mannheim.

Bresnahan, T.F., Brynjolfsson, E., Hitt, L.M., 2002. Information Technology, Workplace Organisation, and the Demand for Skilled Labor: Firm-level Evidence. Quarterly Journal of Economics 112, 339-376.

Brynjolfsson, E., Hitt, L.M., 2000. Beyond Computation: Information Technology, Organizational Transformation and Business Performance. Journal of Economic Perspectives 14, 23-48.

Canepa, A., Stoneman, P., 2003. Comparative International Diffusion: Patterns, Determinants and Policies. Economics of Innovation and New Technology 13, 279-298.

Canepa, A., Stoneman, P., 2005. Financing Constraints in the Inter Firm Diffusion of New Process Technologies. Journal of Technology Transfer 30, 159-169.

Chang, K., Jackson, J., Grover, V., 2003. E-commerce and Corporate Strategy: an Executive Perspective. Information and Management 40, 663-675.

Chapman, P., James-Moore, M., Szczygiel, M., Thompson, D., 2000. Building Internet Capabilities in SMEs. Logistics Information Management 13, 353-360.

Cohen, W.M., Levinthal, D.H.,1989. Innovation and Learning: the two Faces of R&D. Economic Journal 99, 569-596.

Colombo, M.G., Mosconi, R., 1995. Complementarity and Cumulative Learning Effects in the Early Diffusion of Multiple Technologies. The Journal of Industrial Economics 43, 13-48.

Davies, S. 1979. The Diffusion of Process Technologies, Cambridge University Press, Cambridge.

Dholakia, R.R., Kshetri, N., (2004). Factors Impacting the Adoption of Internet among SMEs. Small Business Economics 23, 311-322.

Easton, G., Araujo, L. 2003. Evaluating the Impact of B2B E-commerce: a Contingent Approach. Industrial Marketing Management 32, 431-439.

Erdilek, A., Wolf, M.A., 1997. Technology Origins of Foreign-owned Firms in Ohio. Technovation 17, 63-72.

Eurostat, 2004. E-commerce and the Internet in European Businesses, European Communities, Luxembourg.

Freund, C.L., Weinhold D., 2004. The Effect of the Internet on International Trade. Journal of International Economics 62, 171-189.

Fuentelsaz, L., Gomez, J., Polo Y., 2003. Intrafirm Diffusion of New Technologies: An Empirical Application. Research Policy 32, 533-551.

Garicano, L., Kaplan, S.N., 2000. The Effects of Business-to-Business E-commerce on Transaction Costs. NBER Working Paper 8017, Cambridge.

Heckman, J.J., 1976. The Common Structure of Statistical Models of Truncation, Sample Selection, and Limited Dependent Variables and a Simple Estimator for Such Models. The Annals of Economic and Social Measurement 5, 475-492.

Heckman, J.J., 1979. Sample Selection Bias as a Specification Error. Econometrica 47, 153-162.

Hollenstein, H., 2004. The Determinants of the Adoption of Information and Communication Technologies (ICT). An Empirical Analysis Based on Firm-level Data for the Swiss Business Sector. Structural Change and Economic Dynamics 15, 315-342.

Hollenstein, H., Sydow, N., Wörter, M., 2003. Der Einsatz von Informations- und Kommunikationstechnologien in den Schweizer Unternehmen. KOF/ETH-Panelumfrage 2002 mit internationalem Vergleich. Swiss Federal Office of Statistics, Neuchâtel.

Kaefer, F., Bendoly, E., 2004. Measuring the Impact of Organizational Constraints on the Success of Business-to-Business E-commerce Efforts: a Transactional Focus. Information & Management 41, 529-541.

Karshenas, M., Stoneman, P., 1995. Technological Diffusion. In: Stoneman, P., (Ed.), Handbook of the Economics of Innovation and Technological Change. Blackwell, Oxford, pp. 265-297.

Lange, T., Ottens, M., Taylor, A., 2000. SMEs and Barriers to Skills Development: a Scottish Perspective, Journal of Industrial Training 24, 5-11.

Liang, T.P., Huang, J.S., 1998. An Empirical Study on Consumer Acceptance of Products in Electronic Markets: a Transaction Cost Model. Decision Support Systems 24, 29-43.

Lucking-Reiley, D., Spulber, D.F., 2001. Business-to-Business Electronic Commerce. Journal of Economic Perspectives 15, 55-68.

Mansfield, E., 1963. Intrafirm Rates of Diffusion of an Innovation. The Review of Economics and Statistics 45, 348-359.

Mansfield, E., 1968. Industrial Research and Technological Innovation, Norton, NY.

McWilliams, B., Zilberman, D., 1996. Time of Technology Absorption and Learning by Using. Economics of Innovation and New Technology 4, 139-154.

OECD, 2000. The Economic and Social Impacts of Electronic Commerce: Preliminary Findings and Research Agenda, Paris.

Pires, G.D., Aisbett, J., 2003. The Relationship Between Technology Adoption and Strategy in Business-to-Business Markets. The Case of E-commerce. Industrial Marketing Management 32, 291-300.

Rivers, D., Vuong, Q.H., 1988. Limited Information Estimators and Exogeneity Tests for Simultaneous Probit Models. Journal of Econometrics 39, 347-366.

Rubin, D.B., 1987. Multiple Imputation for Nonresponse in Surveys, Wiley, New York.

Steinfield, C., Mahler, A., Bauer, J., 1999. Electronic Commerce and the Local Merchant: Opportunities for Synergy Between Physical and Web Presence. Electronic Markets 9, 51-57.

Stoneman, P., 1990. Technological Diffusion and Vertical Product Differentiation. Economics Letters 31, 277-280.

Wooldridge, J.M., 2006. Introductory Econometrics. A Modern Approach, Third Edition, Thomson South-Western.

Table 1: Diffusion of Internet-based E-commerce in the Swiss economy by sector [1]

	Proportion of firms engaged in E-commerce (%)		E-sales and E-purchases as a proportion of total sales and intermediate inputs respectively (%)			
	Based on all firms		Sector means based on firms with:			
Industry / Sector [2]	E-purchases	E-sales	E-purchases		E-sales	
	2002	2002	2001	2002	2001	2002
Manufacturing	48	20	2.1	3.7	2.0	3.3
- High-tech	52	20	1.3	2.3	2.4	4.1
- Low-tech	46	19	3.2	5.7	1.4	2.1
Construction	41	14	4.1	5.4	1.4	2.5
Services	43	16	3.1	3.8	1.2	1.8
- Knowledge-intensive	54	18	4.8	5.8	1.2	1.5
- Other services	40	15	2.6	3.2	1.2	1.9
Total	44	16	2.9	3.8	1.3	2.0

[1] Weighted to account for deviations of the sample structure from that of the underlying population, for different response rates by "size-industry cells" of the sample and for „unit" non-response. E-selling is weighted by sales, E-purchasing by intermediate inputs.

[2] *High-tech*: chemicals/pharmaceuticals, rubber/plastics, electrical and non-electrical machinery, vehicles, electronics/instruments. *Low-tech*: other manufacturing industries and energy/water. *Knowledge-intensive services*: banking/insurance, IT-/R&D-services, business services. *Other services*: other than knowledge-intensive service industries.

Source: Hollenstein et al. (2003)

Table 2: Diffusion of Internet-based E-commerce in 2001 by country [1]

Country	Enterprises using the Internet: share of firms (%) having *purchased* via the Internet	Enterprises using the Internet: share of firms (%) having *sold* via the Internet
Austria	37	25
Denmark	49	25
Finland	54	17
Germany	45	19
Greece	17	14
Ireland	46	26
Italy	10	5
Luxembourg	29	15
Norway	na	27
Spain	8	3
Sweden	62	14
Switzerland	59	23
United Kingdom	47	19

[1] The results for Switzerland differ from those reported in Table 1 for three reasons: Firstly, international comparable data only are available for firms with 10 or more employees, whereas the threshold is 5 employees in Table 1. Secondly, the reference group in Table 2 are the Internet users as against all firms in Table 1. Thirdly, the degree of diffusion refers to the year 2001 in Table 2 as against 2002 in Table 1. Whereas the first two adjustments imply a higher percentage of adopters of E-commerce, the opposite holds true for the third difference. On balance, we find that the extent of diffusion is higher in Table 2 as compared to Table 1 for E-purchasing (59% vs. 44%) as well as for E-selling (23% vs. 16%).

Source: Eurostat (2004), Hollenstein et al. (2003)

Table 3: Specification of the dependent variables [1]

Variable	Definition
E-selling	
Adoption of E-selling	
ESALE	E-selling adopted up to 2002: *yes / no (1, 0)*
If E-selling has been a adopted up to 2002:	
ESALEPCT	Share of E-sales as a *percentage* of total sales (logarithm)
E-purchasing	
Adoption of E-purchasing	
EBUY	E-purchasing adopted up to 2002: *yes / no (1, 0)*
If E-purchasing has been adopted up to 2002:	
EBUYPCT	Share of E-purchases as a *percentage* of total intermediate inputs (logarithm)

[1] E-selling and E-purchasing throughout refer to Internet-based transactions; electronic commerce realised via EDI or networks other than Internet is not considered.

Table 4: Specification of the explanatory variables [1]

Variable	Description	Sign [2], [3], Selling	Buying
RANK effects			
Firm size			
L	5 dummy variables based on the number of employees: L5-19, L20-49, L50-99, L100-199, L200-499 (reference group: firms with 500 and more employees)	-	+ or ns
Technological prerequisites of adoption			
ICTINFRA	*ICT infrastructure in 2001*: Number of ICT elements in use (value range 1 to 9: digital assistant, laptop, PC/workstation, E-mail, Internet, EDI, LAN/WLAN, intranet, extranet)	+	+
	Speed of data transmission via the Internet: 2 dummies *(reference group: analogue modem and/or ISDN)*:	does not apply	
DSL	Use of xDSL (ADSL, HDSL, SDSL, etc.)		+
HSPOTHER	TV cable, satellite, other high-speed fixed or wireless connection (if more than one type of connection is used, that with the highest speed of transmission is assigned)		+
Absorptive capacity			
INNO	Introduction of new products and/or processes in the period 2000-2002 (yes/no)	+	+
NETUSER	Diffusion of the Internet within the firm in 2002: *5 categories* based on the percentage of employees using the Internet: 81-100% (value 5), 61-80% (value 4), 41-60% (value 3), 21-40% (value 2), 1-20% (value 1)	+	+
Potential of application			
POTENTIAL	Extent to which a firm's product is suited for *E-selling* (as assessed by the firms on a 3-point scale)	+	na
Foreign-owned			
FOREIGN	Firm owned by foreign company 2002 (yes/no)	+	+
Intensity of competition	*(Scores of a principal component factor analysis of the importance of 5 dimensions of the intensity of competition on the product market, as assessed by the firms on a 5-point scale)* Variance accounted for by the first two factors: 59.6% For details see Table A1 in the appendix		
CHANGE	Rapid change of process technologies, short product cycles	+	+
ENTRY	Low entry barriers	+	+
Market distance			
	Two dummy variables representing the principal market for a firm's products (reference group: international markets)		
NATIONAL	National markets beyond a distance of 50 km	+ or ns	does not
LOCAL	Regional/local markets (within a distance of 50 km at most)	+or ns	apply
Industry affiliation *(15 dummies)*	Food; textiles/clothing; wood/paper/printing; chemicals/pharmaceuticals/plastics; non-metallic minerals/base metals; metal products; machinery/vehicles/electrical machinery; electronics/instruments/watchmaking; wholesale trade; retail trade/personal services; hotels/restaurants; transport/telecommunication; banking/insurance; IT-/R&D services; business services (*reference group*: energy/water/construction).		

(to be continued)

(continued)

EPIDEMIC effects			
Within-firm learning			
EDI	EDI adopted in the years up to 2001 (yes/no)	+	+
EDISELLPCT	Share of *sales* realised via EDI (or networks other than Internet) as a percentage of total sales in 2001	?	does not apply
EDIBUYPCT	Share of *purchases* realised via EDI (or networks other than Internet) as a percentage of total intermediate inputs in 2001	does not apply	?
Between-firm learning			
Inter-firm			
EPIDINTERSELL	Percentage share of firms active in E-selling in 2001 in the industry the company is affiliated to (log-transformation)	+	does not apply
EPIDINTERBUY	Percentage share of firms active in E-purchasing in 2001 in the industry the company is affiliated to (log-transformation)	does not apply	+
Intra-firm			
EPIDINTRASELL	Average share of sales realised via E-selling in 2002 in the industry the company is affiliated to	+	does not apply
EPIDINTRABUY	Average share of purchases realised via E-purchasing in 2002 in the industry the company is affiliated to	does not apply	+
COSTS of technology use			
Obstacles to E-selling			
(Scores of a principal component factor analysis of the importance of 18 obstacles to the adoption and the extent of usage of E-selling, as assessed by the firms on a 3-point scale) Variance accounted for by the first seven factors: 75.7% For details see Table A2 in the appendix			
TECHCOST	High investment and current costs of technology	- / - or ns	na
SECURITY	Problems concerning data protection, security of payment or the legal framework	- / - or ns	na
ORG	Insufficient compatibility (ICT infrastructure, organisation), problems/costs of reorganisation, unwanted opening of the firm's internal network to other companies	- / - or ns	na
RESIST	Resistance to the new technology within the firm, insufficient attention for E-commerce on the management side	- / - or ns	na
TECH	Technological uncertainties, technical standards not clear	- / - or ns	na
KNOWHOW	Insufficient information with respect to technology or market opportunities, lack of qualified personnel	- / - or ns	na
ECON	Economic uncertainties: customers not ready to use E-commerce, economic benefits too uncertain	- / - or ns	na

(to be continued)

(continued)

ANTICIPATED BENEFITS (of using this particular technology)			
E-selling *(Scores of a principal component factor analysis of the importance of 12 types of anticipated benefits from using E-selling, as assessed by the firms on a 3-point scale*) Variance accounted for by the first four factors: 65.6% For details see Table A3 in the appendix			
MARKET	Opportunities of developing new markets/launching new products	na / +	does not apply
COSTSALE	Cost reduction in general, particularly in selling (marketing, after-sales services)	na / +	does not apply
PROCESS	Speeding up internal business processes, improving internal ICT networks, improving interfaces with customers	na / +	does not apply
COMPET	Keeping up to competitors, improving the firm's image and presence on the market	na / +	does not apply
E-purchasing *(Scores of a principal component factor analysis of the importance of 8 types of anticipated benefits from using E-purchasing, as assessed by the firms on a 3-point scale*) Variance accounted for by the first two factors: 52.5% For details see Table A4 in the appendix			
SUPPCOST	Better transparency of the input market, easier access to suppliers, lower purchasing costs, lower inventory requirements, improving business processes	does not apply	na / +
SUPPLINK	Improving internal ICT networks, keeping up to competitors, improving the firm's image and presence on the market	does not apply	na / +

[1] E-selling and E-purchasing throughout refer to Internet-based transactions; electronic commerce realised via other networks (e.g. EDI) is not considered.

[2] In case of different expectations for inter- and intra-firm diffusion with respect to the direction of the influence of a specific variable, the first sign refers to inter-firm diffusion, the second one to intra-firm diffusion. A question mark indicates that the direction of influence cannot be decided based on theoretical considerations or previous empirical work.

[3] Abbreviations: ns (not significant); na (not available).

Table 5: Inter- and intra-firm diffusion of E-selling and E-purchasing: cross-section estimates for 2002 [1]

Explanatory Variable	E-selling				E-purchasing			
	Adoption		Intensity		Adoption		Intensity	
	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error	Coefficient	Robust standard error
RANK EFFECTS								
Firm size								
L5-19	-0.135	0.159	0.551	0.340	-0.060	0.132	0.723***	0.264
L20-49	-0.009	0.149	0.126	0.333	-0.157	0.127	0.569**	0.261
L50-99	-0.069	0.152	-0.123	0.360	-0.164	0.127	0.462*	0.254
L100-199	-0.172	0.149	-0.114	0.403	-0.174	0.129	0.230	0.243
L200-499	-0.033	0.155	-0.632*	0.368	-0.019	0.131	0.232	0.255
Technological prerequisites								
ICTINFRA	0.082***	0.029	n.a	n.a	0.115***	0.021	n.a.	n.a.
DSL	n.a	n.a	n.a	n.a	0.412***	0.058	0.260*	0.141
HSPOTHER	n.a	n.a	n.a	n.a	0.304***	0.068	0.219	0.156
Absorptive capacity								
INNO	0.238***	0.081	0.593***	0.224	0.194***	0.059	-0.045	0.135
NETUSER	0.004***	0.001	0.007*	0.004	0.001	0.001	0.003	0.003
Potential of application								
POTENTIAL	0.389***	0.044	0.478**	0.215	n.a	n.a	n.a	n.a
Foreign-owned								
FOREIGN	-0.237**	0.100	0.418	0.318	-0.222***	0.074	0.011	0.173
Competition								
CHANGE	0.036	0.035	0.141	0.092	0.022	0.028	0.076	0.063
ENTRY	0.005	0.035	0.051	0.084	0.106***	0.026	0.128**	0.061
Market distance								
NATIONAL	0.129	0.098	0.392	0.292	n.a	n.a	n.a	n.a
LOCAL	0.131	0.090	0.304	0.277	n.a	n.a	n.a	n.a
Industry dummies	*Yes (2)*		*No*		*Yes (2)*		*Yes (1)*	
EPIDEMIC EFFECTS								
Within-firm learning								
EDI	0.116	0.086	0.451**	0.212	0.084	0.064	0.155	0.129
EDISELLPCT / EDIBUYPCT	0.003	0.002	-0.002	0.005	0.001	0.002	0.006*	0.004
Between-firm learning								
Inter-firm								
EPIDINTERSELL / EPIDINTERBUY	0.593***	0.195	0.471	0.561	0.227	0.194	0.000	0.433
Intra-firm								
EPIDINTRASELL / EPIDINTRABUY	0.207	0.147	0.989**	0.428	-0.053	0.072	0.603***	0.174

(to be continued)

(continued)

COSTS of technology use								
Obstacles								
TECHCOST	0.052	0.074	-0.090	0.183				
SECURITY	-0.122*	0.073	0.285	0.197	n.a	n.a	n.a	n.a
ORG	-0.122	0.076	-0.303	0.186	n.a	n.a	n.a	n.a
RESIST	-0.016	0.077	0.116	0.187	n.a	n.a	n.a	n.a
TECH	0.098	0.076	0.181	0.174	n.a	n.a	n.a	n.a
KNOWHOW	0.146*	0.075	0.103	0.198	n.a	n.a	n.a	n.a
ECON	-0.038	0.079	-0.456**	0.189	n.a	n.a	n.a	n.a
BENEFITS of technology use								
Benefits								
MARKET	n.a	n.a	0.205	0.181	n.a	n.a	n.a	n.a
COSTSALE	n.a	n.a	0.199	0.181	n.a	n.a	n.a	n.a
PROCESS	n.a	n.a	0.564***	0.191	n.a	n.a	n.a	n.a
COMPET	n.a	n.a	-0.060	0.182	n.a	n.a	n.a	n.a
SUPPCOST	n.a	n.a	n.a	n.a	n.a	n.a	0.433***	0.121
SUPPLINK	n.a	n.a	n.a	n.a	n.a	n.a	0.165	0.129
STATISTICS [2], [3],								
N	1472				1463			
Censored	1146				643			
Uncensored	326				820			
Wald test	chi2(44) = 135.22***				chi2(34) =94.57***			
Log Pseudo-Likelihood	-1264.459				-2466.622			
Wald test of rho=0	chi2(1)=0.40 (Prob>chi2=0.5286)				chi2(1)=0.0 (Prob>chi2=0.9470)			

[1] The statistical significance of the estimates is indicated with ***, ** and * representing the 1%, 5% and 10%-level respectively. The estimates for 15 industry dummies are omitted; we only indicate the number of statistically significant industry dummies.

[2] In case of E-purchasing, we had to exclude 9 observations because of inconsistent data.

[3] Parameter rho = corr (u_1,u_2) with u_1 = residual of the OLS regression (intensity equation) and u_2 = residual of the probit estimate of the selection equation.

APPENDIX

Table A1: Factor analysis of indicators of the intensity of competition
(based on assessments of the respondents on a 5-point scale)

Indicator	Rotated factor pattern (varimax)	
	Factor loadings	
	1	2
Rapidly changing production technologies	.87	
Goods/services shortly become obsolete	.87	
Actions of competitors difficult to foresee		.78
Low entry barriers		.66
Demand perspectives highly uncertain		.61
Statistics		
Number of observations		2586
Kaiser's overall measure of sampling adequacy (MSA)		.595
Variance accounted for by the first two factors		.596
Root mean square off-diagonal residuals (RMSE)		.159
Variance accounted for by each factor	1.53	1.45
Final communality estimate (total)		2.98

Characterisation of the two factors:

(1) Rapidly changing production technologies and short product cycles (CHANGE)
(2) Low entry barriers, market uncertainties (ENTRY)

The table shows only factor loadings of 0.4 and higher.

The factor analysis is based on the innovation survey only (all respondents).

Table A2: Factor analysis of obstacles to the adoption and the extent of usage of E-selling
(based on assessments of the respondents on a 3-point scale)

Type of obstacle	Rotated factor pattern (varimax)						
	Factor loadings						
	1	2	3	4	5	6	7
Investment volume to large	.86						
Software too expensive	.84						
Current costs too high	.80						
Problems of data protection		.86					
Security problems concerning payments		.82					
Uncertainty with respect to the legal framework		.70					
Logistical problems			.80				
Insufficient compatibility with ICT infrastructure			.69				
Large organisational adjustment requirements			.60				
Opening up the firm to others is not wanted		.46	.48				
Resistance to new technology within the firm				.85			
Insufficient attention of the management				.83			
Technological uncertainties					.82		
Technical standards not clear enough					.82		
Insufficient information (technology, market)						.78	
Lack of qualified personnel						.73	
Customers not ready to use E-commerce							.87
Uncertainty concerning economic benefits							.70
Number of observations							2968
Kaiser's measure of sampling adequacy (MSA)							.903
Variance accounted for by the first seven factors							.757
Root mean square off-diagonal residuals (RMSE)							.050
Variance accounted for by each factor	2.63	2.48	2.09	1.76	1.75	1.48	1.41
Final communality estimate (total)							13.6

Characterisation of the seven factors:

(1) Investment and current costs (TECHCOST)
(2) Security and secrecy problems (SECURITY)
(3) Organisational and compatibility problems (ORG)
(4) Resistance of workers and management (RESIST)
(5) Technological uncertainty (TECH)
(6) Lack of know-how and information (KNOWHOW)
(7) Economic uncertainty (ECON)

The table shows only factor loadings of 0.4 and higher.

The factor analysis is based on the ICT survey only (firms using the Internet).

Table A3: Factor analysis of anticipated benefits from using E-selling
(based on assessments of the respondents on a 3-point scale)

Type of benefit	Rotated factor pattern (varimax)			
	Factor loadings			
	1	2	3	4
Developing new market segments	.75			
Developing new regional markets	.74			
Launching new products	.71			
Reducing costs in general		.81		
Reducing costs of after-sales services		.79		
Reducing costs of marketing	.44	.70		
Speeding up business processes			.70	
Linking the elements of the internal ICT infrastructure			.68	
Improving customer orientation			.67	
Improving product quality and variety	.47		.54	
Keeping up to competitors				.86
Improving the firm's image and market presence				.84
Statistics				
Number of observations				824
Kaiser's overall measure of sampling adequacy (MSA)				.810
Variance accounted for by the first four factors				.656
Root mean square off-diagonal residuals (RMSE)				.076
Variance accounted for by each factor	4.05	1.55	1.27	1.01
Final communality estimate (total)				7.88

Characterisation of the four factors:

(1) Developing new markets (MARKET)
(2) Reducing (selling) costs (COSTSALE)
(3) Improving business processes and interfaces (PROCESS)
(4) Preserving the market position (COMPET)

The table shows only factor loadings of 0.4 and higher.

The factor analysis is based on the ICT survey only (firms performing E-selling).

Table A4: Factor analysis of anticipated benefits from using E-purchasing
(based on assessments of the respondents on a 3-point scale)

Type of benefit	Rotated factor pattern (varimax)	
	Factor loadings	
	1	2
Lower costs of buying transactions	.75	
Lower purchase prices	.75	
Lower inventory requirements	.62	
Speeding up business processes	.60	
Better knowledge of supply, easier access to suppliers	.45	
Keeping up to competitors		.86
Improving the firm's image and market presence		.85
Linking the elements of internal ICT infrastructure		.64
Statistics		
Number of observations		1724
Kaiser's overall measure of sampling adequacy (MSA)		.745
Variance accounted for by the first two factors		.525
Root mean square off-diagonal residuals (RMSE)		.104
Variance accounted for by each factor	2.18	2.02
Final communality estimate (total)		4.20

Characterisation of the two factors:

(3) Lowering purchasing costs, improving business processes/interfaces (SUPPCOST)
(4) Improving presence on the supplier market, linking ICT elements (SUPPLINK)

The table shows only factor loadings of 0.4 and higher.
The factor analysis is based on the ICT survey only (firms performing E-purchasing).