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On the Determinants of Cloud Computing Adoption

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Abstract

Cloud computing is widely seen as a new source of innovation as well as a driving factor of productivity improvements of firms. This paper analyses the determinants of cloud computing adoption in general as well as for specific deployment (Public vs. Private) and service models (SaaS, IaaS, PaaS). Our data set contains a representative sample of 2,970 German firms and refers to the years 2014 and 2015. The econometric analysis confirms our three main hypothesis regarding firms' decision to adopt cloud computing in general. The share of workers with mobile internet access, being a start-up, as well as the regional availability of high-speed fixed-line internet access increase the likelihood of a firm for using cloud computing services.

Keywords: Adoption of ICT, Cloud Computing, Multivariate Probit

JEL Classification Numbers: L10, L86, O33

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1 Introduction

It is well established in the literature that the implementation of information and communication technologies (ICT) improves firms' productivity and their overall competitiveness (Cardona et al., 2013; Draca et al., 2007; OECD, 2003). Currently we are experiencing a new era of digitization. In the light of the increasing availability of high performance internet connections and the enormous advantages that one expects from the automation and interconnection of production processes, digitization and digital strategies are highly ranked on the agenda of politics, industry and the firms themselves.

Since the mid of the first decade of the 21st century, a new concept called cloud computing was introduced by digital industry giants like Google and Amazon (Yang and Tate, 2012). Meanwhile, it has become one of the central trends to the current discussions about corporate information technology.¹ Given the definition by the US National Institute of Standards and Technology (NIST), cloud computing “enables ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources [...] that can be rapidly provisioned and released with minimal management effort or service provider interaction” (Mell and Grance, 2011). Consequently, cloud computing services can, at least in the long run, be operated by fewer IT staff and with less investment cost and therefore at the end with overall lower cost (Yang and Tate, 2012).

To some extent cloud computing builds upon and is an evolution of earlier approaches in the light of IT outsourcing, e.g. application service providing (ASP). By now it has become a popular concept to achieve some of the challenges firms are confronted in the age of digitization. However, to realize assumed productivity gains through cloud computing, the adoption and use of this concept and technology is imperative. So, it is essential to understand the determinants of cloud adoption.

The literature on cloud computing adoption is already very extensive, especially in the field of information system research (see for example the surveys by Hoberg et al., 2012, Asatiani, 2015 and Schneider and Sunyaev, 2016). Usually these studies are based on selective data sets or just case studies with small numbers of observations. This paper contributes to the literature of cloud computing adoption by using a vast data set with about 3,000 German firm-level observations across almost all industries and (employment) size classes. Methodologically, we use econometric techniques that enable us to explore the interdependencies of firm level characteristics assumed to influence cloud computing adoption behaviour. Additionally, this study is not only focusing on the adoption of cloud computing as a broad firm level measure. With our data and econometric approach, we can also draw conclusions about specific cloud computing ser-

¹Venters and Whitley (2012).

vice models (SaaS, IaaS, PaaS) and deployment models (Public vs. Private) used by firms and show that adoption drivers differ between service and deployment models. Therefore, this study is one of the first to take such an in-depth and methodologically advanced approach to the topic.

Recent figures show that the adoption of cloud computing in Germany is very heterogeneous across industries (see Figure 1.1). While almost half of the firms in the ICT industry claim that they already refer to cloud services, transportation services and metal manufacturer are located at the end with shares ranging from 6 to 9 percent. Especially firms from the service industries use cloud computing above average. Not surprisingly, since especially service sector companies have usually higher shares of information and communication technology users (e.g. higher share of employees working predominantly at a computer, etc.) they are more eager to invest in new information technology.

Figure 1.1: Share of Firms Using Cloud Computing in Germany



Source: ZEW ICT Report 2015 - data representative for the population of firms in these industries.

2 Background and Hypotheses

In 2013, the McKinsey Global Institute defined cloud computing as one of twelve potentially economically disruptive technologies. The authors predict that cloud computing “*creates tremendous value for [...] businesses by making the digital world simpler, faster, more powerful, and more efficient. In addition to delivering valuable Internet-based services and applications, the cloud can provide a more productive and flexible way for companies to manage their IT. Cloud technology has the potential to disrupt entire business models, giving rise to new approaches that are asset-light, highly mobile, and flexible.*” (McKinsey Global Institute, 2013, p. 57).

The OECD sees the main advantage of cloud computing from an economic perspective as “*the ability to access IT resources on demand without the need for significant capital expenditure*” (OECD, 2014, p. 4).

2.1 Definition of Cloud Computing

A commonly accepted definition of cloud computing, which is actually the bundling of various technologies and previous approaches, is provided by the US National Institute of Standard and Technology (NIST). According to that definition, cloud computing is characterized by five essential characteristics,² three service models and four deployment models .

The three service models can be distinguished between Software, Infrastructure and Platform as a Service. The exact definition, according to NIST (see Mell and Grance 2011) are given in the following paragraphs:³

Software as a Service (SaaS) is defined as the capability provided to the consumer [in our case a firm or the employees of a firm] to use the provider’s applications running on a cloud infrastructure. The applications are accessible from various client devices through either a thin client interface, such as a web browser (e.g., web-based email) or a program interface. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.

Infrastructure as a Service (IaaS) The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications, and possibly limited control of select networking components (e.g., host firewalls).

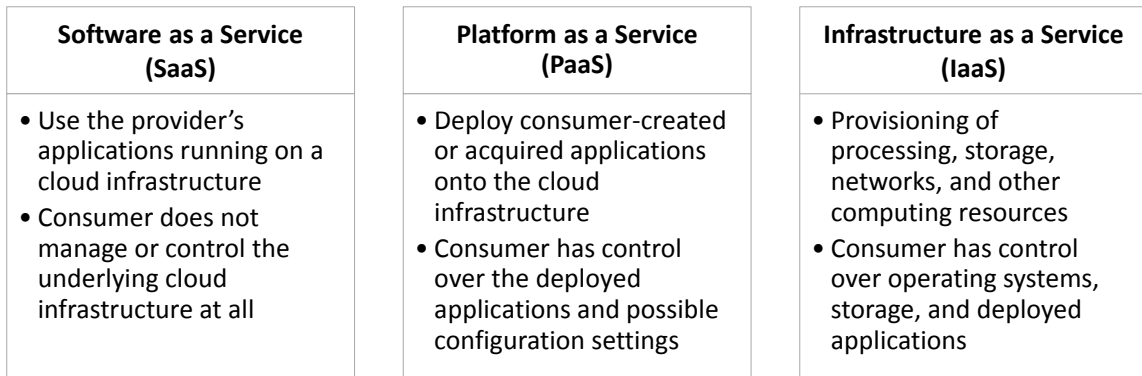
Platform as a Service (PaaS): The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming

²Those are *on-demand self-service, broad network access, resource pooling, rapid elasticity* and *measured service*. For more information on those aspects, see Mell and Grance (2011).

³See also Figure 2.1.

languages, libraries, services, and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment.

Figure 2.1: Cloud Computing Service Models



Source: Authors’ own diagram based on Mell and Grance (2011).

According to NIST, the deployment models are defined as follows:⁴

Private Cloud: The cloud infrastructure is provisioned for exclusive use by a single organisation comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by the organisation, a third party, or some combination of them, and it may exist on or off premises.

Public Cloud: The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organisation, or some combination of them. It exists on the premises of the cloud provider.

Hybrid Cloud: The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds).

2.2 Hypotheses

In the following section we postulate our three main hypotheses which are primarily based on previous results from the literature on the adoption of new (information) technologies and specifically cloud computing. We aim at validating these hypotheses in the empirical models presented later on.

Hypothesis 1 (H1): *Higher shares of employees with mobile broadband access increase the probability of cloud computing adoption.*

⁴We do not cover the rarely used Community Cloud in this paper.

One advantage of cloud computing is, at least when it comes to public cloud solutions, that there is universal accessibility from almost every place on earth, assuming a sufficient broadband connection is available. With mobile broadband internet, the concept of ubiquitous working, which means working either at any place on-premises, on the way from home to work and vice versa, or at any activity off-premises is possible. We therefore assume that a higher share of employees which are equipped with mobile broadband access and corresponding hardware equipment (smartphones, tablets and notebooks) leads to a higher probability of cloud computing adoption, especially when it comes to the use of SaaS cloud services.

Hypothesis 2 (H2): *Younger firms are more likely to use cloud computing services.*

Younger firms often face capital constraints and therefore are more likely to choose cloud computing services instead of investing in own ICT. Furthermore, they usually do not have legacy software applications that could hinder the move to a cloud environment. We therefore assume that younger firms are more likely to use cloud computing services.

Hypothesis 3 (H3): *A higher share of households with high-speed fixed-line internet access in the same municipality increases the probability of cloud computing adoption.*

In addition to Hypothesis 1 with the focus on mobile internet access, fixed broadband availability is also expected to play a crucial role for the firms' cloud computing adoption decision. Remote access of the firms' employees to cloud services of their employer requires high-speed internet at their place of residence. Moreover, the availability of high-speed internet for households of the municipalities where the firms are located increases the probability that the firms also have high-speed fixed-line internet access. We therefore assume that a higher share of households with high-speed fixed-line internet access in the same municipality increases the probability of cloud computing adoption.

The existing literature lists quite a number of additional factors that potentially influence the cloud computing adoption decisions by the firms. We therefore control for the general ICT intensity of the firm, the firm size as measured by the number of employees, population density, an index of organisational measures, self-assessed competitiveness, as well as the age and qualification structure of the firm.

3 Data and Descriptive Statistics

3.1 Data

The data used for the analysis stems from the ZEW ICT survey which is a broad survey of about 4.500 German manufacturing and services firms⁵ with at least five employees.⁶ In 2014 and 2015, the sixth wave of this survey was conducted via computer-aided telephone interviews (CATI). All waves⁷ contain information about the ICT usage of the firm as well as other more general firm characteristics like the turnover or the number of employees. The 2014 wave was the first one containing detailed information on the implementation of cloud computing and is therefore the only wave used for our empirical analysis. After controlling for implausible values and due to item non-response, we end up with an estimation sample of 2,970 firm observations.⁸ The firms were asked several questions regarding their cloud computing usage. Apart from the question whether they are using this new technology at all, there were specific questions about the deployment models (public or private cloud) as well as the particular service models (SaaS, PaaS and IaaS). In addition, we use data on high-speed broadband availability and population density for the municipalities where the firms are located. Data on high-speed broadband comes from the German Broadband Atlas (BMVI 2016), the population density data is provided by the German National Statistical Office (Destatis 2015).

3.2 Descriptive Statistics

Table 3.1 shows some descriptive statistics for the estimation sample for cloud computing adopters and non-adopters. A total of 594 or 20 percent of the firms in our sample are using some form of cloud services in the year 2014. Out of the cloud computing users, 59 percent use SaaS, 61 percent IaaS and only 27 percent (or 5 percent of the total sample) PaaS. There is no clear trend about the deployment model. About 48 percent of the cloud computing users opted for public cloud services and 59 employ private cloud solutions. This implies that there are also enterprises that combine services from public and private clouds (hybrid clouds).

Firms that use cloud computing services have on average a higher share of employees equipped with mobile internet devices (34 vs. 21 percent). They are also on average slightly younger than the firms that do not use cloud computing. Furthermore, it is much more likely that they are located in municipalities where at least 90% of the households have high-speed fixed-line internet access with more than 50 Mbit/s (26 vs. 17 percent). There are also significant differences between cloud computing adopters and non-adopters regarding the use of other forms

⁵Table A.1 shows the distribution of firms across industries.

⁶The data are available at the ZEW Research Data Centre - <http://kooperationen.zew.de/en/zew-fdz>.

⁷Years 2000, 2002, 2004, 2007, 2010 and 2014.

⁸We dropped firms with less than 5 employees (163) and with more than 5.000 employees (19). Since ICT investment is taken in logs, zero investment is replaced by the 10th percentile of investment per employee observed in the corresponding industry multiplied by the number of employees (322 firms).

of ICT and their general firm characteristics.⁹ Cloud computing adopting firms are in general much more ICT intensive. They have a higher share of employees working predominantly with computers (57 vs. 39 percent) and a higher share of employees with internet access at work (71 vs. 53 percent). Firms that use cloud computing services also have much more in-house IT staff (11 vs. 5 percent) and slightly higher online sales. They also invest about three times more in ICT equipment than the non-adopters, despite having only about twice as much employees. Cloud computing adopters are also located in regions with a higher population density (1.18 vs. 0.87 people per square km of land area).

The count variable organisational measures contains the sum of six binary variables describing the level of advanced management practices of the firms like having self-managed teams or units with profit and loss responsibility. As the rollout of cloud computing is often related to organisational changes, it is no wonder that cloud computing adopters show higher numbers for the organisational measures (2.87 vs. 1.96). Enterprises that use cloud computing services also consider themselves to have a competitive advantage over other firms in their respective industry. With a share of 27 percent, they also employ nearly twice as much highly qualified employees compared to the firms that do not use any form of cloud computing services. The differences regarding the share of employees above the age of 50, the firm location (East or West Germany) and whether the firm exports or not are in contrast rather modest.

⁹Independent group t-tests for all variables of Table 3.1 show significant differences between cloud computing adopters and non-adopters at the 10 percent level.

Table 3.1: Summary Statistics by Cloud Computing Use: Estimation Sample

	With CC		Without CC		Total	
	N	Mean	N	Mean	N	Mean
Cloud Computing	594	1.00	2376	0.00	2970	0.20
SaaS	594	0.59	2376	0.00	2970	0.12
IaaS	594	0.61	2376	0.00	2970	0.12
PaaS	594	0.27	2376	0.00	2970	0.05
Public Cloud	594	0.48	2376	0.00	2970	0.10
Private Cloud	594	0.60	2376	0.00	2970	0.12
% of Emp. Using Mob. Internet	594	0.34	2376	0.21	2970	0.24
Firm Age 0-3	594	0.05	2376	0.03	2970	0.04
Firm Age 4-7	594	0.07	2376	0.05	2970	0.06
Firm Age >7	594	0.88	2376	0.91	2970	0.91
90% High-Speed Fixed-Line	594	0.26	2376	0.17	2970	0.19
% of Emp. Predom. Using PC	594	0.57	2376	0.39	2970	0.43
% of Emp. Using Internet	594	0.71	2376	0.53	2970	0.56
% of Emp. IT Staff	594	0.11	2376	0.05	2970	0.06
% of Online Sales	594	0.06	2376	0.04	2970	0.05
ICT Investment in Mill. Euro	594	0.34	2376	0.10	2970	0.15
Employees	594	179.91	2376	79.96	2970	99.95
Population Density	594	1.18	2376	0.87	2970	0.93
Organisational Measures (1-6)	594	2.87	2376	1.96	2970	2.14
Highly Competitive	594	0.61	2376	0.46	2970	0.49
% Highly Qualified Employees	594	0.27	2376	0.16	2970	0.18
% of Employees > Age 50	594	0.23	2376	0.28	2970	0.27
East Germany Dummy	594	0.20	2376	0.26	2970	0.25
Export Dummy	594	0.49	2376	0.45	2970	0.45

Detailed Summary Statistics can be found in Table A.2. Furthermore, a comparison between manufacturing and services firms is given in Table A.3.

4 Estimation Strategy

We basically use three different regression models to analyse the (1) general cloud computing adoption, (2) the two different deployment models (public or private cloud) and (3) the particular service models (SaaS, PaaS and IaaS). For the general cloud computing adoption, we apply a standard probit regression model. As we expect that neither the adoption of the two deployment models nor the choice between the three service models are mutually exclusive respectively uncorrelated, simple probit regressions are not advisable. Models that simultaneously estimate the equations and incorporate the covariance structure are in general more efficient (see e.g. Cappellari and Jenkins 2003 and Trivedi and Zimmer 2007, p. 75). We

therefore estimate (multivariate) probit models¹⁰ of the following form:

$$\begin{aligned}
y_m^* &= \mathbf{x}'_m \boldsymbol{\beta}_m + \epsilon_m, & y_m &= 1 \text{ if } y_m^* > 0, & 0 & \text{ otherwise} & m &= 1 \dots M, \\
E[\epsilon_m | \mathbf{x}_1, \dots, \mathbf{x}_M] &= 0, \\
Var[\epsilon_m | \mathbf{x}_1, \dots, \mathbf{x}_M] &= 1, \\
Cov[\epsilon_j, \epsilon_m | \mathbf{x}_1, \dots, \mathbf{x}_M] &= \rho_{jm}, \\
(\epsilon_1, \dots, \epsilon_M) &\sim N(0, \mathbf{R})
\end{aligned} \tag{1}$$

where y represents the observed binary indicator (for the specific type) of cloud computing adoption and x the vectors of explanatory variables. For the case of the general cloud computing adoption, we estimate $m = 1$ equations and therefore a simple probit model. The decision on private vs public cloud computing leads to $m = 2$ equations (bivariate probit). The trivariate probit estimations ($m = 3$) for the specific types of service models (SaaS, PaaS and IaaS) were carried out using the *cmp* add-on for Stata developed by Roodman (2011).¹¹

5 Empirical Results

Table 5.1 presents average marginal effects from probit regressions for the general adoption of cloud computing for the total sample as well as the manufacturing and services firms subsamples. For all three samples, we present basic regression results as well as additionally estimates with an extended set of explanatory variables.

A higher share of workers equipped with mobile internet devices has a significantly positive impact on the probability of using cloud computing services in the manufacturing and the service sector (H1). Being a younger firm (age 0-3 and 4-7) is only a determinant of cloud computing adoption in the total sample. Moreover, firms of age 4-7 in the manufacturing sector are more likely to use cloud computing services (H2). The local availability of high-speed internet is positively associate with cloud adoption in the total sample and the manufacturing subsample, but not for services firms (H3).

The next five variables of Table 5.1 all describe the general ICT intensity of the firms. The share of employees working predominantly with a computer does not influence the cloud computing adoption decision in all three samples. We also do not find a significant correlation between ICT investments and cloud computing in the manufacturing sector. In general, the ICT intensity positively affects the cloud computing adoption decision. Firm size only affects the cloud computing adoption decision in the manufacturing sector. Following good organisa-

¹⁰See e.g. Greene (2012, p. 792).

¹¹*cmp* stands for conditional mixed process estimator. For recent applications of the *cmp* add-on in a multivariate probit context see e.g. Aristei et al. (forthcoming) and Hottenrott and Peters (2012).

tional practices, like having self-managed teams or units with profit and loss responsibility is associated with a higher probability of using cloud computing services. We do not find any impact of the qualification level of employees on using cloud computing services, neither in the total sample nor in one of the subsamples. Furthermore, firms' competitiveness is positive and significantly correlated with the probability of cloud computing usage in the total sample and manufacturing subsample. An older workforce has a significantly negative impact on the probability of adopting cloud computing services in the full sample and service sector subsample.

Table 5.2 shows the results of a bivariate probit regression on the adoption of a specific deployment model. The four columns are the average marginal effects for the four possible outcomes of the bivariate model.¹² The marginal effects of using no cloud computing services at all is the negative sum of the other three combinations of using cloud computing (hybrid, only public or only private). A Wald test based on the estimated correlation of $\rho = 0.448$ suggests that estimating a bivariate model is more efficient than having two separate probit regressions for public and private cloud computing.

A higher share of employees equipped with mobile internet devices is associated with a higher probability of having a hybrid cloud (public and private clouds) environment as well as private clouds (H1). The same is true for very young firms of age 0-3 (H2). Furthermore, high-speed fixed-line internet access is relevant for hybrid and public clouds (H3).

The share of IT employees increases the probability to use a combination of public and private clouds (hybrid clouds) and to a greater degree the probability of having only a private cloud. The same is true for IT investments, firm size (measured by the number of employees) and whether firms follow good organisational practices. The qualification level of the employees does not affect the probability of choosing either one of the deployment models. Moreover, an older workforce reduces the probability of having hybrid and private clouds.

¹²Column (1) shows the marginal effects on the probability of both equations being one. Column (2) shows the marginal effects for using public but not private cloud computing services, and column (3) vice versa. The last column depicts the marginal effects of both equations being zero. Simple probit regressions for comparison are provided in columns (1) and (2) of Table A.4 in the Appendix.

Table 5.1: Dependent Variable: Dummy for Adoption of Cloud Computing - Probit Regressions - Average Marginal Effects

	Total		Manufacturing		Services	
	(1)	(2)	(3)	(4)	(5)	(6)
% of Emp. Using Mob. Internet	0.143*** (0.027)	0.119*** (0.028)	0.140*** (0.037)	0.125*** (0.037)	0.159*** (0.041)	0.124*** (0.042)
Firm Age 0-3	0.076** (0.034)	0.066* (0.034)	0.073 (0.046)	0.069 (0.045)	0.079 (0.054)	0.057 (0.055)
Firm Age 4-7	0.068** (0.028)	0.054* (0.028)	0.081** (0.032)	0.069** (0.032)	0.053 (0.050)	0.036 (0.049)
90% High-Speed Fixed-Line	0.037** (0.018)	0.034* (0.018)	0.045** (0.023)	0.042* (0.023)	0.029 (0.028)	0.027 (0.028)
% of Emp. Predom. Using PC	0.007 (0.033)	0.006 (0.034)	-0.026 (0.045)	-0.027 (0.048)	0.028 (0.053)	0.025 (0.053)
% of Emp. Using Internet	0.076*** (0.029)	0.058** (0.029)	0.058* (0.033)	0.047 (0.033)	0.100* (0.055)	0.069 (0.054)
% of Emp. IT Staff	0.160*** (0.060)	0.148** (0.060)	0.240* (0.127)	0.230* (0.126)	0.134* (0.079)	0.116 (0.078)
% of Online Sales	0.097** (0.046)	0.089* (0.046)	0.168*** (0.056)	0.160*** (0.056)	-0.009 (0.074)	-0.024 (0.072)
ICT Investment (in logs)	0.022*** (0.006)	0.019*** (0.006)	0.012* (0.008)	0.009 (0.008)	0.034*** (0.010)	0.030*** (0.010)
Employees (in logs)	0.025*** (0.008)	0.014 (0.009)	0.034*** (0.010)	0.026** (0.011)	0.019 (0.013)	0.003 (0.014)
Population Density	0.010 (0.007)	0.010 (0.007)	0.021** (0.009)	0.022** (0.010)	-0.001 (0.011)	-0.004 (0.012)
Organisational Measures		0.017*** (0.005)		0.011* (0.006)		0.026*** (0.008)
Highly Competitive		0.035** (0.014)		0.051*** (0.017)		0.008 (0.024)
% Highly Qualified Employees		0.028 (0.040)		0.016 (0.067)		0.049 (0.055)
% of Employees > Age 50		-0.116*** (0.039)		-0.065 (0.047)		-0.198*** (0.067)
East, Export, Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R^2	0.109	0.120	0.085	0.097	0.105	0.120
Observations	2970	2970	1721	1721	1249	1249

Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5.2: Dependent Variable: Dummy for Adoption of Public/Private Cloud Computing - Bivariate Probit Regressions - Average Marginal Effects

	(1) Pub. and Priv. CC	(2) Only Pub. CC	(3) Only Priv. CC	(4) No CC
% of Emp. Using Mob. Internet	0.030*** (0.008)	0.007 (0.014)	0.062*** (0.017)	-0.099*** (0.025)
Firm Age 0-3	0.019* (0.010)	-0.008 (0.018)	0.054*** (0.021)	-0.065** (0.030)
Firm Age 4-7	0.006 (0.008)	-0.005 (0.016)	0.021 (0.018)	-0.021 (0.024)
90% High-Speed Fixed-Line	0.011** (0.005)	0.026*** (0.009)	-0.009 (0.011)	-0.028* (0.016)
% of Emp. Predom. Using PC	0.005 (0.010)	0.004 (0.017)	0.006 (0.021)	-0.015 (0.031)
% of Emp. Using Internet	0.030*** (0.009)	0.035** (0.015)	0.023 (0.018)	-0.087*** (0.026)
% of Emp. IT Staff	0.040** (0.018)	-0.033 (0.027)	0.139*** (0.034)	-0.146*** (0.056)
% of Online Sales	0.022 (0.014)	0.039* (0.022)	-0.000 (0.026)	-0.061 (0.043)
ICT Investment (in logs)	0.004** (0.002)	0.000 (0.003)	0.010*** (0.004)	-0.015*** (0.006)
Employees (in logs)	0.006** (0.003)	0.002 (0.004)	0.011** (0.005)	-0.020** (0.008)
Organisational Measures	0.005*** (0.001)	0.004 (0.003)	0.007** (0.003)	-0.015*** (0.004)
Highly Competitive	0.011** (0.004)	0.010 (0.007)	0.012 (0.009)	-0.032** (0.013)
Population Density	0.003 (0.002)	0.002 (0.004)	0.005 (0.004)	-0.010 (0.006)
% Highly Qualified Employees	0.009 (0.012)	0.011 (0.019)	0.007 (0.023)	-0.027 (0.035)
% of Employees > Age 50	-0.033*** (0.012)	0.002 (0.021)	-0.082*** (0.026)	0.113*** (0.037)
East, Export, Industry Dummies	Yes	Yes	Yes	Yes
ρ	0.454			
P-Value Wald Test of $\rho = 0$	0.000			
Observations	2970	2970	2970	2970

Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The estimates in Table 5.3 provide insight for the adoption decision of particular service models. As described in Section 4, we estimate a multivariate (trivariate) probit model, as we expect the decision for the adoption of one specific service model being highly correlated with already using one of the other service models.¹³ The Wald test on the correlation of error terms being zero could clearly be rejected, meaning that the equations should indeed be estimated simultaneously.

Having more employees equipped with mobile internet devices increases the probability of using SaaS, IaaS and PaaS (H1). There is a positive correlation between being a firm of age 0-3 and the adoption of SaaS and IaaS, whereas firms of age 4-7 only affect SaaS (H2). Fixed line internet availability is only a determinant for using Software as a Service (H3).

Having a higher share of in-house IT staff has only a positive and significant effect for using PaaS. Higher IT investments and good organisational practices increase the probability of using either of the three service models. Firm size does not influence the probability of using SaaS, IaaS or PaaS. Being highly competitive is weakly correlated with using IaaS. There is also a strong negative correlation between the share of older employees and the probability of using any of the service models.

¹³Separate probit regressions for all three service models are available in columns (3) - (5) of Table A.4 in the Appendix.

Table 5.3: Dependent Variable: Dummy for Adoption of Specific Type of Cloud Computing - Multivariate Probit - Average Marginal Effects

	(1) SaaS	(2) IaaS	(3) PaaS
% of Emp. Using Mob. Internet	0.061*** (0.021)	0.070*** (0.022)	0.075*** (0.015)
Firm Age 0-3	0.047* (0.028)	0.072*** (0.025)	-0.010 (0.019)
Firm Age 4-7	0.051** (0.020)	0.022 (0.022)	0.016 (0.015)
90% High-Speed Fixed-Line	0.040*** (0.013)	0.012 (0.014)	0.007 (0.010)
% of Emp. Predom. Using PC	-0.011 (0.027)	0.002 (0.027)	-0.022 (0.018)
% of Emp. Using Internet	0.052** (0.023)	0.045* (0.023)	0.013 (0.015)
% of Emp. IT Staff	0.032 (0.047)	0.061 (0.044)	0.056** (0.027)
% of Online Sales	0.058* (0.035)	0.080** (0.033)	0.067*** (0.022)
ICT Investment (in logs)	0.014*** (0.005)	0.009* (0.005)	0.008** (0.003)
Employees (in logs)	0.004 (0.007)	0.011 (0.007)	0.005 (0.004)
Organisational Measures	0.017*** (0.004)	0.014*** (0.004)	0.008*** (0.003)
Highly Competitive	0.015 (0.011)	0.020* (0.012)	0.007 (0.008)
Population Density	0.004 (0.006)	0.004 (0.006)	0.000 (0.004)
% Highly Qualified Employees	0.015 (0.030)	0.044 (0.030)	0.014 (0.019)
% of Employees > Age 50	-0.104*** (0.032)	-0.104*** (0.034)	-0.065*** (0.022)
East, Export, Industry Dummies	Yes	Yes	Yes
ρ_{21}	0.860		
ρ_{31}	0.725		
ρ_{32}	0.737		
P-Value Wald Test of $\rho_{ij} = 0$	0.000		
Observations	2970	2970	2970

Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01.

6 Conclusion and Discussion

Our empirical analysis on the determinants of cloud computing adoption of German manufacturing and services firms shows a number of interesting results. In general, our three main hypotheses are confirmed. However, diverging results for the comparison of the manufacturing and services industries as well as for the specific deployment and service models occur. Firms with a higher share of employees using mobile internet devices are clearly more likely to adopt any cloud computing services (H1). This is probably driven by the fact that cloud computing eases mobile (remote) access to the firms' data. Firm age (H2) only has an effect for the total sample and the manufacturing industries, hybrid and private clouds as well as Software as a Service and Infrastructure as a Service. Fixed line internet availability in the municipality of the firm is only a determinant for the total sample and the manufacturing industries, hybrid and private clouds and for using Software as a Service (H3).

During our analysis, we control for a large number of factors that could potentially also influence the cloud computing adoption decision. Some of them are interesting results on their own. We find for instance that the selection of the specific deployment models is often correlated with the share of in-house IT staff and the amount of ICT investments. In general, it seems that, apart from our three main hypothesis that are relatively robust across all specification, the decision to use (specific types of) cloud computing services varies a lot between different kinds of firms.

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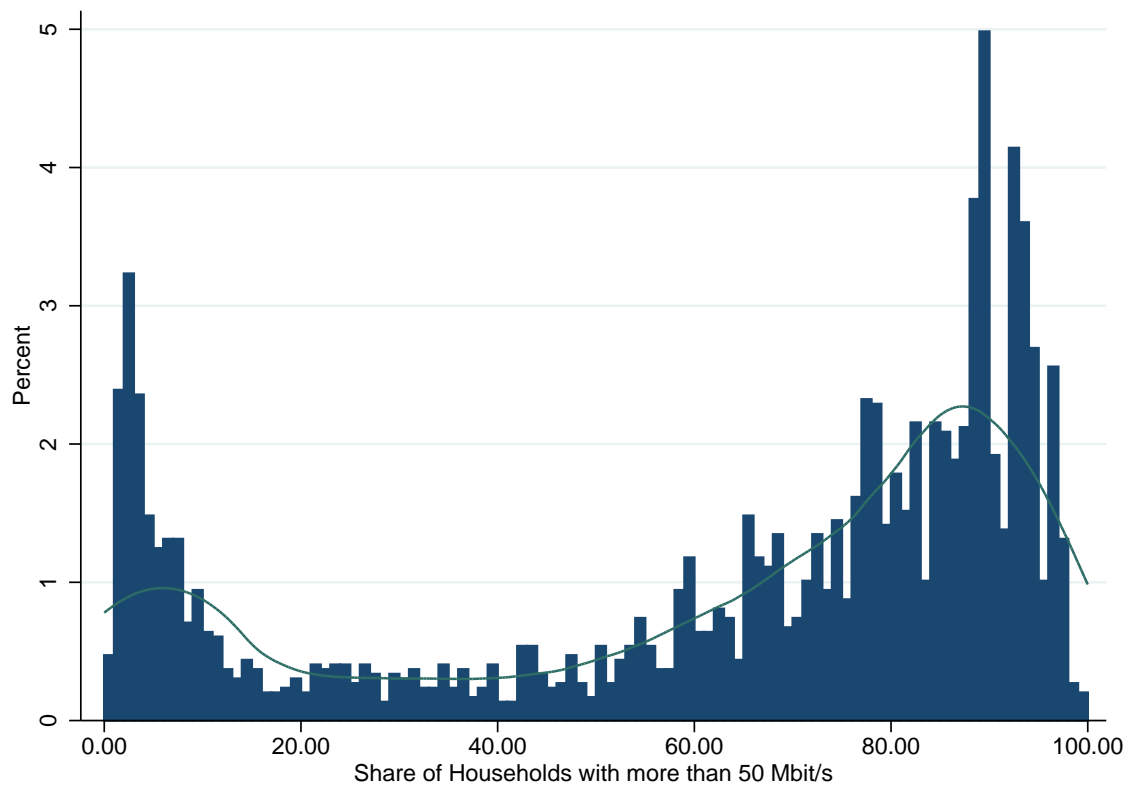
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A Appendix

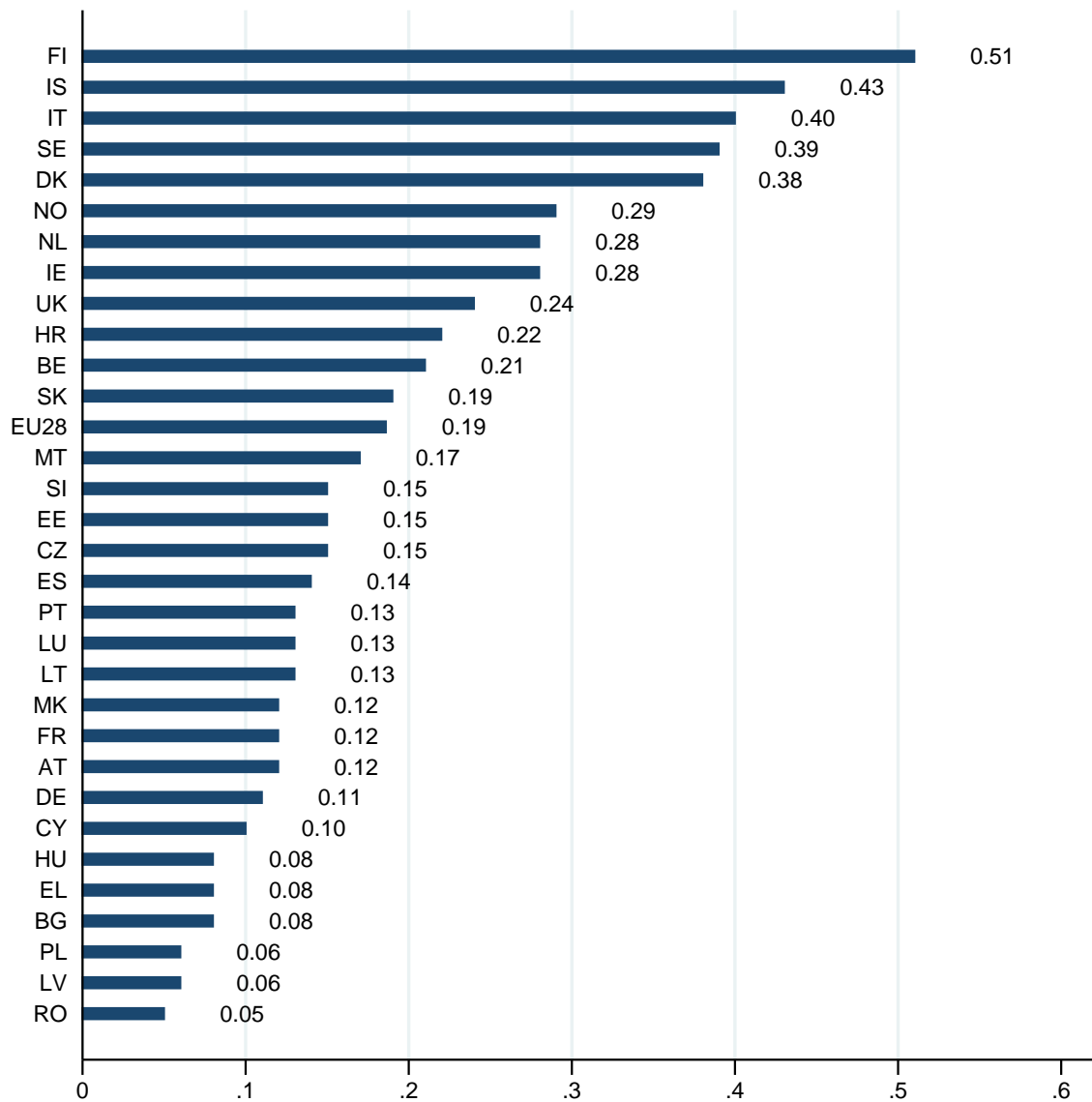
A.1 Additional Graphs

Figure A.1: Share of Households with Fixed-line Internet Access Speeds of more than 50 Mbit/s (Municipality Level)



Source: German Broadband Atlas (BMVI 2016).

Figure A.2: Share of Firms Using Cloud Computing in EU28



Source: Eurostat Community survey on ICT usage and e-commerce in enterprises 2014.

Note: The Eurostat definition of cloud computing does not include private clouds, which explains the lower value for Germany compared to our data.

A.2 Additional Tables

Table A.1: Distribution of Firms across Industries: Estimation Sample

	N	Percentage
Manufacture of Consumer Goods	447	15.05
Manufacture of Chemicals	90	3.03
Manufacture of Basic Materials	246	8.28
Manufacture of Metals	198	6.67
Manufacture of Electronics	174	5.86
Manufacture of Machinery	158	5.32
Manufacture of Motor Vehicles	84	2.83
Manufacture of Furniture and Other Manufacturing	324	10.91
Retail Trade	161	5.42
Wholesale Trade	126	4.24
Transport Services	144	4.85
Media Services	112	3.77
ICT Services	136	4.58
Financial Services	129	4.34
Consulting, Advertising	151	5.08
Technical Services	136	4.58
Business Services	154	5.19
Total	2970	100.00

Table A.2: Detailed Summary Statistics: Estimation Sample

	N	Mean	Median	SD	Min	Max
Cloud Computing	2970	0.20	0	0.40	0	1
SaaS	2970	0.12	0	0.32	0	1
IaaS	2970	0.12	0	0.33	0	1
PaaS	2970	0.054	0	0.23	0	1
Public Cloud	2970	0.096	0	0.30	0	1
Private Cloud	2970	0.12	0	0.32	0	1
SaaS (of CC Users)	594	0.59	1	0.49	0	1
IaaS (of CC Users)	594	0.61	1	0.49	0	1
PaaS (of CC Users)	594	0.27	0	0.44	0	1
% of Emp. Using Mob. Internet	2970	0.24	0.14	0.28	0	1
Firm Age 0-3	2970	0.037	0	0.19	0	1
Firm Age 4-7	2970	0.056	0	0.23	0	1
Firm Age >7	2970	0.91	1	0.29	0	1
90% High-Speed Fixed-Line	2970	0.19	0	0.39	0	1
% of Emp. Predom. Using PC	2970	0.43	0.30	0.34	0	1
% of Emp. Using Internet	2970	0.56	0.50	0.37	0	1
% of Emp. IT Staff	2970	0.057	0.0060	0.15	0	1
% of Online Sales	2970	0.046	0	0.14	0	1
ICT Investment in Mill. Euro	2970	0.15	0.015	0.99	0.00010	30
Employees	2970	99.9	24.5	308.1	5	5000
Population Density	2970	0.93	0.47	1.05	0	4.60
Organisational Measures (1-6)	2970	2.14	2	1.70	0	6
Highly Competitive	2970	0.49	0	0.50	0	1
% Highly Qualified Employees	2970	0.18	0.10	0.24	0	1
% of Employees > Age 50	2970	0.27	0.25	0.19	0	1
East Germany Dummy	2970	0.25	0	0.43	0	1
Export Dummy	2970	0.45	0	0.50	0	1

Table A.3: Summary Statistics by Sector: Estimation Sample

	Manufacturing		Services		Total	
	N	Mean	N	Mean	N	Mean
Cloud Computing	1721	0.15	1249	0.27	2970	0.20
SaaS	1721	0.07	1249	0.18	2970	0.12
IaaS	1721	0.08	1249	0.17	2970	0.12
PaaS	1721	0.03	1249	0.08	2970	0.05
Public Cloud	1721	0.07	1249	0.14	2970	0.10
Private Cloud	1721	0.09	1249	0.16	2970	0.12
SaaS (of CC Users)	259	0.50	335	0.66	594	0.59
IaaS (of CC Users)	259	0.56	335	0.64	594	0.61
PaaS (of CC Users)	259	0.23	335	0.30	594	0.27
% of Emp. Using Mob. Internet	1721	0.18	1249	0.32	2970	0.24
Firm Age 0-3	1721	0.03	1249	0.05	2970	0.04
Firm Age 4-7	1721	0.05	1249	0.06	2970	0.06
Firm Age >7	1721	0.92	1249	0.90	2970	0.91
90% High-Speed Fixed-Line	1721	0.15	1249	0.24	2970	0.19
% of Emp. Predom. Using PC	1721	0.30	1249	0.61	2970	0.43
% of Emp. Using Internet	1721	0.44	1249	0.73	2970	0.56
% of Emp. IT Staff	1721	0.03	1249	0.10	2970	0.06
% of Online Sales	1721	0.04	1249	0.05	2970	0.05
ICT Investment in Mill. Euro	1721	0.08	1249	0.23	2970	0.15
Employees	1721	86.94	1249	117.87	2970	99.95
Population Density	1721	0.70	1249	1.26	2970	0.93
Organisational Measures (1-6)	1721	1.93	1249	2.43	2970	2.14
Highly Competitive	1721	0.46	1249	0.53	2970	0.49
% Highly Qualified Employees	1721	0.12	1249	0.26	2970	0.18
% of Employees > Age 50	1721	0.28	1249	0.26	2970	0.27
East Germany Dummy	1721	0.27	1249	0.22	2970	0.25
Export Dummy	1721	0.58	1249	0.28	2970	0.45

Table A.4: Dependent Variable: Dummy for Adoption of Specific Types of Cloud Computing Services
- Probit Regressions - Average Marginal Effects

	(1)	(2)	(3)	(4)	(5)
	Pub. CC	Priv. CC	SaaS	IaaS	PaaS
% of Emp. Using Mob. Internet	0.036* (0.020)	0.089*** (0.022)	0.064*** (0.022)	0.072*** (0.022)	0.076*** (0.015)
Firm Age 0-3	0.009 (0.025)	0.074*** (0.027)	0.050* (0.027)	0.071*** (0.026)	-0.007 (0.020)
Firm Age 4-7	0.000 (0.022)	0.024 (0.022)	0.050** (0.021)	0.019 (0.023)	0.012 (0.015)
90% High-Speed Fixed-Line	0.035*** (0.013)	0.000 (0.014)	0.037*** (0.014)	0.009 (0.015)	0.004 (0.010)
% of Emp. Predom. Using PC	0.009 (0.024)	0.010 (0.028)	-0.016 (0.026)	-0.008 (0.027)	-0.029 (0.018)
% of Emp. Using Internet	0.067*** (0.021)	0.056** (0.024)	0.060** (0.023)	0.051** (0.024)	0.015 (0.016)
% of Emp. IT Staff	0.009 (0.041)	0.173*** (0.046)	0.042 (0.046)	0.062 (0.045)	0.059** (0.027)
% of Online Sales	0.062* (0.033)	0.024 (0.036)	0.056 (0.036)	0.084** (0.035)	0.066*** (0.022)
ICT Investment (in logs)	0.005 (0.004)	0.014*** (0.005)	0.015*** (0.005)	0.009* (0.005)	0.008** (0.003)
Employees (in logs)	0.008 (0.006)	0.018*** (0.007)	0.006 (0.007)	0.013* (0.007)	0.004 (0.005)
Organisational Measures	0.008** (0.004)	0.011*** (0.004)	0.018*** (0.004)	0.015*** (0.004)	0.009*** (0.003)
Highly Competitive	0.020* (0.011)	0.022* (0.012)	0.012 (0.012)	0.017 (0.012)	0.005 (0.008)
Population Density	0.006 (0.005)	0.007 (0.006)	0.004 (0.006)	0.005 (0.006)	-0.001 (0.004)
% Highly Qualified Employees	0.022 (0.028)	0.020 (0.031)	0.013 (0.030)	0.049 (0.031)	0.022 (0.019)
% of Employees > Age 50	-0.035 (0.030)	-0.118*** (0.033)	-0.096*** (0.033)	-0.102*** (0.034)	-0.061*** (0.023)
East, Export, Industry Dummies	Yes	Yes	Yes	Yes	Yes
Pseudo R^2	0.106	0.143	0.145	0.131	0.180
Observations	2970	2970	2970	2970	2970

Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.5: Correlation Matrix: Estimation Sample

	CC	SaaS	IaaS	PaaS	Pub. CC	Priv. CC	% M. Int.	Age 0-3	Age 4-7	90% HS	IT Inv.	Empl.	Org. M.
CC	1.00												
SaaS	0.73 (0.00)	1.00											
IaaS	0.74 (0.00)	0.64 (0.00)	1.00										
PaaS	0.48 (0.00)	0.41 (0.00)	0.43 (0.00)	1.00									
Pub. CC	0.65 (0.00)	0.55 (0.00)	0.52 (0.00)	0.36 (0.00)	1.00								
Priv. CC	0.74 (0.00)	0.53 (0.00)	0.59 (0.00)	0.37 (0.00)	0.28 (0.00)	1.00							
% M. Int.	0.19 (0.00)	0.15 (0.00)	0.16 (0.00)	0.18 (0.00)	0.13 (0.00)	0.17 (0.00)	1.00						
Age 0-3	0.04 (0.05)	0.03 (0.07)	0.05 (0.00)	0.00 (0.99)	0.01 (0.64)	0.05 (0.01)	0.09 (0.00)	1.00					
Age 4-7	0.03 (0.08)	0.04 (0.02)	0.01 (0.48)	0.02 (0.29)	0.00 (1.00)	0.01 (0.44)	0.03 (0.16)	-0.05 (0.01)	1.00				
90% HS	0.08 (0.00)	0.10 (0.00)	0.05 (0.01)	0.03 (0.09)	0.09 (0.00)	0.04 (0.03)	0.04 (0.01)	-0.00 (0.80)	0.02 (0.20)	1.00			
IT Inv.	0.10 (0.00)	0.06 (0.00)	0.09 (0.00)	0.11 (0.00)	0.03 (0.14)	0.13 (0.00)	0.04 (0.02)	-0.02 (0.29)	-0.01 (0.69)	-0.00 (0.81)	1.00		
Empl.	0.13 (0.00)	0.12 (0.00)	0.12 (0.00)	0.09 (0.00)	0.07 (0.00)	0.16 (0.00)	-0.03 (0.08)	-0.04 (0.02)	-0.00 (0.79)	0.04 (0.01)	0.56 (0.00)	1.00	
Org. M.	0.22 (0.00)	0.22 (0.00)	0.20 (0.00)	0.17 (0.00)	0.14 (0.00)	0.20 (0.00)	0.15 (0.00)	-0.02 (0.27)	0.02 (0.27)	0.08 (0.00)	0.18 (0.00)	0.30 (0.00)	1.00
Observations	2970												

p-values in parentheses