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The Adoption of Business to Business E-Commerce: Heterogeneity and Network Externality Effects

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Abstract[+]

The decision to adopt e-commerce technology depends on a variety of variables. This paper explores the relative importance of structural firm-specific variables, the intrinsic value of the technology, expectations concerning the evolution of the technology, and the adoption behaviour of other agents. Almost all variables pertaining to the conventional structure of firms, including size, and the value of technology, are found to have no importance in the adoption decision, whereas the expected number of other adopters are found to have a positive effect. Moreover, the smaller the percentage of adopters considered to be the threshold beyond which the firm will adopt (critical mass), the higher the probability of adoption.

Keywords: E-commerce, Adoption of new technology; Network Externality; Internet, Logit Regression Models
JEL Classification: L8, O14

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1. Introduction

The impressive diffusion pattern of the Internet has given rise to a recent wave of literature on diffusion processes. In the theory of technology diffusion, a number of sophisticated diffusion models with network externality have been developed. In reality, however, not much is known about the relative importance of network externality effects vis-à-vis the more traditional elements of intrinsic value of the technology or other structural variables at the firm level. The main goal of this paper is to examine the decision of manufacturing firms to adopt a particular type of Internet technology, namely B2B electronic commerce. Several hypotheses will be tested against empirical data. The data was collected in a large-scale survey of firms in mechanical, electromechanical and electronic sectors, using a structured mail questionnaire. Since the objective of the survey is the micro-foundation of the diffusion process, the questionnaire was constructed with a view to gathering a set of factors that may be taken into consideration in the adoption function of firms.

Data is derived on the impact of conventional variables concerning resource endowment, the expected value of technology and technological expectations, and on the probability of adoption. However, in addition, variables describing the subjective evaluation of the adoption behaviour of competitors, and other relevant third parties, are introduced as elements pointing to network externality effects.

The paper is organised as follows. In Section II, the main characteristics of e-commerce technologies are described, paying particular attention to how network effects operate in this case. Specifications for the value of the technology, which is a function of its intrinsic value and of its diffusion, are then proposed. Section III contains a description of the sample and of variables used to test several hypotheses on the determinants of adoption. In Section IV logit regressions are used to test these hypotheses and the findings are summarised.

Section V summarises the main conclusions of the paper. Appendix I contains procedures for checking and correcting sample distortions.

2. Network Externalities and Technology Diffusion in e-Commerce

Before the stock exchange crisis of 2000-2001, e-commerce technology received much attention from technical press and the media, and enjoyed highly optimistic forecasts. According to most reported studies, e-commerce will in a few years substitute traditional means of transaction in many industries. According to all available forecasts, business to business e-commerce (B2B) will have the most rapid and massive development, while business to consumer applications will have a longer penetration period in the corresponding population, and a lower final penetration rate. Whether or not such optimistic forecasts are justified, the new phenomenon has to be studied from a scientific point of view, with explicit reference to economic theory.

The first step in studying the diffusion of e-commerce technologies, is to point out that, although based on the same medium (the Internet Network), e-selling and e-procurement are two separate technologies with distinct adoption decisions, which have to be examined separately. Competition takes place between e-selling and conventional sales and between e-procurement and conventional procurement. The key feature of the diffusion of Internet technologies is the fact that the higher the number of adopters, the higher the utility of the technology for potential adopters, that is, the remaining portion of the population, since "the utility that a user derives from consumption of the good increases with the number of other agents consuming the good" (Katz, Shapiro, 1985, 424). In particular, it is accepted that increasing returns are typical of information-based technologies that are capable of storing, recalling, copying, filtering, seeing, transmitting and receiving information (Shapiro, Varian, 1999, 10). Such “technologies become more attractive - more developed, more widespread, more useful - the more they are adopted” (Arthur, 1988, 590), as has been demonstrated with video recorders, operating systems, computer hardware for telecommunication and, more recently, Internet-based technologies. The Internet community is familiar with the Metcalfe Law (1996), which states that, under certain conditions, the utility of the Network increases with the square of the number of users. For an adopter, the utility of Web surfing is clearly a function of the number of different contents he/she can find, which, in turn, depends on the total number of surfers. For e-commerce, increasing returns of adoption hold true in a unique way and play a central role in the diffusion process.

According to the classic analyses by Katz and Shapiro (1985, 1986) and by Farrell and Saloner (1985), developed by Economides (1996), Liebowitz and Margolis (1994) and Witt (1997), network externalities are of three types: *direct*, *indirect* and generated by *post-purchase services*. Direct externalities originate from physical connection; complementary goods create indirect externalities, while the latter type depends on the quality and availability of after-sales services.

With the presence of network externality, the value of a good or of a technology may be decomposed into two parts (Liebowitz and Margolis, 1998). The first part, which is called synchronisation effect, is determined uniquely by the network effect, while the second part (intrinsic value) is the actual value of the good or the technology.

Both in e-selling and e-procurement, technologies are bilateral, in the sense that they are linked by a complementary relationship: in order for e-selling to take place, there must be e-procurement, and vice versa. This makes the network effects more complex and intriguing.

Let us first consider e-commerce for the sales of products (e-selling). In selling electronically, a firm has relationships with a set of customers who are not directly linked to each other. The structure can be seen as a bipartite graph (Bollobas, Kirwan, Sarnack, Wall, 1998), with no links within the groups and unlimited access to each member of the other group. In reality, every customer can buy from every seller and every seller, in turn, can receive orders from every customer, but customers and sellers are not connected to each other. Each of the e-sellers is the centre of a "star network", and because information runs in both directions, it can be defined as a "two ways network" (Economides, 1996; Economides and White, 1994). The same occurs *mutatis mutandis,* for e-procurement.

As can be seen in figure I, taking into account both technologies and their complementarity relationship, four distinct kinds of network effects can be identified.

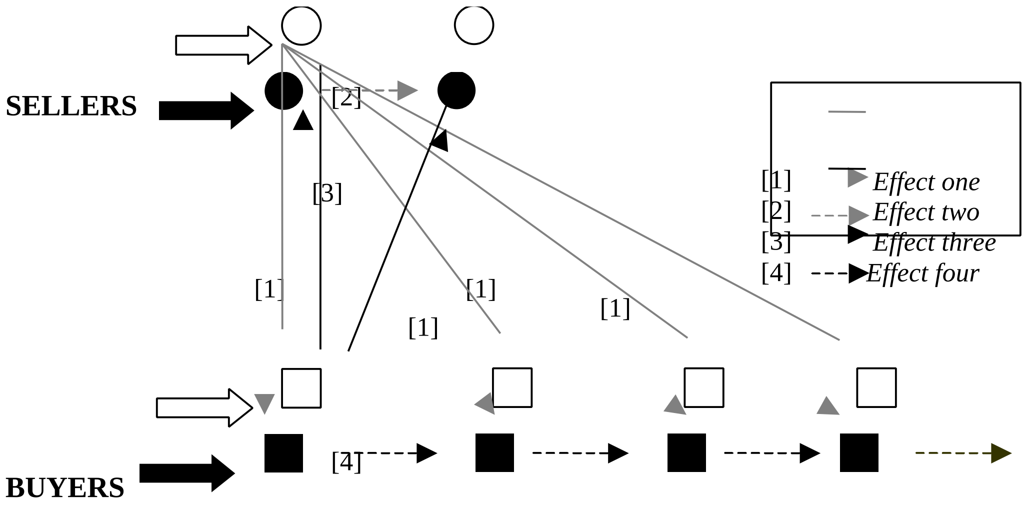

Figure I: Network externality effects in the diffusion of B2B e-commerce.

Effect (1) is a *market size effect*: the utility of adopting e-commerce for a supplier is an increasing function of the proportion of sales made through the Internet, that is of the number of buyers in the relevant market adopting e-procurement. To simplify, the costs of adoption are given by the initial investment in the digitalisation of the product catalogue and in the creation of the proper technical infrastructure. Such investment is not justified if electronic selling represents a small fraction of the sales. If distribution of sales per customer is not, as usually occurs, uniform, it could be assumed that the critical factor is adoption by the *largest* customers.

Nevertheless, at least initially, electronic purchasing does not wholly substitute traditional purchasing, and thus even the biggest customers only make electronic orders for limited volumes. The critical parameter is, then, the *number* of customers making e-procurement. Thus there is an indirect network externality effect arising from market size, insofar as the utility from adoption of e-selling is a positive function of the number of adopting customers.

Effect (2) depends on the competitors of the firm which decides to e-sell. In fact, selling through the Internet leads not only to the display of products on the firm's web site, but also to the unalterable quotation of prices and the possibility for buyers to conclude transactions by confirming the electronic order. Everyone can see the prices quoted on the web site and this determines a loss of discretionary power in negotiation with customers and a disclosure of private information to competitors. The pricing policy becomes irremediably transparent, while competitors are in the position to search price information at zero cost and to engage in strategic maneouvering. If none of the competitors follows, the adoption of e-selling determines a net loss of strategic degrees of freedom.

There is a further element to take into consideration: when the number of e-sellers increases, a sort of cultural effect takes place. The larger presence of firms selling through the Internet makes the customers less distrustful of the new way of managing commercial transactions. This clearly increases the probability of Internet exchanges and thus makes the e-selling technology more profitable. At present, experts maintain that the diffusion of e-selling will increase and there will be a time when all firms will have to adopt, if they want to remain on the market. A bandwagon effect[1] is likely to emerge.

All this can be summarised as *coordination failure effect*. Effect (2) represents a classic example of network externality leading to coordination failure: all the competitors would gain from the

[1] For a brief survey of technology diffusion models with bandwagon effect, see Geroski P.A. (2000).

adoption of electronic commerce but no one wants to be alone in using the new technology.

There is also a network externality effect of a third kind. In reality, e-commerce relies on the Internet network and therefore on the telecommunications infrastructures of the country where the firm is located. The larger the group of firms performing e-commerce in a given country, the larger will be the investment in telecommunications infrastructures in order to make Internet connections easier and faster, and this will have a highly positive influence on the value of the technology. On the other hand, the utility for customers of buying on line relies on the number of suppliers who have adopted e-selling. For a customer, the probability of finding the product that he/she is looking for at a good price on the Web increases with the number of suppliers that are on line. This is the effect (3) labelled *market variety effect*. While for sellers what matters is the total volume of electronic sales (market size), for buyers volume itself is not sufficient, because what is needed is an adequate qualitative covering of purchasing needs (market variety).

Finally, there is the effect (4), which can be named *reinforcement effect*. Buyers do not need other buyers in order to gain advantage from e-procurement. However, it might be assumed that the more customers are on line the more they will receive attention from suppliers in the form of additional services, promotion, information, discounts, etc.. Moreover, there is also a cultural effect among customers. Many studies show that what prevents customers from buying on line is the fear of being tricked, especially in payment. The higher the number of customers on line they see around them, the stronger the perception of legal protection from these risks.

As a result of these effects, the value of e-commerce technologies at any given time t, is a function of the number of adopters of e-selling and e-procurement in t. Consumers of a good that presents network externality phenomena “base their purchase decision on expected network size” (Katz and Shapiro, 1985). It can be argued that this also occurs in the adoption of technologies. In other words, in deciding whether to adopt the new technology, agents take into account not only the current number of adopters but also the future number of adopters. With regard to network externality, the value of e-commerce technology can be expressed formally using a system of two equations:

$$\begin{cases} V_s = f(N_s, \tilde{N}_s^{\,e}) + g(N_b, \tilde{N}_b^{\,e}) + V_s(0) \\ V_b = h(N_b, \tilde{N}_b^{\,e}) + i(N_s, \tilde{N}_s^{\,e}) + V_b(0) \end{cases} \qquad (1)$$

Where N_s and N_b are, respectively, the competitors and customers adopting e-commerce in t, $\tilde{N}_s^{\,e}$ and $\tilde{N}_b^{\,e}$ are the expected numbers of adopters respectively among suppliers and buyers, while $V_s(0)$ and $V_b(0)$ represent the intrinsic values of e-selling and of e-procurement. As a result of the effects described above, we have:

$$f' > 0, g' > 0, h' > 0, i' > 0 \qquad (2)$$

On the other hand we assume that:

$$f'' < 0, g'' < 0, h'' < 0, i'' < 0 \qquad (3)$$

In other words, the advantages of adopting the new technology rise at a decreasing rate. In fact, when the number of new users is high, the benefits brought about by the last user who decides to adopt, progressively diminish. This is due to two reasons. The first is strictly connected with e-selling: "Internet visibility" becomes more difficult and more expensive to maintain as the number of e-sellers increases. The second problem concerns all Internet users: the exponential increase in the number of web sites may lead to Internet congestion phenomena (Maurer, Huberman, 2001; Windrum, Swann, 1999).

As it is clear from our discussion, there are many possible reasons for the technology being trapped into a non adoption equilibrium. The interesting point is that this is true even more if increasing returns to adoption are in place. Agents will anticipate that increasing returns will be available only when a certain number of adopters (on both sides of the market) will be there. A wait-and-see outcome is perfectly rational. According to Arthur (1988, 591), "if increasing returns are present, they determine the character of competition between technologies". Besides causing "inflexibility or lock-in of outcome; non predictability; possible inefficiency; and non-ergodicity or path dependence" (Arthur, 1988, 591)[2], increasing returns introduce a strategic element that cannot be overlooked. It is better to wait for other firms to make the early adoption in order to choose the new technology when its value is higher, in a sort of *reverse order effect* (Ireland and Stoneman, 1985). This implies that each firm, in deciding whether and when to use the new mode of commercial transactions, has to take into account the behaviour of other agents in its competitive system. From a game theoretic point of view, such decision problems can be represented as a game in which there are two Nash equilibria (Witt, 1997). In the first equilibrium, all subjects use the old technology, while in the second equilibrium, all agents select the new one. In this case, we can argue that the latter equilibrium is (Pareto) superior to the former (Huberman, 1998): all firms will obtain a larger payoff if they succeed in co-ordinating the equilibrium in which everyone uses e-commerce technology.

As in collective action problems (Hardin, 1971; Marwell, Oliver, 1993), the shift from the first equilibrium to the second may be due to the presence of a *critical mass* of early adopters[3]. This concept is borrowed from physics and is used to describe nuclear fission. According to Schelling (1978), "an atomic pile goes critical when there is a minimum amount of fissionable material that has been compacted together to keep the reaction from petering out". Analogously, social and economic processes can be thought of as physical processes that are triggered when some variables overcome a critical threshold, beyond which the system reaches, more and more rapidly, a new, stable equilibrium. In technology diffusion, these variables correspond to the

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[2] These topics are discussed in depth by Arthur (1988, 1989,1990, 1994) and David (1985). From a formal viewpoint, the seminal paper is the work of Arthur, Ermeliev, Kaniovski (1983). Other authors, such as Liebowitz and Margolis (1994, 1998), examine the effect of increasing returns and network externalities on the emergence of standards. Shy (2000) offers a concise and complete coverage of models with network externality in a variety of industries.

number of users of the new technology: when a critical mass of users is reached, a snowball effect takes place, the pattern of diffusion creates a catastrophe point, with infinite slope. All potential adopters leave the old technology for the new one. Depending on the carrying capacity of the population, this may lead to the dominance of one technology or to coexistence equilibria.

The relevant problem then becomes how such critical mass can be reached. If network externality effects dominate the adoption decision, then the non adoption equilibrium will be highly stable. On the other hand, if there is sufficient heterogeneity in the population, there may be a subgroup of potential adopters that do not wait for others' adoption and create the initial critical mass, triggering the entire process.

This discussion leaves then open the empirical question of the *relative* importance of several factors in influencing adoption decisions: variables describing firms' endowments and the perceived intrinsic value of the technology, which allow for population heterogeneity, or the observed number of other agents adopting, and the expected number of other agents adopting, which depend on the dynamics of the process. We are interested in the empirical question of the relative importance of these factors on adoption decisions.

3. Sample Description and Definition of Variables

The I.T.E.M.S. questionnaire was sent by mail to 1200 firms in mechanical, electromechanical and electronic industries. The universe was selected from the list of companies whose purchasing managers are members of the professional association ADACI, one of the largest professional management associations in Italy. The list was selected on the basis of the sectoral definition. The three sectors are industries in which products can be appropriately sold on the

[3] Varian and Shapiro (1999) apply this concept to Internet technologies and argue that critical mass phenomena can be found in their diffusion processes because of network externality effects.

Internet, and in which procurement of components is a complex activity.

The respondents were purchasing managers for the e-procurement side, and marketing managers for the e-selling side. The introductory letter was sent to the purchasing manager asking to fill his sections and then to refer to the marketing colleague for other sections.

The whole process was backed by on-line assistance during the compilation of the questionnaire. In order to understand qualitatively the answers, 40 case studies were carried out by the research team in four regions. Finally, a phone follow up was undertaken after the questionnaire administration in order to check for non-response biases. A random sample of 200 non respondents was drawn from the original list. After three failed attempts to get the answer by phone, non respondents were replaced by other non respondents in the list. However, the rate of response to the follow up was extremely high (more than 80%).The results of the follow-up are illustrated in Appendix 1.

We obtained 200[4] valid answers, with a response rate of 16,6%: a very good response rate for mail surveys in general, and particularly good for Italy where 10% rates are considered acceptable. Data refer to 1999. The behaviour of firms with respect to e-commerce is described in Table 1.

	ADOPTERS	NON ADOPTERS
E-selling	12 (6%)	188 (94%)
E-procurement	41 (20.5%)	159 (79.5%)
Both activities	10 (5%)	190 (95%)
Total	43 (21.5%)	157 (78.5%)

Table1

[4] Firms could also answer the questionnaire on the Internet. We constructed a special web site with a form in which operators could insert their data which went directly onto our database. The URL was http://link.sssup.it/LEM/project/ITEMS

The questionnaire included a long list of uses of the Internet, ranging from the simple promotional website to sophisticated interactive or agent mediated B2B sites. We label companies that used the Internet for placing or accepting orders directly on-line, with, in the latter case, complete listing of product prices, as “adopters”.

The survey does not make any attempt to measure the *extent* to which e-commerce is used in terms of sales or purchases. It was thought at the time of the survey that the phenomenon was so young that the simple use of the technology was a reliable indicator of adoption. All companies declared they use both on-line and off-line methodologies for selling and purchasing. Qualitative survey and case studies showed that the average utilization is still quite limited in terms of percentage of volumes exchanged[5].

As is clear from Table 1, e-commerce is still in its infant stage among manufacturing firms in these industries. Without considering non-response biases (see Appendix), we conclude that e – selling is adopted by 6% of the sample, e-procurement by more than 20%. Data are consistent with those subsequently provided by the National Office of Statistics (ISTAT) on the adoption of Internet technologies.

It is interesting to explore potential determinants of the adoption decision. Based on the above discussion, we consider 4 classes of variables:

(a) Structural variables

(b) Subjective perception of obstacles to the adoption

(c) Expectation about the evolution of the technology

(d) Beliefs about the (current and future) adoption behaviour of the other agents

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5 On the other hand, there were no cases of complete substitution between traditional techniques and e-commerce. At the time of the survey there were not mandatory processes across the customer industries for imposing suppliers to sell components on-line. Some of the most advanced programmes (e.g. FIAT, Pirelli, ENEL, to name a few large customers) were beginning to define the standards for their suppliers. This process was almost completed in 2001-2002, but was far from being generalized in 1999, at the time of the survey.

Table 2 shows descriptive statistics of the variables. Structural variables are directly observable and refer to standard firm structure and market activity measurements. NE and T can be considered as proxy for firm size, while DG and RD can be seen as a measure of firms' competencies. Such variables are present in several technology diffusion6 studies. In general, size is assumed to influence positively the probability of adoption. The rate of turnover growth (TV) is introduced in order to test the effect of growth on the probability of adoption. The variables describing export turnover, the number of customers and the number of products, aim to demonstrate the potential benefits of adopting e-commerce. The hypothesis holds that the larger the number of customers, and the higher the export turnover, the larger the benefits from the adoption of e-selling, all other things being equal. The reason is that the global nature of the Internet network makes it possible to reach customers all over the world at low costs.

Moreover, we suppose that if a firm sells a large number of different products it may have an advantage in displaying them in an electronic catalogue that can be accessed easily and quickly by customers[7].

The next 5 variables (from S_PS to S_FA) try to capture the subjective perception of obstacles to the adoption of e-commerce. Among obstacles to adoption, the subjective evaluation of product suitability for selling (for e-sellers) and buying electronically (for e-purchasers) is crucial. In fact, operators will have a greater incentive to use e-commerce if they believe that their goods can be exchanged easily and smoothly through the Internet[8].

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[6] Examinations of the effect of firm size on technology adoption are contained in David (1969) and Davies (1979). Cohen and Levinthal (1989) examine the influence of R&D on the diffusion of new technologies.

[7] If the cost of digitalising the catalogue is, at least partially, independent of the number of items, the net benefit of adoption will be larger for firms with many products.

[8] This has also been observed in some interviews: firms that produce "to order" showed very little interest in e-selling.

Variable	Symbol	Unit of Measurement	Min.	Max.	Mean	St. Dev.
STRUCTURAL VARIABLES						
N° of employees	NE	Unit	1	5,000	226.43	483.98
Graduate employees	DG	%	0	100	8.95	11.95
Turnover	T	Billion ITL	0.30	1,700	89.77	185.08
Turnover growth (1996-1999)	TV	%	-44	500	34.58	66.9
R&D expense/ turnover	RD	%	0	28	5.50	5.94
Export turnover	ET	Billion ITL	0	1,300	43.91	120.17
N° of Customers	NC	Unit	6	25,000	887.24	2,292.31
N° of Product codes[9]	PC	Unit	2	150,000	7,330.40	19,545.38
SUBJECTIVE PERCEPTION OF OBSTACLES TO ADOPTION						
Evaluation of product suitability	S_PS	1to 5 scale	1	5	3.74	1.44
Evaluation of switching costs	S_SC	1to 5 scale	1	5	2.39	1.21
Evaluation of technical security	S_TS	1to 5 scale	1	5	2.62	1.36
Evaluation of legal security	S_LS	1to 5 scale	1	5	2.67	1.37
Evaluation of adoption by other players	S_FA	1to 5 scale	1	5	3.90	1.31
EXPECTATIONS ABOUT THE EVOLUTION OF TECHNOLOGY						
Expected improvement in data security	S_EDS	1to 5 scale	1	5	3.46	1.13
Expected improvement in data integrity	S_EDI	1to 5 scale	1	5	3.39	1.06
Expected improvement use Use easiness	S_EUE	1to 5 scale	1	5	3.41	1.03

[9] Values for NC and PC have been calculated after eliminating outlier observations.

Expected improvement. in interfaceability	S_EI	1to 5 scale	1	5	3.37	1.23

Table 2

At the same time, firms undertake investments for transforming the traditional commercial system. As experience makes clear, these costs relate more to changes in organizational procedures and the training of personnel than to hardware and software. If such costs are high, a firm's propensity to adopt the new technology may be inhibited. Another key obstacle is security: if a firm believes that Internet transaction are not secure in terms of data and payments, it will not feel attraction for adoption. Finally we introduce the number of other adopters as a potential obstacle to adoption. Following the discussion above, the interest lies in measuring the extent of the impact of this externality effect on the probability to adopt.

The expectation variables deal with subjects' expectations about technology improvements. In particular they deal with expected improvement in: data security, data integrity, use easiness, interfaceability with existing management systems (S_EDS, S_EDI, S_EUE, S_EI, respectively).

Table 3 reports descriptive statistics on variables describing network externalities.

Variable	Symbol	Unit of Measurement	Min.	Max.	Mean	St. Dev.
% Of adopting competitors	E_CO	%	0	100	4.95	15.52
% Of expected adopting competitors (in the year 2000)	E_CO2	%	0	100	9.40	21.57
"Critical Mass percentage", competitors	E_COCM	%	0	90	14.31	21.47
% Of adopting customers	E_CU	%	0	100	7.53	16.75
% Of expected adopting customers (in the year 2000)	E_CU2	%	0	90	11.00	19.46
"Critical Mass percentage", customers	E_CUCM	%	0	100	15.37	21.49

Table 3

The meaning of variables E_CO, E_CO2 and E_CU, E_CU2 is clear. They represent the perceived percentage of present and future adoption of e-commerce technology among competitors and customers respectively. Variables E_COCM and E_CUCM need a little explanation: they represent the percentages of competitors and customers that the firm believes must adopt e-commerce in order to induce it to adopt too. These measurements are labelled Critical Mass since they represent the the adoption threshold that agents think is sufficient to trigger their own decision to adopt.

In e-procurement, the suitability of products is clearly less important as an obstacle than in e-selling, while technical and legal security are more important. Expectations are roughly the same in the two cases. Descriptive statistics for these variables are reported in Table 4 (structural variables are the same as in e-selling, except for NC and PC).

Variable	Symbol	Unit of measurement	Min.	Max.	Mean	St. Dev.
SUBJECTIVE PERCEPTION OF OBSTACLES TO ADOPTION						
Evaluation of product suitability	P_PS	1 to 5 scale	1	5	3.08	1.47
Evaluation of switching costs	P_SC	1 to 5 scale	1	5	2.30	1.20
Evaluation of technical security	P_TS	1 to 5 scale	1	5	2.87	1.32
Evaluation of legal security	P_LS	1 to 5 scale	1	5	2.74	1.33
EXPECTATIONS ABOUT THE EVOLUTION OF TECHNOLOGY						
Evaluation of adoption by other players	P_FA	1 to 5 scale	1	5	3.92	1.18
Expected improvement in data security	P_EDS	1 to 5 scale	1	5	3.45	1.11

Expected improvement in data integrity	P_EDI	1 to 5 scale	1	5	3.38	1.04
Expected improvement use easiness	P_EUE	1 to 5 scale	1	5	3.43	1.07
Expected improvement. in interfaceability	P_EI	1 to 5 scale	1	5	3.31	1.22

Table 4

Customers' opinions about the diffusion of e-commerce are substituted by suppliers' opinions (Table 5).

Variable	Symbol	Measurement	Min.	Max	Mean	St. Dev.
% Of adopting suppliers	E_SU	%	0	80	3.82	11.74
% Of future adopting suppliers (in the year 2000)	E_SU2	%	0	95	5.74	15.80
"Critical Mass percentage", suppliers	E_SUCM	%	0	80	9.14	17.26

Table 5

Before moving on to logit regression, it is useful to analyse the mean values of variables for subgroups of adopting and non-adopting firms. From skewness and kurtosis analysis, we observe that most variables are not normally distributed. In order to test whether mean differences vary statistically from zero, we use a non-parametric procedure which is equivalent to the t-test but does not require any assumptions about distribution (Mann-Whitney Test). This makes it possible to have an initial overview of the significant differences between adopting and non-adopting firms. Variables marked with an asterisk are those in which the differences in the mean values in the two groups are significantly different from zero (normally at a significance level of 5%).

	Adoption of e-selling					
	NO			*YES*		
	N	*Mean*	*Std. Deviation*	*N*	*Mean*	*Std. Deviation*
NE	187	220.54	479.39	12	318.25	566.15
DG	183	9.03	12.23	11	7.56	5.47
T	178	85.97	185.83	12	146.13	170.79
TV	157	33.85	68.06	10	46.10	45.81
RD	135	5.59	6.01	9	4.06	4.72
ET	159	41.85	119.97	9	80.24	125.05
NC	146	899.08	2,341.87	7	640.14	711.39
PC	138	6,806.54	17,591.19	8	16,367.13	41,930.78
*S_PS**	166	3.82	1.40	9	2.22	1.39
S_SC	144	2.42	1.21	9	1.89	1.17
*S_TS**	155	2.67	1.37	9	1.67	.71
S_LS	136	2.71	1.36	8	2.00	1.41
S_FA	156	3.90	1.31	9	3.89	1.45
*S_EDS**	148	3.53	1.09	10	2.40	1.17
*S_EDI**	145	3.46	1.03	10	2.50	1.18
S_EUE	152	3.42	1.02	10	3.30	1.25
S_EI	152	3.39	1.21	9	3.00	1.58

Table 6

As is clear from Table 6, there are very few statistical differences between adopters and non-adopters. Differences lie in the perceived obstacles deriving from product suitability and technical security, and the expected improvement in data security and integrity, all of which are higher, as would be expected, for non-adopters.

Interestingly, no structural variable is significantly different in the two groups. In particular, although adopters are larger then non-adopters, the difference is not significant. This runs counter to much diffusion literature, which places great importance on structural heterogeneity.

It is interesting to note that the cost of technology (S_SC), one of the obstacles to adoption, is not considered important, while the intrinsic suitability of the products and the scarce adoption by other actors are considered crucial.

In the expectation variables, it is interesting to note that non-adopters have more optimistic expectations about new technology improvements, often with statistically significant differences. It seems a classic Rosenberg effect situation (Rosenberg, 1976): expected technology improvements slow down the diffusion process leading to a negative relationship between expected improvement in performance and probability to adopt. The latter findings suggest that network externality effects might be important.

We are led to the preliminary conclusion that subjective perception and expectations are much more important than structural variables.

Let us turn to the last group of variables, opinions about the adoption behaviour of other players. Here the number of missing variables is much higher, so we are forced to present data separately. Clearly the two analyses are not strictly comparable. In addition, the number of adopters becomes very small.

Data in Table 7 show that, in general, adopters have significantly different perceptions to non-adopters. Adopters *see* more adopters around them (among competitors and customers) and expect more adopters in the near future. Due to the large variability in a small sample, however, we cannot exclude that these differences are casual. On the other hand, adopters say they need a lower percentage of adopters to induce them to adopt as well. This percentage, called *critical mass*, is the perceived threshold of adoption; below that percentage it is better to postpone the decision to adopt, and over that percentage, it is necessary to rush for adoption.

Below the threshold, the intrinsic benefits of the technology are more than levelled by the disadvantage of being isolated in the use of the technology. Beyond the threshold, those that do not adopt are, on the contrary, excluded from business opportunities. Interestingly enough, the perceived level of critical mass is significantly lower for adopters.

	Adoption of e-selling					
	NO			YES		
	N	Mean	Std. Deviation	N	Mean	Std. Deviation
E_CO	76	3.04	7.89	7	25.71	44.29
E_CO2	78	8.85	19.72	6	16.67	40.82
*E_COCM**	88	15.23	21.89	6	.83	2.04
E_CU	84	6.35	13.87	8	20.00	34.23
E_CU2	77	9.79	17.28	7	24.29	35.05
E_CUCM	89	16.15	21.90	6	3.83	8.01

Table 7

Before drawing conclusions, let us examine the case of e-procurement (Table 8)

The situation appears almost identical to that of e-selling, with the same variables exhibiting significant differences between adopters (with the additional inclusion of P_LS, legal security, as an obstacle to adoption).

	Adoption of e-procurement					
	NO			YES		
	N	Mean	Std. Deviation	N	Mean	Std. Deviation
NE	159	221.65	499.29	40	245.43	422.86
DG	154	8.84	12.43	40	9.34	10.00
T	151	81.61	148.60	39	121.36	286.21
TV	131	29.56	55.15	36	52.83	97.43
RD	111	5.02	5.63	33	7.10	6.71
*P_PS**	136	3.23	1.43	27	2.33	1.41
P_SC	122	2.33	1.18	34	2.21	1.27
*P_TS**	128	3.00	1.31	28	2.29	1.24
*P_LS**	117	2.85	1.36	32	2.34	1.12
P_FA	136	3.92	1.22	37	3.95	1.05
*P_EDS**	121	3.59	1.08	35	2.97	1.10
*P_EDI**	119	3.50	.96	37	2.97	1.19
P-EUE	125	3.44	1.08	37	3.38	1.04
P_EI	120	3.43	1.11	36	2.92	1.50

Table 8

Finally, with regard to opinions about the behaviour of others, the situation is almost identical to that found in e-selling. In the case of diffusion among competitors, all differences have the right sign but only the Critical Mass percentage is statistically different from zero. Moreover, turning to diffusion among suppliers, we observe that adopters present higher levels of all variables, yet no difference is statistically different from zero (Table 9).

	Adoption of e-procurement					
	NO			*YES*		
	N	*Mean*	*Std. Deviation*	*N*	*Mean*	*Std. Deviation*
E_CO	61	3.64	8.69	22	8.59	26.56
E_CO2	59	8.32	18.83	25	11.96	27.24
*E_COCM**	72	16.25	22.76	22	7.95	15.33
E_SU	56	2.61	8.18	19	7.39	18.56
E_SU2	54	4.37	12.81	19	9.63	22.23
E_SUCM	68	9.09	16.32	16	9.38	21.44

Table 9

Preliminary investigation clearly shows that structural variables do not discriminate between adopters and non-adopters, while subjective perceptions of obstacles, expectations and opinions about the behaviour of others are more promising. This pattern is consistent both for e-selling and e-procurement. Structural heterogeneity is not sufficient to induce adoption behavior in a subgroup of potential adopters; network externality effects and related perceptions and expectations seem to play a much more important role.

Let us explore the explanatory power of these variables using econometric modelling.

4. The Logit Models

In the wide-ranging empirical literature on technology adoption and diffusion, Karshenas and Stoneman (1995) identify two main blocks: “the aggregate time-series or cross section models where the dependent variable is the number of adopters or the proportion of output produced by a new technology and the desegregated duration models where the dependent variable is the time of adoption of the new technology by individual agents" (Karshenas, Stoneman, 1995, 280). We follow the cross section approach and try to discover adoption determinants using a model for binary response. The logit model has the following general form:

$$\hat{y} = \Lambda(a \cdot X)$$

Where $\hat{y}$ is the dependent variable that assumes the value one if the firm adopts the new technology and zero if it does not, a is the vector of the coefficients and X is the matrix of the independent variables. Independent and dependent variables are related by the logistic function:

$$\Lambda(u) = \frac{e^u}{1+e^u}\,.$$

In order to test the significance of coefficients we use the likelihood ratio test (LR test) that is more powerful and reliable (Hamilton, 1992; Peracchi, 1995) than the typical test based on statistic Z.

In the LR, the test statistics is:

$$LR = -2\log\frac{L_0}{L_1} = -2\cdot\left(\log L_0 - \log L_1\right) = -2\left(l_0 - l_1\right)$$

where l_0 and l_1 are, respectively, the log-likelihood functions of the restricted model that does not include the variables for which we want to carry out the procedure, and of the unrestricted model that includes it. LR distribution is a $c^2(1)$.

E- SELLING:

We test three logit models in which the dependent variable $\hat{y}$ assumes value 1 if the firm adopts e-selling and 0 if it does not. The independent variables of the first model are structural variables that describe firms' characteristics, such as competence (DG, RD), number of customers (NC), range of products (PC) and rate of turnove growth r (TV). We do not include size indicators, because the non-respondent follow up demonstrated a sample bias with respect to size (see Appendix 1). We insert TV since we suppose independence between the size and growth of an organization. In the second model, dependent variables show the perceived obstacles to the adoption of the new technology. On account of the small number of e-sellers in the sample, it is impossible to run the logit model for the variables dealing with e-selling diffusion among firms' competitors and customers.

Model L1 is highly unsatisfactory. Only two structural variables (NC and PC) are significant, and the Pseudo R2 is very low. Model L2 gives satisfactory results. It includes several perceived obstacles, some of which are statistically significant and with the expected sign.

In model L3, we try to test the influence of size on e-selling adoption. In this case we use a larger sample, merging the respondents with the non-respondents surveyed during the follow up (see Appendix 1). Since follow up was conducted by telephone, it identified few variables with a very short questionnaire. Model L3 confirms beyond doubt, contrary to the literature, that the size of firms does *not* influence the probability to adopt[10]. Again the Pseudo R2 is extremely low.

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[10] The number of employees and the level of turnover are, of course, correlated (Pearson coefficient=0.030), but the test for multicollinearity shows that the distortion of coefficients is negligible.

Variable	Coefficients in L1 (1)	Coefficients in L2
DG	0234274 (.0623418)	
RD	-.0832315 (.1255175)	
NC**	-.0002084 (.0005509)	
PC**	.0000247 (.0000149)	
TV	.3235468 (.0073984)	
_cons	-2.98279 (0.9287264)	11.0177 (6.433892)
S_PS**		-1.556721 (0.7334478)
S_SC		-1.117553 (0.785692)
S_TS		-1.089273 (0.8368824)
S_LS**		.5217112 (0.8649641)
S_FA		.3235468 (0.4290555)
S_EDS*		-2.003301 (1.455093)
S_EDI		-.8611418 (1.282934)
S_EUE		.3516724 (0.9596716)
S_EI		-.0348393 (0.8018816)
LR chi2	3.88	27.01
P	O0.5671	0.0014
Pseudo R2	0.0987	0.5223

** P<0.01; * P<0.05, Standard errors in parentheses

Table 10: Results of the regression

Variable	Coefficient in L3
NE	-.0000214 (.0000713)
T	.0001323 (.0002854)
_cons	-2.467865 (.2153357)
LR chi2	0.37
P	0.8292
Pseudo R2	0.0019

** P<0.01; * P<0.05, Standard errors in parentheses

Table 11: Results of the logistic regressions

– E- PROCUREMENT:

We also run logit models for the e-procurement adoption decision. The independent variables of L4 are structural variables[11] and, once again, we do not take size indicators into account. In L5, we consider the obstacles to the adoption of e-commerce. L6 and L7 include the variables designed to show network externality effects. Finally, as in the case of e-selling, we test the influence of size on e-procurement adoption on the merged sample.

L4 identifies TV and RD as significant variables, but has little explanatory power. Model L5 includes all subjective perceptions of obstacles and all variables related to expectations. Only two variables are significant, all with the right sign. However, the model is moderately powerful. As far as e-selling is concerned, model L8 tests the influence of size on the adoption of e-commerce.

[11]We do not include the number of product codes and of customers, because they are irrelevant to e-procurement.

Variables	Coefficient in L4	Coefficient in L5	Coefficient in L6	Coefficient in L7
DG	-.0136255 (.0248343)			
TV*	.0049446 (.0028358)			
RD**	.061735 (.0356161)			
P_PS*		-.8324084 (.2742181)		
P_SC		-.3100906 (.2968609)		
P_TS		-.0235534 (.3873342)		
P_LS		-.3745816 (.3872766)		
P_FA		.4116065 (.3075132)		
P_EDS*		-1.850581 (.6174674)		
P_EDI		.6663044 (.580737)		
P_EUE		.5815151 (.4294674)		
P_EI		-.0698595 (.2796398)		
E_CO**			.0221387 (.0255294)	
E_CO2**			.0265434 (.0238633)	
E_COCM**			-.0358684 (.0248189)	
E_SU**				.1658022 (.104987)
E_SU2*				-.0745504 (.0687954)
E_SUCM**				-.0050123 (.0242332)
_cons	-1.612718 (.3255824)	2.426354 (2.031111)	-.981542 (.3399011)	-1.470682 (.3650735)
LR chi2	5.50	34.25	4.77	3.37
P	0.1388	0.0001	0.1895	0.3384
Pseudo R2	0.0370	0.3169	0.0679	0.0533

** P<0.01; * P<0.05, Standard errors in parenthesis

Table 12: Results of the regression

Variable	Coefficient in L8
NE	-.0000209 (.0002803)
T	-.0000324 (.0000924)
_cons	-2.467865 (.2153357)
LR chi2	0.8001
P	0.8001
Pseudo R2	0.0016

** P<0.01; * P<0.05, Standard errors in parentheses

Table 13: Results of the logistic regressions

6. Main Results and Conclusions

Observation of the results of logit models shows that structural characteristics of the firms do not play a central role in the adoption of the new e-commerce technology.

Focussing on e-selling, we found only two variables (NC, number of customers and PC, number of product codes) with significant but very low coefficients. In the case of number of customers (NC), the sign was contrary to expectations. Among structural characteristics, the economic literature on technology diffusion highlights the central role played by size. In particular, most studies demonstrate a positive relationship between firm size and adoption. Running the logit models we found that the only significant coefficient is associated with turnover (T), but with a surprising negative sign, although this value is extremely low. Since the result is in sharp contrast to existing literature, we ran regressions not only on the sample of the respondents but also on the merged sample of respondents and follow up. The follow up analysis, reported in Appendix 1, showed that the percentage of small adopters in the respondent sample was biased. However, the result was confirmed over the larger sample. In addition, in the case of e-procurement, the number of employees (NE) is weakly but negatively associated to the probability of adoption. The failure of identifying a strong size effect, both for e-selling and for e-procurement, is remarkable, since most of the literature posits a positive relation between size and adoption. Admittedly, the evidence is preliminary and is obtained from a small sample. An interesting research issue would be to investigate whether Internet-based technology is less sensitive to size than manufacturing technology.

Analysing the impact of the perceived obstacles to the use of e-commerce on adoption, we found a significant and high coefficient for S_SP. Firms that perceive their product as unsuitable to be sold electronically are not likely to adopt. Clearly, the suitability of products is a filtering rather than an explanatory variable. Companies whose products are not suitable for e-commerce may not be among the population of potential adopters. However, it is difficult to discriminate these cases from those of firms that wrongly perceive their products as non suitable. The appropriateness of the technology, in fact, must be determined dynamically.

With regard to the legal security obstacle, we found a positive sign. A possible interpretation of this unexpected result is that firms adopt even though they are aware of serious legal problems. It is easier to interpret the result about S_EDS, the expected improvement in data security. It displays a negative coefficient that is also the highest of the model. We can see this as a Rosenberg effect. A firm that believes that new systems for improving data security will be developed in the future will tend to delay the adoption of current technology.

Switching to e-procurement and analysing firms characteristics, we found significant coefficients for TV and RD: such variables positively influence the adoption decision. In other cases, these coefficients are quite low. As far as firm size is concerned, the tendency is similar to that in e-selling. In this case NE is significant and has a minus sign: it seems that the number of employees has a negative effect on the probability of adoption. Once again, this coefficient is very low.

With regard to the perceived obstacle to adoption, as in the case of e-selling, P_PS and P_EDS have significant coefficients.

Given the above, the main explanation of adoption decisions may be found in network externality effects. Variables E_CO and E_CO2 have positive and significant coefficients. The higher the perceived percentage of competitors that have already adopted, and the higher the percentage of competitors that will adopt in the subsequent year, the higher the probability of adoption.

This confirms the presence of a direct network externality effect, which we called Effect two (*coordination failure effect*). The same occurs for E_SU, while E_SU2 has a significant but negative coefficient. This result supports, at least partially, the presence of an indirect network externality effect, which we call Effect three (*market variety effect*).

In short, we found clear evidence of a network externality effect in the adoption of e-commerce. Although the coefficients are not large and the overall model is only marginally explanatory, the effect is clear and significant.

In addition, critical mass thresholds have significant coefficients with the expected sign: the lower the critical mass percentage, the higher the probability to adopt.

Once again, we interpret these findings as suggestions of a network externality effect mediated by the expectation of a threshold level in the diffusion process. Potential adopters seem to be well-aware of the presence of network effects and expect the increase in utility associated with overcoming the threshold to be non linear.

The structural variables and indicators describing the intrinsic value of technology are extremely weak explanatory variables. On the contrary, all variables describing network externality and critical mass effects enter into a logistic regression model. Firm characteristics and the value of technology are not highly important; opinions and network effects are. These findings support the interpretation of the adoption of network-related technology as a co-ordination game in which there are multiple Nash equilibria and the selection between multiple equilibria is governed by the opinions of agents about the likely behaviour of other agents.

At the same time, the introduction of a game-theoretic perspective does not endorse the classic assumption about agents' rationality, particularly with regard to expectations. Our data show that decision makers have deeply *biased opinions* about both the current and future evolution of technology adoption. Adopters see more adopters around them, both in terms of competitors and customers or suppliers, than non-adopters. Moreover, adopters are more optimistic about the future and the short term evolution of the adoption rate. Lastly, adopters require a lower percentage of critical mass.

Adopters see more diffusion, expect more diffusion, but need less diffusion in order to adopt themselves. How can these findings be reconciled with assumptions about rational expectations in technology evolution and about common knowledge of the co-ordination game?

According to Varian and Shapiro, "expectations are fundamental for reaching Critical Mass" (Varian and Shapiro, 1999, 219). According to our data, the interaction between network externalities and firms' heterogeneity lead to Critical Mass phenomena (Economides, Himmelberg, 1995; Huberman, Lock, 1998). An interesting direction for further research is thus to link the study of the diffusion of technology characterised by network externalities with collective action problems (Hardin, 1971; Marwell, Oliver, 1988a; Marwell, Oliver, Prahal, 1988b; Marwell, Oliver, Teixerira, 1985; Marwell, Oliver, Prahal, 1993; Glance, Huberman, 1993, 1994, 1995). In collective action critical masses are crucial.

Our data give support to an explanation of diffusion pattern of Internet based technologies as critically dependent on sets of expectations, possibly strongly biased, on the behavior of other agents. Structural variables do not matter, beliefs do.

APPENDIX I

In this section we check for sample selection biases. On one hand, our sample is not representative of all Italian firms, but only of those whose purchasing managers joined the above-mentioned association (ADACI) in 1999. One could object that firms belonging to a supply management association are more likely to pay attention to e-procurement.

If this is true, then it is possible that adopters are over-represented in the sample of respondents, since professionals engaged in the new technology are more willing to answer the questionnaire. We therefore carried out a telephone follow up on a sample of 200 non respondents extracted randomly from the list of 1200 initial firms. The total sample of respondents and non respondents is as high as 400.

E-selling adoption

		Answering			
		NO		*YES*	
		Count	*%*	*Count*	*%*
E-selling adoption	*NO*	179	89.50%	188	94.00%
	YES	20	10.00%	12	6.00%
	Missing	1	.50%	0	.00%
Group Total		200	100.00%	200	100.00%

Table A1

E-procurement adoption

		Answering			
		NO		*YES*	
		Count	*%*	*Count*	*%*
E-procurement adoption	*NO*	188	94.00%	159	79.50%
	YES	11	5.50%	41	20.50%
	Missing	1	.50%	0	.00%
Group Total		200	100.00%	200	100.00%

Table A2

Table A1 shows there is no significant difference in the e-selling adoption rate of respondents and non- respondents in. In the case of e-procurement, however (Table A2), the difference is striking. The chi-square test confirms this point: the decision to adopt and the decision to answer the questionnaire are independent for e-selling (X^2 = 2.22), but related for e-procurement (X^2 = 19.73).

A possible explanation is that purchasing managers who have adopted e-procurement are more likely to be willing to report their experience to their professional association.

Distortions in firms' size are another crucial point. Small firms may have a greater incentive to answer the questionnaire. Firstly, they may have perceived that answering the survey would lead to greater visibility within the supply management association, particularly since firms had the possibility of taking part in training courses on e-commerce free of charge. This is more attractive for small firms with fewer resources for investing in training in new technology. Moreover, our questionnaire probably had greater visibility in small firms.

From the sample of respondents we obtained a striking result, that size does not affect adoption. We check this result by cross-tabulating the number of respondents and non respondents by size classes.

From Table A3 and Table A4 it seems that very small adopters of e-selling are only found among respondent firms. The same effect is evident for e-procurement (Table 5A and Table 6A).

E-selling adoption

		Answering			
		NO		*YES*	
		Count	*%*	*Count*	*%*
Turnover class	*1-10*	0	.0%	3	25.0%
	11-50	6	35.3%	2	16.7%
	51-100	2	11.8%	2	16.7%
	101-500	7	41.2%	5	41.7%
	>500	2	11.8%	0	.0%
Group Total		17	100.0%	12	100.0%

Table A3

E-selling adoption

		Answering			
		NO		*YES*	
		Count	*%*	*Count*	*%*
Employees class	*<50*	0	.0%	3	25.0%
	50-100	2	11.8%	2	16.7%
	101-500	12	70.6%	5	41.7%
	>500	3	17.6%	2	16.7%
Group Total		17	100.0%	12	100.0%

Table A4

E-procurement adoption

		Answering			
		NO		YES	
		Count	*%*	*Count*	*%*
Turnover class	*<1*	0	.0%	2	5.1%
	1-10	0	.0%	13	33.3%
	11-50	3	42.9%	9	23.1%
	51-100	2	28.6%	5	12.8%
	101-500	0	.0%	9	23.1%
	>500	2	28.6%	1	2.6%
Group Total		7	100.0%	39	100.0%

Table A5

E-procurement adoption

		Answering			
		NO		YES	
		Count	*%*	*Count*	*%*
Employees class	*<50*	1	12.5%	16	40.0%
	50-100	1	12.5%	5	12.5%
	101-500	4	50.0%	15	37.5%
	>500	2	25.0%	4	10.0%
Group Total		8	100.0%	40	100.0%

Table A6

This shows that the sample is distorted, in so far as it includes more small adopters than the group.

Does this bias make the results of the logit model unreliable? We re-run the model on the large sample of both respondents and non-respondents, with size as an independent variable (turnover and number of employees).

Surprisingly, the results are fully confirmed: neither variables are significant[12] in the model. We conclude, contrary to much literature, that firm size is not a relevant variable in adoption.

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[12] The check for multicollinearity shows that the inclusion of both variables does not distort the coefficients.

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