THE PRICE OF CYBER (IN)SECURITY: EVIDENCE FROM THE ITALIAN PRIVATE SECTOR

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Abstract

This paper presents evidence on the economic dimension of cyber risk in the Italian private non-financial sector, based on Bank of Italy survey data. In 2016, the median amount spent on preventing cyber attacks was a modest €4,530, i.e. 15 per cent of a typical worker's annual gross wages. A wide variation exists across sectors and size classes, reflecting differences in how appealing a target a firm is to attackers and firms' awareness of threats: median values range from €3,120 for small firms to €19,080 in the ICT sector and €44,590 for large firms. The market for cyber defence in our reference universe is worth at least €570 million. Having been attacked in the past proves to be a strong incentive to invest in security. The majority of breached firms suffered damages worth less than €10,000; 0.1 per cent reported costs of at least €200,000. Neither the sampling design nor the questionnaire were geared towards the measurement of tail events: underestimation of large incidents is likely. More information is needed before the economy-wide cost can be estimated.

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Keywords: cyber attacks; cybersecurity; cyber risk.

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1. Motivation[1]

As the threat posed by cyber attacks increases, so does the need for statistically sound data on the subject. In May 2017, the G7 finance ministers and central bank governors declared that "no point of cyberspace can be absolutely secure as long as cyber threats persist in the surrounding environment; our drive to strengthen the financial system against cyber attacks can achieve maximum results only if accompanied by measures that reduce the level of insecurity in cyberspace as a whole. In turn, economy-wide policies must be based on reliable, impartial, comprehensive and widely accessible data" (G7, 2017).

Not only is lack of such data an obstacle to policy design (Biancotti et al., 2017); it also has a direct negative impact on the private sector. Corporate decision-makers often have to choose how much to invest in cybersecurity based on information provided by commercial entities with an incentive to overstate the economic impact of breaches. Estimates of damage from cyber attacks based on the UK Government's Cyber Security Breaches Survey (CSBS in the following; United Kingdom Department for Culture, Media and Sport, 2017), a rare example of official statistics in this area, are markedly lower compared to some widely quoted commercial figures. Low-quality data hinder the growth of a market for cyber insurance and, as a consequence, the efficient management and transfer of cyber risk; the Organization for Economic Co-operation and Development (OECD, 2016) points out that insurers have a hard time designing cyber policies in the absence of reliable historical information on the prevalence of attacks and related losses.

A previous paper (Biancotti, 2017) made a first attempt at addressing the data gap for Italy by estimating the incidence of cyber attacks in the private non-financial sector, based on the business surveys carried out in 2016 by the Bank of Italy. The study proved that firms can provide informative data on cybersecurity in the context of a multi-purpose economic survey; however, as it was a preliminary step, questions did not cover the relationship between expenditure on cyber defence and firm-level vulnerability, nor the impact of cyber breaches. This paper fills the gap, drawing on specific questions that were added to the surveys in 2017.

We find that in 2016 the median firm spent a modest €4,530 to prevent cyber attacks, roughly 15 per cent of median gross annual wages for a representative worker, or 2.5 per cent of median firm-level gross domestic fixed investment. In this case, however, economy-wide indicators have limited relevance, as variation across categories is very high. Median defensive expenditure ranged from €3,240 in low-tech sectors to €19,080 euro in the ICT sector ; technologically advanced firms handle large quantities of valuable data, hence attracting attackers, and they can count on decision-makers who understand the threat.

Size matters, too: the median firm with 500 employees and over spent €44,590, vis-à-vis the €3,120 of its counterpart with less than 50 employees. Large firms have more connected devices to protect, more staff that need to be trained to use them securely, and more potential entry points for attackers. They are also more

[1] I would like to thank Pietro Catte, Paolo Ciocca, Riccardo Cristadoro, Antonino Fazio, and Giovanni Veronese for their comments. The Sample Surveys Division at the Bank of Italy and the cybersecurity community of the Italian government provided substantial help with the survey questions. All remaining mistakes and omissions are mine. The views here expressed are those of the author and should not be attributed to the Bank of Italy.

likely than small ones to have a dedicated IT department which can assess risk levels properly, and they can benefit from economies of scale for certain protective measures.

As expected, differences also emerge between exporters and non-exporters, on account of the former's greater exposure to cross-border attacks compared to firms that are only known locally.

Expenditure is also markedly lower in Southern Italy, with a median value of €2,700, against over €5,000 for Northern regions. This is partly explained by composition effects: the share of small and low-tech firms is higher in the South compared to the rest of the country, and the share of exporters is lower. However, a statistically significant difference remains even after controlling for these factors: it may reflect unobserved characteristics of the context, both on the demand side (e.g. less frequent use of connected devices, lower threat awareness) and the supply side (e.g. a smaller market for cybersecurity services).

Based on our data, the market for cyber protection in 2016 was worth at least €570 million; the ICT sector, which employs 5 per cent of the labour force in the reference universe, accounted for 11 per cent of total expenditure in cyber defense.

Among defensive measures, anti-malware software was nearly ubiquitous, although the survey does not probe whether it was regularly updated. Cybersecurity training for employees was offered by two thirds of firms; analysis of vulnerabilities and encryption were less common. Having been attacked in the past proved a strong incentive to security investment: most firms that reported a breach in 2016 experienced business disruption and/or needed extra working hours for recovery, and 81 per cent upgraded their defences as a consequence.

Informative estimates on the monetary damage caused by attacks are more complex to obtain. More than 90 per cent of firms report having sustained a direct cost below €10,000; only about one per cent reported damages in excess of €50,000, with 0.1 per cent above €200,000. We know from several sources that large-scale incidents exist, and they are a core component of the cybersecurity story; however, they are nearly absent from our sample. More data on tail events, along with correction models for under-reporting, will be needed before the total cost of attacks for the economy can be estimated; this could be achieved via oversampling of high-value targets, combined with auxiliary information from other datasets (e.g. breach notifications sent to the national data protection authority).

Despite differences in the reference universe and in the definitions of some variables, our estimates are broadly in line with those obtained from the UK CSBS. Average expenditure is in the thousands of euros/British pounds[2] for small firms, in the tens of thousands for medium ones, in the hundreds of thousands for large ones; its distribution is highly skewed, and the ICT sector consistently stands out from the rest on all defence metrics. Reported costs from attacks are generally small, mostly in the thousands, but the complete picture is hard to gauge given the asymmetry of the distribution and the limitations of the sample.

[2] At the time of writing, the exchange rate was 1 British pound to 1.10 euros.

The paper is structured as follows. Section 2 describes the data; Section 3 presents key descriptive findings on cybersecurity expenditure at the firm level, the frequency of cyber attacks, and their economic impact; Section 4 looks jointly at all these dimensions so as to identify clusters of firms that are homogeneous with respect to cybersecurity; Section 5 proposes models for robust estimation of expenditure; Section 6 adds some very preliminary results on the effectiveness of defensive expenditure. Section 7 compares our results with those of the UK CSBS. Section 8 concludes. The Appendix provides further statistical details.

2. The data

Every year, the Bank of Italy carries out two surveys of Italian private sector firms, covering industrial and non-financial services firms with at least 20 employees. The sample is randomly selected according to a stratified design; the results are statistically representative by macro-region, size class and certain aggregations of NACE Rev.2 sectors (see Banca d'Italia, various years for methodological documentation).

Between January and May of each year, the main quantitative descriptors of a firm's economic activity (employment, investment, turnover) are measured. Between September and October, a qualitative follow-up records changes in those variables.[3] Questionnaires also include time-varying monographic questions, driven by contingent informational needs. Respondents are typically executives or administrative staff with a broad knowledge of the business, who sometimes consult with field specialists – e.g. IT personnel – to answer some of the more technical questions.

In 2017, the quantitative survey featured a section on cybersecurity, structured into six questions:

Q1. Does your firm adopt the following cybersecurity measures (Yes/No)? Please also consider measures that are outsourced.

(i) Use of defensive hardware/software (e.g. anti-virus, firewall etc.)
(ii) Training for employees on the secure use of IT devices
(iii) Data encryption, even if only applied to a part of the data
(iv) Analysis and management of vulnerabilities in the firm's IT systems

Q2. In 2016, approximately how much did you spend to defend yourself against the risk of cyber attacks? Please consider all the activities indicated above and any other activity aimed at attack prevention, either handled internally or outsourced (e.g.: salaries of employees and/or external consultants working on cybersecurity; price of defensive software or hardware; cost of training). Express your answer in thousands of euros.

Q3. In 2016, was your firm hit by a cyber attack? (Yes/No) Only consider the attacks that had consequences, no matter how limited and/or short-lived and/or easily reversible, on the functioning of the firms' systems and/or on the integrity and confidentiality of data therein stored.

[End of section for firms that reported no attacks]

Q4. Did any of these attacks cause… (Yes/No)

(i) An interruption or a slowdown of ordinary work activities

[3] The dataset is not a full panel due to attrition; the overlap between adjacent surveys is at around 80 per cent.

(ii) Extra working hours (of employees or external consultants) to repair technical damages, communicate with clients and/or suppliers and/or shareholders concerning the attack etc.
(iii) Theft or loss of data, including intellectual property

Q5. In 2016, approximately how much damage did these attacks cause? Consider all the items indicated above and any other monetary cost caused by the attacks (e.g. compensation given to clients or suppliers, legal costs, fines from regulatory entities). Express your answer in thousands of euros.

Q6. Did you strengthen your security measures after the attacks? (Yes/No)

For Q2 and Q5, respondents were given the option of either providing a point value or choosing one of the following options: (i) No expenditure/damage; (ii) Less than € 10,000; (iii) Between € 10,000 and € 49,999; (iv) Between € 50,000 and € 199,999; (v) € 200,000 and over.

In order for the questionnaire to be considered valid by the Bank of Italy, a set of core items on employment, turnover, and investment have to be answered: all the rest are optional. In the 2017 wave, the optional sections covered, among other themes, cybersecurity, hydrogeological risk, skill shortages, and the uptake of certain public incentives to investment. Of the 4,209 firms interviewed in the survey, 8.4 per cent did not answer any of the optional questions. We chose to exclude such firms from our analysis, so as to preserve the information that we can extract from section-specific non-response patterns. Sometimes the absence of an answer can be informative *per se*, as shown in Biancotti (2017). Non-response limited to individual cybersecurity questions, or even the whole section, might be correlated with the existence of a data breach: firms that have not been attacked have no reason to hide anything, while firms that have been hit may choose to skip the question to avoid reputational damage. However, this should not be conflated with non-response to a large set of optional questions related to heterogeneous topics: firms that only provided values for the core variables were probably pressed for time, rather than reluctant to report a cyber attack. Our final sample comprises 3,824 firms (Appendix Table A1)[4].

3. Descriptive results

3.1 Cyber defence

Data on cyber defence measures adopted by firms conveys two main messages. First, large firms and companies operating in the ICT sector are significantly more invested in cybersecurity. Second, having been attacked is a key motivation for spending on defence, possibly indicating a lack of risk awareness prior to being hit.

3.1.1 Defensive measures

Figure 1 shows the prevalence rates of some cyber defence measures overall, by technological level and size of firms. Adoption of defensive software or hardware, such as anti-virus programs or firewalls, is omitted from the figure: 99 per cent of firms report it, with minimal variation across categories. This is in line with the previous survey, carried out in the fall of 2016, which found that only 1.5 per cent of

[4] The paper also includes some very preliminary results based on the 2018 quantitative survey, which only included Q3 (referred to 2017). At the time of writing, the sample for the 2018 survey comprised 4,079 firms that had answered at least one optional question.

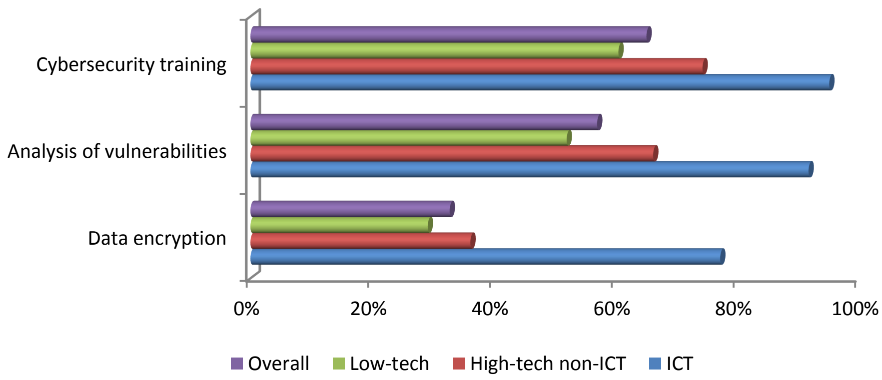
respondents did not deploy any cybersecurity measure (Biancotti, 2017). It does not, however, imply generalized safety, or awareness of cyber risk. Anti-virus software mostly comes pre-installed so its presence does not necessarily reflect a deliberate choice of the system manager. We do not know whether the software is updated whenever needed and the hardware is appropriately configured.[5]

Cybersecurity training for employees is quite widespread, at 65 per cent of firms; analysis and management of vulnerabilities follows, at 56.9 per cent; encryption is only adopted by 32.7 per cent. Proportions are very variable according to size and technological maturity, but the ordering remains the same.

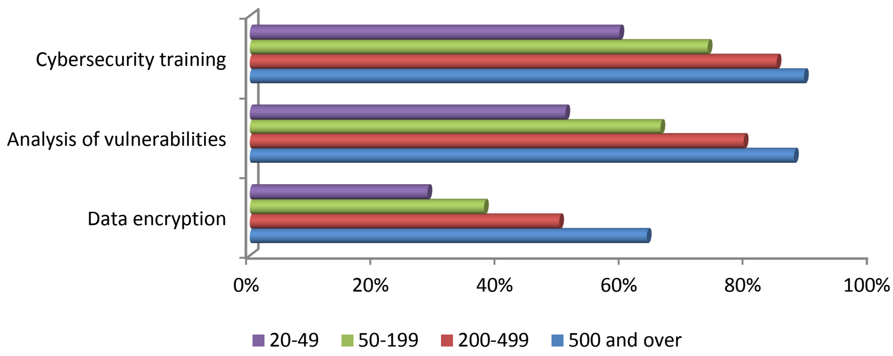
Figure 1

Cyber defence measures adopted by firms, 2016
(percentages of firms)

a. overall and by technological level(*)



b. by number of employees



(*) ICT sector: OECD classification. High-tech non-ICT: non-ICT manufacturing firms with high or medium-high technological intensity, and non-ICT service firms with high knowledge intensity, according to OECD/Eurostat classification. Low-tech: all other firms. Firms in the energy sector, not covered by the original classification, are reclassified as non-ICT high-tech.

The relative unpopularity of encryption is puzzling at first glance. Of the measures surveyed, it is the cheapest one: military-grade encryption algorithms are freely available in the public domain, and they can be

[5] More generally, quality is not measured for any of the defensive measures surveyed; while the questionnaire offered definitions, there is no guarantee that all firms took the same words to mean the same activity.

applied with almost no effort to some type of data, such as business emails. Large-scale encryption has a cost in terms of working hours, it can result in cumbersome operation of some devices, and data may be lost if encryption keys are not properly managed; however, it is still likely to be less expensive compared to training or analysis of vulnerabilities. So why do firms spend on these two measures, but forego a low-cost way to protect the confidentiality of their data?[6]

The vendor-driven nature of the market for cybersecurity (Anderson, 2001) is a prime suspect. Asymmetric information is an issue: most consumers of defensive products are unlikely to fully understand the nature of the threat, and the effectiveness of each proposed solution. Vendors have an incentive to suggest whatever maximizes their own profit, rather than what is appropriate for the client[7,8]. From their perspective, security training and toolkits/services of vulnerability analysis are a safer bet compared to encryption, where the competition of free solutions is strong[9]. On the demand side, data theft might just not be enough of a concern for firms to trigger the use of encryption (see Subsection 3.2 for further details).

Simple frequency estimates already reveal some key patterns (Appendix Table A2). The ICT sector has near-ubiquitous security training and network analysis, with 77 per cent of firms encrypting at least some of their data[10]; low-tech firms have prevalence rates for training, network analysis and encryption around 60 per cent, 50 per cent and slightly less than 30 per cent respectively. ICT firms are attractive to attackers, because they store large quantities of valuable data in electronic form; they can also count on decision-makers who understand the threat, including that of data theft. These two factors combine to yield an intensive use of various protection systems.

Larger firms also deploy more defences compared to smaller ones; the prevalence of all measures increases monotonically with size. They have more connected devices to protect, more staff that needs to be trained to use them securely, more entry points even for unsophisticated, untargeted attacks. As shown by works in game theory applied to cybersecurity (see Fielder, 2014 for a review), in some cases hackers only need to find one weak link in their target's IT systems to succeed, whereas defenders have to cover all bases ("attack anywhere/defend everywhere" model). Large firms are also more likely than small ones to have a dedicated IT department which can assess risk levels properly, with its own budget; they can benefit from economies of scale for certain protective measures.

[6] Response error might lead to some underestimation of the prevalence of encryption. Some routine encryption/decryption procedures might run in the background on a firm's IT systems, and they might not be reported because only a handful of specialists are aware of their existence.

[7] In the wake of the WannaCry ransomware crisis in May 2016, one senior security expert in the UK government pointed out in a newspaper interview that this in itself contributes to cyber insecurity, as firms are pushed towards expensive solutions that are nonetheless not sufficient to keep them safe (Kaminska, 2017).

[8] A survey by the Australian government shows that companies with a high degree of cyber resilience are more likely than the rest to look to official sources for security guidance, as opposed to the private sector (Australian Cyber Security Centre, 2016).

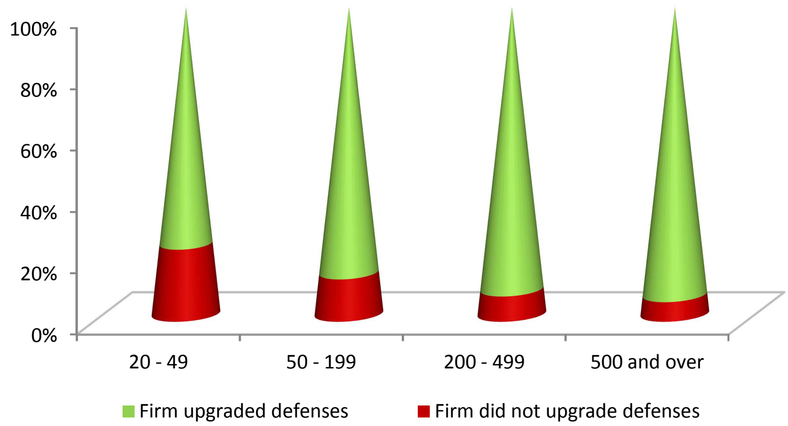
[9] According to a recent survey, more than 40 per cent of encryption products available on the internet are free, and 34 per cent are open-source, allowing anyone to check their validity (Schneider et al., 2016).

[10] Note that the figures for the ICT sector appear not to have a significant impact on the general mean. The ICT sector as defined in this paper only accounts for about 4 per cent of firms in the reference universe; the differences with other sectors are statistically significant in most cases, but the incidence of the sector on the total economy is limited, especially when only weighting for the number of firms.

The data suggest that falling victim to an attack is a strong incentive to cybersecurity investment. Indeed, the overwhelming majority of firms that reported a breach strengthened their defences in the aftermath (Figure 2).

Figure 2

Upgrade of defences after attacks, 2016
(*percentages of firms that reported attacks*)



Regression analysis confirms that size, technological maturity and attack status have an impact on defensive choices (Table 1; the dependent variable is the number of defensive measures reported by a firm[11]). An ICT firm deploys 1.15 measures more than its low-tech counterparts; firms that were attacked and upgraded their defences have 0.41 more than those that were not attacked[12]. Belonging to the smallest size class has roughly the same effect, with the opposite sign.

A few other dimensions emerge as significant. Firms located in the South of Italy have a slightly lower level of protection (-0.14 measures) compared to the rest of the country, even after controlling for the higher prevalence of small and low-tech firms in the region. This may reflect unobserved characteristics of the context, such as less intensive use of connected devices, and a smaller market for cybersecurity services.

Exporters and firms that operate infrastructures, such as ports or water distribution systems, have more defences; both results are expected. Firms with an international dimension are more likely to have experience in conducting business online, resulting in higher threat awareness, and they are more exposed to cross-border attacks. Infrastructure is a high-value target for hackers, because it allows them to jeopardize all activities that rely on it with a single stroke; cyber defence has become a priority for infrastructure operators long before it was a matter of general interest, especially in sectors where an attack could threaten public safety.

Interestingly, manufacturing fares worse than services, after technological content is controlled for; this is probably because some services that fall in the low-tech category according to the OECD/Eurostat

[11] The same results also obtain for different specifications, and for three separate logistic regressions where the dependent variables indicate, respectively, whether a firm provides cybersecurity training, performs analysis of vulnerabilities, and uses encryption.

[12] The difference with firms that were attacked but did not upgrade their defences has the expected sign, but it is not significant. Results on this group of firms generally lack robustness, because the group is small and concentrated in the bottom size class.

classification used in this paper, such as trade and hospitality, are more likely to have an online presence, however small, compared to low-tech manufacturing. While the explanatory power of the regression is limited, suggesting that unobserved idiosyncratic characteristics play a large role in explaining defensive choices, effects are significant and have the expected sign (for definitions of covariates, see Appendix Table A3).

Table 1

Determinants of the adoption of defensive measures, 2016
(linear regression)

Intercept	2.910	***
	(0.054)	
Small	-0.409	***
	(0.038)	
South	-0.140	**
	(0.046)	
ICT	1.147	***
	(0.090)	
High-tech non-ICT	0.312	***
	(0.043)	
Manufacturing	-0.334	***
	(0.038)	
Export share: less than 1/3	-0.175	***
	(0.044)	
Infrastructure	0.315	**
	(0.129)	
Attacked, upgraded defences	0.409	***
	(0.044)	
Attacked, did not upgrade defences	-0.102	
	(0.085)	
N	3,456	
R^2	0.14	

Levels of statistical significance of coefficients : *** 1% ** 5% *10%

3.1.2 Expenditure on cyber defence

39 per cent of the sample provided a point estimate for expenditure on cyber defence; 50 per cent provided an interval estimate, and the rest declined to answer the question. As point estimates can readily be turned into intervals but not vice versa, in this Section we only present results by intervals. In Section 5 we return to this issue using model-based estimates of point values. Obvious material response errors in point values were rectified before turning them into intervals[13].

[13] In the questionnaire, respondents that provided a point estimate were asked to do so in thousands of euros: some of them, however, clearly misread the instructions and answered in euros. This is a well-known occurrence in sample surveys (Biemer et al., 2004). The errors were identified by applying a conservative criterion: if the answer exceeded 50 times the median of cybersecurity expenditure in the respondent's size class, calculated either as a fraction of turnover or as a per-employee value, it was labeled as incorrect and divided by 1,000. The adoption of relative measures prevents the automatic labeling of data provided by very large firms as erroneous. Evaluation of individual observations, helped by auxiliary variables and context, confirmed this to be a reasonable

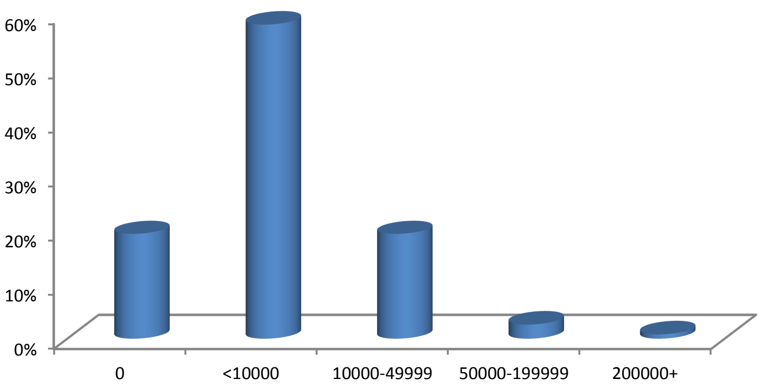
In the population, modal expenditure in 2016 was below 10,000 euros, with 17 per cent of firms reporting no expenditure at all and only 0.7 per cent choosing the "more than 200,000 euros" bracket (Figure 3; Appendix Table A4). The firm-level median gross annual wages for an average employee amounted to 29,700€ in 2016: the majority of firms did not spend enough in cybersecurity to cover the cost of a representative full-time resource. In the questionnaire, respondents are explicitly instructed to include in their estimate the cost of personnel, whether internal or external, e.g. contractors and consultants; barring very pervasive response error, the data indicate that most firms do not employ specialists, and only allocate a modest share of their generic IT human resources to cybersecurity.

The distribution is shifted to the right for larger firms, high-tech and internationally exposed ones, to the left for small and low-tech firms. More than 30 per cent of firms with 500 employees and over invested at least 50,000 euros for cybersecurity in 2016, and 15 per cent invested more than 200,000[14]. Attacks matter here, too: those who reported a breach indicated zero expenditure only in 5.2 per cent of cases, against 22.4 per cent for those who didn't. This suggests that for many firms an attack is the watershed between not considering cybersecurity an issue at all and starting to look at it as a component of risk management.

Figure 3

Firms' expenditure on cyber defence, 2016

(percentages of firms; expenditure brackets in euros)



An ordered logistic regression[15] confirms that, even after all other factors are controlled for, small firms and low-tech ones spend less, while the ICT sector spends more[16,17] (Table 2).

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criterion. The correction applied to 2.5 per cent of observations. All results that follow on point estimates, including those in Section 5, incorporate this correction.

[14] For per-employee estimates, see Section 5.

[15] To estimate this and subsequent models, we exclude the 5.5 per cent of respondents who gave inconsistent answers, reporting zero expenditure in the presence of at least one costly cybersecurity measure. Conservatively, we only consider security training and network analysis as costly measures. Encryption, as mentioned in the previous Section, can indeed be free; free or very cheap anti-virus programs exist, and smaller firms are indeed likely to prefer them to more established and expensive solutions. On the other hand, training and network analysis definitely have a cost, even if only in terms of working hours of internal staff. We also aggregate the "No expenditure" and "Less than 10,000 euros" category to improve the fit of the model, as zeros appear to be difficult to predict.

Table 2

Determinants of expenditure on cyber defence at the firm level, by intervals, 2016
(ordered logistic regression)

Small	-3.635	***
	(0.070)	
Medium (low)	-2.527	***
	(0.070)	
Medium (high)	-1.531	***
	(0.079)	
South	-0.434	***
	(0.034)	
ICT	2.313	***
	(0.050)	
High-tech non-ICT	0.539	***
	(0.028)	
Manufacturing	-0.228	***
	(0.026)	
Infrastructure	0.870	***
	(0.073)	
Attacked, upgraded defences	0.311	***
	(0.027)	
Attacked, did not upgrade defences	-0.460	***
	(0.064)	
Turnover per employee	$5.38*10^{-4}$	***
	$(2.20*10^{-5})$	
Turnover per employee squared	$-1.23*10^{-8}$	***
	$(6.44*10^{-10})$	
Export share: less than 1/3	-0.280	***
	(0.029)	
Intercept: 200,000+	-2.379	***
	(0.082)	
Intercept: 50,000-199,999	-0.700	***
	(0.072)	
Intercept: 10,000-49,999	1.887	***
	(0.074)	
N	3,005	

Levels of statistical significance of coefficients : *** 1% ** 5% *10%

The predictive fit of the model is strongly differentiated across expenditure classes, as shown in Appendix Table 5. More than 89 per cent of firms that spend up to 10,000 euros are correctly classified, and all of the misclassification occurs in the adjacent class. Conversely, almost none of the firms that spend between 50,000 and 199,999€ is classified correctly, although most errors are small; only 14 per cent of top spenders are correctly predicted, with several large discrepancies. This depends on the small number of (highly heterogeneous) observations in the upper classes, from issues with the attack indicators that are

[16] An alternate specification shows that the use of each of the defensive measures is associated with higher expense. However, given the correlation between the prevalence of defensive measures and attack status, the dummy variable indicating whether a firm has been attacked and upgraded defences is no longer significant.
[17] The same patterns described in Section 3.1 emerge for Southern Italy.

discussed below, and it is also likely to reflect unobserved factors: for example, outside of sectors where it is now commonplace to be concerned with cybersecurity, subjective attitudes of board members can make the difference.

3.1.3 Frequency of cyber attacks

The raw prevalence rates of reported attacks for 2016 are of 23.3 per cent when responses are weighted by number of firms, and 32.1 when they are weighted by number of employees[18] (Table 4; see Appendix Table A6 for non-response rates).

Self-reports on the part of firms are not sufficient to estimate the true prevalence of cyber attacks. Among others, Gal-or and Ghose (2005) and Laube and Böhme (2016) show that firms have scant incentives to disclose cyber incidents, even in the presence of legal obligations; the reputational costs and subsequent loss of competitiveness can outweigh the benefits of information sharing. Moreover, especially in low-tech sectors, firms may not even be aware that a breach occurred: ransomware and denial-of-service are noticeable, fraudulent access to company networks sometimes is not.

Correction methodologies for self-reported data are not the focus of this paper; for a detailed discussion of the issue, see our work on the previous survey (Biancotti, 2017). Table 4 shows, along with estimates on the unedited data, the results of one of the many possible editing and imputation models that takes into account misdetection and under-reporting of attacks, yielding a total upward correction of 19.3 percentage points on the share of attacked firms:

- firms that reported no attacks in 2016, but had reported two or more in the survey covering September 2015-September 2016, are attributed a positive response (inconsistency correction, accounting for 8.3 percentage points of the total);
- data for firms that reported no attacks and deployed no security measures other than an anti-virus program are deleted[19], and imputed based on a simple model where the probability of being attacked is a function of size class, location, technological level and total software investment[20] (misdetection correction, 5.8 percentage points);
- firms that provided no response are treated as reticent and attributed a positive response (reticence correction, 5.2 percentage points).

Independent of corrections, larger firms and exporters report cyber attacks more frequently than others, while being small or located in the South lowers the chances of being attacked. The same arguments presented in Section 3.1 apply: large firms are more visible both offline and online, and rely more on

[18] In this wave of the survey, only a binary indicator was collected (at least one attack / no attack). According to the results of the previous wave, among those attacked 37.9 per cent were hit only once between September 2015 and September 2016, 44.5 per cent between two and five times, 6.5 per cent between 6 and 10 times, and 11 per cent over 10 times (Biancotti, 2017). High-tech firms and large ones were more likely than average to suffer multiple breaches.

[19] Lack of cybersecurity training and network analysis, in particular, appear to be reasonable proxies of low ability to detect attacks. We are aware that, by only deleting data for firms that reported no attacks, we may introduce bias in our imputation model. However, this risk is mitigated by the fact that false positives are very unlikely. Results for specifications that do not include this asymmetric correction are available in the Appendix.

[20] Note that information on defensive measures and security expenditure is not included in the model. These variables are, as shown, correlated with reported attacks; however, they do not add significant predictive power to the regressions, while preventing imputation for firms who did not provide an answer on the questions on defence. Software investment, which is available for all observations, is used as a loose proxy.

connected devices; firms that operate on a local scale are less exposed compared to those with business contacts in several jurisdictions. Again, the difference between Southern Italy and the rest of the country partly depends on composition effects; however, it is still statistically significant, although smaller, after controlling for size, sector and internationalisation (see Biancotti, 2017 for regression analysis showing this).

Table 3

Firms hit by at least one cyber attack, unedited and corrected data, 2016
(*percentages; estimates on full sample*)

	Share of firms, unedited	*Share of firms, corrected*	*Total correction (points)*	*Inconsistency correction (points)*	*Misdetection correction (points)*	*Reticence correction (points)*	*Share of employees, unedited*	*Share of employees, corrected*
Geographical area								
North-West	22.6	42.0	19.4	8.8	4.6	6.0	30.1	49.2
North-East	27.4	46.8	19.4	9.1	4.4	5.9	34.0	51.9
Centre	21.8	43.3	21.5	9.1	8.4	4.0	37.4	55.6
South and Islands	20.0	36.6	16.6	5.2	7.2	4.2	24.5	40.3
Number of employees								
20 – 49	21.3	40.8	19.5	8.0	6.6	4.9	21.4	41.7
50 – 199	26.1	45.4	19.3	8.6	5.1	5.6	26.4	44.8
200 – 499	31.6	49.2	17.6	10.1	1.0	6.5	31.4	48.7
500 and over	34.4	51.3	16.9	8.0	0.7	8.2	41.6	58.7
Tech / knowledge intensity of sector								
ICT	26.4	39.8	13.4	6.0	2.0	5.4	41.4	49.7
High-tech, non-ICT	26.2	42.9	16.7	7.4	4.0	5.3	36.1	52.6
Low-tech	22.2	42.7	20.5	8.7	6.5	5.2	29.4	49.2
Exports as share of turnover								
Less than 1/3	21.9	41.5	19.6	8.6	6.0	5.0	29.6	48.5
Over 1/3	27.3	45.7	18.4	7.3	5.2	5.9	38.0	54.5
Total	**23.3**	**42.6**	**19.3**	**8.3**	**5.8**	**5.2**	**32.1**	**50.2**

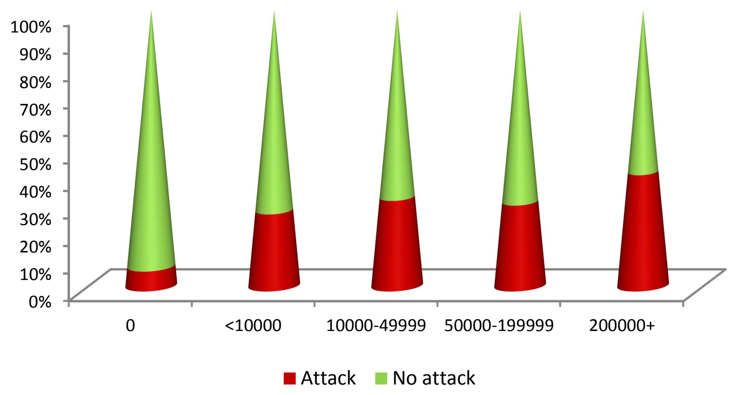
After corrections, the share of breached firms climbs to 42.6 per cent (representing 50.2 per cent of employees) overall, peaking at 51.3 per cent (58.7) for large firms, with a minimum of 36.6 per cent (40.3) in the South. Note that in this particular specification the aggregate adjustment is stronger for low-tech and smaller firms, more likely to have scarce detection abilities compared to the rest. Corrected hit rates for low-tech and non-ICT high-tech firms are the same, and they are marginally higher compared to the ICT sector, whereas in the unedited data ICT and other high-tech firms were slightly more likely to report an attack than low-tech ones. This inversion is not unrealistic. The probability of being hit is a function of both attractiveness and defence abilities; it may well be the case that, on balance, weak defence-low appeal combinations result in roughly the same breach rates as strong defence-high appeal.

Based on the ranking of firm types by prevalence of attacks, the distribution of defensive expenditure appears to be consistent with rational choice; from a purely private perspective, low-risk groups such as small or Southern firms are justified in spending less compared to high-risk groups. Note that this may well result in a socially suboptimal level of private investment, on account of the negative externalities produced by cyber vulnerabilities (Anderson and Moore, 2011).

Figure 4 shows the prevalence of attacks by expenditure class; it confirms that suffering a breach is a strong incentive to cybersecurity expenditure.

Figure 4

Firms hit by at least one cyber attack, unedited data, by expenditure class, 2016
(*percentages*)



No single estimate in Table 4 should be taken at face value. While probably much closer to the truth than the unedited data, different but equally reasonable specifications for corrections yield estimates of the prevalence of cyber attacks that range between one third and one half of firms (see Appendix Tables A7-A8 for a summary of results across alternate specifications): the message that should be extracted from the data is therefore not a "best point estimate" but a reliable range of values that gives a ballpark estimate.

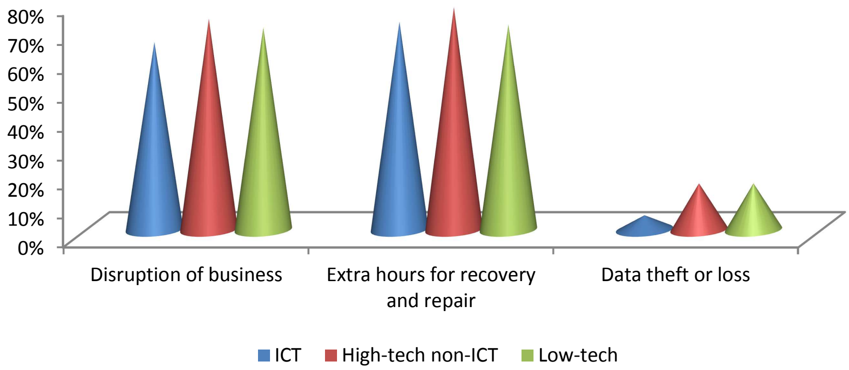
3.2 Economic impact of cyber attacks

Disruption of ordinary business and extra working hours employed for recovery and repair were reported by about 70 per cent of breached respondents, with negligible differences across sectors and size classes (Figure 5; see Appendix Table A9 for a full breakdown). Data theft or loss was an uncommonly observed occurrence, at 16 per cent of victims in the non-ICT economy, and 5 per cent in the ICT sector. It was reported with lower frequency in Northern regions.

Data theft reports suffer from the same drawbacks described for attack reports, only to a greater extent. Among the consequences of an attack, data theft is the one with more relevant legal ramifications, and accordingly also more likely to be under-reported. Third parties – customers, suppliers etc. – whose data are illegally accessed could sue the custodian firm for lack of proper security[21]. This is especially serious for data-intensive sectors, such as ICT.

Figure 5

Observed consequences of cyber attacks, by technological level of sector, 2016
(*percentages of firms that reported an attack*)



Misdetection is quite likely, too, as attacks aimed at espionage are designed to be as unobtrusive as possible, and several high-profile cases have shown that hackers can infiltrate sensitive, oft-monitored IT systems for years without being caught (Mandiant Consulting, 2016). The masses of personal records for sale on the dark web prove that data theft indeed is a large-scale phenomenon[22], notwithstanding what firms report. The likelihood that many occurrences go undetected contributes to explain the limited uptake rate for encryption (see also Subsection 3.1.1). Firms that upgrade their defenses after an attack probably focus on preventing a repeat of the damage that they have already observed. If ransomware delivered via an email attachment triggered recovery costs they will train employees not to open suspicious messages; if a denial-of-service attack interrupted business they will buy a stronger firewall and maybe a specialized defensive toolkit; but they will not encrypt information if they believe that no data was stolen.

About 92 per cent of the firms that reported being hit also provided an indication of the aggregate cost sustained as a result of all breaches. The estimate is limited to direct monetary costs, such as those of repair, recovery and business lost as an immediate consequence of a breach: it does not include reputational costs and the attendant loss of competitiveness, nor loss of share value. While those components are important, they are also very difficult to gauge for most respondents. What was reported during the survey should be considered as a lower bound for actual costs[23].

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[21] At the time of writing, only a minority of Italian firms had a legal obligation to disclose data theft incidents to interested parties. Disclosure obligations will become much stronger in 2018, when the new General Data Protection Regulation of the European Union comes into force.

[22] The website https://haveibeenpwned.com/, a service that allows internet users to verify if their email address has been published online as part of the loot from a data breach, lists 1.4 billion stolen records.

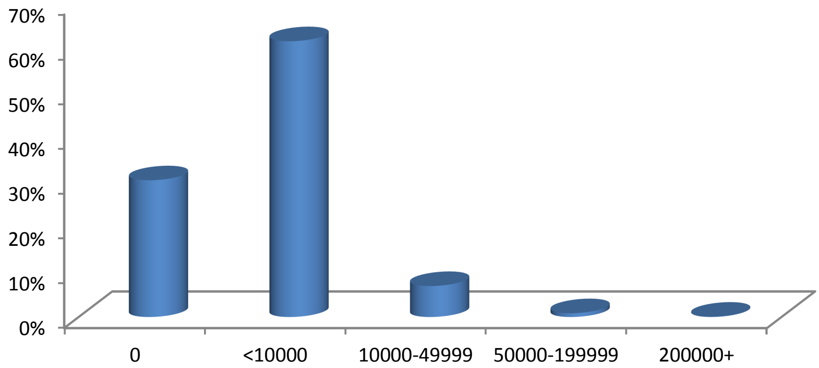
[23] A possible additional source of underestimation comes from the fact that firms may not keep records of internal incident-related costs, e.g. the number of extra working hours of IT staff that were needed for repair and recovery; a similar problem may exist for firms that outsource cybersecurity, if no dedicated incident-response service is bought separately from the rest.

Figure 6 shows the overall distribution of reported costs; see Appendix Table A10 for a full breakdown. The modal category overall is “less than 10,000 euros”, at 61.6 per cent, followed by “no cost” at 30.5 per cent and “between 10,000 and 49,999 euros” at 6.9 per cent. Only 0.1 per cent of attacked firms reported damage exceeding 200,000 euros. As with expenditure, the distribution is shifted to the left for larger firms, where the cost is in the top bracket in 2.2 per cent of cases, and for high-tech ones; it is shifted to the right for small and low-tech firms. Those less likely to be attacked are also less likely to suffer significant damage in case they are: one possible interpretation is that they are hit by simple attacks deployed on a massive scale, such as run-of-the-mill email phishing, rather than by sophisticated, highly disruptive and highly targeted ones.

Figure 6

Monetary costs of all cyber attacks suffered in 2016, at the firm level

(*percentages of firms that reported an attack; cost brackets in euros*)



There is also a predictable correlation between the type of damage caused by attacks and their cost. Among firms that reported no business interruption, no need for extra working hours for repair and recovery, and no data loss the cost was zero in 72 per cent of cases, and below 10,000 euros for the rest; conversely, firms that experienced all three consequences reported no cost in 11 per cent of cases, and costs exceeding 10,000 euros in 10 per cent of cases (Appendix Table A11[24]).

Note that “no cost” answers for firms that listed at least one of the types of damage included in the questionnaire are of dubious reliability. Extra working hours for recovery and repair could theoretically go unpaid, or data lost in a crash could have no commercial value, but these are unlikely occurrences; the share of no-cost attacks is probably overestimated.

An ordered logistic regression confirms those messages (Appendix Tables A12); however, the fit for higher cost brackets is very unsatisfactory, on account of the few observations found in these brackets (Appendix Table A13).

[24] Information in the Table appears to suggest that firms that only suffer data theft face higher-than-average costs. This is not a conclusion that should be drawn, because the size of the “data theft only” group is very small.

Based on our data, it is not possible to provide a meaningful estimate of the economy-wide cost of cyber attacks. This is partly because a point value was provided only by 32 per cent of breached firms that answered the question on costs, i.e. less than 7 per cent of the sample; this subsample is too small even to form a basis for the estimation of exact position measures such as means and medians. There is also a significant methodological issue, which would remain even if we had more responses: the distribution of costs in the reference universe, besides being skewed, is also likely to have a long right tail. Information on tail events is not necessary to get a feeling for the impact that a typical firm should expect; robust position measures suffice. However, it is essential when attempting to estimate the total cost for the economy.

While most attacks appear to cause limited damage, a handful of mega-breaches exist with documented costs in the millions or even, occasionally, in the hundreds of millions (see, for example, the cases of Target and Yahoo!). In the United States this is well-known, because class action lawsuits of customers whose personal data have been stolen have a significant impact; it is likely that serious damage also happens elsewhere, and remains mostly unknown because there is either no legal obligation to disclose it, less media attention on the subject, and/or a smaller constituency of potentially affected individuals. Sometimes, these cases may surface in surveys: in the first wave of the UK CSBS, a £3 million incident was reported; in the second, a single attack caused £0.5 millions in repair and recovery costs alone. Sparse points are, however, not enough for general conclusions. This problem is compounded by the fact that, as we mentioned before, the impact of industrial espionage is likely to be severely underestimated.

The literature on survey methodology puts forward several ways to measure a skewed, long-tailed variable where under-reporting and non-response are significantly higher on the right tail compared to the rest of the distribution. One preferred option is oversampling of the right tail. The problem is how to identify a universe of firms potentially located on it, considering that the survey gives no information on the matter; information from other sources must be exploited. For example, in the field of household wealth measurement, it is useful to oversample the very rich, who are unlikely to answer surveys and likely to under-report their assets when they do (OECD, 2013); lists from which to draw an extra sample of affluent households can be compiled based on public records of ownership of luxury property or vehicles. In the field of cybersecurity, firm types that are at risk for large-scale incidents could be identified based on lists of major cyber events such as the one compiled by the Center for Strategic and International Studies (2017), or breach notifications sent to national data protection authorities, or indicators of a firm’s strategic relevance (e.g. firms operating in sectors where the Committee for Foreign Investment in the United States, which has the power to block foreign investment in American companies based on national security considerations, has most often chosen to open a statutory investigation as opposed to granting immediate approval). Detailed information on the type of damage caused by incidents, such as that collected in the CSBS, would definitely help in terms of modeling costs.

Independent of which technical solution may work best, we believe that the evidence from surveys and other sources is now enough to build a strong case for the development of appropriate sampling and measurement techniques for this specific phenomenon[25]. So far we can only conclude that the direct monetary cost of cyber attacks, net of any undetected consequences, has been modest for the representative firm in the Italian private non-financial sector, and serious for a very small percentage.

4. Cluster analysis

Univariate conditional distributions of answers to survey questions are not enough to gain an understanding of the state of cybersecurity in the Italian private non-financial sector. The results described so far suggest that the interplay between variables is highly complex. When we observe a "yes" response to the question on attacks, we may be dealing with a large, technologically advanced firm that, despite good defences being in place, looked attractive to competent hackers. The same response could come from a low-value firm, protected very poorly, or anything in between. The same ambiguity applies for a "no" answer. In the same vein, high expenditure could reflect a long-standing concern with cybersecurity, accompanied by successful defence; it could also be the result of recent adjustments made in the wake of a painful breach.

Drawing on results shown so far, technological level, size and degree of internationalisation predict both expenditure and the probability of being attacked. Experiencing an attack affects defensive choices, and some firms are more reliable than others when reporting breaches. We need to look at all of these components simultaneously.

As a first step, we perform multiple correspondence analysis (MCA) on all relevant variables. MCA is dimensionality-reduction technique equivalent to principal component analysis for categorical variables (Greenacre, 1984): it transforms a set of n variables into a set of $m<n$ principal factors, i.e. linear combinations of the original variables that can be interpreted as latent dimensions explaining all variables jointly.

The fit of MCA on our data is satisfactory, with the first two principal factors explaining about 93 per cent of variation in the original variables. Appendix Table A14 shows the signs of factor loadings for response categories of selected variables. Factor loadings can be interpreted as regression coefficients, where the latent factor is the dependent variable, and dummies for response categories of the original variables are the covariates. Each coefficient has to be considered jointly with how much the response category weighs in explaining the variance of a factor.

Both latent factors increase with firm size, technological content, number of defensive measures deployed, and security expenditure. There are, however, two key differences. One, reporting an attack followed by an upgrade of defences contributes positively to the first factor, negatively to the second. Two, structural characteristics of firms and defensive profile have a significant weight in explaining the variability of the first factor, while reporting an attack and upgrading defenses afterwards outweigh everything else by far in explaining the variability of the second.

[25] An understanding of how the distribution looks helps to explain the very large difference between our estimates and those found in some widely quoted commercial sources, according to which the average firm-level annual loss caused by cyber incidents in the world is in the millions of dollars, pounds or euros. This could be a technically legitimate result on a sample of large ICT firms where a single mega-breach with six-figure costs happened; it is, however, not representative of the economy as a whole.

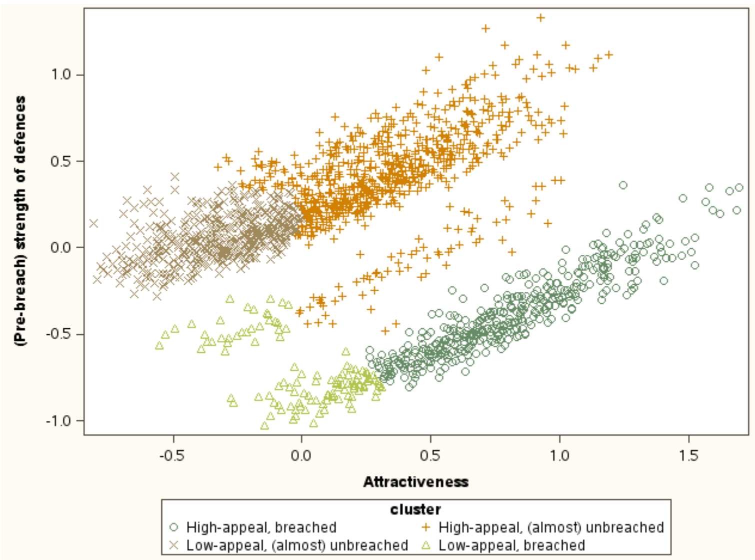
The first factor can be loosely interpreted as a measure for attractiveness of a firm in the eyes of attackers, assessed on the basis of structural variables and on the revealed preferences of the attackers themselves, i.e. attack status. The second factor does not lend itself to interpretation as easily: it can be read as a broad measure of defensive adequacy, but for breached firms that upgraded their defenses after an attack it approximates a measure of the strength of *pre-breach* defenses, not observed ones. Such firms can simultaneously have high observed cybersecurity expenditure, several defensive measures in place, and a low score on the second factor: if defensive adequacy is gauged by the fact that the attacker was successful, maybe pre-breach, pre-upgrade defenses were not strong. This cannot by any means be read as a rigorous measure, but it still teases out a very important unobserved dimension.

A large ICT firm that was not attacked on account of its good defenses will attain a high score on the first factor, and a high score on the second one. The same firm, if hit by especially canny attackers despite the good defenses, will score even more on the first factor, but will score low on the second. Conversely, a small low-tech firm with poor defenses that was not attacked because of its low appeal will score low on the first factor, but high on the second. If attacked, the first factor will be higher, the second lower.

Once latent factors are computed for all firms, we perform hierarchical cluster analysis on them, based on Ward's criterion (Ward, 1963): firms are aggregated into clusters in such a way that within-cluster variance, based on the values of the two latent factors, is minimized. Striking a balance between the share of explained variance (Appendix Figure A1) and the interpretability of results, we set the number of clusters at four[26]. Figure 7 shows cluster membership of firms together with scores on the two latent dimensions.

Figure 7

Clusters of firms



[26] We overlook optimality indicators such as the cubic clustering criterion: while more efficient in statistical terms, the optimal number of clusters according is way too large to afford any meaningful interpretation. In this paper, cluster analysis has the sole purpose of making multivariate results easier to read; we are satisfied with explaining more than 70 per cent of variance with four clusters that fit a reasonable narrative.

Table 4 presents the characteristics of clusters.

Table 4

Characteristics of clusters

	High-appeal, (almost) unbreached	*Low-appeal, (almost) unbreached*	*High-appeal, breached*	*Low-appeal, breached*
Geographical area				
North-West	37.4	29.9	32.4	25.3
North-East	27.7	25.3	35.9	30.9
Centre	20.1	21.7	17.1	22.9
South and Islands	14.8	23.1	14.7	20.9
Number of employees				
20 – 49	50.6	80.9	49.5	83.9
50 – 199	37.8	18.0	36.8	14.8
200 – 499	8.1	1.0	8.6	1.4
500 and over	3.5	0.2	5.0	.
Tech / knowledge intensity of sector				
ICT	9.7	0.0	5.3	.
High-tech, non-ICT	31.5	16.4	30.6	15.7
Low-tech	58.8	83.6	64.1	84.3
Defensive measures adopted				
Cybersecurity training	94.6	40.8	90.3	28.3
Data encryption	63.5	7.9	51.0	2.5
Analysis of vulnerabilities	92.7	27.0	91.7	20.1
Expenditure on cybersecurity, euros				
0	8.2	33.0	2.0	12.0
<10000	46.3	63.0	54.0	87.2
10000-49999	37.9	4.0	36.9	0.8
50000-199999	6.1	.	4.8	.
200000+	1.5	.	2.3	.
Attack status, 2016				
Reported attack	7.9	.	100.0	100.0
Did not report attack	92.1	100.0	.	.
Upgraded defences after attack				
Yes	2.4	NA	100.0	71.5
No	97.6	NA	.	28.5
Possible inconsistency in answers across the two survey waves				
Yes	15.2	5.8	NA	NA
No	84.8	94.2	100.0	100.0
Attack status, corrected				
Yes	23.1	19.9	100.0	100.0
No	76.9	80.2	.	.
Share of population	32.5	45.5	15.1	6.9

. = no observations NA = not applicable

The first cluster is mostly composed of high-appeal firms that did not report a breach. These are the best performers in the system: despite being an attractive target, they were mostly able to repeal attacks. The North of Italy, the ICT sector, and large firms are over-represented compared to the reference universe; uptake rates for cybersecurity training and network analysis are over 90 per cent, and even encryption applies to almost two thirds.

In the second cluster we find smaller firms (less than 200 employees) that reported no breach; their defensive assets and their cybersecurity expenditure are below average, although not the lowest in the population; low-tech sectors and the South are over-represented. This group is low-appeal and might, indeed, have gone unscathed because it is of little interest to attackers and has at least some security in place.

The third cluster is high-appeal, and presumably high pre-breach vulnerability. Structural characteristics mimic the high-appeal, no-breaches cluster: Northern, large and ICT firms are over-represented. Also, security measures are widely adopted and expenditure is higher than average. However, an attack was observed. This cluster may identify high-value firms that were unaware of cyber risk until a short time ago, but they received a wake-up call from an attack and are now adequately protected.

Finally, the fourth cluster comprises small low-tech firms that, despite their low appeal, were hit, possibly on account of exceptionally poor defenses. More than two thirds upgraded their security in the aftermath, but expenditure and the prevalence of defensive measures remain at the lowest point of the population. This group is likely to remain vulnerable at least for some time, as it did not seem to learn from its mistakes.

The relative size of clusters paints a very optimistic picture of the reference universe in terms of cybersecurity, consistent with the low frequency of attacks in the unedited data: three fourths of the population are allocated to good, resilient clusters where very few attacks were reported. If the corrections presented in Table 3 are taken into account, the share of unbreached firms goes down from 92.1 to 76.9 per cent in Cluster 1, and from 80.2 to 19.9 per cent in Cluster 2.

5. Robust estimation of expenditure

Contrary to what we stated for the cost of attacks, in the case of expenditure we have enough point values to attempt a robust estimation of location measures, and even an estimate of the size of the cybersecurity market. The distribution of firm-level expenditure is long-tailed, with individual reported values exceeding €20 million, but the per-employee distribution is more tractable.

As a first step, we use the subsample of respondents who provided a point value for expenditure to impute point values for those who only provided an interval. Imputation is based on a generalized linear model with a log link function where the independent variable is per-employee expenditure on defence, and the key covariates are the levels on the two principal factors resulting from the MCA. Per-employee expenditure data are treated with winsorisation[27] to prevent the few outliers that remain from influencing the estimates; the

[27] Winsorisation is a technique for robust estimation based on the substitution of values above a certain percentile with values observed at that percentile. In this exercise, we only winsorise the right tail, at the 95th percentile calculated by size class.

model is also estimated by size class, to account for varying elasticities. Alongside the principal factors, the covariates include some of the structural characteristics of the firm already used in computing the factors, so as to better elicit their marginal contribution to expenditure. Note that this exercise is not meant to be explanatory – the coefficients on principal factors (Appendix Table A15) would be very difficult to interpret – but to be predictive, therefore the specification is chosen based on rates of correct prediction on the training sample, identified as the share of predicted point values that fall in the correct interval for respondents that only provided an interval value[28].

The model performs well on average, with 85 per cent of correct predictions, and most of the incorrect ones falling in the interval immediately adjacent to the true one (Appendix Table A16). However, the fit varies across firm types. It is best on small and low-tech firms, worst in the ICT sector and for big spenders. Again, predicting tails is difficult. Whenever a prediction is in the incorrect interval, we use the closest limit of the interval provided by the respondent.

Table 5 shows the main results[29]. Median expenditure on cyber defence stands at €4,530 overall, and it varies widely across areas, sectors and firm sizes, consistently with results shown in previous Sections. It ranges from €3,240 in low-tech sectors to €19,080 euro in the ICT sector; the median firm with 500 employees and over spent €44,590, vis-à-vis the €3,120 of its counterpart with less than 50 employees. A large difference existed between those who reported no attack, at €2,630, and those who did, at €7,000.

Means are presented in two version. One set of results (column "mean" in Table 5) stems from the model's predictions, not subjected to any treatment besides the fact that the model is, from the onset, estimated based on winsorised values of observed per-employee expenditure. Another set of results (column "winsorised mean" in Table 5) is based on further treatment of predictions[30]. The latter certainly understates the influence of outliers and it should be taken as a very stable, but also very conservative lower bound for the mean. Non-winsorised mean expenditure amounts to €12,560 overall, and it ranges from €5,890 in Southern Italy to €187,750 for larger firms. Those who reported attacks are at €23,910, against €7,140 for those who did not. Winsorised mean expenditure is approximately twice the median in most firm categories.

In per-employee terms the median stands at €90.9, the mean at €142.7. On account of economies of scale, per capita expenditure is lower in large firms compared to smaller ones; it is much higher in the ICT sector where, depending on the indicator chosen, it is between three and five times the estimate for low-tech firms.

[28] "No expenditure" and "< €10,000" are collapsed in a single category for the purposes of this model, as predicted values are unlikely to be exactly zero.

[29] The estimates should be taken as indicative, especially in the case of non-winsorised means, as they are the result of several modeling and estimation steps: a full boot-strapping exercise for variance estimation will be carried out in the future. We believe, however, that they still give credible insight on orders of magnitude, and how much outliers matter in shaping the distribution of expenditure.

[30] Right-tail winsorisation at the 95th percentile calculated by size class.

The model cannot be used to predict expenditure for respondents who gave no quantitative information on the subject whatsoever. In order to attempt an estimate of total expenditure in the reference universe, we need to impute values for those respondents, and also for firms that did not provide any response to any of the voluntary sections. For such cases, we perform simple hot-deck imputation: we calculate the mean of estimated expenditure for cells based on geographical area, size class and technological level, and then we attribute it to observations for which there is no expenditure data at all.

Table 5

Firms' expenditure on cyber defence, point estimates
(*euros; respondents providing expenditure data in any form*)

	Per firm			*Per employee*		
	Mean	*Winsorised mean(*)*	*Median*	*Mean*	*Winsorised mean(*)*	*Median*
Geographical area						
North-West	14,270	10,430	5,000	145.9	133.8	98.2
North-East	12,290	9,890	5,440	157.1	140.7	102.8
Centre	16,460	9,620	4,000	143.3	124.0	77.1
South and Islands	5,890	5,060	2,700	115.1	99.5	71.1
Number of employees						
20 – 49	5,420	4,530	3,120	144.9	133.3	95.9
50 – 199	14,080	11,560	7,770	148.0	124.2	87.4
200 – 499	32,720	25,320	10,000	99.6	77.4	42.2
500 and over	187,750	92,520	44,590	91.2	75.4	41.7
Tech / knowledge intensity of sector						
ICT	58,800	27,500	19,080	508.8	323.3	398.9
High-tech, non-ICT	20,270	12,790	6,930	175.6	159.3	129.7
Low-tech	7,570	6,900	3,420	112.1	106.2	76.3
Exports as share of turnover						
Less than 1/3	11,130	8,340	4,000	143.2	126.8	88.9
Over 1/3	16,650	11,210	5,450	141.1	128.4	98.2
Reported attack in 2016?						
No	7,140	5,990	2,630	96.5	93.4	70.8
Yes	23,910	14,460	7,000	181.4	161.1	125.3
Total	**12,560**	**9,090**	**4,530**	**142.7**	**127.2**	**90.9**

(*) One-tailed winsorization at the 95th percentile of the distribution of estimated values, by class size.

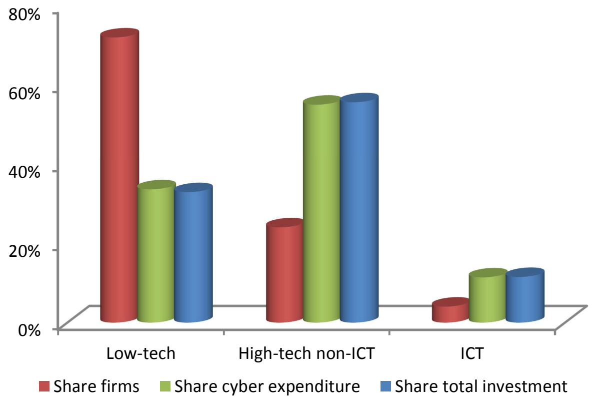
The total for the reference universe amounts to €570 million in the winsorized version, and €780 million in the version where an attempt at estimating tail values is made. The first figure is less dependent on the model's (modest) ability to predict outliers correctly; we can take it as a very conservative lower bound for the size of the market for cyber defence. This result is compatible with the €972 million estimated for Italy in its entirety by a research group on information security and privacy at the Polytechnic of Milan (Osservatorio Security e Privacy, 2017); the methodology is not public, so we cannot make an exact comparison, but it can be safely assumed that the figure is higher because it includes sectors not covered in our sample.

ICT firms, about 4 per cent of firms in the reference universe, account for a share of aggregate expenditure on cyber defence between 11 and 18 per cent, depending on how outliers are treated (Figure 8a shows winsorised estimates); their weight on total investment[31,32] is similar, at 11 per cent. Conversely, low-tech firms make up 72 per cent of the universe and only account for 55 and 56 per cent of defensive expenditure and aggregate investment respectively.

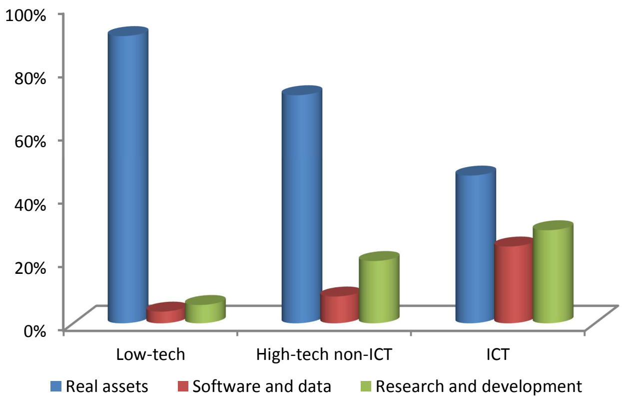
Technological maturity is key in determining the composition of investment: in the ICT sector, investment on research, development, software and data makes up 53 per cent of the total, almost double compared to non-ICT high-tech firms, and five times compared to low-tech ones (Figure 8b). These significant gaps are reflected in different degrees of attention to cybersecurity.

Figure 8

A – Distribution of estimated expenditure on cyber defence vis-à-vis investment, 2016, by technological level



b - Distribution of total gross domestic investment by destination, 2016, by technological level



Based on the estimated point values, median cybersecurity expenditure in 2016 was roughly 15 per cent of gross annual wages paid by the median firm to a representative worker[33], or 2.5 per cent of median firm-level investment in the same year. Only 4.5 per cent of firms spent enough to cover the wages of at least one resource[34]; however, this does not mean that they all employed specialists, as the variable also includes expenditure on security software and hardware.

[31] This reference is given for comparison only: in our questionnaire, we ask firms to quantify an aggregate of cybersecurity expenditure that is not fully included in the aggregate of investments, as it includes some current expenditure (see Section 2).

[32] Gross domestic fixed investment in real estate, vehicles, machinery, software, databases, research and development.

[33] Average wages paid by the median firm, computed over all non-management staff, including employees' taxes and social security contributions, and excluding employers' social security contributions.

[34] Share computed based on the ratio between firm-level cybersecurity expenditure and firm-level average gross annual wages.

6. Effectiveness of defensive expenditure: preliminary results

The data described so far do not lend themselves well to an estimation of how effective defensive expenditure is in preventing damage from cyber attacks: all information refers to the same year, and for breached firms there is no way of separating pre-breach and post-breach investment. The share of firms that did not upgrade their defenses in the wake of an attack is too small for any meaningful inference on how large the average post-breach investment is. The results presented in Section 4 allow for some inference on overall quality of defense pre-breach, but they do not give direct information on returns on investment.

We use preliminary data from the survey carried out in 2018, which includes a single question on attacks suffered in 2017 (see also Section 2), to address this issue[35]. We find that, after controlling for firm characteristics, adoption of specific technologies and previous attack history, defensive expenditure in 2016 is still positively correlated with the probability of being damaged from an attack in 2017; the result does not apply to the ICT sector, where the correlation is negative (but mostly not significant).

This evidence is puzzling at first glance, as it seems to suggest that the more a firm spends on defense, the more vulnerable it is to attacks. One likely explanation is that latent variables that are not perfectly captured by our controls, such as attractiveness to hackers, drive both; however, if we add the measure of attractiveness estimated in Section 4 to our regressions the effect of expenditure simply disappears, rather than changing its sign. Further work should explore firm characteristics that have not been considered yet and could explain both security investment and probability of being breached.

Another possibility has to do with the effectiveness of expenditure. It is possible, and consistent with results presented in Section 3, that a large share of Italian firms do not have the ability to discern which defensive measures are most appropriate; it is also possible that off-the-shelf products are bought but not used correctly. This would explain why results for the ICT sector, where risk awareness and technical abilities are higher, are different.

7. Comparison with the UK Cyber Security Breaches Survey

Our point estimates are not directly comparable with the UK CSBS. The reference universe is not the same: we only cover private industrial and non-financial services firms with at least 20 employees, while the CSBS also includes the financial sector and smaller businesses; health care, social care, education and academic research are excluded from our sample, as they are mostly part of the public sector in Italy, whereas private providers of such services are included in the CSBS. The difference is relevant: these sectors are prime targets for attackers, as they handle large amounts of sensitive data in electronic form. While the definition of expenditure is the same, net of some small wording differences in the questionnaires, the definitions of cost diverge: the CSBS includes more cost categories, such as reputational damage and abandonment of business plans. More generally, our survey is likely to be less accurate, despite a higher

[35] These results are computed on a sample of firms that answered cybersecurity questions in both surveys. While robust across regression specifications, they are likely to suffer from selection bias of unknown sign. Also, survey weights have not been re-calibrated yet to take into account panel attrition. All conclusions should be treated as very preliminary and subject to revision.

sampling fraction: it is not single-purpose, it was not answered by IT specialists, the questionnaire is much shorter, and the fieldwork techniques employed were less sophisticated[36].

This notwithstanding, the order of magnitude of estimated defensive expenditure and damage from attacks is the same, and the distribution across firm categories is similar. Expenditure is in the thousands of euros/pounds for small firms, in the tens of thousands for medium ones, in the hundreds of thousands for large ones; its distribution is highly skewed. The proportion between expenditure in the ICT sector and expenditure in the rest of the economy is comparable. One notable difference is that in the UK, the average expenditure for large firms is much higher than ours, at £387,000, even if the class of large firms starts at 250 employees: this may reflect the presence of the aforementioned data-intensive industries, the higher level of digitalisation of the UK economy compared to Italy, and the larger size of the market for high-tech services, such as cybersecurity consulting. Maximum expenditure is around €/£ 20 millions in both surveys. Post-attack upgrade of defenses is commonplace on both samples.

When it comes to the prevalence of cyber attacks, the two surveys employ definitions that differ in one significant way. In the 2017 CSBS, some types of attempted attacks are counted, even if they were blocked[37]: e.g. "attempted hacking of online bank accounts" is listed as a possibility, and so are "staff receiving fraudulent emails" and organisation impersonation, even if they did not lead to any damage. In our survey, respondents are specifically instructed to only take into account attacks that yielded at least some damage[38]. Our estimates should not be compared with the UK figures on the prevalence of breaches, but with those on "breaches with an outcome". This category is the closest to our definition, although it is not identical. Breaches with an outcome happened to 19 per cent of the British reference universe, against 23.3 per cent in our unedited data; the difference likely stems from our non-coverage of firms with less than 20 employees, less likely to report a breach compared to the average. The CSBS report does not feature any statistical model for correction of under-reporting or misdetection; comparison with our model-based estimates is therefore not feasible. Where the distribution of attacks is concerned, large firms and the ICT sector stand out from the rest according to both sources; the British distribution is more skewed than the Italian one, with larger differences between higher and lower size classes.

The CSBS records much more information on attacks, such as what tools the attackers used, how they were able to defeat the firm's defences, how they were detected. The number of breaches over the survey period is documented; we collected the former variable in the previous survey, and results are comparable, with large firms, the ICT sector and utilities subjected to more per-firm attacks compared to others. With respect to the type of outcome, added staff time for repair and recovery is more common than business interruption in the UK, while the prevalence rates are roughly equal in Italy; for both countries, the incidence of data loss or theft is much lower.

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[36] The fieldwork was conducted in three stages: before interviews were conducted, firms in the sample were given time to prepare based on a detailed description of the quantitative information (defensive expenditure and cost of attacks) they needed to provide; then telephone interviewed were administered; finally, a qualitative in-depth analysis of a few case studies was carried out.

[37] In the 2016 CSBS, unsuccessful attempts were almost entirely excluded.

[38] Whenever respondents requested clarifications, they were also instructed not to consider fraudulent emails that were thrown away without clicking on any malicious link or attachment.

With respect to costs, the order of magnitude of the phenomenon is the same; reported costs are generally small, in the thousands and occasionally in the tens of thousands. The CSBS data provides insights that are not evident from our survey: for example, meaningful point estimates by size class are possible, and they show that large firms withstand more serious damage in absolute terms compared to small ones. However, a similar problem appears to exist with respect to tail values; only one large incident appears in the microdata, and it cannot be used as a basis for any generalization.

Even allowing for different reference universes, cybersecurity training for employees appears to be more common in Italy than in the UK; the average rate of prevalence in our sample is closer to the one for large firms in the CSBS. We were not able to find a convincing explanation for this. On the contrary, encryption is more popular in the UK, possibly because of the 2015 attack against telephone and internet provider Talk Talk: 150,000 personal records of customers were stolen, the company was fined £450,000 by the Information Commissioner's Office, and lawsuits followed; the company reported that, overall, the direct and indirect costs of the breach reached £40 million. At the time, Talk Talk had approximately 4 million customers: the case made headline news and was probably known enough to trigger increased cybersecurity awareness.

8. Conclusions

This paper presented evidence on expenditure related to preventing and managing cyber attacks in the Italian private non-financial sector, based on the Bank of Italy's annual surveys. In 2016, most firms allocated at least some resources to cybersecurity, but the differences across sectors and size classes were sizable. Median expenditure ranged from €3,240 for low-tech firms to €19,080 in the ICT sector, and from €3,120 for smaller firms to €44,590 for firms with at least 500 employees. The overall median was €4,530, roughly 15 per cent of gross annual wages paid by the median firm to a typcial worker, or 2.5 per cent of median firm-level gross domestic fixed investment.

We estimate that the market for cyber defence in Italy is worth at least €570 million; this is a very conservative lower bound because, among other things, all public-sector expenditure is excluded from the survey. Having been attacked in the past leads firms to boost their security investment: among breached firms, 81 per cent upgraded their defences. Direct monetary costs from attacks were less than €10,000 for the majority of firms; about one per cent reported damage worth over €50,000, and 0.1 per cent above €200,000.

We cannot give a meaningful estimate of aggregate costs for the whole economy because large incidents are absent from our dataset: we know from external sources that they exist, and they can cause damage running into the hundreds of millions, but they are rare in the population and cannot be documented with sampling techniques that are not tailored to such events. However, we can extrapolate an important feature of the threat posed by cyber attacks and of the typical firm's response. In most cases, a breach will not impose significant costs upon the victim; our estimates do not include indirect costs, but, even if we allow for those to be at least equal to direct costs, the impact remains small. In this sense, the limited investment that firms make in cybersecurity can be seen as subjectively rational. On the other hand, a handful of tail events can do more damage to the economy than all of the run-of-the-mill attacks combined. On account of externalities, smallish attacks can constitute vehicles for large incidents: from a systemic perspective, they still pose a significant risk despite their low direct impact and they should not be overlooked. This has policy implications that need to be explored further.

While our point estimates are not perfectly comparable with those obtained from the UK Cyber Security Breaches Survey, which constitutes the only example of official statistics in this field, the order of magnitude of estimated defensive expenditure and the damage from attacks is the same. The ranking of sectors and size classes with respect to key variables is also very similar, with the ICT sector and large firms standing out from the rest of the private sector in terms of awareness, expenditure and how appealing a target they are to attackers.

Appendix

Table A1

Sample composition

(*number of firms*)

	Full sample			*Answered at least one optional question*		
	Industrial	*Service*	*All*	*Industrial*	*Service*	*All*
Geographical area						
North-West	764	290	1,054	657	261	918
North-East	568	245	813	524	224	748
Centre	674	284	958	590	267	857
South and Islands	979	404	1,383	945	386	1,331
Number of employees	1,069	400	1,469			
20 – 49	1,188	464	1,652	963	373	1,336
50 – 199	443	171	614	1,080	433	1,513
200 – 499	285	188	473	413	158	571
500 and over				260	174	434
Tech / knowledge intensity of sector(*)	69	78	147			
ICT	907	174	1,081	61	75	136
High-tech, non-ICT	2,009	971	2,980	815	161	976
Low-tech				1,840	902	2,742
Exports as share of turnover						
Less than 1/3	1,612	1,104	2,716	1,468	1,027	2,495
Over 1/3	1,373	119	1,492	1,248	111	1,359
Total	**2,985**	**1,223**	**4,208**	**2,716**	**1,138**	**3,854**

(*) ICT sector: OECD classification. High and medium-high: non-ICT manufacturing firms with high or medium-high technological intensity, and non-ICT service firms with high knowledge intensity, according to OECD/Eurostat classification. Low and medium-low: all other firms. Firms in the energy sector, not covered by the original classification, are reclassified as high-technology.

Table A2

Cyber defense measures adopted by firms, unedited data, 2016

(*percentages of firms*)

	Defensive software/hardware	*Cybersecurity training*	*Analysis and management of vulnerabilities*	*Data encryption*
Geographical area				
North-West	98.7	65.3	62.1	32.6
North-East	99.5	70.2	60.7	34.5
Centre	99.2	62.1	51.7	31.8
South and Islands	98.5	59.9	47.4	31.3
Number of employees				
20 – 49	99.1	59.5	50.8	28.6
50 – 199	98.7	73.7	66.1	37.7
200 – 499	99.2	84.8	79.5	49.8
500 and over	99.3	89.2	87.6	63.9
Tech / knowledge intensity of sector (*)				
ICT	99.9	95.0	91.6	77.1
High-tech, non-ICT	99.4	74.2	66.1	36.1
Low-tech	98.8	60.4	51.9	29.1
Exports as share of turnover				
Less than 1/3	99.2	63.1	55.8	32.0
Over 1/3	98.4	70.7	60.2	34.9
Reported attack in 2016?				
No	98.9	62.2	52.7	30.5
Yes	99.5	73.7	69.6	37.9
Total	**99.0**	**65.0**	**56.9**	**32.7**

Table A3

Definition of variables used in regressions(*)

Descriptor	*Type*	*Content*
Small	Binary	Number of employees between 20 and 49, 2016 average
Medium (low)	Binary	Number of employees between 50 and 199, 2016 average
Medium (high)	Binary	Number of employees between 200 and 499, 2016 average
South	Binary	Administrative headquarters located in Southern Italy or Islands, as of May 2017
ICT	Binary	ATECO sector (main activity) in 2016 classified by OECD as Information and Communication Technology
High-tech non-ICT	Binary	ATECO sector in 2016 classified by OECD/Eurostat as high or medium-high technological intensity (manufacturing), or high knowledge intensity (services), with the exclusion of sectors classified as ICT by OECD. Energy sector not considered by OECD/Eurostat, classified as high-tech non-ICT.
Industrial	Binary	ATECO sector as of May 2017: manufacturing, mining, energy
Export share	Multinomial	Value of exported goods or services as a fraction of turnover, 2016
Infrastructure	Binary	ATECO sector: production, transmission or distribution of electricity or natural gas; collection, treatment or distribution of water; operation of sewer networks; operation of airports, ports, railway or road networks; operation of communication networks

(*) Excluding variables already defined in the main text

Table A4

Firms' expenditure on cyber defence, interval estimates on unedited data, 2016
(*percentages of firms; expenditure brackets in euros*)

	No expenditure	*<10,000*	*10,000-49,999*	*50,000-199,999*	*200,000+*	*Don't know / No answer*
Geographical area						
North-West	15.6	47.0	18.6	2.5	0.9	15.4
North-East	16.0	53.0	18.3	2.3	0.8	9.6
Centre	15.2	56.1	17.6	3.1	0.8	7.2
South and Islands	24.6	54.3	12.5	1.4	0.2	7.2
Number of employees						
20 – 49	19.8	57.0	12.0	0.8	0.1	10.3
50 – 199	12.8	45.7	26.3	3.5	0.8	10.8
200 – 499	9.9	29.5	34.4	11.1	2.6	12.6
500 and over	7.8	13.1	28.5	18.3	15.1	17.3
Tech / knowledge intensity of sector						
ICT	7.0	27.3	36.9	13.2	3.0	12.5
High-tech, non-ICT	13.8	48.0	21.7	2.5	1.7	12.3
Low-tech	18.9	54.3	14.7	1.7	0.3	10.1
Exports as share of turnover						
Less than 1/3	18.8	52.6	15.8	2.0	0.7	10.1
Over 1/3	12.9	49.5	21.1	3.3	1.0	12.3
Reported attack in 2016?						
No	22.4	52.8	16.5	2.3	0.6	5.3
Yes	5.2	60.1	23.7	3.0	1.3	6.7
No answer	3.1	7.9	0.7	0.0	0.0	88.3
Total	**17.2**	**51.8**	**17.2**	**2.3**	**0.7**	**10.7**

Table A5

Expenditure on cyber defence at the firm level, 2016: distance between reported interval and interval predicted by ordered logistic regression, by reported interval
(percentages of firms)

	Number of intervals			
	0 (correct prediction)	*1*	*2*	*3*
<10,000€	89.8	10.0	0.0	0.2
10,000-49,999€	37.9	61.8	0.3	.
50,000-199,999€	0.5	73.4	26.1	.
200,000€ and over	14.3	13.2	63.7	48.8
Total	**66.7**	**29.1**	**3.9**	**0.4**

Table A6

Firms hit by at least one cyber attack, unedited data, 2016
(*percentages of firms*)

	As a share of total firms			*As a share of total employees*		
	No attack	*At least one attack*	*Don't know/ No answer*	*No attack*	*At least one attack*	*Don't know / No answer*
Geographical area						
North-West	70.9	22.6	6.5	60.5	30.1	9.4
North-East	66.0	27.4	6.6	58.2	34.0	7.8
Centre	72.6	21.8	5.6	54.9	37.4	7.7
South and Islands	75.1	20.0	5.0	70.2	24.5	5.3
Number of employees						
20 – 49	73.1	21.3	5.6	73.0	21.4	5.6
50 – 199	67.4	26.1	6.5	67.6	26.4	6.0
200 – 499	60.9	31.6	7.5	61.0	31.4	7.6
500 and over	54.8	34.4	10.8	47.6	41.6	10.8
Tech / knowledge intensity of sector						
ICT	68.1	26.4	5.5	53.1	41.4	5.5
High-tech, non-ICT	67.4	26.2	6.4	56.4	36.1	7.5
Low-tech	71.8	22.2	6.0	62.1	29.4	8.5
Exports as share of turnover						
Less than 1/3	72.6	21.9	5.4	61.8	29.6	8.6
Over 1/3	64.9	27.3	7.8	55.2	38.0	6.9
Total	**70.6**	**23.3**	**6.1**	**59.9**	**32.1**	**8.1**

Table A7

Prevalence of cyber attacks: data correction models

Model	Corrects for… Non-response	Mis-detection	Inconsistency	Data treatment
Base	**Yes**	*No*	*No*	Imputed for non-respondents
A	**Yes**	**Yes**	*No*	Base + imputed for respondents reporting no security measures or only anti-virus program
B1	**Yes**	*No*	**Weak, imputed**	Base + imputed for respondents reporting at least two attacks in the first survey (covering 9/15-9/16), but no attack in the second survey (covering 1/16-12/16)
B2	**Yes**	*No*	**Strong, imputed**	Base + imputed for respondents reporting at least one attack in the first survey, but no attack in the second survey
C1	**Yes**	**Yes**	**Weak, corrected**	A + corrected to "attack reported" for respondents reporting at least two attacks in the first survey, but no attack in the second survey
C2	**Yes**	**Yes**	**Strong, corrected**	A + corrected to "attack reported" for respondents reporting at least two attacks in the first survey, but no attack in the second survey

Table A8

Firms hit by at least one cyber attack: summary across data correction models
(*percentages of firms)*

	Base	*A*	*B1*	*B2*	*C1*	*C2*
Share of firms	0.25	0.32	0.27	0.28	0.39	0.45
…if all non-respondents attacked	0.29	0.36	0.32	0.33	0.43	0.48
Share of employees	0.35	0.38	0.38	0.39	0.47	0.51
…if all non-respondents attacked	0.40	0.43	0.43	0.44	0.50	0.54

Table A9

Observed consequences of cyber attacks, 2016
(*percentages of firms that reported an attack*)

	Disruption of business	*Extra hours for recovery and repair*	*Data theft or loss*
Geographical area			
North-West	0.68	0.72	0.13
North-East	0.70	0.78	0.09
Centre	0.75	0.79	0.24
South and Islands	0.70	0.57	0.26
Number of employees			
20 – 49	0.70	0.71	0.16
50 – 199	0.70	0.74	0.15
200 – 499	0.73	0.81	0.18
500 and over	0.68	0.78	0.17
Tech / knowledge intensity of sector (*)			
ICT	0.65	0.72	0.05
High-tech, non-ICT	0.73	0.77	0.16
Low-tech	0.70	0.71	0.16
Exports as share of turnover			
Less than 1/3	0.70	0.72	0.17
Over 1/3	0.70	0.73	0.13
Total	**0.70**	**0.73**	**0.16**

Table A10

Cost of cyber attacks, interval estimates on unedited data, 2016
(percentages of firms that reported attacks; cost brackets in euros)

	No cost	*<10,000*	*10,000-49,999*	*50,000-199,999*	*>200,000*	*Don't know / No answer*
Geographical area						
North-West	32.2	50.5	5.1	0.3	0.1	11.7
North-East	24.7	59.8	5.6	1.0	0.0	8.8
Centre	15.0	70.5	10.5	0.9	0.0	3.0
South and Islands	42.0	47.5	5.8	1.1	.	3.7
Number of employees						
20 – 49	30.0	58.9	2.6	0.5	.	8.0
50 – 199	26.0	53.2	12.4	0.9	.	7.5
200 – 499	19.4	60.5	8.3	2.0	.	9.9
500 and over	29.5	41.5	17.2	2.2	2.2	7.4
Tech / knowledge intensity of sector						
ICT	21.7	38.4	11.1	1.3	0.2	27.4
High-tech, non-ICT	23.5	63.3	5.3	1.4	0.0	6.4
Low-tech	30.3	55.4	6.4	0.5	0.1	7.3
Exports as share of turnover						
Less than 1/3	28.2	58.7	5.6	0.4	0.1	7.1
Over 1/3	28.0	52.4	8.1	1.6	0.1	9.7
Total	**28.1**	**56.7**	**6.4**	**0.8**	**0.1**	**7.9**

Table A11

Cost of cyber attacks, interval estimates on unedited data, by observed consequences, 2016
(percentages of firms that reported attacks; cost brackets in euros)

	No cost	*<10,000*	*10,000-49,999*	*50,000-199,999*	*>200,000*	*Don't know / No answer*
No consequences	72.4	13.2	.	.	.	14.4
Only disruption of business	47.2	41.6	3.4	.	.	7.9
Only extra working hours	26.7	56.7	5.8	1.4	0.1	9.4
Only data theft/loss	29.9	42.3	4.6	15.6	.	7.6
Disruption of business + extra working hours	16.0	70.5	8.9	0.5	0.1	3.9
Disruption of business + data theft/loss	9.1	87.0	3.8	.	.	.
Extra working hours + data theft/loss	13.7	79.2	3.9	0.7	0.8	1.7
All three consequences	11.2	70.6	9.0	1.4	.	7.7
Did not answer question on consequences	2.7	5.5	.	.	.	91.8
Total	**28.1**	**56.7**	**6.4**	**0.8**	**0.1**	**7.9**

Table A12

Determinants of the cost of cyber attacks at the firm level, 2016
(ordered logistic regression)

Small	-2.055	***	*Turnover per employee*	$1.81*10^{-3}$	***
	(0.166)			$(1.39*10^{-4})$	
Medium (low)	-0.512	***	*Turnover per employee squared*	$-2.59*10^{-7}$	***
	(0.159)			$(3.25*10^{-8})$	
Medium (high)	-0.854	***	*No disruption of business*	-0.353	***
	(0.192)			(0.094)	
Number of employees	$1.47*10^{-4}$	***	*No extra working hours for repair/recovery*	-1.437	***
	$(0.44*10^{-5})$			(0.126)	
Number of employees squared	$-1.11*10^{-9}$	**	*No data theft/loss*	-0.398	***
	$(5.58*10^{-10})$			(0.092)	
South	0.220	**	*Intercept: 200,000+*	-6.341	***
	(0.110)			(0.382)	
ICT	0.996	***	*Intercept: 50,000-199,999*	-3.747	***
	(0.150)			(0.203)	
High-tech non-ICT	-0.103		*Intercept= 10,000-49,999*	-1.414	***
	(0.071)			(0.182)	
Industrial	0.534	***			
	(0.078)				
N			794		

Levels of statistical significance of coefficients : *** 1% ** 5% *10%
“No cost” and “<10,000 €” were aggregated as a single category in the dependent variable

Table A13

Cost of cyber attacks at the firm level, 2016: distance between reported interval and interval predicted by ordered logistic regression, by reported interval
(percentage of firms)

	Number of intervals			
	0 (correct prediction)	*1*	*2*	*3*
<10,000€	99.0	1.0	.	.
10,000-49,999€	2.8	97.2	.	.
50,000-199,999€	.	.	100.0	.
200,000€ and over	.	25.0	.	75.0
Total	**84.0**	**14.1**	**1.5**	**0.4**

Table A14

Factors from multiple correspondence analysis: sign of loadings and contribution to inertia for response categories, selected variables
(*signs; percentage points*)

	Sign of loading, factor 1 (attractiveness)	*Contribution to inertia*	*Sign of loading, factor 2 (quality of pre-breach defense)*	*Contribution to inertia*
Number of employees				
20 – 49	-	1.9	-	0.5
50 – 199	+	1.5	+	0.3
200 – 499	+	1.9	+	0.6
500 and over	+	2.2	+	0.6
Tech / knowledge intensity of sector				
ICT	+	2.6	+	4.5
High-tech, non-ICT	+	1.2	+	0.0
Low-tech	-	1.0	-	0.4
Defensive measures adopted				
Cybersecurity training: yes	+	4.8	+	1.6
Cybersecurity training: no	-	8.9	-	2.9
Data encryption: yes	+	8.0	+	4.9
Data encryption: no	-	3.8	-	2.3
Analysis of vulnerabilities: yes	+	7.5	+	1.7
Analysis of vulnerabilities: no	-	10.2	-	2.3
Expenditure on cybersecurity, euros				
0	-	6.0	+	0.1
<10000	-	0.3	-	2.1
10000-49999	+	6.1	+	2.0
50000-199999	+	1.6	+	0.4
200000+	+	2.5	+	2.5
Attack status, 2016				
Reported attack	+	9.7	-	23.4
Did not report attack	-	3.2	+	7.6
Upgraded defences after attack				
Yes	+	11.0	-	23.4
No	-	2.8	+	5.9
Possible inconsistency in answers across the two survey waves				
Yes	-	0.1	+	0.0
No	+	0.1	-	0.0
Geographical area				
North-West	+	<0.1	+	<0.1
North-East	+	<0.1	-	<0.1
Centre	-	<0.1	+	<0.1
South and Islands	-	<0.1	-	<0.1

Table A15

Predictors of expenditure on cyber defence at the firm level, point values, 2016
(*generalized linear model, log link, by size class*)

	Number of employees							
	20-49		50-199		200-499		500 and over	
Intercept	4.645	***	3.570	***	0.811	**	0.567	
	(0.110)		(0.134)		(0.391)		(0.396)	
South	0.185	*	0.015		-0.223		0.118	
	(0.099)		(0.089)		(-0.200)		(0.294)	
Industrial	-0.423	***	0.065		0.751	***	0.818	***
	(0.085)		(0.059)		(0.131)		(0.125)	
First principal factor	3.476	***	4.339	***	2.244	***	4.078	***
(attractiveness)	(0.302)		(0.288)		(0.480)		(0.462)	
Second principal factor	0.209		-0.515	**	2.587	***	-0.249	
(pre-breach strength of defences)	(0.252)		(0.200)		(0.473)		(0.432)	
Third principal factor	-0.813	***	0.623	***	0.973	***	0.625	***
	(0.112)		(0.100)		(0.180)		(0.195)	
No cybersecurity training	0.571	***	0.442	***	0.389		0.486	
	(0.105)		(0.147)		(0.356)		(0.312)	
No data encryption	0.495	***	1.139	***	1.599	***	0.578	***
	(0.085)		(0.084)		(0.134)		(0.198)	
No analysis of vulnerabilities	0.799	***	0.793	***	-0.281		1.812	***
	(0.102)		(0.096)		(0.281)		(0.330)	
Attacked, upgraded defences	-1.368	***	-2.55	***	1.231	***	-2.647	***
	(0.334)		(0.281)		(0.476)		(0.447)	
Attacked, did not upgrade defences	-1.036	***	-1.390	***	0.781	***	-1.228	
	(0.222)		(0.192)		(0.291)		(1.420)	
Software investment in 2016, per employee	0.038	**	-0.054	***	-0.024	***	0.009	
	(0.018)		(0.007)		(0.004)		(0.006)	
N	475		493		424		344	

Levels of statistical significance of coefficients : *** 1% ** 5% *10%

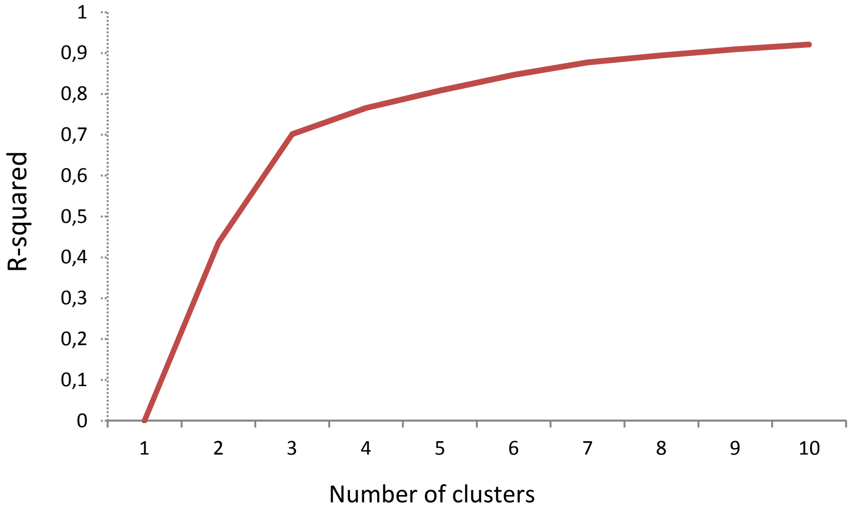
Table A16

Determinants of expenditure on cyber defence at the firm level, point values, 2016: distance between reported interval and interval predicted by model, by reported interval
(*percentages of firms*)

	Number of intervals		
	0 (correct prediction)	*1*	*2*
<10,000€	92.3	7.6	0.1
10,000-49,999€	69.7	30.2	0.1
50,000-199,999€	37.4	55.6	7.0
200,000€ and over	28.9	43.5	27.6
Total	**85.1**	**14.3**	**0.5**

Figure A1

Cluster analysis: fit statistics



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