

Appendix A: The relationship between IT, R&D and innovation performance in previous research

| | Kleis, Chwelos, Ramirez and Cockburn (2012) | Joshi, Chi, Datta and Han (2010) | Ravichandran, Han and Mithas (2017) | Current study |
|-----------------------------|---|--|---|--|
| Sample | Large U.S. manufacturing firms (1,829 obs.) | Firms listed in InformationWeek 500 (110 firms) | Manufacturing firms listed in InformationWeek (161 firms) | Spanish manufacturing firms (15,781 and 15,645 obs.) |
| Dependent variable | Citation-weighted patents | Patent applications New product and services introductions | Citation-weighted patent count | Patent counts New product introductions |
| Effects studied (IT) | Direct effect of IT Interaction between IT and R&D | Direct effect of IT | Direct effect of IT Interaction between IT and R&D | Direct effect of IT Interaction between IT and R&D Interaction between IT and openness |
| Findings | Direct effect of IT significant Interaction between IT and R&D not significant | Direct effect of IT on patent applications significant Direct effect of IT on new product and service introductions significant | Direct effect of IT significant Interaction between IT and R&D not significant. Significant mitigating effect of IT on the diminishing returns to R&D. The mitigating effect is higher for firms facing greater complexity in R&D activities. | Direct effect of IT on patents significant Direct effect of IT on product introductions not significant Significant interaction between IT and R&D for patents and product innovations Significant moderation of IT on the inverted U-shaped relationship between the extent of use of external R&D and patents/product innovations |

Source: Own elaboration.

Appendix B: Descriptive statistics and correlation

Tables A2, A3, A4 and A5 offer descriptive statistics and correlations of the variables of interest. The statistics are reported in two tables because the number of observations is slightly different for each dependent variable, due to the different patterns of missing values. In any case, the statistical differences between the samples are negligible.¹

When interpreting these data, it is important to take into account that Europe has lagged behind the U.S. in both new high-technology sectors and in the use of information and communication technologies (Van Ark, O'Mahony and Timmer 2008, Cincera and Veugelers 2014). Additionally, Spain has been characterized as a “follower” in Europe, both in terms of economic and technological development (Mate-Sanchez-Val and Harris 2014). For example, R&D intensity stood at 1.27% of Gross Domestic Product in 2012, below the average European Union figure for 28 countries which stood at 2.01% and those corresponding to the U.S. (2.81%) for the same year (Eurostat, 2014). Similarly, investments in information and communication technologies in Spain amounted to 11.6% of total gross fixed capital formation, just below the average of the European Union (15 countries) and far from those of the U.K (19.9%) and the U.S. (22.1%) (OECD 2013). These differences need to be taken into account when interpreting our results *vis à vis* previous studies carried out in the U.S. (Joshi et al. 2010, Kleis et al. 2012 and Bardhan et al. 2013) and other countries (see Huang and Liu 2005 for Taiwan).

These statistics reveal important features about the variables used in the analysis. The first is the low mean values for both the number of patents (the average value is 0.478) and the number of product innovations (the average value is 1.490). These values are very far from their maximum values (299 and 319, respectively), indicating a high presence of firms with low patenting activity and product introductions. The quantile plots graphically confirm this (see Figures A1 and A2). In fact, the most frequent value for both variables is zero: in the case of

¹ Variance inflation factors were calculated for all the models proposed and the maximum values reported were 8.50 and 8.51 for the number of patents and the number of product innovations, respectively.

patents, 94.02% of the total number of observations and, in the case of product innovations 81.25%.

A second observation that can be made is that the correlation between the number of patents and investments in information technologies, on the one hand, and the number of patents and R&D investments, on the other, is positive but small. Something similar can be said of the correlation between these two independent variables and the number of product innovations. On a more general note, the correlations between the different variables used are very similar in the two subsamples. The biggest difference arises when considering the correlation between diversification (concentration) and the two innovation outcomes: it is positive (negative) in the case of the number of patents, but negative (positive) when product innovations are considered.

Table A2. Descriptive statistics of the variables (first analysis, number of patents)

| | Unit | Obs. | Mean | St. Dev. | Min. | Max. |
|-----------------------------------|-----------|--------|--------|----------|-------|--------|
| Number of patents | Number | 15,781 | 0.478 | 6.436 | 0 | 299 |
| Stock of IT * | Ratio | 15,781 | 10.995 | 5.076 | 0 | 19.187 |
| Stock of total R&D * | Ratio | 15,781 | 7.635 | 7.765 | 0 | 23.199 |
| Extent of openness | Ratio | 15,781 | 0.176 | 0.304 | 0 | 1 |
| Size (employees) | Thousands | 15,781 | 0.201 | 0.600 | 0.001 | 14.4 |
| Market stability | Dummy | 15,781 | 0.366 | 0.482 | 0 | 1 |
| Diversification (Entropy measure) | Index | 15,781 | 0.068 | 0.193 | 0 | 1.459 |
| Concentration ratio | Index | 15,781 | 42.987 | 13.735 | 19.95 | 89.69 |

*Variables in natural logarithm.

Table A3. Correlations between the variables (first analysis, number of patents)

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|-------------------------|----------|-----------|-----------|-----------|----------|-----------|-----------|
| Number of patents (1) | 1 | | | | | | |
| Stock of IT (2) | 0.040*** | 1 | | | | | |
| Stock of total R&D (3) | 0.086*** | 0.332*** | 1 | | | | |
| Extent of openness (4) | 0.029*** | 0.178*** | 0.550*** | 1 | | | |
| Size (5) | 0.089*** | 0.130*** | 0.247*** | 0.119*** | 1 | | |
| Market stability (6) | -0.013 | -0.067*** | -0.104*** | -0.035*** | -0.009 | 1 | |
| Diversification (7) | 0.003 | 0.042*** | 0.051*** | 0.004 | 0.031*** | -0.033*** | 1 |
| Concentration ratio (8) | -0.013* | 0.058*** | 0.062*** | 0.056*** | 0.101*** | -0.017** | -0.056*** |

***, **, *: Variable statistically significant at 1%, 5% or 10%, respectively.

Table A4. Descriptive statistics of the variables (second analysis, number of product innovations)

| | Unit | Obs. | Mean | St. Dev. | Min. | Max. |
|-----------------------------------|-----------|--------|--------|----------|-------|--------|
| Number of product innovations | Number | 15,645 | 1.490 | 10.382 | 0 | 319 |
| Stock of IT * | Ratio | 15,645 | 10.987 | 5.080 | 0 | 19.187 |
| Stock of total R&D * | Ratio | 15,645 | 7.598 | 7.761 | 0 | 23.199 |
| Extent of openness | Ratio | 15,645 | 0.176 | 0.305 | 0 | 1 |
| Size (employees) | Thousands | 15,645 | 0.197 | 0.593 | 0.001 | 14.4 |
| Market stability | Dummy | 15,645 | 0.366 | 0.482 | 0 | 1 |
| Diversification (Entropy measure) | Index | 15,645 | 0.068 | 0.193 | 0 | 1.459 |
| Concentration ratio | Index | 15,645 | 42.996 | 13.735 | 19.95 | 89.69 |

*Variables in natural logarithm.

Table A5. Correlations between the variables (second analysis, number of product innovations)

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|-----------------------------------|-----------|-----------|-----------|-----------|----------|-----------|-----------|
| Number of product innovations (1) | 1 | | | | | | |
| Stock of IT (2) | 0.048*** | 1 | | | | | |
| Stock of total R&D (3) | 0.102*** | 0.334*** | 1 | | | | |
| Extent of openness (4) | 0.020** | 0.178*** | 0.551*** | 1 | | | |
| Size (5) | 0.038*** | 0.128*** | 0.251*** | 0.123*** | 1 | | |
| Market stability (6) | -0.036*** | -0.067*** | -0.106*** | -0.036*** | -0.007 | 1 | |
| Diversification (7) | -0.001 | 0.042*** | 0.051*** | 0.004 | 0.025*** | -0.033*** | 1 |
| Concentration ratio (8) | 0.002 | 0.059*** | 0.061*** | 0.056*** | 0.100*** | -0.016** | -0.056*** |

***, **, *: Variable statistically significant at 1%, 5% or 10%, respectively.

Figure A1. Distribution of the number of patents.

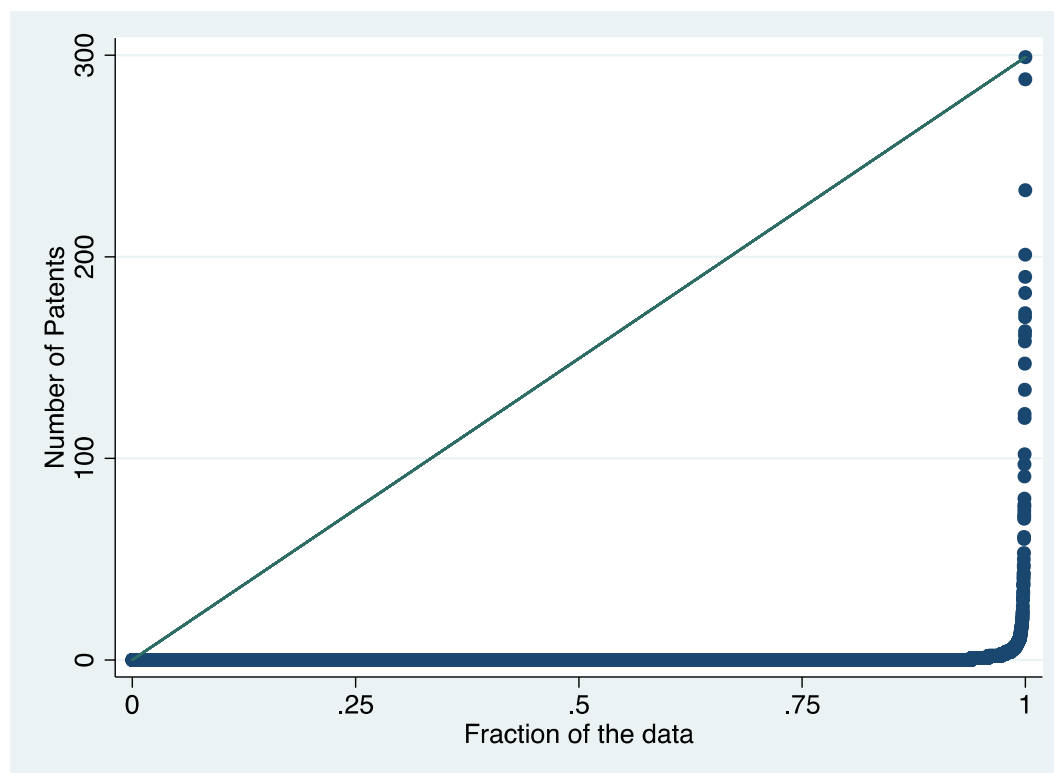
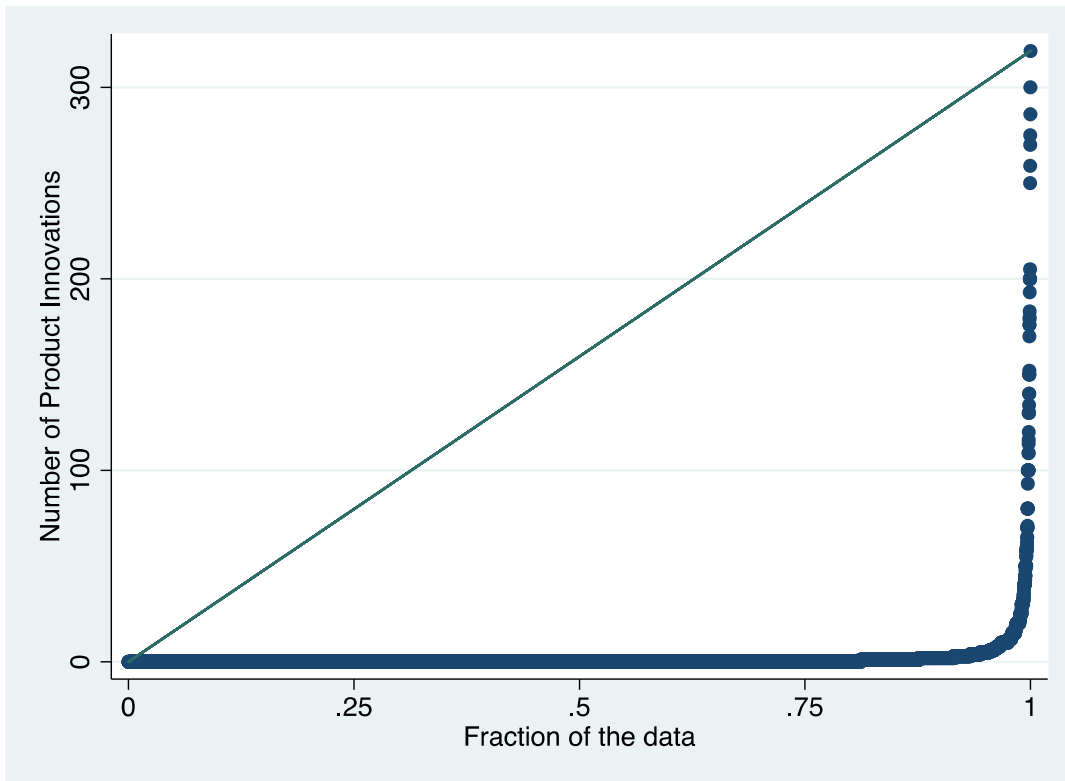


Figure A2. Distribution of the number of product innovations.



Appendix C: Model

We used a log-linear knowledge production with patent and product counts as the output measures and the stock² of R&D and IT as input measures. We start by considering a basic model in which the innovation performance of a firm, $ioutcome_{it}$, is explained by the logarithm of the stock of investments that firm i has at time t , $\ln IT_{it}$, and the logarithm of the stock of total investments in R&D activities. Equation (1) represents this model:

$$ioutcome_{it} = \alpha + \beta_1 \ln IT_{it} + \beta_2 \ln SGTD_{it} \quad (1)$$

where β_1 and β_2 are the parameters to be estimated.

Following previous papers (see, for example, Kleis et al. 2012), we introduce the moderating role of investments in IT. This enabling characteristic of IT suggests that these investments should interact with total investments in R&D in order to produce innovations. Therefore, we modify equation (1) to capture this interaction in the following way:

$$\begin{aligned} ioutcome_{it} = & \alpha + \beta_1 \ln IT_{it} + (\delta_1 + \delta_2 \ln IT_{it}) \ln SGTD_{it} = \\ & \alpha + \beta_1 \ln IT_{it} + \delta_1 \ln SGTD_{it} + \delta_2 \ln IT_{it} \ln SGTD_{it} \end{aligned} \quad (2)$$

where α , β_1 , δ_1 and δ_2 are the parameters to be estimated. We would expect δ_2 to be positive and significant.

Hypotheses 1a and 1b propose that IT reduces the costs of open innovation, making the curvilinear relation between the *Extent of openness* and innovative performance steeper. To consider the effect of IT on open innovation strategies, we have to decompose $SGTD_{it}$, the stock of total R&D investments of firm i at time t , into its internal ($SGIRD_{it}$) and external components ($SGERD_{it}$). Moreover, as internal and external R&D investments are likely to differ in their performance, we follow Bönnte (2003) in introducing differences between them. One possibility is to attribute a different weight (μ) to the stock of external investments ($SGERD_{it}$). The weighted R&D stock can be expressed as: $SGTD_{it}^* = SGIRD_{it} + (1 + \mu)SGERD_{it} =$

² The advantages of using stock measures are highlighted in Beneito (2006). Specifically, the use of stock measures avoids making assumptions about distributed lags and it prevents having to throw out much of the data in order to have a given number of lags present in the R&D spending pattern of firms.

$SGTD_{it} \left(1 + \mu \frac{SGERD_{it}}{SGTD_{it}}\right)$. If μ is greater than 0, external R&D investments are able to attain more innovation output than internal R&D, while external R&D investments are less productive if μ is lower than 0. Substituting the weighted R&D stock in equation (2) and approximating the term $\ln \left(1 + \mu \frac{SGERD_{it}}{SGTD_{it}}\right)$ by $\mu \frac{SGERD_{it}}{SGTD_{it}}$ we obtain:

$$ioutcome_{it} = \alpha + \beta_1 \ln IT_{it} + \delta_1 \ln SGTD_{it} + \rho \frac{SGERD_{it}}{SGTD_{it}} + \delta_2 \ln IT_{it} \ln SGTD_{it} + \vartheta \ln IT_{it} \frac{SGERD_{it}}{SGTD_{it}} \quad (3)$$

where α , β_1 , δ_1 , δ_2 , ρ and ϑ are the parameters to be estimated. As in Bönke (2003), our estimations will also consider the quadratic term of $\frac{SGERD_{it}}{SGTD_{it}}$. We expect ϑ to be positive and significant, and the coefficient accompanying $\ln IT_{it} \left(\frac{SGERD_{it}}{SGTD_{it}}\right)^2$ to be negative and significant for invention and product innovation.

Appendix D: Further analyses

Extant research tends to use samples of large or very large firms. This means that our knowledge about the enabling effects of IT innovation is limited to these types of firms. As has been stressed throughout the paper, a positive feature of our sample is that it is representative and includes small, medium-sized and large firms. Therefore, it allows an investigation into the validity of our results for small and medium-sized firms (SMEs).³ To identify SMEs, we used the recommendation of the European Commission (2003/361/CE) and we built a sample of firms with fewer than 250 employees. The results are presented in Tables A6 and A7 (Columns 1 and 2). For patents, the results reveal (1) an inverted U-shaped relationship of *Extent of openness* and the number of patents and (2) a moderating effect of *Stock of IT* on the *Extent of openness* of the form described in the main text (inverted U-shaped). Regarding the number of new product innovations the results reveal a negative effect of *Extent of openness* and the expected curvilinear relationship of the interaction between *Extent of openness* and *Stock of IT*.

Table A6. The impact of IT investments on invention

| | SMEs | |
|---|---------------------|---------------------|
| | Count (1) | Logit (2) |
| Stock of IT | 0.017 (0.039) | -0.073* (0.039) |
| Stock of total R&D | 0.033 (0.021) | -0.118** (0.049) |
| Stock of IT x Stock of total R&D | -0.004 (0.003) | |
| Extent of openness | 1.343* (0.715) | |
| Extent of openness ² | -2.837** (1.228) | |
| Stock of IT x Extent of openness | 0.277** (0.139) | |
| Stock of IT x Extent of openness ² | -0.508** (0.215) | |
| Constant | -0.785 (1.446) | 1.981 (1.760) |
| No. Observations | 12,693 | |

***, **, *: Variable statistically significant at 1%, 5% or 10%, respectively. Standard errors in parentheses. Industry, time dummies and the other control variables are included.

³ We attempted to build a sample of large firms similar to the ones used in previous research. However, the overlap did not provide the minimum number of observations needed to perform the estimations.

Additionally, in order to make sure that our results were not driven by the method used, we tested Hypotheses 1a and 1b through an alternative method, a population average model (see, for example, Kleis et al. 2012 for the application in a similar context). Remember that the selection of the zero-inflated negative binomial model was justified by overdispersion and by the existence of two types of zeros in the dependent variables (structural and non-structural). In other words, the reason why some of the firms do not obtain patents (product innovations) could be that the innovation process does not produce them. However, in other cases, the reason could be that the firms are not involved in innovation activities. As the population average model does not distinguish between these two types of zeros, we have to make sure that this different type of behaviour towards innovation does not bias our results. To select the firms that are active innovators, we created a subsample of firms that have positive values in the variable *Stock of R&D*. Although the selection might look restrictive, other papers studying the consequences of IT investments in the innovation process have used similar approaches. For example, Bardhan et al. (2013) removed observations with zero R&D and Kleis et al. (2012)'s sample only includes firms with R&D expenses.^{4,5}

The results of the population average model (not shown) strongly support our findings. In the case of patents, they show (1) a positive and significant interaction of *Stock of IT* and *Stock of Total R&D*, (2) an inverted U-shaped relationship of *Extent of openness* and the number of patents and (3) a moderating effect of *Stock of IT* on the *Extent of openness* of the form described above (inverted U shape). In the case of product innovations, the results reveal that (1) the *Stock of IT* has a positive and significant effect, (2) there is an inverted U-shaped

⁴ Additionally, we divided the number of patents into tertiles and compared the amount invested in IT (*Stock of IT*) for different values of the variable *Extent of openness*. The results show that firms obtaining more patents (third tertile) invest more in IT for low and medium levels of openness than firms obtaining fewer patents (first tertile). The difference is not significant for high levels of openness. This is consistent with the results presented before. We repeated the same exercise for product innovations. The results show that firms obtaining more product innovations (third tertile) invest more in IT than firms obtaining fewer product innovations (first tertile), for medium and high levels of openness. This is consistent with our hypotheses.

⁵ We also compared investments in IT and R&D for low and high inventors/innovators. The results show that firms that obtain more patents invest more in R&D and IT. However, the results show that firms that obtain more product innovations invest more in R&D and IT, but the differences are not significant. These two results are also consistent with the estimations presented in the main text.

relationship of *Extent of openness* and the number of product innovations and (3) the positive effect of the interaction between *Extent of openness* and *Stock of IT*. In this case, the interaction of *Stock of IT* and the quadratic term of the variable *Extent of openness* is negative but not significant.

We also used a complementary way of measuring open innovation. The results presented in the main text (see Tables 1 and 2) support the idea that IT investments facilitate the production of patents and product innovations in firms using open innovation strategies. Our characterization of open innovation has been through a variable that measures the percentage of external R&D investments. However, firms can also acquire external knowledge by collaborating with external partners such as suppliers, clients, competitors and universities and research centers (Sofka and Grimpe 2010, Un et al. 2010). Therefore, we defined several dummy variables taking a value of one when the firm collaborates with these four types of external agents, and zero otherwise. Then, we considered augmented models in which the four types of collaboration and *Extent of openness* were used as measures of open innovation to explain patents and product innovations. As in the exercise presented above with the variable *Extent of openness*, we interacted the variables measuring collaboration and the investments of firms in R&D. The results (not shown) reveal that the interactions are never significant. This suggests further lines of enquiry. For example, our results may mean that IT investments only moderate the intensity with which a given source of external knowledge is used. Additionally, we do not focus on other alternatives for acquiring external knowledge, such as licenses from patents or the acquisition of embodied knowledge (Veugelers and Cassiman 1999).

Finally, innovation models suggest that there are inputs of innovative activities other than IT and R&D especially when product innovations are concerned. For example, new products may be the consequence of market research activities.⁶ The Survey of Business Strategies collects information on “Market research and marketing for commercialization of new products”. This is a “yes/no” question whose information is available every four years. The

⁶ We thank an anonymous referee for suggesting this analysis.

results of introducing the corresponding variable into our model are presented in columns 3 and 4 in Table A7. The variable “Investments in market research for new product development” is not significant. The findings on the effects of IT on product innovation are similar to those obtained previously.

Table A7. The impact of IT investments on product innovation

| | SMEs | | All firms | |
|---|----------------------|----------------------|--------------------|----------------------|
| | Count (1) | Logit (2) | Count (3) | Logit (4) |
| Stock of IT | 0.008 (0.026) | -0.052*** (0.017) | 0.050 (0.033) | -0.020 (0.025) |
| Stock of total R&D | 0.009 (0.015) | -0.166*** (0.015) | 0.019 (0.018) | -0.150*** (0.015) |
| Stock of IT x Stock of total R&D | 0.002 (0.002) | | 0.004 (0.004) | |
| Extent of openness | 0.291 (0.540) | | 0.399 (0.546) | |
| Extent of openness ² | -2.402*** (0.820) | | -1.439* (0.874) | |
| Stock of IT x Extent of openness | 0.257** (0.100) | | 0.193* (0.115) | |
| Stock of IT x Extent of openness ² | -0.269* (0.151) | | -0.138 (0.181) | |
| Investment in market research for new product development (EMYM) | | | 0.231 (0.154) | -1.983*** (0.323) |
| Constant | 0.820 (0.629) | 0.700 (0.777) | 0.956** (0.479) | 2.121** (0.840) |
| No. Observations | 12,621 | | 3,811 | |

***, **, *: Variable statistically significant at 1%, 5% or 10%, respectively. Standard errors in parentheses. Industry, time dummies and the other control variables are included.

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