

Appendix A: Robustness Tests

We conducted a series of additional tests to further explore the robustness of our findings. Table A1 presents the results of these tests. First, Model 1 provides the results when second lags are used instead of first lags to estimate the effect of R&D and its related interactions^a. Model 2 provides an analysis of firms for which the environmental turbulence categorization (stable or turbulent) remains consistent and unchanged between one year before, one year after, and in the year the dependent variable is measured. We do so to check whether the sub-sample analysis of stable and turbulent environments is based on a longer-term view of turbulence.

We further supplement the results with alternative measures for environmental turbulence, Tobin's Q, and the control variables. Model 3 reports the results using a different measure of environmental turbulence, where turbulence is viewed as the variability of a firm's returns, computed as the standard deviation of the firm's daily idiosyncratic returns for the year. We compute daily idiosyncratic returns as the residual of the regression of the firm's daily return on the daily return of an equally-weighted market portfolio (Bhushan 1989). Model 4 reports the results with an alternative computation of Tobin's Q in which inventory is excluded from the numerator. Finally, Model 5 examines the effect of organizational slack in addition to the other controls to capture the effect of increased budgetary flexibility. For this purpose, we compute organizational slack as liquidity (current assets/current liabilities) (Chiu and Liaw 2009). Results of all five models in Table A1 are consistent with the main results.

--- Insert table A1 here ---

References

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Chiu Y, Liaw Y (2009) Organizational slack: Is more or less better? *Journal of Organizational Change Management* 22 (3): 321-342.

^a We thank an anonymous reviewer for suggesting that a longer lag may be more appropriate for measuring the realized benefits of R&D investments.

Table A1. Alternative Specifications, Measures, and Controls^a

	Model 1	Model 2	Model 3	Model 4	Model 5
DV = Tobin's Q	Longer R&D Lag	Consistent Yearly EnvTurb	Different Measure of EnvTurb	Different Measure of Tobin's Q	Organizational Slack Included
EnvTurb ^b	-0.273*** (0.038)	-0.303*** (0.036)	-0.120*** (0.014)	-0.194*** (0.022)	-0.346*** (0.057)
IT	0.084** (0.030)	0.095** (0.034)	0.067* (0.028)	0.105*** (0.011)	0.096* (0.042)
R&D	0.151*** (0.030)	0.189*** (0.034)	0.135*** (0.023)	0.298*** (0.035)	0.261*** (0.069)
ADV	0.078*** (0.008)	0.062* (0.026)	0.012* (0.005)	0.015* (0.007)	0.078* (0.036)
IT * R&D	0.058* (0.024)	0.071** (0.023)	0.024* (0.011)	0.109** (0.042)	0.068* (0.034)
IT * ADV	0.122*** (0.019)	0.112*** (0.020)	0.168*** (0.043)	0.063* (0.032)	0.178*** (0.029)
R&D * ADV	0.114*** (0.015)	0.256*** (0.029)	0.216*** (0.024)	0.261*** (0.028)	0.212*** (0.057)
EnvTurb * IT	-0.003 (0.002)	-0.002 (0.001)	0.007 (0.006)	0.002 (0.001)	0.007 (0.004)
EnvTurb * R&D	0.042* (0.017)	0.082** (0.026)	0.158*** (0.022)	0.155*** (0.024)	0.091* (0.045)
EnvTurb * ADV	-0.056* (0.025)	-0.050* (0.023)	-0.034* (0.014)	-0.019* (0.008)	-0.073* (0.030)
EnvTurb * IT * R&D	0.067* (0.027)	0.088** (0.028)	0.081** (0.027)	0.078** (0.026)	0.088** (0.030)
EnvTurb * IT * ADV	-0.092*** (0.022)	-0.084** (0.032)	-0.025* (0.012)	-0.046* (0.019)	-0.057** (0.019)
EnvTurb * R&D *ADV	0.620** (0.211)	0.197*** (0.023)	0.085* (0.038)	0.063* (0.024)	0.118*** (0.028)
N	957	934	1,042	1,042	1,042
Wald's χ^2	4,412.5	6,267.8	5,431.2	6,967.5	7,198.3

^a * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The χ^2 index of fit is significant at $p < 0.001$ in all models. The interaction variables pass the Wald's test at $p < 0.001$. The same control variables were used as in the main regressions (Table 3) but are omitted from this table for space considerations. The standard error of each coefficient is reported in parentheses.

^b The variables below are represented as follows: EnvTurb = Environmental Turbulence; IT = Information Technology Investment; R&D = R&D Investment; and ADV = Advertising Investment. All investment measures are calculated as ratios of sales for each firm-year observation.

Appendix B: Further Tests to Address the Issue of Endogeneity

The implementation of the system GMM, as reported in the main paper (Table 3, Model 6), only involves instrumenting the IT investment variable and the second lag of the first differences. In order to further examine the robustness of our results to the methodological approaches that deal with endogeneity of model variables, we conduct seven additional tests reported in this appendix¹.

Additional GMM estimation tests: We start by estimating two models with slightly different instruments. The first model considers R&D and ADV and their interaction terms, along with IT and its related interaction terms, as endogenous variables (Table B1, Model 1), whereas the second model considers second and longer lags of the first differences when instrumenting the IT investment variable (Table B1, Model 2).

--- Insert table B1 here ---

Additional approaches to instrument IT investment: Next, in addition to system GMM, we follow three additional approaches to instrument IT investment. First, following Mithas and Rust (2016), we use the second lag of the IT investment by each firm as the instrument of the IT investment. This approach has been adopted by similar BVIT studies to deal with the endogeneity of error terms to various IT investment measures. Model 3 in Table B1 reports the panel 2SLS (G2SLS) estimates using this approach to test the main model of the study. However, this approach uses only one instrument of IT investment, precluding over-identification tests of the exogeneity of instruments. To address this issue, we further conduct two estimations with multiple IT investment instruments.

In the first estimation with multiple instruments, we follow Lewbel's (2012) approach, which uses a heteroscedastic covariance restriction to create internal instruments that are not subject to the usual instrument validity issues. We use the Lewbel's internal instrument of IT investment along with the second lag of the IT investment in a system GMM estimation. Model 4 in Table B1 reports the results of this estimation. The Sargan's test of over-identification fails to reject the null hypothesis that the set of instruments used in Model 4 are exogenous to error terms ($p = 0.183$).

¹ We thank the Senior Editor, Associate Editor, and reviewers for recommending these additional techniques.

In the second estimation with multiple instruments, we follow Xue et al.'s (2012) approach using the multiple instruments of IT investment they suggest, namely: the firm's previous year IT investment, the industry IT investment (from the Current-Cost Investment in Private residential Fixed Assets Table from the Bureau of Economic Analysis [BEA]), the industry tax ratio (GDP-by-industry tables reported by the BEA), the industry-operating surplus (from the BEA's GDP-by-industry tables), the industry material-energy input ratio (calculated using the BEA's value-added-by-industry tables), the industry service-energy input ratio (calculated using the BEA's added-by-industry tables), and the industry import-export value (from the BEA's industry input-output use tables). The industry variables are weighted by firm's sales in that industry (Xue et al. 2012). Model 5 in Table B1 reports the results of a panel 2SLS regression using these instruments. The Sargan's test of over-identification fails to reject the null hypothesis that the set of instruments used in Model 5 are exogenous to error terms ($p = 0.411$). The results of all five additional models in Table B1 converge with our main findings, indicating that the results of the hypothesis testing are robust to alternative instrumental approaches.

Alternative approaches for estimating models with endogenous variables: In addition to the instrumental variable approaches, we use two alternative approaches for estimating models with endogenous variables. In the first such approach (Garen 1984), we correct for the selectivity of continuous endogenous variables through a two-stage procedure. In stage one, the continuous endogenous variable is predicted by a set of instruments. In stage two, we control for the residual from stage one (i.e., η , the endogenous variable's actual value minus its predicted value based on the stage one regression) and the interaction of the endogenous variable and the residual, where the endogenous variable predicts the primary dependent variable. This approach has been used recently in the BVIT literature (e.g., Ho et al. 2017) and allows the endogenous variable to remain continuous when estimating stage one (Garen 1984) to account for the endogeneity of IT investment. In specifying stage one, Ho et al. follow Mitra (2005) and suggest that a firm's level of IT intensity depends on the level of the industry's average IT intensity, the cash flow available to the firm, its growth (revenue growth)², sales, and the interaction between cash flow and growth. Likewise, we specify stage one using the mentioned instruments and then include additional residual terms, as explained

² Following an approach similar to Xue et al. (2012), we measure revenue growth in a two-step approach. First, the natural log of each firm's revenue is regressed over an index variable of years over a period of five years. Then, the antilog of the index variable's coefficient is used as the measure of revenue growth for that firm.

earlier in the main model of the study. The results of Garen's correction, reported in Table B2, show that the hypothesized three-way interactions exhibit patterns that are similar to the main results (Model 6, Table 3).

--- Insert table B2 here ---

Finally, in the second approach for estimating models with endogenous variables, we conduct the Granger Causality test (Granger 1969), which explicitly accounts for potential variable simultaneities by running a vector autoregression (VAR) with first and second lags of the dependent and independent variables used as inputs. This test indicates if the independent variables cause the dependent variable, by considering the effects of the independent variables while controlling for the lagged values of the independent and dependent variables. In Table B3, the equation for the VAR that has Tobin's Q as the dependent variable is provided with the *F*-test of each variable's contribution to the model after controlling for the first and second lags. The results provide further evidence that the direct effects and the three-way interaction effects discussed in the main study have a causal impact on a firm's Tobin's Q.

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References

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Table B1. Alternative Instrumental Variable Estimations^a

DV = Tobin's Q	Model 1	Model 2	Model 3	Model 4	Model 5
Instrumental Variable Approach	System GMM, R&D and ADV instrumented	System GMM, second and longer lags used	Mithas and Rust (2016)	Mithas and Rust (2016) and Lewbel (2012)	Xue et al. (2012)
Firm size	0.163# (0.090)	0.077 (0.050)	0.187*** (0.054)	0.265*** (0.029)	0.273*** (0.037)
Assets	0.010 (0.013)	0.008 (0.014)	0.006 (0.003)	0.007 (0.006)	0.005 (0.003)
Median Tobin's Q	0.244** (0.077)	0.138** (0.044)	0.358*** (0.037)	0.332*** (0.060)	0.299*** (0.041)
Median capital intensity	0.021 (0.020)	0.023 (0.028)	0.011 (0.009)	0.008 (0.005)	0.006 (0.004)
Concentration ratio	0.012 (0.015)	0.013 (0.018)	0.021* (0.008)	0.039* (0.017)	0.051** (0.018)
Regulation	-0.057 (0.056)	-0.096 (0.147)	-0.047* (0.021)	-0.091* (0.037)	-0.054* (0.024)
Related diversification	-0.019 (0.018)	-0.030 (0.032)	-0.020 (0.014)	-0.020 (0.011)	-0.018 (0.015)
EnvTurb ^b	-0.097* (0.045)	-0.118* (0.056)	-0.327*** (0.061)	-0.286*** (0.034)	-0.234*** (0.045)
IT	0.171* (0.067)	0.170* (0.071)	0.077* (0.035)	0.069* (0.030)	0.036* (0.016)
R&D	0.085# (0.044)	0.109* (0.049)	0.369*** (0.041)	0.133** (0.049)	0.162** (0.059)
ADV	0.085# (0.048)	0.096# (0.056)	0.023* (0.011)	0.010 (0.006)	0.007 (0.005)
IT * R&D	0.074# (0.042)	0.076# (0.039)	0.119** (0.042)	0.101* (0.044)	0.048* (0.021)
IT * ADV	0.189** (0.067)	0.144** (0.051)	0.049* (0.021)	0.161* (0.074)	0.148* (0.063)
R&D * ADV	0.035 (0.036)	0.078* (0.031)	0.239*** (0.027)	0.326*** (0.060)	0.149** (0.054)
EnvTurb * IT	0.010 (0.015)	0.016 (0.023)	0.008 (0.005)	0.006 (0.005)	0.007 (0.006)
EnvTurb * R&D	0.026 (0.042)	0.012 (0.013)	0.113* (0.051)	0.125* (0.063)	0.066 (0.041)
EnvTurb * ADV	-0.018 (0.021)	-0.014 (0.020)	-0.045* (0.017)	-0.063* (0.027)	-0.037** (0.011)
EnvTurb * IT * R&D	0.153* (0.071)	0.147# (0.084)	0.079* (0.038)	0.064** (0.020)	0.094* (0.048)
EnvTurb * IT * ADV	-0.107# (0.062)	-0.102* (0.045)	-0.081* (0.033)	-0.086* (0.039)	-0.083*** (0.010)
EnvTurb * R&D * ADV	0.184* (0.082)	0.104# (0.054)	0.075** (0.024)	0.098** (0.034)	0.113** (0.037)
N	736	881	881	881	914
Wald's χ^2	1,323.56	1,416.98	4,719.27	3,592.39	2,881.62

^a * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. χ^2 index of fit is significant at $p < 0.001$ in all models. The interaction variables pass the Wald's test at $p < 0.001$. Year and industry dummies are included in the estimation but are omitted from this table for space considerations. The standard error of each coefficient is reported in parentheses.

^b The variables below are represented as follows: EnvTurb = Environmental Turbulence; IT = Information Technology Investment; R&D = R&D Investment; and ADV = Advertising Investment. All investment measures are calculated as ratios of sales for each firm-year observation.

Table B2. Garen's (1984) Test^a

Stage 1	DV = IT	Stage 2	DV = Tobin's Q
IT industry	0.641*** (0.083)	Firm size	0.087** (0.027)
Free Cash Flow	-0.008 (0.004)	Assets	0.067** (0.021)
Growth	-0.011* (0.005)	Median Tobin's Q	0.432*** (0.047)
Free Cash Flow * Growth	0.403*** (0.053)	Median capital intensity	0.017 (0.011)
Sales	0.003 (0.002)	Concentration ratio	0.098*** (0.018)
		Regulation	-0.057* (0.023)
		Related diversification	-0.015 (0.011)
		EnvTurb ^b	-0.120*** (0.017)
		IT	0.165*** (0.022)
		R&D	0.389*** (0.048)
		ADV	0.040* (0.016)
		IT * R&D	0.092* (0.037)
		IT * ADV	0.108* (0.043)
		R&D * ADV	0.086* (0.035)
		EnvTurb * IT	0.003 (0.002)
		EnvTurb * R&D	0.044* (0.019)
		EnvTurb * ADV	-0.059* (0.026)
		EnvTurb * IT * R&D	0.068* (0.028)
		EnvTurb * IT * ADV	-0.076* (0.032)
		EnvTurb * R&D * ADV	0.124*** (0.021)
		η^c	-0.014* (0.006)
		IT * η	0.008 (0.005)
Adjusted R^2	0.54***	Adjusted R^2	0.44***

^a * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. $N = 1,042$; χ^2 index of fit is significant at $p < 0.001$ in all models. The interaction variables pass the Wald's test at $p < 0.001$. Year and industry dummies are included in both stages' estimations but are omitted from this table for space considerations; Standard errors (reported in parentheses) are clustered by firm and heteroscedasticity-consistent estimations are used in both of the models above.

^b The variables below are represented as follows: EnvTurb = Environmental Turbulence; IT = Information Technology Investment; R&D = R&D Investment; and ADV = Advertising Investment. All investment measures are calculated as ratios of sales for each firm-year observation.

^c η is the actual value of IT for each firm-year observation minus the predicted value of IT for that observation based on the stage one regression equation.

Table B3. Granger Causality Test with Alternative Dependent Variables

Variable	F-test	p-value
EnvTurb ^a	4.43	$p < 0.05$
IT	2.83	$p < 0.10$
R&D	3.92	$p < 0.05$
ADV	2.77	$p < 0.10$
IT * R&D	1.21	$p > 0.10$
IT * ADV	1.13	$p > 0.10$
R&D * ADV	4.53	$p < 0.05$
EnvTurb * IT	1.34	$p > 0.10$
EnvTurb * R&D	3.03	$p < 0.10$
EnvTurb * ADV	3.14	$p < 0.10$
EnvTurb * IT * R&D	4.23	$p < 0.05$
EnvTurb * IT * ADV	4.76	$p < 0.05$
EnvTurb * R&D * ADV	6.95	$p < 0.01$
		$N = 533$

^a The variables below are represented as follows: EnvTurb = Environmental Turbulence; IT = Information Technology Investment; R&D = R&D Investment; and ADV = Advertising Investment. All investment measures are calculated as ratios of sales for each firm-year observation.