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Geopolitical Risk and R&D investment

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Abstract

Although most empirical studies conclude that uncertainty delays firms' investments based on real options theory, empirical evidence regarding the impact of uncertainty on innovation is mixed. This study examines the impact of geopolitical risk (GPR) on corporate research and development (R&D) investment using newly developed indices. We find a negative relationship between GPR and R&D investment. The R&D investment rapidly drops and rebounds several quarters after high GPR. The impact of GPR is most significant for high-tech firms, small firms, and firms with high growth options. However, when GPRs are realised, these significant and negative effects disappear. These results are shown to be robust after controlling for firm characteristics, macroeconomic environment, other uncertainty measures, time, and alternative GPR and R&D measures, as well as considering the simultaneity and endogeneity issues. Overall, our study suggests that GPR plays a key role in determining R&D investment.

Keywords: R&D; Political uncertainty; Geopolitical risk; Innovation

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1. Introduction

Uncertainty has received much attention since the outbreak of global financial crisis in 2008 and the following Euro Zone debt crisis. For example, Mark Carney (2016), the incumbent Governor of the Bank of England, notes that economic uncertainty, policy uncertainty, and geopolitical uncertainty could have significant economic negative effects. The IMF country reports suggest that uncertainty is a key factor that leads to weaker economic performances in many countries, such as South Africa and the United Kingdom.[2]

Although most studies conclude that uncertainty delays firms' investments based on real options theory (e.g., Bernanke, 1983; McDonald and Siegel, 1986; Rodrick, 1991; Dixit and Pindyck, 1994; Julio and Yook, 2012; Baker et al., 2016; Gulen and Ion, 2016)[3], the impact of uncertainty on R&D investment may differ due to differences in relative adjustment costs (Bloom, 2007). Based on theoretical studies (Bean, 1990; Gali and Hammour, 1992; Hall, 1993; Bloom, 2007), the relative cost of long-term innovation investments, compared to short-term capital investments, is lower in recessions than in booms; hence, the ratio of long-term R&D investment to total investment should increase during an economic recession or period of uncertainty.[4] Moreover, there also exist other channels that affect the relationship between uncertainty and innovation. For example, Weeds (2002) shows that, theoretically, uncertainty

2 Please see the IMF 2017 country report for example.

3 Under the real options theory, the investment opportunity is viewed as an option to invest, which can be exercised optimally. Based on this insight, the value of delay increases when a firm faces uncertainty. This approach is better over the traditional NPV-based investment appraisal methods by allowing the value of delay and the flexibility. Some theoretical studies have even shown that a real options channel might strengthen investment in intangible assets such as patents (Holmstrom, 1989; Aghion and Tirole, 1994; Manso, 2011; Ferreira et al., 2012).

4 Bloom (2014) and Bloom et al. (2018) noted that policy uncertainty increases when the economy enters a downturn (recession).

may encourage R&D investment when the expected benefit of preemption outweighs the option value of delay. The notion behind this is that a firm may fear that its competitor may seize an advantage by acting first due to the threat of preemption induced by strategic rivalry.

Empirical evidence regarding the impact of uncertainty on R&D is mixed. Schwartz (2004) described R&D as a common investment project and argued that uncertainty reduces corporate investment in R&D based on the real options approach. Bloom (2009) estimated the impact of uncertainty shock on hiring and investment, and showed that it produces a rapid drop and rebound in employment and investment. Bhattacharya et al. (2017) found that while policies have no significant effect on corporate innovation as companies promptly adapt to different policies, policy uncertainty often induces firms to make mistakes thereby hindering corporate innovation. On the one hand, Feng and Johansson (2017) used political turnover events as proxy for political uncertainty and showed that political uncertainty hinders Chinese firms' R&D spending. On the other hand, Stein and Stone (2013) used expected volatility of stock prices as implied by equity options to obtain forward-looking measures of uncertainty, and showed that uncertainty encourages R&D investment. Taking US state elections as exogenous changes in governmental policy uncertainty, Atanassov et al. (2018) empirically addressed the impact of political uncertainty on firms' R&D activities. They found that an increase in political uncertainty increases corporate R&D spending.

Clearly, no consensus has been reached in the literature regarding the impact of uncertainty on R&D activities. This study addresses this issue by using new geopolitical risk (GPR) indices introduced by Caldara and Iacoviello (2018). GPR has large effects on economy. For instance, Abadie and Gardeazabal (2003) observe that GDP per capita in the Basque Country declined by 10 percentage points after the outbreak of terrorism.[5] In line with Baker et al. (2016), Caldara and Iacoviello (2018) applied a text-searching technique using geopolitical-related keywords on newspapers in the US to construct a measure for GPR. Unlike many studies that have used dummy variables to isolate geopolitical events, the GPR index is a continuous news-based index. It reflects the level of risk, allowing us to observe the effects of GPR at various phases (e.g., when the index indicates high or low risk). Another advantage of this index is that its GPR measure is largely exogenous to economic conditions as it does not systemically increase during economic crises.

Using the GPR index, we document a strong adverse relationship between R&D investment and uncertainty. We find that the ratio of R&D/Assets is negatively associated with GPR at a 1% significance level in the absence of firm characteristics and aggregate variables. The coefficient of GPR is -0.609 (t-statistic = -4.721), suggesting that if GPR increased by 100%, it would reduce the R&D/Assets ratio by 0.00609 units. Given the fact that the sample mean of R&D/Assets ratio is 0.125, a 100% increase in GPR would lead to about 4.87% (0.00609/0.125) decrease in R&D investment. This economic magnitude is pronounced as the GPR index more than tripled during the Gulf Wars and the 9/11 terrorist attacks. Upon including firm-specific variables and aggregate controls, including other types of uncertainties, the coefficient of GPR becomes more negative, at -0.818 with t-statistic of -5.72, which suggests an even stronger effect

[5] Some other studies have similar findings, including Abadie and Gardeazabal (2008), and Becker and Rubinstein (2011).

of GPR on R&D. The effect of GPR persists beyond by two quarters as shown by the R&D investment, which dropped for six quarters and rebound thereafter, similar to the case of Bloom (2009). However, when the geopolitical event associated with the risk actually occurs, it is possible that these significant and negative effects might disappear.

Further analyses focusing on the role of firm heterogeneity show that this negative relationship is especially strong for small firms. The coefficient of the interaction term GPR*Small is significantly negative at the 1% level. This suggests that when GPR index increases, its negative impact on the next-year R&D investment is greater for small firms than for large firms. As such, this result supports the view that small firms are more sensitive than large firms to GPR. It is also consistent with the notion that firms with greater financial constraints are more sensitive to GPR, as small firms are usually considered to be more financially constrained.

Next, we consider rival preemption. The value of an R&D project will be greatly reduced if and when a competitor completes a similar product first (e.g., Weeds, 2002). Thus, the negative effect of GPR on R&D is expected to be weaker for firms subject to a high level of product market competition. However, the effect of rival preemption might weaken due to firm heterogeneity (Novy-Marx, 2007). To better understand the role of rival pre-emption in driving the R&D-uncertainty relationship, we use the interaction between Herfindahl-Hirschman Index (HHI) and GPR. Our results tend to support the view of Novy-Marx (2007) in that we observe a very weak effect of pre-emption. Moreover, we observe that high-tech firms and high-growth firms are more sensitive to GPR. All these analyses are shown to be robust after controlling for firm characteristics, the macroeconomic environment, other uncertainty measures, and time trend.

Finally, we conduct several robustness checks. The GPR proxy used in the study is based on news reported in US newspapers, which are naturally biased in their coverage to emphasise issues that are of interest to their readers. Hence, we show that the negative effect of GPR on R&D continues to exist if we use the actual number of international political crises events to proxy GPR. Next, we use dynamic R&D regressions and generalised method of moments (GMM) estimations to consider the simultaneity problem and to show that the conclusion continues to hold. To further address endogeneity concerns, we employ a measure of religious tension as an instrumental variable. The instrumental variable analysis results suggest that religious tension is a good instrument and the fitted GPR variable is strongly negatively associated with R&D investment. To verify that our results do not depend on the method of measuring R&D activities, we construct several alternative measures of R&D and show that our baseline results are not driven by the choice of R&D measure.

Our study relates to several different strands of literature. First, the present analysis relates to the growing literature on the firm-level effects of uncertainty. Using political events, such as elections, early empirical studies found that firms' financing decisions (Dai and Ngo, 2014; Chen et al., 2017; Çolak et al., 2017), investments (Julio and Yook, 2012), and mergers and acquisitions (Jens, 2016; Cao et al., 2017) are different during election years. Using the recently developed economic policy uncertainty (EPU) index, Waisman et al. (2015), Melolinna et al. (2018), and Drobetz et al. (forthcoming) linked policy uncertainty (PU) to the corporate capital structure and the cost of capital.[6] Our results shed light on the impact of GPR on a firm's R&D investment.

Our study is also related to the literature on the drivers of corporate innovation. Prior studies have identified determinants of innovation, such as firm strategy (Hoskisson and Hitt, 1988; Baysinger and Hoskisson, 1989; Baysinger et al., 1991), internal and external finance (Himmelberg and Petersen, 1994; Brown et al., 2009; Hall and Lerner, 2010; Brown and Petersen, 2011), anti-takeover provisions (Atanassov, 2013), the choice of financing (Atanassov, 2016), corporate income taxes (Atanassov and Liu, 2016), and corporate tax credits (Bloom et al., 2002; Wilson, 2009; Rao, 2016), among others. Although these studies improved the understanding of corporate innovation, they largely ignored uncertainty. In this study, we document GPR as an essential determinant of a firm's R&D investment.

The remainder of this study proceeds as follows. Section 2 defines key variables and describes the data sources. The main methodology and empirical results are summarised in Section 3. Section 4 concludes this study.

2. Data and descriptive statistics

In this section, we discuss our data sources, descriptive statistics, and definitions of variables.

2.1 Measuring geopolitical risk

[6] Other studies have used different proxies for PU. Bradley et al. (2016) used the political alignment index of Kim et al. (2012) to show that state-level policy risk is positively related to firms' cost of debt.

We use Caldara and Iacoviello's (2018) GPR index, which uses text searching techniques to count the occurrence of words related to geopolitical tensions in 11 leading international newspapers (namely The Boston Globe, Chicago Tribune, The Daily Telegraph, Financial Times, The Globe and Mail, The Guardian, Los Angeles Times, The New York Times, The Times, The Wall Street Journal, and The Washington Post) from January 1985 to the present. The search identifies six groups of words. The first group includes words that explicitly mention geopolitical risk and military tensions. Next, the second group involves words associated with nuclear tensions. The third and fourth groups include war and terrorist threats, respectively, while the fifth and sixth groups capture negative events leading to increasing geopolitical uncertainty, including the start of a war or terrorist acts. The GPR index is obtained by calculating the proportion of GPR-related news among the total number of news articles for each month. This GPR index is normalised to 100 for the period 2000–2009.

The baseline GPR index is constructed on the basis of all six groups while two sub-indices, geopolitical threats (hereafter, GPT) and geopolitical acts (hereafter, GPA), are constructed on the basis of Groups 1 to 4 and Groups 5 and 6, respectively. Caldara and Iacoviello (2018) constructed the two sub-indices to differentiate between the possibility of geopolitical action and the actuality of geopolitical events. Further data and detailed construction description are available online.[7]

According to Caldara and Iacoviello (2018), their GPR index is advantageous compared to other available indices, which have the following inherent shortcomings: (1) they are often

[7] https://www2.bc.edu/matteo-iacoviello/gpr.htm#overview.

qualitative and subjective; (2) they either remain relatively constant over time or are only available over a short period; and (3) some of the measures, although quantitative, are constructed on the basis of variables meant to indicate market conditions, not measure GPR (e.g., gold prices, the dollar index, and several other financial market indicators). Compared with other uncertainties, the GPR index is more "exogenous" to economic conditions than other uncertainty measures are.

Figure 1 plots the GPR index since January 1985. As shown, GPR has experienced several spikes, each corresponding to key geopolitical events, as summarized in Table 1. For example, the index spikes in January 1991, which corresponds to the outbreak of the Gulf War. We observe two other spikes in September 2001 and March 2003, which correspond to the 9/11 attacks and the beginning of the Iraq War, respectively. Some smaller spikes are observed more recently, such as the 2015 Paris terrorist attack and Russia's annexation of Crimea in 2014. Overall, the GPR index effectively captures geopolitical events. In comparison with other existing measures, Caldara and Iacoviello (2018) show that their index moves in correspondence with the number of international crises per month based on the International Crisis Behavior (ICB) database. For example, the GPR index moves in accordance with the number of crises as per the database, during WWI, the Gulf War, and the Iraq War.[8]

2.2 R&D investment proxies and other variables

Our main dependent variable and firm-level control variables are from the S&P Capital IQ's

[8] Please see the text and Figure 7 in Caldara and Iacoviello (2018) for more details.

Compustat annual file. On the Compustat database, R&D expenses cover all costs incurred including salaries and departmental expenses that relate to the development of new products or services during the financial year. The key variable in this study is R&D investment. A common way to measure R&D investment is to use the ratio of R&D expenditure to other accounting measures such as total assets. Following Brown et al. (2009), we primarily use the ratio of R&D expense to total assets (R&D/Assets) to measure R&D intensity.[9] In line with existing literature, we control for firm characteristics such as *leverage, Tobin's Q*, and *profitability*. We also follow Brown et al. (2009; 2012) by controlling for financial constraint factors including *cash flow*; we control for *tangibility* in accordance with Atanassov (2013, 2016) and Atanassov et al. (2018), which document *tangibility's* positive relationship with R&D investment.[10] The definitions of the variables used and details of data sources are summarised in the Appendix.

2.3 Descriptive statistics

Table 2 reports the summary statistics of the key variables used in this study. We exclude financial firms (SIC code 6,000 to 6,999) and utility firms (SIC 4,900 to 4,999) as the two industries are highly regulated and characterised by capital requirements that would affect our statistical measures. By combining data from several sources, we obtain 11,164 firms and 95,823 firm-year observations. The sample period ranges from the first quarter of 1985 to the fourth quarter of 2018. We require our sample to have non-missing firm-year observations and

[9] There exist other measures of R&D intensity such as R&D expense relative to total sales. We provide robustness checks in the empirical results section using various R&D measures.
[10] In our robustness check we also use additional measures whose definitions are included in the Appendix.

non-missing R&D expense data, which, therefore, results in an unbalanced panel.[11] All continuous variables are winsorised at the 1st and 99th percentiles to reduce the influence of extreme outliers.[12]

As shown in Table 2, we observe that the mean (median) firm has a R&D/Assets ratio of 12.5% (4.3%), which is slightly lower than the values reported in Brown et al. (2009), who obtained an average R&D/Assets ratio of 17%. The reason for this difference is that their study only considered R&D-intensive firms operating in high-tech sectors. Our sample firms have an average Tobin's Q equal to 3.762, cash flow of -2.4%, profitability of -1.7%, tangibility of 21.8%, leverage ratio of 26.3%, and Chicago Fed National Activity Index (CFNAI) of -0.086. Regarding the uncertainty measure, GPR has an average value of 78.489. Macroeconomic uncertainty (MU), financial uncertainty (FU), and economic policy uncertainty (EPU) have average values of 0.641, 0.901, and 108.486, respectively.

3. Identification strategy and results

This section documents our empirical method and findings regarding the relationship between GPR and firm-level R&D investments. We perform both univariate and multivariate regression analyses, controlling for firm characteristics, economic conditions, and other types of

[11] We understood that R&D expense might be biased because about 50% of Compustat firms do not report R&D expenses (Chemmanur and Tian, 2018). Moreover, Koh and Reeb (2015) observe that some firms have filed patents even if their R&D expenses are missing. To reduce such concerns, we follow Brown and Petersen (2011) and Hirschey et al. (2012) to replace missing value of R&D with zero in unreported analysis (results are available upon request). The main conclusion remains robust.

[12] We also test the results using the data that winsorised for top and bottom 5%, and the conclusions are robust. The results are available upon request.

uncertainties. Further, we investigate the cross-sectional heterogeneity effect of GPR on R&D. Lastly, we perform a robustness check by introducing several different model specifications.

3.1 Baseline regression and results

The baseline empirical model is specified as follows:

$$\mathrm{R\&D}_{\mathrm{i,t+1}} = \alpha + \beta_1 \mathrm{GPR}_{\mathrm{t}} + \gamma_1 \mathrm{X}_{\mathrm{i,t}} + \gamma_2 \mathrm{M}_{\mathrm{t}} + \mathrm{Year}_t + \varphi_{\mathrm{i}} + \varepsilon_{\mathrm{i,t+1}} \quad (1)$$

where i denotes the firm; t denotes the year; $R\&D_{i,t+1}$ is a measure of R&D activities (R&D/Assets ratio) for firm i in year *t+1*; GPR_t is the logarithm of the GPR index, as developed by Caldara and Iacoviello (2018), and β_1 is the primary variable of interest; $X_{i,t}$ is a set of variables controlling for firm characteristics, as discussed in Section 2.2 and in the Appendix; M_{t} is a set of time-series controls including macroeconomic conditions and other uncertainty measures; and φ_i is a vector of fixed effects (firm and industry), capturing firm-specific differences as well as industry-level characteristics. Controlling these two fixed effect also help us to reduce the concern of omitted variables problem. The year dummy variable, Year_t, captures the possible time trend in R&D investment. Following Petersen (2009), standard errors are clustered by firm and year to control for potential cross-sectional and serial correlation in the error term.

One potential challenge faced in our study pertains to omitted variables. If these unobservable variables remain stable over time, we can use firm fixed effects to control them. To handle time-varying omitted variables (the increasingly widespread use of computer-based technologies or the time-series pattern of R&D), we include time fixed effects.

Table 3 reports the estimation results of our baseline regression model. For the sake of brevity, we focus on the impact of GPR on R&D/Assets. Column (1) of Table 2 reports the impact of GPR on R&D/Assets with firm fixed effects and yearly dummy variables. We find that R&D/Assets is negatively associated with GPR in the presence of firm and industry fixed effects as well as yearly dummies at the 1% significance level. The coefficient of GPR is -0.609 (t-statistic= -4.721), which suggests that if GPR increased by 100%, the R&D/Assets ratio would be reduced by 0.00609 units. Given the fact that the mean R&D/Assets ratio is 0.125, a 100% increase in GPR would lead to about 4.87% (0.00609/0.125) decrease in R&D investment. This economic magnitude is important as the GPR index more than tripled during the Gulf Wars and the 9/11 terrorist attacks. When the lagged R&D/Assets ratio and firm characteristics (columns (2) and (3), respectively) are included in the model, the impact of GPR remains negative and significant at the 1% level, with even stronger statistical and economic magnitudes. For example, the GPR coefficient in column (3) is -0.684 with t-statistic -5.569 (-0.684/0.123).

The last two columns show the outcomes when we control for aggregate variables. Column (4) controls for the CFANI and Michigan's consumer sentiment index (MCSI), which are proxied for macroeconomic conditions; we observe that GPR's coefficient remains significantly negative at the 1% level. Column (5) includes other types of uncertainties, which helps to rule out the possibility that the GPR-R&D relationship is driven by other uncertainties. We include Jurado et al.'s (2015) MU and FU indices and Baker et al.'s (2016) EPU index. We observe that the negative relationship between GPR and R&D/Assets remains. The economic magnitude of GPR is even stronger after controlling for aggregate variables. For example, the coefficient of GPR in column (5) is -0.818, which is more negative than the coefficient of GPR in all other columns.

In short, our results confirm the negative relationship between GPR and R&D activities as argued by Bhattacharya et al. (2017), Feng and Johansson (2017), and Xu (2017), who found a negative relationship between political uncertainty and R&D activity. Xu (2017) provides a possible explanation in that high uncertainty increases the cost of capital, thereby reducing R&D investment.

3.2 Event realisation versus threat

This subsection focuses on the question of which components of geopolitical risk are most likely to affect R&D investment. Firms may respond differently to the possibility of geopolitical action and the actuality of geopolitical events. Caldara and Iacoviello (2018) break down their GPR index into GPT and GPA indices. GPT captures geopolitical threats that are not contemporaneously linked with geopolitical acts (at the time of classification), such as escalation of tensions before wars. GPA reflects the realisation of actual adverse geopolitical events. We rerun equation (1) to identify which of the two, geopolitical threats or realisations, has the largest impact on R&D investment.

Table 4 shows the estimation results of these components of GPR with R&D investment. In column (1), the results indicate that GPT has a statistically significant negative impact on R&D/Assets ratios. Its coefficient is -0.74 with 0.131 standard error (t-statistic= -5.649) and is significant at the 1% level. GPA also has negative relationship with the next-year's R&D/Assets

ratio at the 1% significance level. However, its economic and statistical magnitudes are smaller than those of GPT. The coefficient of GPA is -0.560, which is less negative than that of GPT, with a t-statistic of -3.889 (-0.560/0.144), which is slightly lower than that of GPT. These findings suggest that when either GPT or GPA is high, the R&D investment in the next year will be lower, and this negative effect is larger for GPT.

The last column reports the result when both components are included in the equation at the same time. We observe that GPT's coefficient remains significant and strong at the 1% level, while GPA's effect, though remaining negative, becomes very close to zero and is not statistically significant. This supports the previously described findings that show that GPT has the stronger effect. Further, this result is consistent with the view that event realisation usually entails the resolution of uncertainty, thereby preventing uncertainty from having a significant impact on R&D investment.

3.3 The persistence effect of GPR

The effect of GPR on R&D investment might persist for a period of time as uncertainty has lagged effects on firm decisions, such as investment and employment. Bloom (2009) finds that hiring and investment rates drop dramatically four months after an uncertainty shock because higher uncertainty increases the real-option value to waiting, and rebound at around six months. We run the baseline regression using the future value of R&D/Assets ratio for up to eight quarters as the dependent variables and plot the coefficients of GPR in Figure 2. The area between the upper boundary and the lower boundary is the 95% confidence interval. It is clear that R&D investment initially drop at time 0, with significance at 10% level only. The negative effect of GPR on R&D peaks at time t+1 (i.e., one quarter after). At t+2, the negative relationship weakens but remains statistically significant at the 1% level. At t+3 and beyond, the R&D investment rebounds and even has a positive relationship with GPR at period t+5 and t+6. In sum, our results are very similar to Bloom's (2009) finding that increased uncertainty causes a drop and a rebound in investment, which is consistent with the so-called delay-effect.

3.4 Cross-Sectional Heterogeneity

This subsection considers whether GPR has a cross-sectional effect on R&D investment.

Large versus small firms

One extension of the present analysis is to investigate how GPR affects R&D with respect to firm size. Acs and Audretsch (1988) emphasised the existence of different determinants of R&D investment for large and small firms. Cohen and Klepper (1996) found that larger firms have advantages in R&D as their larger output enables them to apply their innovations with greater effect and, thus, distribute the cost of R&D. Brown et al. (2009, 2012) and Brown and Petersen (2011) demonstrated that firm size affects R&D investment because small firms often rely on external equity finance, have less ability to access capital markets, and are more financially constrained. This finding is also supported by Fama and French (1992) and Beck et al., (2005). Therefore, we expect small firms to be more sensitive to GPR as they typically face significant financial insecurity and have fewer resources to mitigate the negative effect of uncertainty.

We create two iterations of a “small firm” dummy variable, which takes a value of 1 if a firm is classified as small. First, in line with Acs et al. (1994), we consider firms to be “large” if they have over 500 employees and “small” otherwise. Our second approach is to follow Brown et al. (2009) and Brown and Petersen (2011), whereby a firm is “large” if their average number of employees over the sample period is above the 70th percentile and “small” otherwise.[13] Thus, we include the interaction term of GPR and a size dummy variable in our base specification. Our main interest lies in the coefficient of the interaction term; the regression results are reported in Table 5.

As shown in column 1, where the “small” dummy is based on Acs et al.’s (1994) approach, the coefficient of the interaction term is negative and very strong. The coefficient of the interaction term GPR*Small is -0.778 and significant at the 1% level. This suggests that when the GPR index increases by 1%, its negative impact on next-year R&D investment is -0.00778 units (or 6.224%= -0.00778/0.125) greater for small firms than large firms. If we follow the classification of Brown et al. (2009, 2012) and Brown and Petersen (2011), GPR still has a greater negative effect on small firms’ R&D. The coefficient of the interaction term (GPR*Small) is significantly negative at -0.508. These results support the view that small firms are more sensitive than large firms to GPR. It is also consistent with the notion that firms with greater financial constraints are more sensitive to GPR, as small firms are usually considered to be more

[13] The reason these studies use this classification is because of a skewed size distribution. Our sample also has a skewed size distribution.

financially constrained.

High-tech versus non-high tech

Next, we test the effect of GPR on high-tech and non-high-tech firms, because high-tech firms' innovation and R&D behaviours are found to account for the overwhelming share of R&D activity (Hirschey et al., 2012) and to be crucial to the economy (Acs and Audretsch, 1990). We follow Brown et al. (2009) and classify firms as high-tech and non-high-tech based on their three-digit Standard Industrial Classification (SIC) codes, where firms operating in the drug industry (SIC code 283), office equipment and computers (357), communication equipment (366), electronic components (367), scientific instruments (382), medical instruments (384), and software (737) are classified as high-tech firms. To account for these firms, a dummy variable, which is equal to one if the firm belongs to one of these industries and zero otherwise, is included in the model.

The results reported in Table 6 show the negative effect of GPR on R&D investment for high-tech and non-high-tech firms. This negative effect of GPR is statistically significant and particularly strong for high-tech firms. Regarding economic magnitude, the coefficient of GPR for high-tech firms is -1.404, which is four times greater than that of non-high-tech firms and is significant at the 1% level. However, the coefficient of GPR in the case of non-high-tech firms is about -0.39 and only significant at the 5% level. By looking at the coefficient of the interaction between GPR and high-tech dummy, it is also significantly negative. In sum, our results suggest that high-tech firms are more sensitive to GPR.

Growth options

R&D investment sensitivity to GPR might depend on a firm's growth opportunities (Kulatilaka and Perotti, 1998). To test for the existence of growth options channels that affect the relationship between uncertainty and R&D investment, we use the ratio of market value to book value of assets and Tobin's Q as proxies for growth options. Anderson and Garcia-Feijóo (2006) provide empirical evidence that these measures are good proxies for growth opportunities. We create two iterations of a high-growth dummy variable according to the median value of each measure and then examine the interaction between the high-growth dummy variable and GPR. Our main interest is again the coefficient of the interaction term.

As displayed in the first column of Table 7, the estimation results suggest that high-growth firms, although theoretically having less incentive to delay investment, are more likely to decrease R&D investment under high GPR. Using the dummy variable based on ratio of market value to book value of assets, our results suggest that high-growth firms decrease their R&D/Assets ratio by -0.00546 units more than low-growth firms, which implies a drop in R&D investments of about 4.368% given the fact that the sample mean of R&D/Assets is 0.125. If we observe the interaction between GPR and the iteration of the high-growth dummy variable using Tobin's Q, the economic and statistical magnitudes are even stronger because the coefficient of GPR*Small is more negative (-0.564) with a greater t-statistic (2.421). The coefficient of the interaction term in the second column is more negative than that in the first column. In short, our results do not support the theoretical prediction that high firm growth options might, at least partially, offset the negative impact of uncertainty (Kulatilaka and Perotti, 1998).

Strategic rivalry

R&D investment sensitivity to GPR might depend on the level of competition faced by a firm (Weeds, 2002; Novy-Marx, 2007). For example, Weeds (2002) shows, theoretically, that a firm's optimal R&D investment strategy depends on the balance between the value of delay and the expected benefit of pre-emption. If the expected benefit exceeds the value of delay, firms may increase R&D investment under conditions of uncertainty. In contrast, Novy-Marx (2007) theoretically shows that firm heterogeneity leads to different opportunity costs of investment, which may reduce (or eliminate) the expected value of preemption. In this case, higher uncertainty discourages current R&D investment as its negative effect cannot be offset by strategic rivalry.

To test how competition affects the relationship between uncertainty and R&D investment, we calculate the Herfindahl-Hirschman Index (HHI) based on the 3-digit SIC industry classification. The industry-level measure of $\text{HHI} = \sum_{i=1}^{N} S_i^2$, where S_i is the market share of firm *i*'s sales within a 3-digit SIC industry. We sum up all N firms' market shares in that industry to construct each industry's HHI. HHI reflects market concentration; a higher market concentration (i.e., market closer to a monopoly) represents lower market competition. To simplify the interpretation of the estimation results, we multiply HHI by -1 and create an interaction term between transformed HHI and GPR. In this case, a higher transformed HHI indicates higher competition. Our interest lies in the coefficient of this interaction term. This coefficient should be significantly positive if strategic rivalry played a role in driving the uncertainty-R&D relationship (Weeds, 2002).

Table 8 summarises the results. It is clear that the coefficient of the term GPR*HHI is positive. However, the coefficient is not significant implying that the expected benefit of pre-emption may not exceed the value of waiting. Therefore, the firms still reduce current R&D investment. Another reason that competition cannot reduce the negative effect of GPR on R&D is the presence of firm heterogeneity in size and scope. As Novy-Marx (2007) has shown, heterogeneity could reduce or even eliminate the expected value of preemption while the value of waiting remains because it prevents firms from competing directly over investment opportunities.

3.5 *Additional robustness checks*

In previous sections, we explicitly control for investment opportunities and other uncertainty using various proxies to reduce the concern that our results may be driven by other forces. The effectiveness of this approach depends on the accuracy of the proxies used. This subsection provides several additional robustness checks for our main conclusions. We consider the problems of endogeneity, simultaneity, change of GPR measures, and change of R&D measures. Our results remain robust.

Instrumental variable analysis

To address the endogeneity concern, a classic approach is to use instrumental variables. In our case, we need to find an instrument that is associated with GPR and affects R&D investment only through its relationship with GPR. Based on these conditions, we propose to use the measure of religious tensions provided by International Country Risk Guide (ICRG) as an instrument for GPR. Based on ICRG, religious tension might arise from a religious group that seeks to replace civil law by religious law and to exclude other religions from the political and/or social process. Based on ICRG definition, the lower the religious tension score, the higher the level of conflict and disagreement among religious groups. This seems counter intuitive. One would think that religious tension is a negative or not preferred phenomenon, and hence would expect that the higher the religious tension score, the higher the level of conflict among religious groups. Thus, to simplify the interpretation of the estimation results, we multiply ICRG's religion tension score by -1 and use the transformed religious tension score in instrumental analysis.

Religious tension is clearly related to the GPR index as a higher level of religious tension reflects more conflicts among religions and thus, a higher level of GPR (see Agnew, 2006; Sturm, 2013). However, R&D decisions are unlikely to be directly correlated to religious tension. Since GPR and religious tension measures are cross-sectionally invariant[14], we follow Gulen and Ion (2016) and run a time-series regression in the first stage and a panel regression in the second stage. The first stage regression is as follows:

$$GPR_t = \alpha + \beta \cdot Religious_t + \gamma_1 X_t + +\gamma_2 \mathrm{M_t} + \mathrm{Year}_t + \varepsilon_t \tag{2}$$

where X_t and $\mathrm{M_t}$ are the same as per the baseline regressions. As a higher level of transformed religious tension measure reflects a higher risk, we expect β to be positive if religious tension is highly correlated with GPR. Using the fitted value from equation (2), we re-estimate the effect of GPR on R&D investment with the fitted GPR ($\widehat{\mathrm{GPR}}$) capturing the exogenous variation in GPR, which is shown as:

[14] In this situation, the conventional two-stage least-squares regression would overstate the correlation between the endogenous variable and its instrument.

$$\mathrm{R\&D}_{i,t+1} = \alpha + \beta_1 \widehat{\mathrm{GPR}}_t + \gamma_1 \mathrm{X}_{i,t} + \gamma_2 \mathrm{M}_t + \mathrm{Year}_t + \varphi_i + \varepsilon_{i,t+1} \quad (3)$$

As shown in Table 9, there is a significant and negative relationship between GPR and religious tension, suggesting that religious tension is indeed significantly associated with GPR. The F-test for weak instrument (F-statistic=18.45) rejects the hypothesis that religious tension is a weak instrument. In the second stage, the fitted GPR variable is strongly negatively associated with R&D investment. Overall, the relation between R&D and GPR is not tainted by potential endogeneity.

Dynamic R&D regressions

To control for the possible simultaneity of GPR and R&D investment, we first use the GMM estimator developed for dynamic panel models by Arellano and Bover (1995) and Blundell and Bond (1998). This method jointly estimates the baseline regression in differences using lagged levels as instruments, with the regression in levels using lagged differences as instruments. The model is estimated using the following moment conditions.

$$\mathrm{E}\left[\left(\mathrm{R\&D}_{i,t-s}\right)\left(\varepsilon_{i,t} - \varepsilon_{i,t-1}\right)\right] = 0 \text{ for } s \geq 3; t = 3, \ldots, T \quad (4)$$

$$\mathrm{E}\left[\left(\mathrm{X}_{i,t-s}\right)\left(\varepsilon_{i,t} - \varepsilon_{i,t-1}\right)\right] = 0 \text{ for } s \geq 3; t = 3, \ldots, T \quad (5)$$

$$\mathrm{E}\left[\left(\mathrm{R\&D}_{i,t-s} - \mathrm{R\&D}_{i,t-s-1}\right)\left(\varphi_i + \varepsilon_{i,t}\right)\right] = 0 \text{ for } s = 1 \quad (6)$$

$$\mathrm{E}\left[\left(\mathrm{X}_{i,t-s} - \mathrm{X}_{i,t-s-1}\right)\left(\varphi_i + \varepsilon_{i,t}\right)\right] = 0 \text{ for } s = 1 \quad (7)$$

where X_t is a set of explanatory variables, including GPR. The GMM estimation results in the first column of Table 10 show that the coefficient of GPR is very similar to that in Table 3, demonstrating that the estimated effect of GPR on R&D is consistently negative and statistically significant.

We also use Brown et al.'s (2009) R&D dynamic regressions model by including the GPR index, as follows:

$$\mathrm{R\&D}_{\mathrm{i,t}} = \beta_1 \mathrm{GPR}_{\mathrm{t-1}} + \beta_2 \mathrm{R\&D}_{\mathrm{i,t-1}} + \beta_3 \left(\mathrm{R\&D}_{\mathrm{i,t-1}}\right)^2 + \beta_3 sales_{i,t-1} + \beta_4 \mathrm{CF}_{i,t-1} + \mathrm{Year}_t + \varphi_{\mathrm{i}} + \varepsilon_{\mathrm{i,t}} \quad (8)$$

$$\mathrm{R\&D}_{\mathrm{i,t}} = \beta_1 \mathrm{GPR}_{\mathrm{t-1}} + \beta_2 \mathrm{R\&D}_{\mathrm{i,t-1}} + \beta_3 \left(\mathrm{R\&D}_{\mathrm{i,t-1}}\right)^2 + \beta_4 \mathrm{Sales}_{\mathrm{i,t}} + \beta_5 \mathrm{Sales}_{\mathrm{i,t-1}} + \beta_6 \mathrm{CF}_{\mathrm{i,t}} + \beta_7 CF_{i,t-1} + \beta_8 \mathrm{stk}_{i,t} + \beta_9 \mathrm{stk}_{i,t-1} + \mathrm{Year}_t + \varphi_{\mathrm{i}} + \varepsilon_{\mathrm{i,t}} \quad (9)$$

where $\mathrm{stk}_{i,t}$ is the net cash raised from stock issues in period *t* divided by the book value of total assets for firm *i*, and *Sales* is the natural logarithm of one plus the net sales/turnover. Equation (8) is the model in the absence of financial friction while equation (9) contains the presence of financial friction. We use these two model specifications to estimate the relationship between GPR and R&D investment, with corresponding results reported in columns (2) and (3) of Table 10, respectively. We observe that the relationship remains significantly negative when using the R&D dynamic regressions provided by Brown et al. (2009).

Alternative measure of GPR

To verify that our results do not depend on the method of measuring GPR, we employ several alternative methods of measurement. To address the influence of the choice of search terms, Caldara and Iacoviello (2018) provide two separate, alternative versions of the GPR index based on broad and narrow sets of search terms. The first two columns of Table 11 show that both broad and narrow versions of GPR indices are negatively correlated with R&D activity at the 1% significance level.

Additionally, the GPR proxy used in the study is based on news reported in US newspapers, which are naturally biased in their coverage to emphasise issues that are of interest to their readers. While this proxy measures GPR, it also captures attention paid to GPR by US media. Such biases might affect our conclusion about the GPR-R&D relationship. To mitigate this concern, we employ the actual number of international crises from the ICB database created by Brecher and Wilkenfeld (2000), and several crises indices created by Berkman et al. (2011) based on the ICB database. The remaining columns of Table 11 indicate that the strong negative correlation between R&D/Assets and GPR persists if we use Berkman et al.'s (2011) indices or the actual number of international political crises.[15] Thus, the results in Table 10 indicate that our baseline results are not driven by the choice of GPR measure.

Alternative measures of R&D Investment

Lastly, to verify that our results do not depend on the method of measurement of R&D activities, we construct several alternative measures of R&D. Following Li (2011) and Gu (2016), we utilise logarithm of one plus R&D expenditure, R&D/Sales, and R&D expenditure scaled by

[15] Note that Berkman et al. (2011) only update their indices until 2006 while the actual number of international crises events at ICB is updated until 2015. Therefore, the last several columns of Table 9 are based on fewer observations.

number of employees (R&D/Employee) as dependent variables in the baseline regression model. Table 12 shows that GPR is significantly and negatively correlated with each of these alternative measures of R&D activity, which indicates that our baseline results are not driven by the choice of R&D measure.

4. Conclusion

The impact of uncertainty on corporate R&D investment has been the object of investigation by both academics and practitioners. R&D investment is an essential driver of economic growth; however, previous studies have not reached an agreement regarding the effect of uncertainty on R&D investment. Our study investigates the impact of uncertainty on R&D by using the newly created GPR index. Our results indicate the existence of a strong adverse relationship between GPR and R&D investment, in line with the findings of Bloom (2009) and Bhattacharya et al. (2017). This negative effect of GPR lasts for two quarters and R&D investment bounces back following the third quarter. Further analysis shows that this negative relationship is particularly strong for high-tech firms, small firms, and firms with better growth options. This negative effect disappears when the uncertain event is realised. Future work may try to explain why uncertainty has this conflicting impact on R&D and innovation.

Appendix A. Variable definitions and data sources

Variables	Definition	Source
GPR	Geopolitical risk index that measures the level of geopolitical risk based on text-searching in newspapers	Caldara and Iacoviello (2018)
R&D	The level of R&D expenditure	Compustat
Ln (R&D+1)	The logarithm of (one plus R&D expense (xrd))	Compustat
R&D/AT	The ratio of R&D expense (xrd) to total assets (at)	Compustat
R&D/Sales	The ratio of R&D expense (xrd) to total sales (sale)	Compustat
R&D/Employee	The ratio of R&D expense (xrd) to total number of employees	Compustat
Size	logarithm of the book value of total assets	Compustat
Cash flow	Firm's cash flows. It is defined as income before extraordinary items (ib) plus depreciation and amortization (dp) divided by book value of total assets (at)	Compustat
Tobin's Q	The market value of equity [(prcc_f* csho) plus book value of assets (at) minus book value of equity (ceq) minus balance sheet deferred taxes (txdb)] divided by book value of asset (at),	Compustat
Tangibility	The ratio of property, plant, and equipment (*ppegt*) to total assets (*at*).	Compustat
Leverage	The ratio of total debt (dlc+dltt) to the book value of assets (at)	Compustat
Profitability	The earnings before interest, taxes, depreciation and amortization (ebitda) divided by book value of total asset (at)	Compustat
Stock Issue	Net cash raised from stock issues in period t divided by the book value of total assets, where net cash from stock issues is equal to the sale of common and preferred stock minus the purchase of common and preferred stock	Compustat
Sales	Defined as natural logarithm of one plus the net sales/turnover (sale).	Compustat
MU	Macroeconomic uncertainty index. This measure is constructed using the aggregation of individual conditional volatilities, which are	Jurado et al. (2015)

	estimated based on the unpredictable component of the future value of 132 macroeconomic series.	
FU	Financial uncertainty index.	Jurado et al. (2015)
Market-to-book value (MtB)	The ratio of the market value of assets (*csho*prcc+at–ceq*) to the book value of total assets.	Compustat
MCSI	University of Michigan's Consumer Sentiment Index, proxy for the consumer expectations regarding the overall economy	http://www.sca.isr.umich.edu/
EPU	Measure of US policy-related economic uncertainty	http://www.policyuncertainty.com/
High-tech industries	Indicator variable set equal to one for firms operating in the following high-tech industries: Industries drugs (283), office equipment and computers (357), communication equipment (366), electronic components (367), scientific instruments (382), medical instruments (384), and software (737). The above industry classification is based on 3-digit SIC codes as defined in Brown et al. (2009).	Brown et al. (2009)
HHI	Herfindahl-Hirschman Index. The Herfindahl-Hirschman Index (HHI) based on the 3-digit SIC industry classification. The industry-level measure of $\mathrm{HHI} = \sum_{i=1}^{N} S_i^2$, where S_i is the market share of firm *i*'s sales within a 3-digit SIC industry. We sum up all N firms' market shares in that industry to construct each industry's HHI. HHI reflects market concentration; a higher market concentration (i.e., market closer to a monopoly) represents lower market competition.	Author's calculation

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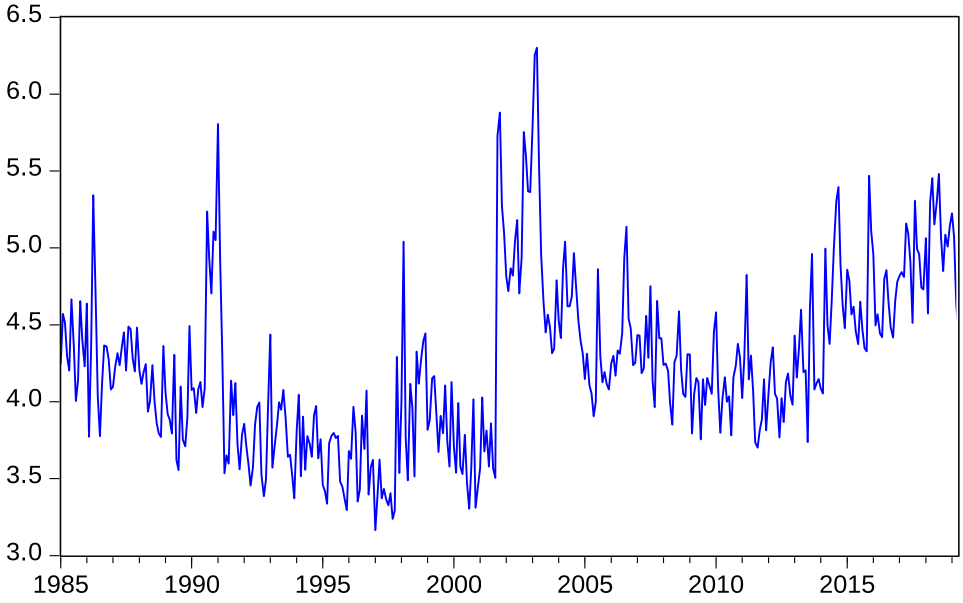

Figure 1. Log geopolitical risk index, January 1985 to April 2019

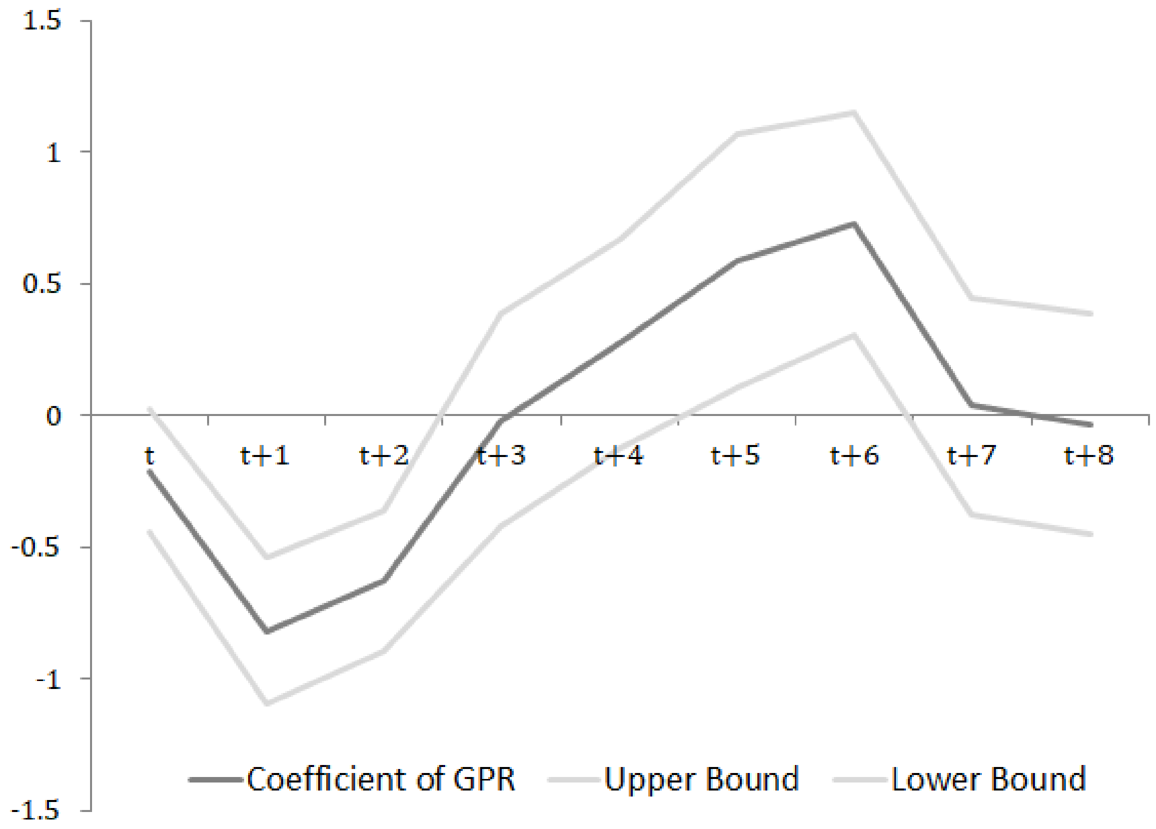

Figure 2. The Persistent effect of GPR on R&D investment

Notes: We run the baseline regression using the future value of R&D investment for up to 8 quarters as the dependent variables.

Table 1. Summary of key geopolitical events

Date	Event	Date	Event
June, 1985	TWA Hijacking	Mar 2003	Beginning of the Iraq War
Apr, 1986	US bombs Libya	Mar 2004	Assassination of Sheik Yassin, Middle East Tensions
Apr, 1987	U.S.-Russia negotiations over nuclear weapons	Aug 2004	Terrorist threats in New York and Washington
Oct 1987	War Threats in Persian Gulf	Jul 2005	London Bombings 7/7
Dec 1989	U.S. Invasion of Panama	Aug 2006	Transatlantic Aircraft Plot
Aug 1990	Iraq Invades Kuwait	May 2007	War and Terrorism Concerns, Protests in Turkey
Jan 1991	Gulf War	Aug 2008	South Ossetian War Escalation
Jan 1993	Air strike against Iraq	Dec 2009	Flight 253 Failed Bombing Attempt
Jun 1993	U.S. Raid on Baghdad	May 2011	U.S. Announces Death of Osama Bin Laden
Feb 1996	Taiwan strait crisis	Aug 2013	Escalation of Syrian Crisis
Sep 1996	U.S. Raid on Iraq	Mar 2014	Russia invades Crimea
Feb 1998	Clinton Makes Case for Strike Against Iraq	Sep 2014	Escalation Ukraine/Russia
Dec 1998	Iraq Disarmament Crisis Escalation	Nov 2015	Paris Terrorist Attacks
Dec 1999	Holidays' Terrorist Concerns	Jul 2016	Turkish Coup Attempt
Sep 2001	9/11 Terrorist Attack	Jul 2016	Middle East Concerns: Chilcot Report Released
Oct 2001	U.S. invades Afghanistan	Aug 2017	Escalation of Tensions Between U.S. and North Korea
Sep 2002	War Fears U.S. / Iraq		

Sources: Caldara and Iacoviello (2018)

Table 2. Summary statistics

This table reports the summary statistics of the sample with non-missing variables. All variables are measured at the annual frequency from 1985 to 2018.

	N	Mean	Median	Std. Dev.
GPR	95,823	78.489	67.313	39.817
R&D	95,823	60.489	2.993	234.994
R&D/Assets	95,823	0.125	0.043	0.254
Cash flow	95,823	-0.240	0.054	1.075
Tobin's Q	95,823	3.762	1.703	8.429
Tangibility	95,823	0.218	0.163	0.192
Leverage	95,823	0.263	0.143	0.531
Profitability	95,823	-0.170	0.082	0.960
CFNAI	95,823	-0.086	0.000	0.582
MU	95,823	0.641	0.633	0.068
FU	95,823	0.901	0.859	0.164
EPU	95,823	108.486	104.720	26.808

Table 3. Baseline results

The unit of observation is at firm-year level. The dependent variable in all regressions is the ratio of R&D expenditure to total assets. Independent variables include GPR, lagged R&D/Assets ratio, Tobin's Q, Cash flow, Size, Tangibility, Profitability, Leverage, CFNAI, Michigan's consumer sentiment index, macroeconomic uncertainty, financial uncertainty, economic policy uncertainty, and year dummies. Please see the Appendix A for detailed descriptions of each variable. The baseline specification is used and we control for firm fixed effects. Standard errors are clustered at the firm level and corrected for heteroskedasticity. The clustered standard errors are in parentheses. Data is from 1985 to 2018.

	Dependent variable :R&D/Assets*100				
	(1)	(2)	(3)	(4)	(5)
GPR	-0.609***	-0.709***	-0.684***	-0.746***	-0.818***
	(0.129)	(0.122)	(0.123)	(0.126)	(0.143)
Lagged R&D		0.329***	0.352***	0.352***	0.352***
		(0.011)	(0.013)	(0.013)	(0.013)
Cash flow			0.329	0.332	0.330
			(0.493)	(0.493)	(0.493)
Size			-1.028***	-1.062***	-1.072***
			(0.115)	(0.116)	(0.116)
Tobin's Q			-0.051	-0.052	-0.052
			(0.035)	(0.035)	(0.035)
Tangibility			-4.296***	-4.435***	-4.251***
			(0.995)	(0.996)	(0.999)
Leverage			-0.501	-0.506	-0.506**
			(0.445)	(0.445)	(0.445)
Profitability			0.773	0.770	0.774
			(0.610)	(0.610)	(0.610)
CFNAI				-0.341***	-0.102
				(0.121)	(0.162)
MCSI				2.714***	3.276***
				(0.564)	(0.667)
MU					4.579***
					(1.152)
FU					-1.876***
					(0.482)
EPU					0.146
					(0.365)
Constant	-43.842**	-21.793	-134.683***	-169.095***	-159.462***
	(17.999)	(15.915)	(24.645)	(25.572)	(25.520)
Firm FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.597	0.640	0.641	0.641	0.641
Observations	95,823	95,823	95,823	95,823	95,823

Table 4. Realisation versus threat

The unit of observation is at firm-year level. The dependent variable in all regressions is the ratio of R&D expenditure to total assets. GPT is the geopolitical threat index, and GPA is the geopolitical act index. Control variables lagged R&D/Assets ratio, Tobin's Q, Cash flow, Size, Tangibility, Profitability, Leverage, CFNAI, Michigan's consumer sentiment index, macroeconomic uncertainty, financial uncertainty, economic policy uncertainty, and year dummies. Please see the Appendix A for detailed descriptions of each variable. The baseline specification is used and we control for firm fixed effects. Standard errors are clustered at the firm level and corrected for heteroskedasticity. The clustered standard errors are in parentheses. Data is from 1985 to 2018.

	Dependent variable : R&D/Assets*100		
	(1)	(2)	(3)
GPT	-0.740***		-0.734***
	(0.131)		(0.147)
GPA		-0.560***	-0.009
		(0.144)	(0.157)
Constant	Yes	Yes	Yes
Other controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Adj. R^2	0.641	0.641	0.641
Observations	95,823	95,823	95,823

Table 5. Large firms versus small firms

The unit of observation is at firm-year level. The dependent variable in all regressions is the ratio of R&D expenditure to total assets. Independent variables include GPR, lagged R&D/Assets ratio, Tobin's Q, Cash flow, Size, Tangibility, Profitability, Leverage, CFNAI, Michigan's consumer sentiment index, macroeconomic uncertainty, financial uncertainty, economic policy uncertainty, and year dummies. Column (1) is based on the Acs and Audretsch (1988) where the small firms is the firms with less than 500 employees. Column (2) is based on Brown et al.'s (2009, 2012) method where the small firms if their average level of employment over the sample period is below the 70th percentile, and "large" otherwise. Please see the Appendix A for detailed descriptions of each variable. The baseline specification is used and we control for firm fixed effects. Standard errors are clustered at the firm level and corrected for heteroskedasticity. The clustered standard errors are in parentheses. Data is from 1985 to 2018.

	Dependent variable :R&D/Assets*100	
	(1)	(2)
	Employees No. >500	Brown et al.'s (2009, 2012)
GPR	-0.425***	-0.568***
	(0.083)	(0.089)
GPR*Small	-0.778***	-0.508**
	(0.243)	(0.251)
Small	2.940***	2.623**
	(1.036)	(1.055)
Constant	Yes	Yes
Other controls	Yes	Yes
Firm FE	Yes	Yes
Industry FE	Yes	Yes
Year dummies	Yes	Yes
Adj. R^2	0.650	0.641
Observations	90,656	95,823

Table 6. Firm characteristics: High-tech firms

The unit of observation is at firm-year level. The dependent variable in all regressions is the ratio of R&D expenditure to total assets. Independent variables include GPR, lagged R&D/Assets ratio, Tobin's Q, Cash flow, Size, Tangibility, Profitability, Leverage, CFNAI, Michigan's consumer sentiment index, macroeconomic uncertainty, financial uncertainty, economic policy uncertainty, and year dummies. High-tech industry is an indicator variable set equal to one for firms operating in the following seven high-tech industries: drugs (283), office equipment and computers (357), communication equipment (366), electronic components (367), scientific instruments (382), medical instruments (384), and software (737). Firms belong to these industries are high-tech firms. Please see the Appendix A for detailed descriptions of each variable. The baseline specification is used and we control for firm fixed effects. Standard errors are clustered at the firm level and corrected for heteroskedasticity. The clustered standard errors are in parentheses. Data is from 1985 to 2018.

	Dependent variable :R&D/Assets*100		
	(1)	(2)	(3)
	High-tech	Non High-tech	
GPR	-1.404***	-0.390**	-0.595***
	(0.272)	(0.162)	(0.153)
GPR*Hi-tech			-0.442*
			(0.242)
Constant	Yes	Yes	Yes
Other controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Adj. R^2	0.512	0.492	0.641
Observations	46,891	48,932	95,823

Table 7. Firm characteristics: Growth options

The unit of observation is at firm-year level. The dependent variable in all regressions is the ratio of R&D expenditure to total assets. Independent variables include GPR, lagged R&D/Assets ratio, Tobin's Q, Cash flow, Size, Tangibility, Profitability, Leverage, CFNAI, Michigan's consumer sentiment index, macroeconomic uncertainty, financial uncertainty, economic policy uncertainty, and year dummies. A high growth firm is the firms that with above median market-to-book ratio (or Tobin's Q). Please see the Appendix A for detailed descriptions of each variable. The baseline specification is used and we control for firm fixed effects. Standard errors are clustered at the firm level and corrected for heteroskedasticity. The clustered standard errors are in parentheses. Data is from 1985 to 2018.

	Dependent variable :R&D/Assets*100	
	(1)	(2)
	Market-to-book ratio	Tobin's Q
GPR	-0.544***	-0.534***
	(0.109)	(0.109)
GPR*Growth	-0.546**	-0.564**
	(0.233)	(0.233)
Growth	2.503**	2.604***
	(0.999)	(0.999)
Constant	Yes	Yes
Other controls	Yes	Yes
Firm FE	Yes	Yes
Industry FE	Yes	Yes
Year dummies	Yes	Yes
Adj. R^2	0.641	0.641
Observations	95,823	95,823

Table 8. Industry characteristics: Market Competition

The unit of observation is at firm-year level. The dependent variable in all regressions is the ratio of R&D expenditure to total assets. Independent variables include GPR, lagged R&D/Assets ratio, Tobin's Q, Cash flow, Size, Tangibility, Profitability, Leverage, CFNAI, Michigan's consumer sentiment index, macroeconomic uncertainty, financial uncertainty, economic policy uncertainty, and year dummies. We use Herfindahl-Hirschman Index (HHI) to proxy for the degree of market competition. We calculate Herfindahl-Hirschman Index (HHI) based on 3-digit SIC industry classification. The industry-level is measured as $\mathrm{HHI} = \sum_{i=1}^{N} S_i^2$ where S_i is the market share of firm i's sales within a 3-digit SIC industry. We sum up all N firms' market share in that industry to construct each industry's HHI. HHI reflect market concentration, and the higher market concentration (c loser a market is to a monopoly) represent lower market competition. To more straightforward to interpret the estimation result, we multiply (-1) to HHI and create interaction between transferred HHI and GPR. Please see the Appendix A for detailed descriptions of each variable. The baseline specification is used and we control for firm fixed effects. Standard errors are clustered at the firm level and corrected for heteroskedasticity. The clustered standard errors are in parentheses. Data is from 1985 to 2018.

	Dependent variable :R&D/Assets*100
GPR	-0.702***
	(0.204)
GPR*-HHI	0.508
	(0.555)
-HHI	-1.142
	(2.449)
Constant	Yes
Other controls	Yes
Firm FE	Yes
Industry FE	Yes
Year dummies	Yes
Adj. R^2	0.641
Observations	95,823

Table 9. Robustness checks: Endogeneity

The unit of observation is at firm-year level. Column (1) reports the first stage of the two-stage least square regression results where the religious tension index is the instrument. The dependent variable in column (2) is the ratio of R&D expenditure to total assets. Independent variables include GPR, lagged R&D/Assets ratio, Tobin's Q, Cash flow, Size, Tangibility, Profitability, Leverage, CFNAI, Michigan's consumer sentiment index, macroeconomic uncertainty, financial uncertainty, economic policy uncertainty, and year dummies. Please see the Appendix A for detailed descriptions of each variable. The baseline specification is used and we control for firm fixed effects. Standard errors are clustered at the firm level and corrected for heteroskedasticity. The clustered standard errors are in parentheses. Data is from 1985 to 2018.

	First stage	Second Stage
	(3)	(4)
Religious Tension	0.694*** (0.162)	
Fitted GPR		-4.407*** (1.560)
Other Controls	Yes	Yes
Firm FE	Yes	Yes
Industry FE	Yes	Yes
Year dummy	Yes	Yes
Observations	95,823	95,823
R-squared	0.766	0.545
F test of excluding instrument	18.45***	

Table 10. Robustness check: Dynamic regressions

This table reports the robustness check of GPR-R&D relationship by using dynamic regressions. The unit of observation is at firm-year level. The dependent variable in all regressions is the ratio of R&D expenditure to total assets. Independent variables for column (1) include GPR, lagged R&D/Assets ratio, Tobin's Q, Cash flow, Size, Tangibility, Profitability, Leverage, CFNAI, Michigan's consumer sentiment index, macroeconomic uncertainty, financial uncertainty, and economic policy uncertainty. We use one-period lagged term of each independent variable as instruments we performing GMM estimation (column (1)). Independent variables for columns (2) and (3) include GPR, lagged R&D/Assets ratio, squared term of R&D/Assets, current sales and its lagged term, cash flow, lagged cash flow, net cash raised from stock issues in current and lagged period. Please see the Appendix A for detailed descriptions of each variable. The baseline specification is used and we control for firm fixed effects. Standard errors are clustered at the firm level and corrected for heteroskedasticity. The clustered standard errors are in parentheses. Data is from 1985 to 2018.

	Dependent variable :R&D/Assets*100		
	(1)	(2)	(3)
	GMM	Brown et al.'s (2009) model Without constraints	Brown et al.'s (2009) model With constraints
GPR_{t-1}	-0.787***	-0.733***	-0.290***
	(0.171)	(0.120)	(0.112)
$R\&D_{t-1}$		0.765***	0.678***
		(0.022)	(0.023)
$(R\&D_{t-1})^2$		-0.0024***	-0.0023***
		(0.0001)	(0.0001)
$Sales_t$			-0.129
			(0.194)
$Sales_{t-1}$		-1.414***	-0.375**
		(0.105)	(0.191)
$Cash\ Flow_t$			-11.727***
			(0.324)
$Cash\ Flow_{t-1}$		0.712***	3.539***
		(0.257)	(0.318)
$Stock\ Issue_t$			-1.816**
			(0.721)
$Stock\ Issue_{t-1}$			3.457***
			(0.514)
Constant	Yes	Yes	Yes
Firm specific controls	Yes	--	--
Macro controls	Yes	--	--
Firm FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year dummy	--	Yes	Yes
Observations	72,541	95,745	72,470
Adj. R-squared	--	0.652	0.745
No. of firms	8,533	11,159	9,325

Table 11. Robustness check: Change of GPR measure

The unit of observation is at firm-year level. The dependent variable in all regressions is the ratio of R&D expenditure to total assets. Geopolitical risk measure includes additional GPR indices, and Berkman et al's series of crisis indices. Control variables include lagged R&D/Assets ratio, Tobin's Q, Cash flow, Size, Tangibility, Profitability, Leverage, CFNAI, Michigan's consumer sentiment index, macroeconomic uncertainty, financial uncertainty, economic policy uncertainty, and year dummies. Please see the Appendix A for detailed descriptions of each variable. The baseline specification is used and we control for firm fixed effects. Standard errors are clustered at the firm level and corrected for heteroskedasticity. The clustered standard errors are in parentheses. Sample period for columns (1) and (2) is from 1985 to 2018. Sample period of columns (3) is from 1985 to 2015. Sample period of columns (4) to (11) is from 1985 to 2006.

	(1)	(2)	(3)	(4)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
GPR broad	-1.339***										
	(0.238)										
GPR narrow		-0.822***									
		(0.140)									
No of Actual Events			-0.357***								
			(0.110)								
All crises index				-1.508***							
				(0.329)							
Violent					-2.818***						
					(0.821)						
War						-3.781***					
						(1.199)					
Violent break							-3.755***				
							(0.625)				
Protracted								-3.271***			
								(0.640)			
Major power									-4.343***		
									(1.223)		
Grave										-0.563	
										(0.437)	
Crisis severity											-0.511***
											(0.109)
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm & Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.641	0.641	0.643	0.616	0.616	0.616	0.616	0.616	0.616	0.616	0.616
Observations	95,823	95,823	88,273	67,228	67,228	67,228	67,228	67,228	67,228	67,228	67,228

Table 12. Robustness check: Change of R&D measure

The unit of observation is at firm-year level. The dependent variable in each column is different measure of R&D investment. Independent variables include GPR, lagged R&D/Assets ratio, Tobin's Q, Cash flow, Size, Tangibility, Profitability, Leverage, CFNAI, Michigan's consumer sentiment index, macroeconomic uncertainty, financial uncertainty, economic policy uncertainty, and year dummies. Please see the Appendix A for detailed descriptions of each variable. The baseline specification is used and we control for firm fixed effects. Standard errors are clustered at the firm level and corrected for heteroskedasticity. The clustered standard errors are in parentheses. Data is from 1985 to 2018.

	$\ln(R\&D + 1)$	R&D/Sales	R&D/Employee
	(1)	(2)	(3)
GPR	-0.018***	-0.532**	-0.037***
	(0.003)	(0.244)	(0.005)
Constant	Yes	Yes	Yes
Other controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Adj. R^2	0.955	0.823	0.907
Observations	95,823	79,889	79,106