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The impact of economic policy uncertainty on innovation types in enterprises: An empirical study of Chinese listed companies

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ABSTRACT

This study investigates the heterogeneous effects of economic policy uncertainty (EPU) on different types of enterprise innovation, namely invention patents, utility model patents, and design patents, based on a panel dataset of A-share listed companies in China from 2007 to 2022. Employing a random-effects Tobit model to address the left-censoring nature of patent data, the analysis reveals that EPU significantly suppresses innovation across all categories, with the strongest inhibitory effect observed on invention patents. The influence of EPU is further moderated by firm-level characteristics such as market power and profitability, as well as regional institutional environments. Monopolistic firms reduce radical innovation under uncertainty, while higher profitability, and research and development (R&D) intensity consistently promote innovation output. Regional comparisons show that eastern firms emphasise short-cycle innovations, western firms benefit from policy subsidies supporting core technologies, and central firms lag across all innovation dimensions. Robustness checks using alternative EPU indices and instrumental variable techniques confirm the reliability of the findings. The study concludes with tailored policy recommendations aimed at stabilising the innovation climate and enhancing inter-regional coordination.

1. Introduction

Economic policy uncertainty (EPU) has emerged as a critical determinant of corporate innovation in transitional economies, where institutional volatility interacts with market forces to shape firm-level strategic choices (Baker et al., 2016). In China, the world's largest emerging economy, frequent policy adjustments ranging from industrial restructuring to financial deregulation generate pervasive uncertainty that may reconfigure firms' innovation portfolios.

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While extant literature establishes EPU's aggregate negative effect on R&D investment (Gulen & Ion, 2016), its heterogeneous impact across innovation types, such as invention patents, utility models, and designs, remains underexplored. In addition to innovation typology, researchers are also paying more attention to how different sectors respond to EPU. For instance, recent real-world evidence shows that industry diversity is very important for the effectiveness of green innovation. When environmental regulations change, some industries become more innovative while others become less so. This evidence shows that sectoral context affects EPU innovation dynamics (Huo et al., 2022). These results show how important it is to consider sector-level variables when looking at how policy uncertainty affects different types of innovation. Also, research from many countries shows that the quality of institutions, as shown by stable governance, clear rules, and openness to foreign investment, has a big effect on the EPU-innovation relationship in emerging economies. A study of 22 countries shows that better institutional quality reduces the harmful impact of economic policy uncertainty on firm-level innovation (Qamruzzaman et al., 2021). This study, on the other hand, groups different sorts of innovation together and doesn't look at how different categories of innovation (such as invention, utility, and design) react to policy uncertainty in different institutional settings. Lastly, discussions about EPU are more common alongside other significant uncertainties, such as climate policy changes and geopolitical issues that could facilitate or hinder innovation (Zhang et al., 2025). These several types of uncertainty make it harder for companies to decide how to innovate, especially when it comes to green innovation or ESG compliance. This gap is especially clear in China, where differences in resources and policy exposure between regions may make these effects much worse.

Theoretical tensions persist regarding how EPU influences innovation typology. Real options theory posits that uncertainty induces firms to delay irreversible R&D commitments (Bernanke, 1983), disproportionately affecting long-cycle inventions. Firms evaluate the benefits of postponement against opportunity costs, risks associated with sunk investments, and the possible advantages of being a first mover in uncertain markets (Trigeorgis & Reuer, 2017). In high-tech sectors, postponement may mitigate vulnerability to unsuccessful innovations amid unstable policies, although it also poses the risk of forfeiting patent competitions. Consequently, firms adjust their delay strategies dynamically, informed by their internal absorptive ability and external institutional signals.

Institutional theory suggests that firms may accelerate incremental innovations (e.g., utility models) to maintain regulatory legitimacy under volatile policy regimes (Oliver, 1991). In China, EPU is considered as a sign of changing policy goals, including the push for a greener economy or the digital economy, which firms see as regulatory signals. However, the situation determines the strategic interpretation of these signals. Some firms see legislative uncertainty as a reason to show compliance through fast-cycle innovation, while others see it as noise and cut down on innovation spending (Zhu et al., 2021). So, the connection between EPU and innovation is not one-way. It depends on how companies interpret and deal with institutional uncertainty. These theoretical points of view show that there is a need to look at the situation separately, not just by type of innovation, but also by firm characteristics like state ownership, industry position, and policy exposure in order to completely understand the behaviour under EPU.

Fiscal uncertainty (e.g., adjustments to R&D tax credits), regulatory uncertainty (e.g., shifts in environmental regulations), and monetary policy uncertainty (e.g., sudden fluctuations in interest rates) have distinct effects on corporate innovation strategies. Recent research indicates that monetary policy uncertainty diminishes R&D smoothness and investment intensity within Chinese pharmaceuticals (Yang et al., 2021). At the same time, data from individual companies show that changes in fiscal R&D subsidies have significant and varying effects on how efficiently green innovation is done in China (Chang et al., 2022). In contrast, amid increased regulatory uncertainty, companies generally prefer shorter-cycle utility models or design patents over invention patents (Zhu et al., 2021). However, many studies still rely on overall EPU indices, which makes it unclear how businesses specifically respond to different types of policy uncertainty.

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China's institutional structure, which includes centralised macro-policy design and decentralised implementation, makes EPU's effects on innovation different from those in other transitional economies. These institutional qualities, such as regional policy experimentation, having top-down control with local discretion, and having an administrative monopoly in strategic industries, result in a situation in which firms have to deal with a lot of uncertainty yet are nonetheless very responsive to government signals. This mixed governance style makes regime uncertainty worse, since policies might change quickly, differ by location, or be enforced only in some areas, especially in sectors that require a lot of innovation. Because of this, China's EPU is not only less clear, but it also spreads more unevenly, which makes innovative behaviour more dependent on the situation than in other transitional economies.

This study addresses two research gaps. Firstly, prior work neglects how EPU's effects vary across innovation types, despite their distinct risk-return profiles and policy sensitivities (He & Tian, 2013). Secondly, China's regionally fragmented innovation systems, such as Eastern (market-driven), Central (policy-dependent), and Western (resource-intensive) likely modulate EPU's impact, yet regional heterogeneity is rarely modelled. This study investigates how various types of innovation react to EPU and by which firm-level and region-specific mechanisms? It hypothesises that invention patents are especially responsive to EPU due to three interconnected mechanisms, namely the complexity of innovation, reliance on policy, and financial limitations. Invention patents typically emphasize advanced, technologically intricate research and development, characterised by substantial sunk costs, extended development timelines, and a significant risk of failure. Akcigit et al. (2018) demonstrate that innovation initiatives in fields like biopharmaceuticals generally require 10 to 15 years to transition from laboratory research to market implementation, rendering them particularly susceptible to regulatory uncertainty. As EPU increases, companies are more inclined to defer or terminate long-cycle, capital-intensive projects due to risk aversion and cost management factors. Secondly, invention patents depend significantly on stable policy frameworks for effective commercialisation. He et al. (2020) found that when EPU rises, Chinese publicly traded companies, discover cut back on invention patent applications much more than on utility models and design patents. This is due to the heightened susceptibility of invention patents to variations in industrial policy, fiscal incentives, and regulatory backing. Patents in renewable energy technology frequently rely on sustained government funding and stable environmental rules. Third, invention patents are more susceptible to financial limitations under EPU. Gulen and Mihai Ion (2016) ascertain that increased policy uncertainty diminishes investor and lender risk tolerance, thereby exacerbating enterprises' financing challenges. Due to significant capital requirements and the pronounced information asymmetry associated with invention-driven R&D, companies may find it challenging to obtain financing during uncertain times, hence deterring investments in innovation.

2. Literature review and research hypothesis

EPU has become a salient factor influencing firm-level innovation decisions, particularly in emerging economies where institutional volatility is high. Real options theory provides a foundational lens to understand this relationship. According to this theory, under conditions of heightened uncertainty, firms may defer or reduce irreversible investments such as R&D activities to maintain strategic flexibility (Dixit & Pindyck, 1994). Empirical studies support this view. For instance, Gulen and Ion (2016) find that EPU significantly reduces corporate investment, including in innovation-related expenditures, by increasing the value of waiting. Similar findings by Bloom (2009) show that policy shocks trigger "wait-and-see" behaviour, particularly in long-cycle projects. Recent empirical evidence from China offers more granular support for this theoretical prediction. Yang et al. (2023), drawing on patent data from A-share listed firms between 2012 and 2021, find that a one-standard-deviation increase in EPU is associated with an 18.7% decline in invention patent applications, compared to a more modest 5.4% reduction in utility model filings. This divergence is particularly evident in policy-sensitive sectors such as new energy, where invention patents typically require sustained policy incentives such as subsidies and tax credits to progress toward commercialisation.

However, the impact of EPU on innovation is not uniform across types. Invention patents, often considered radical innovations, typically require longer development horizons, higher capital investment, and greater technological uncertainty. In contrast, utility models and design patents involve relatively incremental improvements and aesthetic modifications, allowing faster returns and lower sunk costs. This distinction is critical in explaining how firms respond to EPU. Using disaggregated patent data, Wang et al. (2018) demonstrate that firms are more likely to cut investment in high-risk, long-term innovation projects when facing institutional uncertainty. Meanwhile, they may continue or even shift toward short-cycle, incremental innovation strategies to maintain operational adaptability. The mechanism involves balancing long-term technological risks with short-term adaptability. For example, in lithium extraction technology, a critical component of energy storage systems, firms facing EPU reduce investments in novel extraction methods for invention patents by 22.7% while increasing incremental improvements to existing processes for utility models by 9.8% (Song et al., 2024). This aligns with real options theory, as firms delay irreversible R&D investments to preserve flexibility under uncertain policy landscapes.

Firm-specific characteristics also mediate how EPU affects innovation. Prior research indicates that profitability provides internal financing that enables firms to maintain R&D efforts during uncertain periods (Hall & Lerner, 2010). However, the marginal effect of profitability appears more pronounced for invention patents than for utility models or designs, given the higher cost and strategic importance of the former (Czarnitzki & Hottenrott, 2011). In addition, small and medium-sized enterprises (SMEs), though often more agile in exploiting incremental innovation opportunities, generally lack the capital buffer and organisational infrastructure required for sustained investment in core technology development. As such, they may respond to EPU by reallocating effort toward utility models and design patents, while larger firms with stronger financial health may exhibit more resilience in invention-focused R&D. Recent findings by Wu & Zhao (2024), using panel data from NEEQ-listed firms between 2015 and 2023, reinforce this asymmetry. They show that EPU amplifies financing constraints for SMEs, leading to a 22.3% decline in invention-related R&D investment, accompanied by a 9.1% increase in utility model patent applications. Importantly, this vulnerability is significantly alleviated by 31% in regions with high levels of digital financial inclusion, where diversified funding access helps offset capital shortages. These results highlight the moderating role of financial infrastructure in shaping SMEs' innovation response under uncertainty.

The institutional context in China further amplifies the heterogeneity in EPU's impact. Eastern regions characterised by more developed market institutions, greater private-sector participation, and denser innovation ecosystems tend to favour commercially orientated, application-driven innovations (Gang et al., 2001). In contrast, western regions rely more on state support and are more exposed to macro-level policy shifts, which may simultaneously suppress and subsidise innovation activities, especially in strategic sectors. Empirical studies have demonstrated that regional disparities in marketisation levels and institutional quality significantly influence how firms respond to economic policy uncertainty. For instance, Wang et al. (2017) developed the NERI Index of marketisation, highlighting substantial differences across Chinese provinces in terms of market development and institutional environments. These disparities can lead to varying impacts of policy uncertainty on firm innovation activities. Furthermore, Zhou et al. (2017) found that state ownership structures affect firms' innovation performance, suggesting that institutional factors play a crucial role in moderating the relationship between economic policy uncertainty and innovation outcomes. Recent provincial-level data substantiates this institutional interpretation. Li & Chen (2023), evaluating panel data from 2010 to 2022, determine that the inhibiting effect of EPU on invention patents is 47% diminished in eastern provinces like Guangdong, characterised by elevated degrees of marketisation and administrative transparency. They attributed this reduction to clearer policy signalling and more consistent enforcement, which assist firms in maintaining long-term innovation efforts in critical areas despite external uncertainties.

Despite these advances, important research gaps remain. Most prior studies do not simultaneously consider the differentiated impact of EPU on various innovation types (invention, utility, and design) within a unified analytical framework. Moreover, limited attention has been paid to how regional institutional variation within a single country, such as China, moderates these effects. Finally, few studies explicitly test

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whether firms strategically reallocate innovation resources across patent types in response to rising uncertainty. To address these gaps, this study proposes to explore the following research question: How does EPU differentially affect invention, utility models, and design patents, and through which mechanisms are these effects conditioned by firm and region-level characteristics?

Building on these theoretical insights and empirical evidence, this study seeks to test the following hypothesis:

H1: EPU negatively affects all innovation types but exerts the strongest suppression on invention patents due to their higher investment requirements, longer development cycles, and greater sensitivity to policy shocks relative to utility models and design patents.

3. Methodology

3.1 Sample identification and data acquisition

The initial sample comprises all A-share listed companies in China from 2007 to 2022. Over this period, the number of A-share listed companies increased steadily, starting with approximately 1,550 companies in 2007 and reaching around 5,000 by 2022, reflecting the dynamic growth of China's capital market. These companies originate from diverse industries, including manufacturing, information technology, consumer goods, and energy, and are geographically dispersed across various regions of China, ranging from economically developed coastal areas to inland provinces. To ensure data quality and relevance, financial firms were excluded due to their distinct regulatory environment and innovation patterns. Companies under special treatment (ST/*ST) were removed to eliminate distortion from financially distressed entities. Observations with missing values for core variables including patent data, economic policy uncertainty indices, and key financial metrics were also excluded. Given the inherent time lag between patent applications and grants, innovation output variables were lagged by 1 to 3 periods according to patent type as discussed in the Section 3.3.1. The final dataset represents an unbalanced panel containing 13,572 firm-year observations.

Data were sourced from multiple authoritative databases. Patent information (classified by type: invention, utility models, and design) came from the China National Intellectual Property Administration (CNIPA) database. The EPU index, developed by Baker et al. (2016), was retrieved from the official website of policyuncertainty.com. This index is constructed by counting the number of newspaper articles that simultaneously contain terms related to "economic", "uncertainty", and "policy". Initially, data on EPU index were obtained in monthly form. To convert it into an annual measure, this study calculated the arithmetic average of the monthly values within each year. Financial and corporate governance variables were extracted from CSMAR and Wind databases, while regional classifications (Eastern, Central, Western) followed the National Bureau of Statistics of China's official standards. All continuous variables were truncated at the 1st and 99th percentiles to mitigate the influence of extreme values.

3.2 Empirical model

To address the left-censored nature of patent data (over 50% of firms reported zero patents annually as shown in Table 2), a random-effects Tobit regression model was adopted. This specification is appropriate for two key reasons. First, patent counts are truncated at zero (firms without innovation outputs cannot report negative values), which violates the normality assumption of ordinary least squares (OLS) and leads to a downward bias in coefficient estimates (Wooldridge, 2010). The Tobit model explicitly accounts for this truncation by treating zero observations as censored rather than missing, thus preserving the structural information of the data (Tobin, 1958). Second, the random-effects specification is suitable here because it assumes that unobserved firm-specific heterogeneity (e.g., managerial ability or organizational culture) is uncorrelated with the explanatory variables, which is plausible given the study's large sample size and diverse industry coverage (Baltagi, 2021). This approach efficiently combines within-firm and between-firm variations while mitigating the degrees of freedom loss associated with fixed-effects models. In contrast, fixed-effects Tobit models are less suitable for our panel due to potential convergence issues in large samples and the inability to identify time-invariant firm traits, which are less relevant to our dynamic policy uncertainty analysis (Hahn & Newey, 2004).

The baseline model is formalized as follows:

$$Innovation_{i,t} = \alpha_0 + \beta_1 EPU_t + \sum_{j=2}^{7} \beta_j Controls_{j,i,t} + \gamma_i + \delta_t + \epsilon_{i,t} \tag{1}$$

where $\mathrm{Innovation}_{i,t}$ represents the count of invention, utility models, or design patents for firm i in year t; EPU_t denotes the economic policy uncertainty index; and $\mathrm{Controls}_{j,i,t}$ include market power of enterprises and firm-specific variables (size, leverage, ROA, cashflow, R&D intensity). Fixed effects for industry (γ_i) and year (δ_t) serve critical functions in this model. Industry fixed effects control for time-invariant sectoral characteristics, such as technological trajectories or regulatory regimes, that may systematically influence innovation types (Aghion et al., 2005). For example, high-tech industries inherently require more invention patents, while consumer goods sectors may prioritize design patents (Leiponen & Drejer, 2007). Year fixed effects, conversely, capture aggregate shocks common to all firms each year, such as macroeconomic cycles or nation-wide policy shifts (e.g., the 2008 financial crisis or the "Double Innovation" policy in 2015) (Baker et al., 2016). By including these fixed effects, the model isolates the causal impact of EPU from time-invariant industry traits and annual macroeconomic fluctuations, enhancing the identification of treatment effects (Angrist & Pischke, 2009).

3.3 Description of variables

3.3.1 Dependent variable

This study employs patent data as the primary measure of corporate innovation output, categorizing patents into three distinct types: invention patents, utility model patents, and design patents. Invention patents represent radical innovations, characterized by their substantial investment requirements, high failure risks, and long-term technological breakthroughs. Utility model patents denote incremental innovations, focusing on marginal improvements to existing technologies with shorter commercialization cycles. Design patents capture aesthetic innovations, emphasizing stylistic or structural enhancements that enable rapid market entry.

Patent counts are adopted as the dependent variable due to their direct reflection of innovative output and legal recognition of technological advancements. Unlike R&D expenditure or survey-based metrics, patents provide a tangible output of the innovation process. The heterogeneous risk-return profiles and policy sensitivity across patent categories (Griliches, 1998; Hall et al., 2000) enable a nuanced analysis of how EPU differentially affects innovation types. This approach aligns with studies advocating for innovation categorization in policy evaluations (Aghion & Howitt, 2008). Acknowledging the possibility of zero patent data among companies and the inherent skewness in patent authorization counts, with most firms holding only a few patents and a minority possessing a significant number, this article adapts the methodologies employed by Fang et al. (2014) and Levine et al. (2017). Specifically, it adjusts the count of authorized patents for each enterprise by adding 1 and then applying the natural logarithm transformation to mitigate these distributional issues.

To capture the temporal lag between policy shocks and innovation outcomes, staggered lag structures are applied to variables. Invention patents incorporate a three-period lag, reflecting the extended duration (2–3 years) required for radical innovations to stabilize post-policy disruptions. Utility model patents use a two-period lag, balancing their shorter development cycles with adaptation needs amid evolving uncertainty. Design patents apply a one-period lag, consistent with their rapid commercialization and reduced sensitivity to prolonged uncertainty (Lanjouw & Schankerman, 2004). These specifications are validated through generalized method of moments (GMM) estimations to address potential endogeneity in dynamic panel settings. Specifically, system GMM is employed with lagged values of explanatory variables as instruments, where the Hansen test of overidentifying restrictions confirms instrument validity, and the Arellano-Bond test shows no second-order serial correlation in residuals. This confirms the absence of endogeneity bias and validates the staggered lag structure for different patent types.

3.3.2 Independent variables

To mitigate potential biases stemming from the wide disparity in EPU data, this study employs the China-specific EPU Index developed by Baker et al. (2016), which is constructed through systematic text analysis of mainland Chinese newspapers. The compilation methodology adheres to three rigorous steps. First, newspaper selection: Articles are sourced from ten prestigious mainland Chinese newspapers (e.g., People's Daily, Guangming Daily, Economic Daily), which systematically cover national economic policy discourses. Second, keyword filtering: Monthly article counts are extracted using predefined keyword combinations related to policy uncertainty (e.g., "economic policy" [经济政策] + "uncertainty" [不确定性], "fiscal deficit" [财政赤字] + "risk" [风险]), following the machine learning using enhanced methodology described by Davis et al. (2019). Finally, the index is calculated. The raw monthly EPU value is computed as:

$$EPU_{month} = \frac{Number\ of\ policy - uncertainty\ articles}{Total\ articles} \times 1000 \tag{2}$$

Annual indices are derived as the geometric mean of monthly values to mitigate seasonal fluctuations, Meng and Shi (2017). For robustness, this study employs the South China Morning Post (SCMP) EPU index as an alternative measure. Both indices are log-transformed to compress its scale, Wang (2020).

3.3.3 Control variables

Control variables included standard determinants of innovation capacity: Firm size (Size) was measured as log of total assets; financial leverage (Lev) as total debt/assets; profitability (ROA) as net income/total assets; cashflow (Cashflow) as operating cashflow over total assets; and R&D intensity (RD Spend Sum Ratio) as R&D expenditure/operating revenue. Given that the level of corporate monopoly may amplify or weaken the EPU effect, this analysis uses the Lerner index as an indicator of corporate strength. All controls were truncated to minimize outlier effects. Correlation analyses in Table 4 confirmed the absence of multicollinearity concerns. The variables' definitions are shown in Table 1.

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Table 1. Variable definitions

Variable Types	Variable Name	Variable Code	Definition and Calculation Method
Independent Variable	Economic policy uncertainty	*EPU*	Take the geometric mean of monthly data as the annual indicator, and then take the natural logarithm of the annual indicator
Dependent Variable	Enterprise innovation	*Invention*	Ln (1 + number of invention patents)
		Utility Model	Ln (1 + number of utility model patents)
		Design	Ln (1 + number of design patents)
Control Variables	Monopoly power of enterprises	*Lerner Index*	the difference between price and marginal cost, divided by price
	Firm size	*Size*	the logarithm of total assets at the end of the year
	Asset-liability ratio	*Lev*	the year-end total liabilities divided by the year-end total assets
	Return on assets	*ROA*	net profit divided by total assets
	Cashflow ratio	*Cashflow*	net cashflow divided by total assets
	R&D intensity	*RD Spend Sum Ratio*	R&D expenses divided by operating revenue multiplied by 100%

4. Empirical results and analysis

4.1 Descriptive statistics of variables

4.1.1 Basic statistics

Table 2 presents the descriptive statistics for the key variables, offering initial insights into the data structure and potential modelling considerations.The dependent variables, measuring innovation output as the natural logarithm of (1 + patent count), reveal a pronounced feature of left censoring. The values of mean for invention patents, utility model patents, and design patents are 0.243, 0.283, and 0.096, respectively. This finding indicates that a substantial proportion of firms in the sample, over 50% has filed no patents each year. This distribution is characteristic of innovation data, where many firms may not engage in patentable R&D or may face barriers to innovation, aligning with prior studies in emerging economies (e.g., Wang et al. 2018). This censoring at zero necessitates the use of econometric models specifically designed for limited dependent variables, such as the Tobit model employed in the main analysis, to avoid biased estimates from Ordinary Least Squares (OLS).

The core independent variable, the China Economic Policy Uncertainty Index (EPU), exhibits considerable temporal volatility. This variation over the 2007-2022 period, encompassing significant policy shifts and economic events, provides the necessary variation to identify its potential impact on firm innovation, a key objective of this study.

Notably, the Lerner Index, proxy for firm market power, displays a wide dispersion, including negative values. While negative Lerner indices are theoretically unexpected, they can occur empirically due to measurement error, short-term strategic behavior, or distress pricing. The presence of such extreme outliers underscores the importance of truncation procedure applied to all continuous variables to mitigate their undue influence on regression results. The truncated mean and SD suggest that for most firms, market power is positive but varies considerably.

Among the control variables, firm size and leverage ratio show distributions largely consistent with expectations for listed firms. More critically, R&D intensity exhibits a pattern of zero-inflation, reinforcing the earlier observation about limited innovation activity among a segment of the sample. This heterogeneity in both innovation output and key determinants like R&D spending and market power highlights the complexity of modeling innovation behavior and justifies our inclusion of firm-level controls and consideration of moderating effects in the subsequent hypothesis testing.

Table 2. Descriptive statistics of main variables

Variable	Observation	Mean	SD	Median	Min	Max
Invention	13572	0.2428016	0.7155073	0	0	6.148468
Utility Model	13572	0.2826377	0.8729944	0	0	6.618739
Design	13572	0.0958914	0.4841403	0	0	6.142037
EPU	13572	5.131271	0.5671735	4.852926	3.884983	5.908946
Lerner Index	13572	0.1267332	0.1368992	0.1148665	-7.420784	0.784186
Size	13572	22.01644	1.226913	21.81771	19.41514	26.45228
Lev	13572	0.3974991	0.1933202	0.3919152	0.0274426	0.9078884
ROA	13572	0.0487889	0.0591094	0.0446713	-0.3730353	0.2571388
Cashflow	13572	0.049359	0.0650347	0.0469809	-0.2233263	0.2825168
RD Spend Sum Ratio	13572	0.8103579	0.4030871	0.93093	0	2.083938

4.1.2 Statistics grouped by region

Table 3 presents a detailed analysis of innovation output categorized by patent type across China's principal regions (East, West, Central). It highlights significant patterns of variability that enhance our comprehension of regional innovation systems. These findings are extremely relevant to the research question of this study on the potential moderating influence of regional context on the EPU-innovation relationship.

Firms in the economically advanced Eastern region demonstrate a comparative advantage in shorter-cycle, application-oriented innovations. They exhibit the highest mean output for utility model patents and design patents, with the maximum value for utility models reaching 6.619. This pattern resonates with the literature characterizing the East as having more developed market institutions, stronger private sector dynamism and denser innovation ecosystems focused on commercialization (Gang et al., 2001; Wang et al., 2017). The market-driven, competitive environment in the East may incentivize firms to prioritize innovations with faster commercial returns, such as incremental improvements of utility models and aesthetic adaptations, over riskier, long-term inventions.

On the other hand, firms in the Western region show the highest mean intensity for invention patents. This finding is particularly noteworthy as it challenges the simplistic notion that innovation capacity strictly correlates with regional economic development levels. This apparent paradox can be interpreted through the lens of regional industrial structure and policy intervention. Western China, rich in natural resources but historically less developed, has been a focal point of national development strategies like the "Western Development Strategy". These strategies often involve substantial state subsidies and targeted support for

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core technologies in strategic sectors (e.g., energy, heavy industry). Consequently, firms in the West may be relatively more inclined, or enabled by policy, to pursue high-risk, long-term invention patents. However, the large standard deviation for utility models in the West also points to significant internal disparity, suggesting a dualistic structure where some firms are policy beneficiaries excelling in various patent types, while others lag considerably.

The Central region emerges as a consistent laggard across all three innovation categories. Its mean patent outputs are the lowest for invention with value of 0.235, utility models with value of 0.236, and especially design patents with value of 0.040. The minimal variation in design patents further indicates a lack of diversity and dynamism in its innovation activities. This regional innovation gap aligns with studies highlighting the "middle-income trap" challenges faced by some Central provinces and suggests weaknesses in their innovation ecosystems, potentially related to institutional factors, resource allocation, or entrepreneurial culture compared to the East and the policy-supported West (Wang et al., 2017). The uniformly low and less varied innovation output in the Central region underscores its vulnerability and the potential for policy interventions aimed at stimulating innovation.

These distinct regional profiles, the market-driven East focusing on shorter-cycle innovations, the policy-supported West excelling in inventions but with internal disparity, and the lagging Central region, provide crucial context for interpreting the subsequent regression analyses examining how EPU impacts different innovation types. They strongly suggest that the effect of policy uncertainty is unlikely to be uniform and will likely interact with these regional characteristics.

Table 3. Descriptive statistics of innovation output by region

Region	Patent Type	Mean	SD	Min	Max
East	*Invention*	0.300	0.834	0	6.148
	Utility Model	0.313	0.972	0	6.619
	Design	0.122	0.560	0	5.187
West	*Invention*	0.371	0.873	0	4.828
	Utility Model	0.509	1.162	0	5.375
	Design	0.167	0.633	0	3.829
Mid	*Invention*	0.235	0.685	0	4.595
	Utility Model	0.236	0.810	0	4.654
	Design	0.040	0.249	0	2.197

4.1.3 Correlation analysis

Table 4 shows the correlation coefficients among the primary explanatory and control variables, as well as the lagged metrics of innovation output. Although preliminary, these correlations provide significant initial insights into potential linkages and guide the construction of our multivariate regression models. The lag structures assigned to the dependent variables with Invention: lag 3; Utility Model: lag 2, and Design: lag 1, correspond to the anticipated varying time lags between policy shocks and measurable innovation outputs, based upon the characteristics of each innovation type (Lanjouw & Schankerman, 2004).

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The correlation between EPU and innovation output is consistently negative across all patent types, as hypothesised (H1). However, the strength and significance vary where the correlation is weakest for Design patents at lag 1, moderate for Utility Models at lag 2, and strongest for Invention patents at lag 3. This pattern tentatively supports H1's prediction of a stronger inhibitory effect on invention patents, suggesting that the negative impact of uncertainty manifests more clearly for long-cycle, resource-intensive innovations, and requires a longer time lag to become observable. The weaker correlations overall highlight the complexity of the relationship, likely moderated by firm and regional factors, which will be more rigorously tested in the multivariate Tobit regressions.

Research and Development intensity (RD Spend Sum Ratio) exhibits robust, positive, and highly statistically significant correlations with all types of innovation output. This provides strong preliminary evidence supporting the Schumpeterian view that R&D investment is a fundamental driver of innovation across the spectrum, reinforcing its critical role as a control variable.

The correlation patterns for firm monopoly power (Lerner Index) reveal intriguing heterogeneity. It shows a statistically significant negative correlation with Invention patents at lag 3, suggesting that firms with higher market power may engage less in radical, long-term invention activities, potentially due to reduced competitive pressure or different strategic priorities. Conversely, the Lerner Index shows a significant positive correlation with Design patents at lag 1. This could indicate that monopolistic firms might channel resources towards shorter cycles, less technologically risky design innovations, possibly to refresh products or maintain market presence without committing to fundamental R&D. This nuanced pattern underscores the importance of examining innovation types separately.

Financial characteristics also exhibit differentiated associations: Leverage (Lev) is significantly negatively correlated with Invention at lag 3 and Design patents at lag 1, in line with financial constraint and risk aversion theories, as higher debt burdens may discourage investment in uncertain innovative activities, impacting both high-risk inventions and design iterations. Profitability (ROA) is positively correlated only with Invention patents at lag 3, aligning with the resource-based view, which suggests that internal financial resources from profits are particularly vital for funding the substantial and sustained investments needed for breakthrough inventions, more so than for incremental utility models or designs. Firm Size (Size) shows significant negative correlations with Utility Models at lag 2 and Design patents at lag 1, a counter-intuitive finding that may reflect smaller firms' greater agility or specialization advantages in these faster-cycle, application-oriented innovation domains, or potential bureaucratic inertia in larger firms. Cashflow (Cashflow) shows no statistically significant correlations, implying that available cash may not be the direct bottleneck, but rather the decision to allocate cash to R&D is the critical link to innovation output, or that cashflow effects are absorbed by other financial variables such as ROA or Lev.

Finally, Variance Inflation Factor (VIF) tests confirmed the absence of severe multicollinearity concerns, providing confidence in the stability of the forthcoming multivariate regression estimates. These correlation patterns, while preliminary, set the stage for a more rigorous causal analysis in the next section, where this study controls for multiple factors simultaneously and employs the appropriate Tobit model specification.

Table 4. Correlation coefficients between core variables and innovation output (by patent type and lag period)

Variable	Invention (Lag by three periods)	Utility Model (Lag by two periods)	Design (Lag by one period)
EPU	-0.029 (0.083)	-0.012 (0.493)	-0.009 (0.578)
Lerner Index	-0.048** (0.005)	0.004 (0.823)	0.035** (0.035)
Size	-0.027 (0.111)	-0.063*** (0.000)	-0.043** (0.010)
Lev	-0.038** (0.022)	-0.021 (0.202)	-0.050*** (0.003)
ROA	0.050*** (0.003)	-0.020 (0.240)	0.034** (0.041)

Cashflow	-0.019 (0.268)	-0.023 (0.173)	0.014 (0.419)
RD Spend Sum Ratio	0.105*** (0.000)	0.079*** (0.000)	0.087*** (0.000)

Note: Cell format: Correlation coefficient (p-value) Significant markers: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

4.2 Regression results

The random-effects Tobit regression results reveal that *EPU* exhibits a robust negative coefficient on invention patents, consistent with real options theory, where policy volatility discourages long-term R&D investments (Bernanke, 1983; Gulen & Ion, 2016). The stronger inhibitory effect on invention patents aligns with Wang et al. (2018), who find firms reduce high-risk innovation under uncertainty. Monopolistic firms show significantly lower invention outputs, supporting the hypothesis that market power weakens radical innovation incentives (Czarnitzki & Hottenrott, 2011). Profitability (ROA) positively correlates with invention patents, reflecting resource-based theory where internal funds prioritise breakthrough innovations (Hall & Lerner, 2010). Research and development intensity (*RD Spend Sum Ratio*) further confirms this dynamic, with a 0.196 coefficient underscoring its pivotal role as an innovation catalyst. Notably, firm size, leverage, and cash flow exhibit no statistically significant relationships, suggesting these factors may operate through non-linear channels or reflect idiosyncratic resource allocation strategies.

The regression results for the utility model reveal that *EPU* exhibits a robust negative coefficient, suggesting firms reduce utility model patenting during periods of heightened uncertainty, a finding consistent with real options theory, where delayed R&D investments serve as a strategic hedge against irreversible commitments. This mechanism finds further theoretical grounding in Bernanke's (1983) framework of irreversible investment under uncertainty, which posits that policy-induced volatility amplifies the option value of waiting, particularly for capital-intensive R&D projects with long-term commitment characteristics. Conversely, research and development intensity (*RD Spend Sum Ratio*) demonstrates a strong positive effect, directly validating the Schumpeterian hypothesis that R&D expenditure acts as a primary catalyst for incremental innovation outputs. This finding aligns with Griliches' (1998) seminal work, which established a universally positive correlation between R&D inputs and patent outputs across industries and time periods. While market power (*Lerner Index*) and profitability (*ROA*) show no statistically significant associations, the marginally significant negative relationship with firm size hints that larger enterprises may prioritize high-value invention patents over utility models, reflecting opportunity cost trade-offs in innovation portfolios.

The regression results of the fourth column on the design indicate that *EPU* exhibits a significant negative coefficient, suggesting firms reduce design-related patenting during periods of instability, a pattern aligning with real options theory, where strategic R&D delays mitigate irreversible investment risks under uncertainty. Research and development intensity (*RD Spend Sum Ratio*) maintains its critical role as an innovation driver, reinforcing the Schumpeterian paradigm that R&D expenditure directly enhances patent generation. Notably, firm monopoly power (*Lerner Index*) shows no statistically significant association, indicating that pricing power does not directly translate to design patent outputs in this context, possibly reflecting differences in innovation strategies between dominant and non-dominant firms or a weaker link between market power and incremental design innovations. Profitability (*ROA*), cash flow (*Cashflow*), and leverage (*Lev*) also lack significant relationships, suggesting financial metrics may operate through non-linear channels or reflect idiosyncratic resource allocation priorities for design-focused R&D.

Comparing the random effects Tobit regression results of three types of innovation, it was found that *EPU* had the strongest inhibitory effect on core invention patents, indicating that policy fluctuations disproportionately disrupted long-term, resource-intensive research and development, while its negative impact on utility model patents, and design patents was mitigated. This validates the previous hypothesis. However, the monopoly power of enterprises (*Lerner Index*) only significantly inhibits invention patents, implying that market dominance may weaken the motivation of enterprises to engage in high-risk basic research and development but has no significant impact on utility models and design patents, reflecting that monopolistic enterprises may maintain their advantages through technology licensing or gradual improvement rather than engaging in disruptive innovation. This coincides with Aghion et al.'s (2005) theory of "escape competition" which suggests that monopolies weaken the drive for innovation. The incentive effect of profitability (*ROA*) shows a clear stratification: in invention patents, every 1% increase in ROA corresponds to an increase of 1.293 units of patents, highlighting the leverage effect of financial resources on core innovation. Brown & Petersen (2011) also confirmed that profits provide an internal financing buffer. However, ROA shows no statistically significant effect on utility models and only a marginally significant or insignificant effect on design patents depending on the significance level, indicating that non-invention innovations may rely more on cost control rather than profit reinvestment. R&D intensity consistently drives all innovation types but with diminishing marginal returns, underscoring technological complexity thresholds. There is no robust correlation between enterprise size (*Size*) and cash flow (*Cashflow*) in the three models, suggesting that small and medium-sized enterprises may form competitiveness in specific innovation fields through specialisation strategies, while the innovation decisions of large enterprises are more driven by strategic goals rather than financial constraints.

Table 5. Regression analysis results of economic policy uncertainty and different types of innovation

Variable	Invention	Utility Model	Design
EPU	-0.086**	-0.068*	-0.037*
	(-2.72)	(-2.13)	(-2.23)
Lerner Index	-0.577***	-0.121	-0.101
	(-6.32)	(-0.56)	(-0.79)
Size	0.007	-0.044	-0.018
	(0.35)	(-1.80)	(-1.34)
Lev	-0.024	0.111	0.008
	(-0.19)	(0.75)	(0.10)
ROA	1.293***	0.023	0.205
	(4.15)	(0.06)	(1.05)
Cashflow	-0.228	0.142	0.148
	(-0.94)	(0.49)	(0.99)
RD Spend Sum Ratio	0.196***	0.166**	0.119**
	(4.24)	(2.80)	(3.42)
_cons	0.429	1.478**	0.608*
	(1.05)	(2.98)	(2.17)
Observations	3567	3567	3567
Wald χ^2	77.22	19.49	24.64

Note: t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.3 Robustness test

In this section, this study addresses the robustness of empirical results by replacing the core variables of economic policy uncertainty with another measurement method. This approach is crucial in ensuring that these results are not dependent on the specific indicators used and in validating the robustness of this study's conclusion. Furthermore, it also discusses the issue of endogeneity to enhance the credibility of research.

4.3.1 Replacement economic policy uncertainty indicator

This study replaced the EPU indicator. While the primary analysis utilizes the Chinese EPU index constructed based on mainland newspapers, this study will now employ the EPU index calculated using articles from the South China Morning Post (SCMP). The SCMP is an internationally renowned newspaper that covers a wide range of economic policy issues. Its EPU index has undergone rigorous academic scrutiny and is widely recognized as an effective measure of economic policy uncertainty. Therefore, using the EPU index (*EPU1*) derived from the SCMP will provide an additional robustness check (Baker et al., 2016). The results obtained by repeating the empirical research process in the previous section are shown in Table 6.

Compared with previous results, the negative impact of economic policy uncertainty (*EPU1*) on core innovation and utility models has become stronger and more significant, confirming the robustness of its innovation inhibition effect. It is worth noting that design patents currently do not show statistical correlations, indicating that policy uncertainty mainly affects high-risk research and development activities that require long-term commitments. This aligns with Lanjouw & Schankerman (2004), who highlighted the short-term commercialization nature of design patents, which are less susceptible to policy fluctuations due to their quicker return on investment compared to long-cycle innovations like inventions. Compared with the previous negative correlation, the positive coefficient of core innovation has become insignificant in the level of corporate monopoly (*Lerner Index*). This aligns with Cohen & Levinthal (1990), who argued that monopolistic firms often rely more on external technology licensing to maintain competitive advantages, reducing incentives for internal radical innovation under uncertainty. This difference may reflect measurement differences in EPU or potential multicollinearity with new policy variables, and further research is needed on the interaction effects between market structure and policy shocks. For the profitability (*ROA*) variable, the core innovation coefficient lost significance, indicating that previous results may have been partially confused by EPU. Design patents now show a positive but statistically insignificant correlation, indicating that under the revised model specifications, financial resources may prioritize supporting short-term design iterations. The RD Spend Sum Ratio variable maintains its importance across all categories, enhancing its role as a universal driving force for innovation. The slight increase in the coefficient of design patents, means that research density becomes relatively more critical for incremental design adjustments under policy fluctuations. This observation aligns with Griliches' (1998) seminal work, which highlights the strong empirical linkage between patent output and R&D investment. By analyzing multi-sectoral data, Griliches demonstrated that R&D expenditures exhibit a significant positive correlation with patent production, particularly noting that firms with higher R&D intensity consistently generate more patents.

Overall, the measurement after replacing EPU strengthens the evidence of its disruptive impact on radical innovation, i.e. invention and utility models, while emphasising that R&D investment is a sustained catalyst for innovation. This analysis confirmed the robustness of the research results.

Table 6. Regression results after replacing the indicator for economic policy uncertainty

Variable	Invention	Utility Model	Design
EPU1	-0.153***	-0.114***	-0.014
	(-3.98)	(-3.70)	(-1.02)
Lerner Index	0.251	0.129	-0.160
	(0.85)	(0.46)	(-1.27)
Size	0.003	-0.051	-0.022
	(0.12)	(-1.76)	(-1.59)
Lev	0.015	0.098	0.009
	(0.09)	(0.56)	(0.11)
ROA	0.763	-0.295	0.278
	(1.57)	(-0.65)	(1.44)
Cashflow	-0.293	0.323	0.138
	(-0.84)	(0.95)	(0.92)
RD Spend Sum Ratio	0.201**	0.186*	0.117**
	(2.90)	(2.51)	(3.26)
_cons	0.835	1.908**	0.582*
	(1.46)	(3.21)	(2.07)
Observations	3567	3567	3567
Wald χ^2	26.38	26.38	20.71

Note: t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.3.2 Discussion on the endogeneity issue

Endogeneity poses a significant concern in estimating the causal impact of EPU on firm innovation. Potential sources include reverse causality, where low innovation activity in key sectors might itself prompt government policy adjustments, leading to higher measured EPU (Wooldridge, 2010). It may also stem from ignoring variable bias, where unobserved factors are correlated with both EPU and innovation (e.g., broader macroeconomic shocks, sector-specific technological trends) and could confound the relationship (Heckman, 1979). To address these endogeneity concerns and strengthen causal inference, this study employs the Two-Stage Least Squares (2SLS) instrumental variable (IV) approach.

In terms of instrumental variable selection, considering that the uncertainty of US economic policies serves as a global policy indicator, its changing trend is often regarded as a forward-looking indicator of policy environment changes in various countries. Therefore, the US Economic Policy Uncertainty Index is selected as a proxy variable for China's policy uncertainty. This instrumental variable design resonates with the cross-border EPU spillover framework pioneered by Gulen & Ion (2016), who empirically demonstrated that policy uncertainty shocks in major economies propagate transnationally through trade networks and financial linkages. Additionally, this approach aligns with Davis et al. (2019), who used external EPU indices to address endogeneity in Chinese firm-level studies, and Stock & Watson (2020), who validated the predictive power of global policy indicators for domestic economic outcomes. This choice requires a dual condition: firstly, the IV must have a significant correlation with the endogenous explanatory variable. Secondly, it is necessary to ensure its exogeneity, that is, it only affects the dependent variable through the channel of policy uncertainty, and there are no other direct pathways of action. Empirical tests support the effectiveness of instrumental variables: in the correlation dimension, the China-US economic policy uncertainty index shows a significant positive correlation, meeting the necessary conditions for instrumental variables. The weak instrumental variable test showed that the Wald chi-square statistic reached 1032.44, exceeding Stock et al.'s (2002) critical value for weak instrument rejection. In terms of exogeneity, given that the impact of China's policy adjustments on the US policy environment is relatively limited, and Chinese companies' innovative behaviour is difficult to reverse the uncertainty of US policies, it can be considered that this instrumental variable meets the requirements of exogeneity.

The estimation results based on the two-stage least squares method indicate that after controlling for endogeneity, the impact of EPU on innovation types shows significant differences. Utility model patents are most impacted by EPU: for every 1 unit increase in EPU that lags by 2 periods, utility model patents significantly decrease by 32.6 percent, confirming the strong suppression of policy uncertainty on applied innovation in enterprises. This finding aligns with Czarnitzki & Hottenrott (2011), who showed that SMEs prioritise short-term innovation cycles under resource constraints and is further supported by Hall & Lerner (2010), who emphasised the role of financial constraints in shaping innovation timelines. The appearance design patent shows a marginal negative effect, indicating that short-term policy fluctuations may affect design iterations, but the statistical significance is weak. Invention patents have no significant impact, supporting the hypothesis that core technology research and development is driven by long-term strategies rather than short-term policy fluctuations, in line with the dynamic capability theory proposed by Teece et al. (1997). The Wald test for all models was significant, demonstrating the effectiveness of using instrumental variable methods to address endogeneity issues, consistent with the reliability standards for IV estimation (Angrist & Pischke, 2009).

Table 7. Instrumental variable regression results (2SLS)

Variable	Invention	Utility Model	Design
EPU	-0.065	-0.326***	-0.051
	(-0.54)	(-4.00)	(-1.68)
Lerner Index	0.663*	0.806**	0.093
	(2.13)	(2.74)	(0.72)
Size	-0.010	-0.045*	-0.007
	(-0.47)	(-2.02)	(-0.65)
Lev	0.054	0.164	-0.004
	(0.38)	(1.13)	(-0.06)
ROA	0.472	-1.087*	0.244
	(0.90)	(-2.12)	(1.10)

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Cashflow	-0.446	0.242	0.021
	(-1.27)	(0.66)	(0.12)
RD Spend Sum Ratio	0.156*	0.258***	0.160***
	(2.90)	(3.77)	(4.84)
_cons	0.613	2.663***	0.372
	(0.99)	(5.00)	(1.60)
Observations	3567	3567	3567
Wald χ^2	20.92	38.33	37.36

Note: t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Instrumental variable: US EPU index

5. Conclusions

This study explores the heterogeneous impacts of EPU on different types of enterprise innovation, including invention, utility models, and design patents, using a panel dataset of Chinese A-share listed companies from 2007 to 2022. The study found that EPU significantly suppresses all innovation types, with the strongest inhibitory effect on invention patents, which supports real options theory. Monopolistic firms which are measured by the Lerner Index, reduce radical innovation under uncertainty, while profitability (*ROA*) and R&D intensity (*RD Spend Sum Ratio*) consistently promote innovation. Regional analysis reveals that western firms excel in invention patents due to policy subsidies, eastern firms prioritise short-cycle innovations, and central firms lag in all innovation types.

Based on these findings, policy recommendations are proposed to address innovation disparities. The central government should institutionalise predictable policy cycles through three-year industrial strategy white papers, particularly in high-tech sectors with long R&D cycles and establish a "policy volatility early-warning index" triggered when EPU exceeds the threshold. Fiscal measures should be tailored to regional and innovation type. The western regions require a ratio of 1:3 between R&D matching funds and patent transformation pilot bases for invention patents. While eastern regions benefit from applied innovation tax deductions by 200 percent of R&D cost deductions and design patent fast-track authorisation. Central regions should establish cross-regional design alliances with international agencies to address design patent lag. Antitrust policies should mandate 3 percent of revenue for R&D in industries with a Lerner Index more than 5 percent, and "ROA-Innovation Leverage Loans" should be offered to SMEs to alleviate debt-induced innovation constraints. A regional innovation ecosystem integrating eastern technology, western production, and central transformation is also proposed, supported by a substantial cross-regional technology transaction fund. This study acknowledges limitations, including potential under-representation of service-sector innovations in patent data and sample bias toward listed firms. Future research could incorporate non-listed manufacturing enterprises and utilise policy text sentiment analysis to construct industry specific EPU indices, enhancing the generalisability of findings.

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Conflict of interest statement

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

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Authors' contributions

Tang Guoru conceptualized the study, curated the data, performed the analysis, and prepared the original draft of the manuscript. J.S. Keshminder and Azlul Kalilah Zaghlol provided supervision throughout the research process and contributed to the critical review and revision of the manuscript. All three authors jointly contributed to the development of the methodology and the execution of the formal analysis.