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Strategies for Mitigating Risks of Government-Led Energy Retrofitting Projects in China

Ling Jia [1,*], Queena K. Qian [2], Frits Meijer [2] and Henk Visscher [2]

[1] Faculty of Civil Engineering and Mechanics, Jiangsu University, 301 Xuefu Road, Zhenjiang 212013, China
[2] Faculty of Architecture and Built Environment, Delft University of Technology, Julianalaan 134, 2628 BL Delft, The Netherlands; k.qian@tudelft.nl (Q.K.Q.); f.m.meijer@tudelft.nl (F.M.); h.j.visscher@tudelft.nl (H.V.)
* Correspondence: lingjia@ujs.edu.cn; Tel.: +86-17826070662

Abstract: Residential energy retrofitting projects in the hot summer and cold winter (HSCW) zone of China face various risks related to project activities, which incur transaction costs (TCs), such as search, negotiation, and monitoring costs. As the leader in project implementation, the Chinese government is responsible for project planning, organisation, and coordination. However, TCs impede the government's ability to execute risk-related project activities effectively, subsequently increasing the probability of the occurrence of risk. Drawing on transaction cost economics (TCE), this study proposes a theoretical framework to understand the barriers—such as asset specificity, uncertainty, and frequency—that prevent the government from performing project activities and mitigating risks effectively. An artificial neural network (ANN) is applied to verify the hypotheses. The results underscore experience and operational maturity in project activities, cost and time constraints, and the immature retrofitting market as significant impediments to the government's execution of risk-related activities. Considering the varying roles of the government in reducing different risks, this study concludes by offering policy recommendations to alleviate these activity barriers and mitigate risks. By employing a TCs perspective, this study not only identifies key barriers but also deepens our understanding of risk mitigation mechanisms, providing robust policy insights tailored to the specific regional context of China, thereby enhancing both the execution and the framework of government-led retrofitting projects.

Keywords: residential energy retrofitting; government strategies; risk mitigation; transaction costs; artificial neural network

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1. Introduction

Globally, the practice of retrofitting urban residential structures for energy savings and pollution reduction has been acknowledged as a means to attain urban sustainability. China is not an exception. Since 2006, there have been endeavours to enhance the energy efficiency of current residential structures in China. However, the progress of energy retrofitting in residential structures located in the hot summer and cold winter (HSCW) zone is currently sluggish, which can be linked to the negative impact of risks on the energy retrofitting process [1]. The risks associated with retrofitting projects in China encompass the entire process and are linked to multiple project activities, including feasibility assessment, formulation of technical standards, negotiation with homeowners, selection of design and construction companies, and monitoring of retrofitting construction [1]. Transaction costs (TCs) are commonly encountered in various stages of retrofitting projects, encompassing expenses related to due diligence, negotiation, and monitoring. High TCs pose a significant hindrance to the adoption of energy-saving technology and the execution of retrofitting projects [2]. The inclusion of risk-related project activities results in TCs, which in turn contribute to the overall increase in TCs during retrofitting projects, hence hindering the implementation of the project.

Risks and their associated TCs prevent the government from performing retrofitting projects [1]. In China, the predominant approach to retrofitting is through local government-led initiatives [3,4]. These initiatives involve the local government taking on the responsibilities of planning, organising, supervising, and coordinating the retrofitting process. In this scenario, the local government is accountable for executing numerous project activities, which encompass risk-related tasks. For instance, the risks pertaining to the competence of designers and contractors are linked to the process of choosing designers and contractors, and the government is responsible for making judgements in this regard. The government primarily holds responsibility for managing TCs associated with risks in residential energy retrofitting projects [1]. TCs limit the actions of the government in these project activities, which include risks. To properly implement the retrofitting project, it is necessary to identify the key elements that contribute to the increase in these risk-related TCs.

Enhancing the government's performance in project running is also a tactic for managing risks. The effectiveness of the government in executing risk-related project activities directly impacts the likelihood of risk events occurring. For example, if the government has the capacity to choose competent designers and contractors, the likelihood of risks related to the capabilities of designers and contractors may be reduced. Reducing the likelihood of an event happening is crucial for effective risk management [5]. The government has a significant role in managing risks in household energy retrofitting projects. Homeowners' attitudes are significantly influenced by the government's promotion of the benefits of retrofitting [6]. The government needs to regulate the energy-saving performance, material quality standards, and energy efficiency coefficient [3,7]. Therefore, policy assistance plays a significant role in the risk management of residential energy retrofitting projects in China.

There is a lack of research that examines the involvement of TCs and the government in the assessment and control of risks in residential energy retrofitting projects. Prior research has mostly examined the risks associated with the energy efficiency gap and investment advantages [8–13]. Additionally, these studies have solely considered the use of energy-savings insurance as a means to transfer these risks [14,15]. Moreover, the current studies neglect the government's responsibilities in carrying out retrofitting projects. Instead, they primarily focus on the government's involvement in promoting the energy retrofitting market, including activities such as operating the market [16,17], driving technology innovation [18–20], attracting private capital [21,22], and encouraging homeowners to accept retrofitting measures [23,24]. Thus, existing research does not adequately address the risks at their origin in government-led energy retrofitting initiatives.

This paper aims to investigate the factors that contribute to the risk-related TCs in government-led energy retrofitting projects in the HSCW zone of China. The objective is to identify strategies for mitigating these risks and provide policy suggestions to help the government successfully carry out these projects. The application of Transaction Cost Theory (TCT) is used to investigate the obstacles that prevent the government from engaging in risk-related project activities. This study contributes to enhancing the government's comprehension of the causes of risk and provides guidance on addressing these issues at their root, thereby minimising the likelihood of the occurrence of risk. It takes a comprehensive perspective on project management and further supports the implementation of residential energy retrofitting.

The remaining portion of the paper is structured in the following manner: Section 2 presents a theoretical framework that includes three assumptions derived from transaction cost economics (TCE). This framework aims to investigate the obstacles faced by the government when carrying out risk-related project activities. Section 3 outlines the methodology employed in this paper. Section 4 presents the results, which include the impact of different risk-related TC variables on the execution of project activities. Section 5 provides an analysis of government approaches to reducing risk. The conclusions are presented in Section 6.

2. Literature Review

The primary objective of developing risk mitigation strategies is to reduce the occurrence of risks and achieve efficient risk management. Risk mitigation strategies typically encompass reactive measures that are implemented as contingency plans following the occurrence of risks, as well as proactive measures that are implemented to lessen risks before they arise [25]. Proactive mitigation techniques, unlike reactive approaches, take into account the reduction in both the likelihood and the consequences of risks before they happen [26]. Proactive measures are more effective than reactive ones, necessitating that risk managers promptly address critical risks [27]. Kartam and Kartam [28] acknowledge that effective risk management involves taking measures to decrease the likelihood of risk events occurring.

Stakeholder involvement is essential for reducing risks in energy retrofitting projects. Stakeholders are the primary contributors to risk in projects [29]. Stakeholders in projects face risks that arise from their actions and behaviours. However, these stakeholders are also the most important assets when it comes to reducing or managing these risks [29]. Enhancing stakeholder behaviours in retrofitting projects can effectively decrease the likelihood of risk occurrence. TCs are a crucial determinant of stakeholders' performance in projects. The successful attainment of project goals and objectives, which is the primary aim of risk management, relies on the successful execution of the designated tasks and activities at each step [30]. The project activities associated with risks result in several TCs, including expenses for looking for project partners and retrofitting solutions, costs for negotiating with other project parties, and expenditures for monitoring technology installation and use. One of the primary challenges in measuring TCs is that the majority of transactions do not occur when TCs are high [31]. High TCs might hinder the implementation of risk-related project activities, not only obstructing project progress but also potentially leading to the occurrence of risks.

The participation of governments is essential for the effective execution of extensive energy retrofitting initiatives, particularly in the residential construction sector [21]. The implementation and promotion of residential energy retrofitting are ineffective without the advice and support of governments [23]. Specifically, private residences in China primarily undergo passive renovations under the guidance of the local government. The primary focus of residential energy retrofitting in China is on historic multi-owner apartment buildings. Homeowners possess individual ownership of their apartments and collectively share ownership of the communal areas within a building, but the land itself is owned by the state. Government finance is the primary source of funding for retrofitting projects in China [3,32]. In China, the government takes on the role of leader and sponsor for retrofitting projects. They not only work to stimulate the demand and supply of energy-efficient products and services in the retrofitting market, but also make decisions regarding the implementation and task actions for each individual retrofitting project.

The project governance structure encompasses the policies, methods, standards, procedures, and guidelines that constitute a framework for managing and overseeing project activities in energy retrofitting projects. Risk management is implemented within this governance framework. The total expenses associated with an institution can be divided into two main components: the costs involved in establishing the institution and the costs incurred in carrying out transactions inside the institution [33]. This study considers TCs as transaction costs within an organisation, namely the additional fees incurred by the government in carrying out risk-related activities in energy retrofitting projects. TCE proposes that three key factors in a transaction contribute to transaction costs: the level of asset specificity, uncertainty, and transaction frequency [34–36]. This study considers these three transaction characteristics as dimensions of risk-related transaction cost barriers to government-run projects.

2.1. Asset Specificity in Project Activities Related to Risks

Asset specificity is the term used to describe an investment that is highly specialised and cannot be easily used for other purposes or by other users without losing its productive value [37]. The relocation of the particular investment involves significant expenses associated with changing or transferring resources [38]. Asset specificity is linked to three factors: site specificity, human asset specificity, and physical asset specificity [39]. Site specificity refers to the location where the transaction parties are involved in a specific transaction. Human asset specificity refers to the specific knowledge possessed by staff members that is relevant to a transaction. Physical asset specificity refers to the specific actions or inputs required for a particular transaction. The assets discussed in this paper mostly consist of human assets and physical assets. Efficient risk mitigation can be attained through proficient project execution. The organisational risk management skill is the most crucial and particular asset in risk management [40]. Likewise, the level of asset specificity in risk-related project activities is contingent upon the government's ability to carry out these activities.

Barriers to conducting risk-related project activities can be defined as obstacles to risk management. Table 1 presents a concise overview of the obstacles that hinder the implementation of project risk management. These barriers are categorised as follows: inadequate learning and training, conflicting strategies, insufficient information, contextual limitations, and resource constraints. The ability to manage risk is implemented through both experience in risk management and the level of maturity in risk management mechanisms, which are also evident in these barriers [40]. A scarcity of proficient and adept specialists is one indication of limitations in resources. The deficiency in education and training is somewhat connected to the level of development in risk management mechanisms. Similarly, the particular asset examined in this study, the government's capacity to carry out project activities, can be seen as the experience in executing risk-related project activities and the level of proficiency in managing risk-related project activities, both of which have an impact on TCs. The transferable experience and knowledge of buyers contribute to the reduction in purchase transaction costs [41]. The mechanism serves as a crucial focal point for learning. Accumulating and storing knowledge can effectively develop capacities, based on designed methods [42]. A mature mechanism can efficiently decrease the costs associated with learning. Thus, the initial hypothesis is formulated as follows:

H1: *Asset specificity impedes the government's ability to undertake risk-related project activities. Specifically, lack of experience and immature operations hamper the government's actions in these activities.*

Table 1. Barriers to risk management implementation and TC implications in the retrofitting context [43–47].

Types	Barriers to Risk Management Implementation	TC-Related Barriers to Risk-Related Activities (by Authors)
Lack of learning/training	Lack of formal training to understand risk management	Asset specificity-Maturity in the operation of risk-related project activities
	Shortage of knowledge/techniques on risk management	
	Resistance to learning something new	
Divergence of strategies	Lack of top management support	Uncertainty-U1: Resistance of other cooperation units U2: Resistance of the residential community
	Lack of consistency in risk control strategies	
	Inappropriate risk allocation	
Information insufficiency	Resistance to talking about risks	Uncertainty-U3: Design complexity U4: Construction complexity
	Insufficient risk and project information	
Contextual restrictions	Lack of organisational culture for risk consciousness	Uncertainty-U5: Stability of supportive policies
	Conflicts among different functions	
	Unstable organisational environment	
	Low degree of mandatory risk management	
	Ineffective monitoring	
	Lack of government legislation	
Resource constraints	Time constraints	Uncertainty-U6: Urgency of energy retrofitting missions U7: Rigidity of limited time and costs
	Cost and budget constraints	
	Shortage of experienced and skilled professionals	Asset specificity-Experience in performing risk-related project activities

2.2. Uncertainty of Project Activities Related to Risks

The execution of the project is susceptible to environmental uncertainty. Environmental uncertainty pertains to unforeseen alterations in the environment in which an exchange occurs [48]. The idea is multidimensional and encompasses both the overall market and specialised business contexts [49]. The energy retrofitting industry in China is currently underdeveloped, and retrofitting projects involving several stakeholders are complex, leading to the presence of environmental uncertainty in project activities. Environmental uncertainty in this study refers to external elements that are outside the control of local government staff when they carry out risk-related project activities. It is the opposite of specific assets, which are internal factors originating from the government itself. Environmental uncertainty is determined by two sources: obstacles to the execution of risk management as described in the literature, and the process of implementing residential energy retrofitting projects.

Previous research has highlighted barriers to risk management, as shown in Table 2. These barriers can offer insights into the environmental uncertainty associated with risk-related activities in residential energy retrofitting projects. The barriers that arise from differences in strategies, lack of information, contextual limitations, and resource limitations are related to uncertainties about the market and project environment. These uncertainties include the level of policy support, resistance from other parties involved in the project, the complexity of the project, and constraints related to time and cost.

Table 2. Environmental uncertainty identified from the implementation process of retrofitting projects.

Stage	Retrofitting Work with Uncertainty	Environmental Uncertainty from a TCs Perspective (by Authors)
Regional survey and project setup	Making an agreement with homeowners for retrofitting [50]	U8: Integrity of agreement provision
	Evaluation and measurement of retrofitting feasibility [51]	U9: Competence of experts for safety appraisal of buildings U10: Detectability of building quality
Project design and budget estimation	Design company selection [52]	U11: Availability to qualified design companies
	Formulation of retrofitting schemes [53]	U12: Ambiguity of energy efficiency standards U13: Competence of experts for drafting standards
Construction bidding and fund appropriation	Material selection [54]	U14: Abnormality in the building material market U15: Maturity of material technology
	Construction company selection [16]	U16: Ambiguity of criteria for construction companies U17: Availability to qualified construction companies
On-site construction	Construction inspection and supervision [55]	U18: Detectability of construction quality
Inspection, acceptance, and use	Retrofitting evaluation for acceptance [56]	U19: Ambiguity of acceptance criteria
	Building maintenance after retrofitting [57]	U20: Availability to property management companies U21: Ambiguity in quality warranty responsibilities

Environmental uncertainty can impact the execution of energy retrofitting initiatives. Table 2 showcases the research that has been carried out on uncertainty, as highlighted by previous studies. These tasks, which involve uncertainty, can indicate the existence of environmental uncertainty in government-performed project activities. Combining with the Chinese retrofitting context, Table 2 also presents the uncertain elements associated with these tasks, taking into account the market and project environment. These aspects are considered environmental uncertainty in the execution of risk-related project activities.

The issues arising from environmental uncertainty typically stem from limited rationality, imbalances in information, and the risk of opportunistic behaviour. Uncertainty can be changed and decreased by enhancing the level of understanding [58]. Data gathering can assist the government in reducing the unpredictability associated with risk management. Nevertheless, elevated transaction costs will limit the ability of decision-makers to gather information, forcing them to make decisions in a state of uncertainty [58]. Due to the presence of uncertainty, it is not possible to write contracts in a comprehensive manner, which in turn results in an increase in ex-post transaction costs [59]. Consequently, the government must incur more expenses for enforcing and monitoring in order to counterbalance the unpredictable outcome of project activities conducted in an uncertain condition. Furthermore, the presence of environmental uncertainty necessitates the processing of vast amounts of information in order to achieve a certain objective [60]. In order to address this level of uncertainty, participants in an exchange have to allocate resources towards acquiring specialised assets that enhance their ability to process information effectively [61]. This study introduces the second hypothesis in the following manner:

H2: *Environmental uncertainty prevents the government from performing risk-related project activities.*

2.3. Frequency of Project Activities Related to Risks

The frequency of transactions has a significant impact on transaction costs, especially when the goods involved are specific to each transaction [34,59]. The presence of a well-designed process and contract enables frequent transactions between the same parties, resulting in reduced transaction costs by leveraging standardised procedures [59]. According to the notion, the entities participating in repeated transactions share similarities, and standardised models and procedures can be utilised across several transactions. As the number of transactions increases, the fixed investment in establishing procedures can be distributed over more transactions, resulting in greater investment benefits [58].

The government's response to risk-related project activities in each project can be seen as a transaction. While the parties involved in various projects, such as homeowners and contractors, may differ, they share common characteristics, particularly in projects situated in the same geographical area. China has standardised procedures for selecting retrofitting projects and design requirements within each province. Municipal government often executes these projects using a standardised and uniform approach, which includes engaging with the public, soliciting bids from partners, and allocating departmental responsibilities. This implies that policies and standardised procedures can be created and established for all retrofitting projects within a specific area. Obtaining effective risk management in construction projects cannot be achieved by a single transaction; it requires a significant amount of time to develop [62]. As a result, regions or urban areas with extensive experience in energy retrofitting initiatives are more inclined to establish standardised protocols for managing risk-related project activities in order to decrease the TCs per unit. The third hypothesis is formulated in the following manner:

H3: *The government's improved performance in risk-related project activities is attributed to the frequent implementation of retrofitting projects.*

3. Research Methodology

This section offers a thorough explanation of the methods used in this study, and the research design is depicted in Figure 1. Initially, a conceptual framework is developed, which consists of three hypotheses derived from transaction cost economics (TCE). The purpose of this framework is to investigate the obstacles that prevent the government from engaging in risk-related project activities. Furthermore, this study constructs a set of metrics to measure asset specificity, uncertainty, frequency, and behavioural intentions towards risk-related project activities. Subsequently, a questionnaire survey is carried out to empirically analyse these metrics. Furthermore, both exploratory factor analysis (EFA) and artificial neural networks (ANN) are utilised to confirm the impact of risk-related TC variables on the execution of project activities. Ultimately, this study combines the government's duty in risk management to effectively mitigate the risks associated with retrofitting projects.

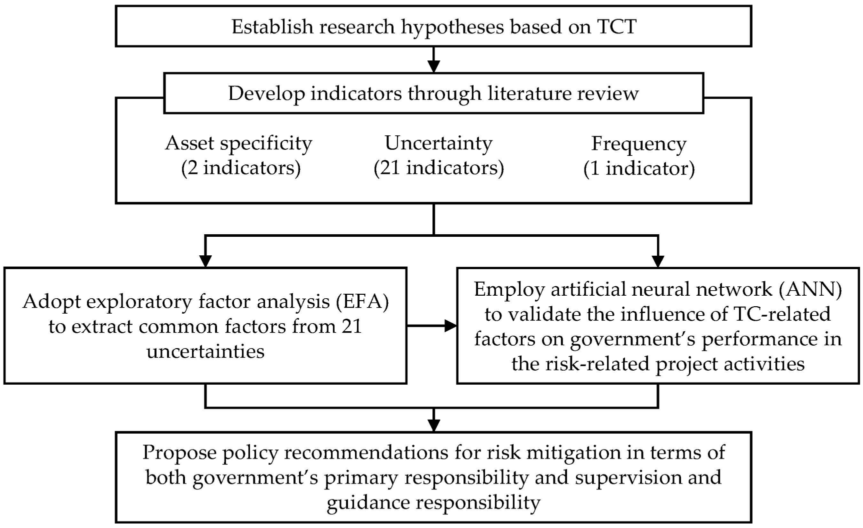

Figure 1. Research Design.

3.1. Questionnaire Survey Procedure and Sample Size

Anhui Province in China was chosen as the research region to represent residential energy retrofitting in the HSCW zone. Anhui Province is among the provinces that have implemented residential energy retrofitting in the HSCW zone at an earlier stage. Since 2016, the provincial administration has actively promoted the implementation of energy efficiency measures in residential structures across the entire province. Anhui Province has greater expertise in residential energy retrofitting compared to other provinces in the HSCW zone. Anhui Province's latest energy-saving plans for buildings (2021–2025) maintain a strong focus on residential energy retrofitting as a primary priority.

The questionnaires were sent electronically in March and April 2020 to government personnel from 9 cities in Anhui Province through social software workgroups. The selection of these cities was based on their status as pioneers in residential energy retrofitting projects in the province, which has provided them with a wealth of experience in comparison to other cities. Each municipality typically employs around 10 to 15 government personnel who are actively engaged in retrofitting initiatives. All survey participants are employed by the local Department of Housing and Urban-Rural Development and serve as government representatives in local residential energy retrofitting projects. The decision to use the questionnaire method was based on its capacity to systematically gather measurable data from a particular population directly involved in the initiatives. This approach ensures that valuable and significant insights are obtained regarding the factors that influence their behavioural intentions towards the risk-related activities of these projects. Questionnaire surveys are extensively utilised in behavioural decision-making research for data collection [63,64].

Although the survey was conducted in 2020 during the COVID-19 pandemic, the accuracy of the data was guaranteed. This was achieved by sending questionnaires through TencentQQ v9.0.7.24121 to the specific workgroups of the department responsible for residential energy retrofitting. This ensured that all relevant staff members could participate and confirmed that the respondents precisely matched the target audience. Furthermore, the significance of the data continues to be relevant in the current day, as the legal and administrative framework that governs household energy retrofitting has remained basically unaltered since 2020 [65]. The stability of the legislative environment guarantees that the insights obtained from the data remain up-to-date and accurately represent the current practices and problems in the area. Liu et al. [65] found that obstacles to building energy retrofitting continue to exist, with elements that were recognised as hindrances to stakeholder participation a decade ago still being widespread today. Furthermore, in projects subsequent to 2020, the government generally abides by established protocols while carrying out activities in retrofitting projects. Hence, the study's findings, derived from data gathered throughout this timeframe, offer a reliable and strong foundation for comprehending current patterns and guiding policy choices in the field of energy efficiency.

The questionnaire is divided into two pieces. Initially, the participants were requested to provide essential details such as the number of years they had worked in government offices, their educational qualifications, and their involvement in residential energy retrofitting projects. These details are presented in Table 3. Furthermore, participants were directed to assess three specific types of variables, namely the government's behavioural intents towards risk-related project activities, asset specificity, and environmental uncertainty. Meanwhile, this study inquired about the perspectives of the questionnaire participants regarding the management responsibility for each risk. The participants were asked about the risks for which the government takes on the main responsibility of management, the risks that can be assigned to other stakeholders as the primary managers, and the specific roles that the government plays in managing these risks.

Table 3. Basic information on survey respondents.

Variables		Frequency	Percent
Years of work experience in government departments	Below 5	35	40%
	5–10	30	34%
	Above 10	23	26%
Education	Junior college or lower	18	20%
	Bachelor	62	70%
	Master or above	8	10%
Number of energy retrofitting projects they have been involved in	1–3	41	46%
	4–5	20	23%
	6–10	14	16%
	Above 10	13	15%
Total		88	100%

A total of 118 questionnaires were ultimately filled out, out of which 88 were deemed suitable for data analysis. In order to maintain the quality and precision of the questionnaires, this survey included a preliminary question to determine whether respondents have prior expertise in residential energy retrofitting. In addition, all participants were asked to assess their understanding of residential energy retrofitting in their respective city using a five-point scale ranging from 1 to 5, with 1 representing no information at all and 5 indicating a high level of expertise. Individuals who provided scores below 3 were not included.

3.2. Variable Identification and Measurement

3.2.1. Behavioural Intentions towards the Risk-Related Project Activities

This study integrates professional risk assessment with homeowners' risk perceptions to establish risk priorities. Table 4 displays a total of 13 risks that managers need to prioritise. Jia et al. [1,66] identified these risks using a combination of expert risk assessment and public risk perception gathered from interviews and questionnaire surveys. Jia et al. [1] identified 10 primary risks, as presented in Table 4, that are considered crucial in the entire process of residential energy retrofitting projects in the HSCW zone of China. These risks were determined through the evaluation of experienced professionals in the field. Table 4 also displays seven risks that homeowners view as highly significant, as identified by Jia et al. [66]. Similar to the viewpoints of Emami-Naeini et al. [67], the general public expresses greater apprehension about certain risks that specialists perceive as relatively unimportant. Nevertheless, even individuals with expertise might exhibit bias when assessing risks [68]. The insights of the general population should be esteemed and valued [69]. By incorporating a broader spectrum of expertise, including both specialists and non-experts, into the process of risk assessment, the likelihood of drawing erroneous conclusions due to limited and insufficient information is minimised [70]. Thus, this study integrates the evaluation of risks by experts with the perception of risks by homeowners in order to establish the order of importance of different risks. Every risk is independently managed as an individual, with the exception of two risks: poor performance in cooperation and opportunistic renegotiation. These two risks pertain to the homeowners' disposition towards collaboration during the on-site development and are therefore combined for analysis. The participants of the questionnaire survey were initially prompted to evaluate the government's behavioural intention towards the project activities related to these risks using a 5-point Likert-type scale.

Table 4. Risks with a high priority to be mitigated in China.

No.	Risks	Expert Risk Assessment [1]	Homeowners' Risk Perception [66]
R1	Lack of awareness of energy efficiency retrofitting	√	
R2	Lack of technical staff with specific expertise	√	√
R3	Lack of appropriate technical standards	√	
R4	Unqualified building materials		√
R5	Lack of construction skills	√	
R6	Moral hazard		√
R7	Poor quality of old residential buildings themselves	√	√
R8	Poor construction management	√	
R9	Poor safety management	√	√
R10	Poor performance in cooperation	√	
	Opportunistic renegotiation	√	
R11	Inadequate maintenance	√	√
R12	Difficulties in post-retrofit repair		√

Note: "√" means that this risk is given the priority in a study.

3.2.2. Asset Specificity

The ability to manage risk can be implemented through both practical experience in risk management and maturity in the risk management mechanism [40,71]. Similarly, the specific asset examined in this study, the government's capacity to carry out project activities, can be seen as the experience in executing risk-related project activities and the maturity in the operation of risk-related project activities. The level of asset specificity is assessed on a five-point scale by the survey respondents in two areas: the experience in carrying out risk-related project activities (AS1) and the maturity in the operation of risk-related project activities (AS2).

3.2.3. Environmental Uncertainty

Environmental uncertainty arises from two distinct sources: the presence of obstacles to the application of risk management strategies as described in the literature and the actual process of implementing residential energy retrofitting projects. Tables 1 and 2 present the identification of 21 factors that contribute to the environmental uncertainty in project activities related to residential energy retrofitting. Respondents in the questionnaire survey were asked to assess the level of uncertainty using a five-point scale ranging from 1 to 5.

3.2.4. Frequency

The frequency of retrofitting transactions is quantified by the number of residential energy retrofitting projects that were completed in each city in 2019. Since 2018, Anhui Province has initiated the implementation of energy retrofitting for residential structures in additional cities. In 2019, there was a notable expansion in the scope and a substantial rise in the quantity of retrofitting projects. All the projects performed in 2019 were executed under identical and most recent policy and market conditions. This study quantified the quantity of retrofitting initiatives carried out in 2019 in individual cities and correlated this information with the survey respondents from various cities.

3.3. Data Analysis

3.3.1. Exploratory Factor Analysis (EFA)

Exploratory factor analysis (EFA) is conducted using SPSS 25.0 to statistically determine the inherent relationships among the variables within the group of uncertainty. The objective is to simplify these variables by identifying a limited number of principal components. This study utilises EFA to statistically identify shared characteristics across 21 uncertainties and categorise these uncertainties into distinct common factors. EFA aids in comprehending the organisation of the data, diminishing the quantity of input variables, and guaranteeing that the inputs to the artificial neural network (ANN) have the most pertinent and significant characteristics [72,73]. The study further incorporated EFA, which serves as the foundation for ANN. To minimise redundancy, the variance of the output variable can be described with the fewest input variables [74]. The outcome of the EFA is utilised to ascertain the input variables of the ANN model. It was suggested to have a range of 5 to 10 participants per variable for EFA [75]. The ultimate ratio of instances to variables employed for EFA is 5.9, which falls within the specified range.

3.3.2. Artificial Neural Network (ANN)

The study utilises an ANN model implemented through SPSS software to assess the impact of TC-related factors on government performance in risk-related project activities and to establish a ranking of these elements. ANNs are highly efficient for predictive data mining applications because they possess attributes such as rapid information processing, mapping capabilities, fault tolerance, adaptability, generalisation, and resilience [76]. The aim of this study is to identify both associative and causative correlations and evaluate the prediction ability of TC-related factors on government performance in risk-related project activities, aligning with the data analysis objectives of previous studies [77,78]. This study utilises ANN to make use of its powerful capabilities in analysing complex data, based on the proven effectiveness of ANN in other research areas.

In this study, the Multilayer Perceptron (MLP) algorithm is utilised to construct the ANN model. MLP, short for Multilayer Perceptron, is a widely used approach for tackling issues that involve regression. The MLP network consists of three layers, as shown in Figure 2: the input layer, the hidden layer, and the output layer. Every layer consists of nodes, also known as neurons, which analyse inputs and transmit their outputs to the subsequent layer. This initial layer receives the input variables directly from the data set, which are key factors identified from the questionnaire survey related to asset specificity, uncertainty, and frequency. The ultimate output node delivers the forecast of the government's inclination towards project activities associated with risks. In this study, the SPSS neural network was used to implement the automatic architectural technique in order to determine the optimal network structure. Consequently, the automatic selection procedure was employed to identify the ideal number of neurons in the hidden layer.

This paper implemented two neural networks for each risk, utilising one hidden layer and two hidden layers correspondingly. A standardised method is considered to be a rescaling technique for scale-dependent variables, aimed at enhancing network training. The original dataset was partitioned into two subsets: one for training and one for testing. In total, there are 88 unique datasets that include samples collected from 9 different cities. A random selection of at least 20% of the samples in each city was made to form the 'testing dataset', while the remaining 80% were designated as the 'training dataset'. The training and testing of all models were conducted using identical datasets. Due to the limited size of the samples, the batch training method was chosen to handle the records. The synaptic weights were estimated using the Scaled Conjugate Gradient optimisation technique.

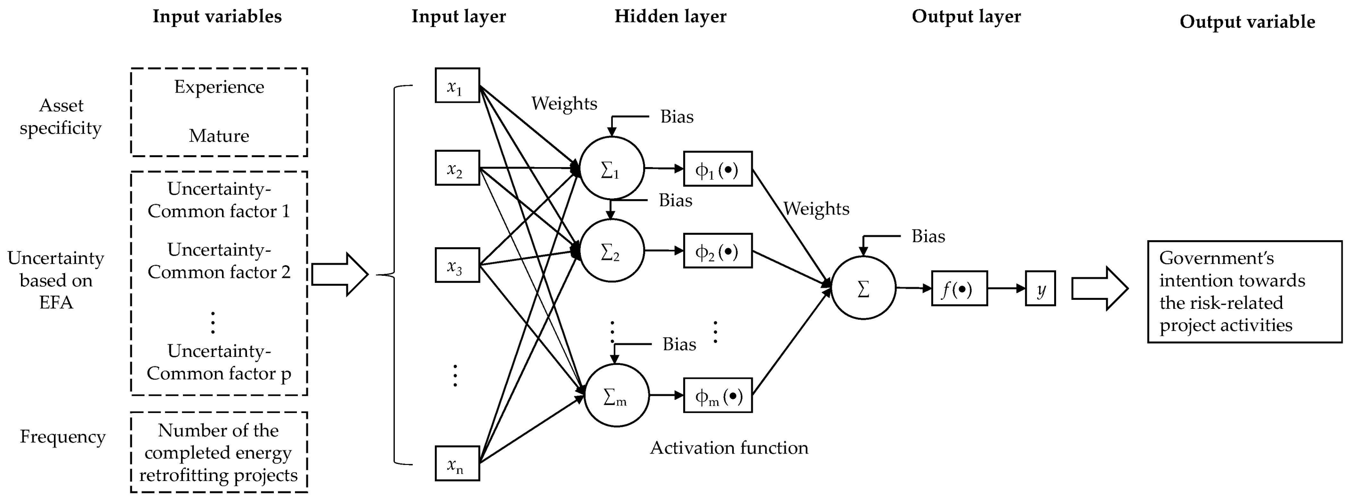

Figure 2. Structure of the three-layer MLP neural network.

The performance of each model was assessed by calculating the Root Mean Square Error (RMSE) for both the training and testing datasets. The selection of the best fit model for each neural network is based on two criteria: the RMSE values for both training and testing should be similar and small. The RMSE is computed using the following formula:

$$\text{RMSE}_{training} = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{n}} \quad (1)$$

$$\text{RMSE}_{testing} = \sqrt{\frac{\sum_{j=1}^{m}(\hat{y}_j - y_j)^2}{m}} \quad (2)$$

where $\hat{y}_i/\hat{y}_j$ and y_i/y_j are the ith/jth predicted and actual outputs in the training/testing dataset, respectively; n/m is the number of training/testing cases.

The neural networks for each risk were represented by two best-fit models, one with a single hidden layer and the other with two hidden layers. The ultimate model for each risk was subsequently chosen from these two models. Furthermore, alongside RMSE, another performance metric called Mean Absolute Percent Error (MAPE) was utilised to compare models that had identical RMSE values. MAPE is defined as follows:

$$\text{MAPE}_{training} = \frac{1}{n}\left(\sum_{i=1}^{n}\frac{|y_i - \hat{y}_i|}{y_i}\right) \times 100\% \quad (3)$$

$$\text{MAPE}_{testing} = \frac{1}{m}\left(\sum_{j=1}^{m}\frac{|y_j - \hat{y}_j|}{y_j}\right) \times 100\% \quad (4)$$

where $\hat{y}_i/\hat{y}_j$ and y_i/y_j are the ith/jth predicted and actual outputs in the training/testing dataset, respectively; $\overline{y}_i/\overline{y}_j$ is the mean of the actual values in the training/testing dataset; n/m is the number of training/testing cases.

4. Results

4.1. Uncertainty Classification Based on EFA

According to the mean values of 21 uncertainty indicators, this study first deleted 6 uncertainties with a mean of less than 3, including U1, U2, U5, U9, U13, and U21. The results of the KMO and Bartlett's tests for 15 uncertainties are shown in Table 5. The KMO value is 0.835, suggesting that the variables are interrelated. Bartlett's sphericity test shows that the overall significance of the correlation matrix is 0.000, which means that the data matrix has sufficient correlation for the purpose of factor analysis. Therefore, factor analysis is considered to be appropriate for these variables.

Table 5. KMO and Bartlett's test.

Kaiser -Meyer-Olkin Measure of Sampling Adequacy	Bartlett's Test of Sphericity		
	Approx. Chi-Square	df	Sig.
0.835	689,242	105	0.000

Table 6 presents the final extracted factors, the uncertainty indicators of each factor, and the corresponding statistical data. After the rotation, four factors are extracted and explain 68.32% of the variance in the data with eigenvalues of more than 1. The communalities for retained variables range from 0.55 to 0.83, indicating that these variables can be fairly well explained by the extracted factors.

Table 6. Results of exploratory factor analysis.

Components/Variables	Factor Loading	Eigen Value	Variance Explained %	Communalities
Retrofit complexity and quality (FAC1)		3.35	22.32	
U3 Design complexity	0.83			0.83
U4 Construction complexity	0.80			0.76
U18 Detectability of construction quality	0.76			0.76
U20 Availability to property management companies	0.70			0.61
U10 Detectability of building quality	0.69			0.69
Retrofitting market maturity (FAC2)		3.12	20.80	
U14 Abnormality in the building material market	0.85			0.76
U15 Maturity of material technology	0.80			0.71
U17 Availability to qualified construction companies	0.66			0.62
U16 Ambiguity of criteria for construction companies	0.59			0.55
U19 Ambiguity of acceptance criteria	0.56			0.62
Costs and time restrictions (FAC3)		2.30	15.35	
U7 Rigidity of limited time and costs	0.80			0.73
U6 Urgency of energy retrofitting missions	0.67			0.55
U8 Integrity of agreement provision	0.62			0.64
Design basis (FAC4)		1.48	9.85	
U12 Ambiguity of energy efficiency standards	0.79			0.73
U11 Availability to qualified design companies	0.75			0.70

The results of EFA show that U3, U4, U10, U18, and U20 are given high factor loadings on retrofit complexity and quality (FAC1). The variables U3, U4, U10, and U18 are related to the complexity of the retrofitting implementation and influence retrofitting quality. The high factor loading of U20 on FAC1 may also be influenced by the poor quality of old residential buildings. Quality problems omitted beforehand would become the responsibility of property management companies, so they would have to bear great losses, leading property management companies to be reluctant to take over old residential communities.

U14, U15, U16, U17, and U19 are classified as retrofitting market maturity (FAC2). These uncertainties are all related to the maturity of the retrofitting market, involving energy-saving materials and retrofitting construction companies. Moreover, the acceptance standard of retrofitting projects also goes into the same category as the technical standards in the energy retrofitting market and is an important criterion for judging the completion of retrofitting tasks.

U6, U7, and U8 are heavily dependent on costs and time restrictions (FAC3). Both U6 and U7 are related to the time limit of the retrofitting project. Meanwhile, U8 may also be affected by the limited construction period, resulting in insufficient time to negotiate with homeowners and propose a complete retrofitting protocol.

U11 and U12 are grouped into design basis (FAC4). These two uncertain factors are associated with energy-saving design, including design standards and designers.

4.2. Effects of TC-Related Factors Based on ANN

The values of RMSE and MAPE of 24 models for 12 risks are shown in Appendix A. There are two models for each risk, involving one hidden layer and two hidden layers. For each risk, the values of RMSE and MAPE were compared between two models to select the one with the best fit. The final model for each risk is also highlighted in Appendix A.

Table 7 presents the normalised importance of TC-related variables in the 12 final models. The larger the percentage, the more important the factor is to participation in project activities. The top three factors for each risk are highlighted in Table 7. To further understand the relationships between these factors and government performance in project activities, this paper visualised the functions fitted by neural network models. Taking examples of R2 and R3 that are mainly affected by the same TC-related factors, Figure 3 plots the relationships between the top three independent variables (Maturity, FAC3, and FAC1) and the predicted value of the dependent variable. More plots are shown in Appendix B.

Table 7. Normalised importance of independent variables in models.

	Asset Specificity		Uncertainty				Frequency
	Experience	**Maturity**	**FAC1**	**FAC2**	**FAC3**	**FAC4**	
R1	41.9%	**100.0%**	22.3%	46.7%	**57.2%**	**51.5%**	41.7%
R2	40.8%	**100.0%**	**41.0%**	34.5%	**48.1%**	36.5%	12.4%
R3	15.3%	**100.0%**	**28.4%**	20.0%	**37.1%**	20.1%	12.9%
R4	17.3%	**100.0%**	18.8%	**32.4%**	**38.4%**	26.3%	26.5%
R5	**100.0%**	**93.1%**	**71.2%**	22.6%	41.1%	32.5%	20.8%
R6	**45.0%**	**100.0%**	**34.1%**	16.0%	27.8%	10.6%	21.1%
R7	**80.9%**	**100.0%**	**55.5%**	17.0%	8.0%	18.7%	13.0%
R8	**76.7%**	**100.0%**	**80.7%**	46.2%	66.9%	2.9%	23.0%
R9	26.8%	**100.0%**	**33.6%**	**46.8%**	13.4%	16.7%	12.4%
R10	**100.0%**	**62.2%**	5.6%	20.0%	**41.2%**	12.9%	36.1%
R11	**100.0%**	**87.0%**	**41.9%**	15.6%	14.8%	13.6%	11.3%
R12	12.1%	**100.0%**	**49.1%**	**49.9%**	32.7%	19.2%	4.4%

Note: The top three factors for each risk are emphasised in boldface.

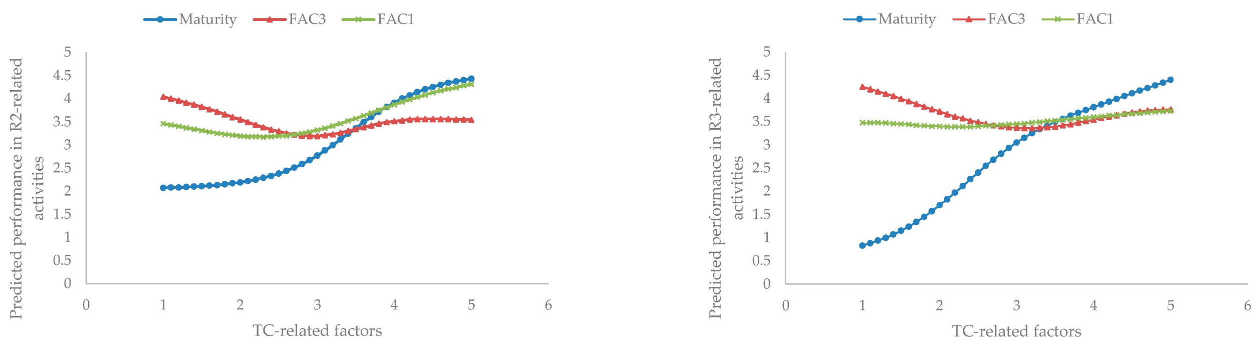

Figure 3. Effects of three top TC-related factors on performance in project activities related to R2 and R3.

4.2.1. Effects of Asset Specificity

The analysis results support hypothesis H1. Maturity in the operation is the most important factor affecting government performance in project activities. Rich experience also contributes to participation in risk-related project activities, but the difference is that experience does not improve government performance in project activities related to all risks as much as maturity does. In particular, the impacts of experience on performing the project activities related to lack of appropriate technical standards (R3), unqualified building materials (R4), and difficulties in post-retrofit repair (R12) are very small.

4.2.2. Effects of Environmental Uncertainty

The uncertainty on retrofit complexity and quality (FAC1) is directly proportional to the performance in risk-related project activities, which is contrary to hypothesis H2.

In H2, TCs caused by project complexity and quality undetectability would hinder the government to perform project activities, but this empirical study shows that these uncertainties are important drivers for activity execution. The exception is that, the role of FAC1 in performing the activities related to homeowners' cooperation (R10) is very small, accounting for only 5.6% of the most influential factor (Experience).

Contrary to FAC1, the remaining factors, FAC2, FAC3, and FAC4, impede the execution of risk-related project activities, a finding that is consistent with H2. Among these three factors, costs and time restrictions (FAC3) are the most important obstacles. The results of this study show that FAC3 is one of the three main factors affecting government performance in project activities related to lack of awareness of energy efficiency retrofitting (R1), lack of technical staff with specific expertise (R2), lack of appropriate technical standards (R3), unqualified building materials (R4), and homeowners' cooperation (R10).

Uncertainty regarding retrofitting market maturity (FAC2) is one of the main barriers to performing the project activities related to unqualified material quality (R4), poor safety management (R9), and difficulties in post-retrofit repair (R12).

The influence of design basis (FAC4) is the least among all uncertainties. The importance of FAC4 is only reflected in project activities regarding lack of awareness of energy efficiency retrofitting (R1).

4.2.3. Effects of Frequency

The impacts of frequency on activity execution are the smallest among all TC-related factors, which cannot support H3. It may be due to the fact that there is little difference in the scale of the completed retrofitting projects among more than half of the cities in the empirical analysis, which leads participation in risk management to be insensitive to frequency.

4.3. The Allocation of Risk Management Responsibility

According to respondents' views on risk allocation, more than 50% of the participants believed that the government should assume the primary responsibility for addressing the risks about homeowners' awareness and cooperation (R1 and R10), expertise of technical staff (R2), technical standards (R3), and building quality (R7). Other project parties, especially contractors, need to be in charge of other risks, and the government is responsible for supervision and guidance.

5. Discussion

This study examines government tactics for risk reduction in two distinct ways, as seen in Figure 4, taking into account the various roles of the government in addressing different risks. This section elucidates the significance of experience in carrying out risk-related activities, the level of maturity required in the execution of these activities, and the obstacles posed by expenses and time limitations that hinder government actions. These hurdles serve as the foundation for formulating government strategies to address the risks associated with homeowners' awareness and collaboration, technical staff expertise, technical standards, and construction quality. Furthermore, the established retrofitting market serves as the basis for the government's role as a supervisor and adviser in mitigating various risks.

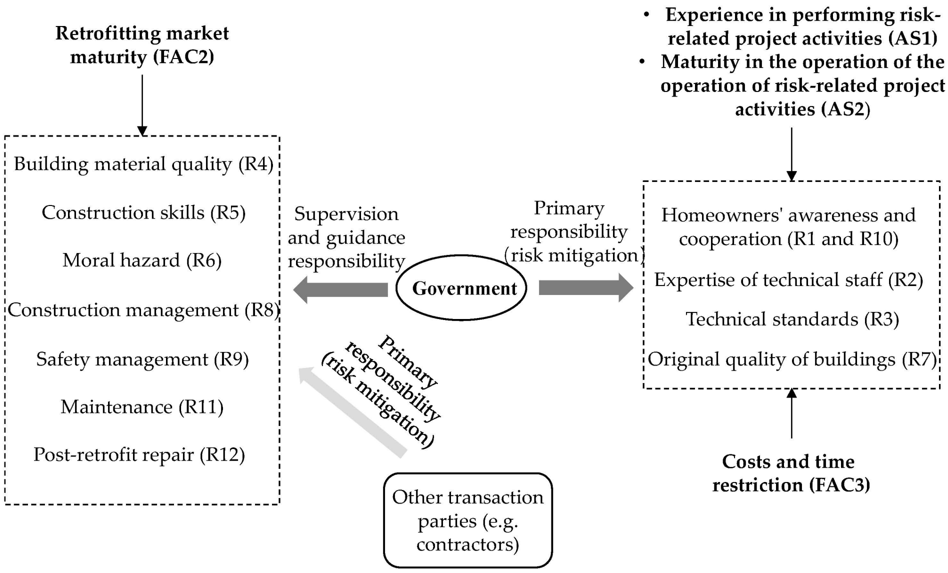

Figure 4. The government's risk management responsibilities and key barriers to performing risk-related activities (by authors).

5.1. Dominant Role of Government Capability of Activity Execution in Risk Mitigation

The government's experience in executing risk-related project activities and its level of expertise in managing such activities are crucial factors that determine the government's performance in this domain. However, it has been proven that experience has a minimal impact on the execution of activities related to risks associated with technical standards, building materials, and post-retrofit repair. Currently, China has implemented a range of policies and standards to encourage the improvement of energy efficiency in buildings. However, these policies mostly focus on new construction and are based on regulations [79]. The government's experience in developing regulations and standards for building retrofitting is mostly focused on residential buildings in China's northern heating zones and public buildings [56,79]. Developing technical standards for housing retrofitting in the HSCW zone is challenging since previous expertise cannot be readily used. For the risks regarding building materials and post-retrofit repair, the government's previous experience is indirect. In finished projects, the local government does not have direct involvement in material procurement, testing, maintenance, and repair. The construction corporations bear the primary obligations for these tasks, which could explain the limited impact of experience on the government's performance in the relevant project activities.

In contrast, the effects of maturity on activity operation are more extensive. A lack of maturity in the operation indicates that the government is likely to be unsuccessful in implementing effective measures to carry out risk-related project activities within the current operational framework. Not only does it diminish the government's trust in these efforts, but it also results in additional costs incurred from handling the consequences of unsuccessful actions. Optimising the operational mechanism of relevant activities can help alleviate hurdles to government activity execution. The survey participants concur that the government should take on the main obligation of mitigating the risks associated with homeowners' awareness and collaboration, technical staff expertise, technical standards, and building quality. Similarly, the execution of project activities associated with these risks should be streamlined to enhance government performance on the corresponding tasks.

5.2. Varying Roles of Environmental Uncertainty in Different Risks

5.2.1. Quality Objectives and Awareness of Responsibility Acting as Impetuses of Risk-Related Activities

The positive role of environmental uncertainty from retrofit complexity and quality in activity execution arises from the direct effect of these uncertainties on project quality.

Quality is a crucial factor in evaluating the success of a project based on three objectives: time, costs, and quality [80]. Project success can be hindered by the presence of environmental uncertainty that is specifically connected to project quality. In the face of significant uncertainty, the government, as the investor in retrofitting projects, can maximise their advantages by enhancing their performance in project activities to minimise the impact of these uncertainties. Huo et al. [61] also verified that addressing environmental uncertainties necessitated more targeted assets, which in turn could lead to a reduction in other expenses. Similarly, efforts to enhance homeowners' understanding and collaboration appear to be ineffective in mitigating the consequences of this lack of clarity. The improvement of homeowners' collaboration is influenced by cognitive factors and has a minimal effect on the quality of retrofitting. This also clarifies why the uncertain environmental conditions have a negligible impact on the government's efforts to promote homeowners' cooperation.

The project's intrinsic challenges include the intricacy of design and construction, as well as the ability to detect building quality. These issues are directly linked to the project selection process in its initial stages. The government is primarily responsible for project selection, and their understanding of their own obligations motivates them to carry out risk-related activities more effectively in order to minimise the effects of uncertainty resulting from project selection. These findings align with the research conducted by Jia et al. [66], which suggests that a strong sense of duty and responsibility can enhance efforts to reduce risks.

5.2.2. Selective Execution of Risk-Related Activities under the Constraints of Costs and Time

The government's investment in additional work is directly limited by the lack of flexibility in time and costs, which hinders their execution of activities. The efficacy of engaging in activities related to market context, such as public persuasion and the formulation of technical standards, cannot be swiftly enhanced. Long-term strategies, such as education, are essential for enhancing public awareness [81]. Furthermore, the process of establishing technical standards is likewise a time-consuming endeavour, spanning from the initial stage to the subsequent rechecking stage [82]. Time and expense limitations further magnify the impacts of additional obstacles. The government's assessment of three risks related to the designer's skill, technical standard applicability, and material quality is relatively low compared to their perception of other risks. However, people prefer to take proactive measures to mitigate these risks, demonstrating a high level of perception [66]. However, economic situations can also restrict people's behaviours, especially when it comes to risks that are considered significant [83]. Moreover, the government is unable to decrease the likelihood of risks that are not well perceived due to limited time and financial resources, which hinders their ability to enhance performance in project activities.

Due to the constraints of funding allocations and the workload of energy retrofitting projects, the government is unable to allocate more resources to achieve optimal performance in all aspects of retrofitting projects. This is a distinguishing feature of the model led by the local government. The local government appears to prioritise the attainment of political objectives related to the quantity of restored buildings, while showing less concern for the technological aspects of retrofitting and the resulting energy-saving impact [3]. In order to meet the necessary number of retrofitting projects within a specific timeframe, the local government is more inclined to utilise conventional energy-saving technologies. This is to ensure that the restricted financial budget can accommodate a greater number of retrofitting initiatives.

5.2.3. Mature Retrofitting Market Contributing to Activity Execution Involving Various Parties

An established retrofitting market is necessary to improve the performance of construction-related project activities and manage risks more effectively. The change in the building material sector in China necessitates the active participation of the government, building materials companies, building developers, and building consumers [84]. The government faces challenges in promptly mitigating the unpredictable aspects associated with the market. Due to the limitations of cost, time, and risk management capabilities, the government may be hesitant to allocate limited resources towards difficult tasks. Furthermore, the maturity of the retrofitting industry is accompanied by the presence of ambiguity regarding construction enterprises within the market setting. In order to enhance safety management in the construction industry, the government needs to investigate the root causes of safety issues and minimise uncertainty in the construction market. This may be achieved by ensuring that competent construction companies are responsible for maintaining construction safety. However, additional transaction costs (such as expenses for training and searching) would be generated during this process, resulting in a decrease in the economic efficiency of these activities.

Similarly, the construction company is engaged in the government's efforts to develop and refine post-retrofit repair programmes. The construction business is required to assume the responsibility of carrying out repairs within the warranty term following the retrofitting. Therefore, enhancing the maturity of the retrofitting market is crucial for achieving optimal performance in this endeavour. This includes not just construction firms that engage in repair projects, but also energy-efficient supplies and equipment. Additionally, this implies that a greater number of stakeholders in this activity are participating, resulting in a higher number of TCs paid during their interactions.

The government is responsible for overseeing and directing risk management pertaining to materials and construction. However, the uncertainty on the retrofitting market, which involves energy-saving supplies and construction businesses, restricts the government's actions in risk-related project activities. As a result, the government's effectiveness in these activities does not decrease the likelihood of the occurrence of risk. Efficient monitoring of the construction market is essential for the government's oversight of public investment projects in China [85]. This implies that the government's role in supervision should also begin with the market.

6. Conclusions and Policy Implications

The government is crucial in facilitating the successful implementation of residential energy retrofitting and plays a significant role in managing the risks associated with retrofitting projects in China. The government's ability to properly implement projects is hindered by the elevated number of TCs. The government's actions in risk-related project activities are limited by TCs, which, in turn, impede the decrease in the likelihood of risk. This study examines the hurdles associated with risks in government-run residential energy retrofitting projects, with an emphasis on TCs, in order to promote their successful implementation. It presents policy recommendations to alleviate these barriers and suggests solutions to mitigate risks.

The study utilised exploratory factor analysis (EFA) and artificial neural network (ANN) to predict the impact of three elements linked to TCs (asset specificity, uncertainty, and frequency) on the government's behavioural intentions towards project activities associated with each risk. The study conducted to develop this model affirms that the two factors of asset specificity and uncertainty have a greater influence. The primary obstacle to the efficient execution of projects is the lack of maturity in operating project activities. The primary challenges to resolve in relation to environmental uncertainty are costs and time restrictions, as well as the underdeveloped market for retrofitting. The primary source of uncertainty in retrofit projects is retrofit complexity and quality. However, rather than hindering progress, this uncertainty actually serves as a catalyst for government action.

By considering the perspectives of survey respondents on risk allocation, this study uncovers the varying roles that the government assumes in managing different risks. This study presents policy implications for risk mitigation in two ways: by emphasising the government's primary duty and its role in monitoring and guidance. These proposals aim to enhance the effectiveness of preventative efforts and alleviate the constraints of costs and time.

(1) The government should enhance the dissemination of information to ensure that homeowners have sufficient access to retrofitting information. The local government frequently fails to engage in communication with residents, resulting in a lack of cooperation among homeowners. Disseminating information on building retrofitting helps increase homeowners' motivation to engage in energy retrofitting [56]. European governments have acknowledged that the internet, TV, and radio are effective instruments for disseminating information. In addition, China possesses a sophisticated mass media infrastructure that may be utilised to disseminate comprehensive information on retrofitting over an extended period of time. This includes regular public announcements through television and radio, as well as the creation of dedicated websites that focus on retrofitting operations, projects, and initiatives.

(2) The government ought to execute retrofitting initiatives with enhanced transparency, particularly on technical and material specifications as well as professional qualifications. The most recent industry norm for energy-efficient retrofitting technologies in residential buildings in the HSCW zone of China was established in 2012. Implementing standardised technical specifications can be challenging, as technical solutions sometimes rely heavily on actual expertise gained from local retrofitting initiatives. In light of Italy and France's successful sharing of energy-saving techniques and technology through the establishment of regional energy networks, the Chinese government should also prioritise similar technological exchanges to gain valuable experience in retrofitting technology. In addition, the reduction of technical risks primarily relies on the careful selection of personnel and materials, taking into account both the project and the market. In order to guarantee the precision and rationality of such selection, the government could promote material and staff certification and build databases for energy services. The certification system has evolved into a novel kind of governance aimed at regulating the market by providing incentives for specific types of conduct [86]. European techniques involve the creation of databases that provide information about companies and experts. These databases facilitate the selection of qualified professionals.

(3) The government should prioritise the assessment of retrofitting quality through both ex-ante and ex-post evaluations. During project execution, the local government sometimes prioritises the quantity of finished projects rather than focusing on the quality and effectiveness of the retrofitting itself. Very few projects actually adhere to technical criteria when conducting energy-saving diagnoses. In such cases, the risk to the project arises from the subpar quality of the original structure. In addition, the number of completed projects is typically the main factor used to assess the achievement of retrofitting goals in China. The assessment standard for retrofitting is seldom used in practice due to its voluntary nature [56]. Greater emphasis should be placed on the energy-saving benefits that can be attained to encourage the implementation of the retrofit evaluation standard in practical settings.

(4) The government should actively pursue further financial assistance for retrofitting initiatives. Financing diversification is a method of alleviating financial limitations. It is necessary to investigate other sources of funding for retrofitting projects rather than depending primarily on government budgetary allocations at all levels. The Chinese government may contemplate implementing further incentives to enhance owners' inclination to participate in energy retrofitting, while also encouraging banking institutions to offer preferential financing services for such projects.

This study enhances the existing knowledge in the areas of barriers to project implementation and risk mitigation policies by offering a TCs lens to comprehend the impact of risk on government-run projects and examine the crucial aspects involved in mitigating risk. The theoretical framework based on TCs not only helps identify barriers that hinder effective project execution but also enhances comprehension of the underlying mechanisms of risk mitigation, hence providing a distinct perspective within the particular regional context. Furthermore, this study offers thorough policy suggestions that are specifically designed to address the unique operational and regulatory aspects of the Chinese context. These recommendations enhance the credibility and applicability of our findings, potentially improving project outcomes and broader policy frameworks. Nevertheless, this study contains certain constraints that can be resolved in future research. The mitigation measures were formulated with a focus on the government's standpoint; however, it is imperative to incorporate other project stakeholders, such as construction companies and homeowners, in the management of certain risks. Future research can investigate strategies to reduce risks by gaining a deeper understanding of the behaviours of other important participants in the project.

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Appendix A

Table A1. RMSE, MAPE, and R2 values of fitted models.

Risk	Hidden Layers	RMSE		MAPE	
		Training	Testing	Training	Testing
R1	1	0.364	0.337	10.52%	8.64%
	2 *	0.350	0.340	10.05%	8.77%
R2	1 *	0.399	0.398	11.33%	11.12%
	2	0.440	0.439	12.85%	10.98%
R3	1 *	0.337	0.337	9.24%	8.52%
	2	0.426	0.418	12.24%	5.65%
R4	1	0.472	0.400	14.41%	16.07%
	2 *	0.461	0.346	14.27%	13.31%
R5	1	0.332	0.262	10.05%	8.40%
	2 *	0.311	0.272	9.06%	8.77%
R6	1 *	0.386	0.385	11.15%	10.37%
	2	0.397	0.396	10.61%	11.99%

Table A1. *Cont.*

Risk	Hidden Layers	RMSE		MAPE	
		Training	Testing	Training	Testing
R7	1 *	0.378	0.336	13.28%	14.25%
	2	0.397	0.335	14.63%	13.54%
R8	1 *	0.438	0.437	12.73%	11.81%
	2	0.519	0.516	16.68%	9.16%
R9	1 *	0.479	0.481	12.13%	10.74%
	2	0.518	0.520	15.67%	13.37%
R10	1	0.476	0.478	20.05%	17.36%
	2 *	0.471	0.482	18.89%	15.57%
R11	1 *	0.506	0.514	14.51%	13.21%
	2	0.524	0.544	16.97%	13.98%
R12	1 *	0.500	0.477	16.56%	15.81%
	2	0.527	0.571	19.19%	15.26%

Note: "*" means the final model for each risk.

Appendix B. Effects of Three Top TC-Related Factors on Performing Project Activities Related to Each Risk

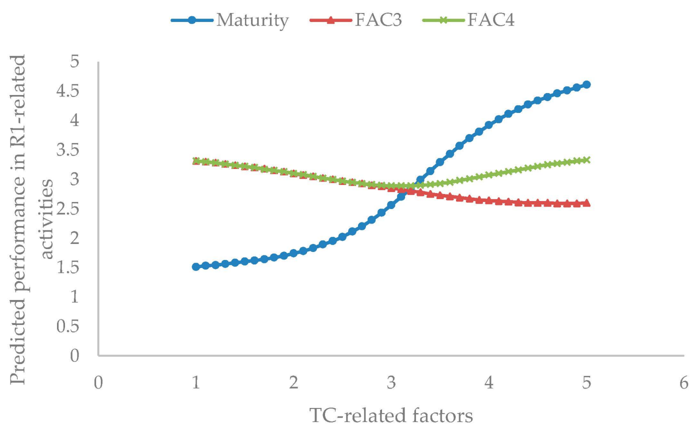

Figure A1. Effects of maturity, FAC3, and FAC4 on performance in R1-related activities.

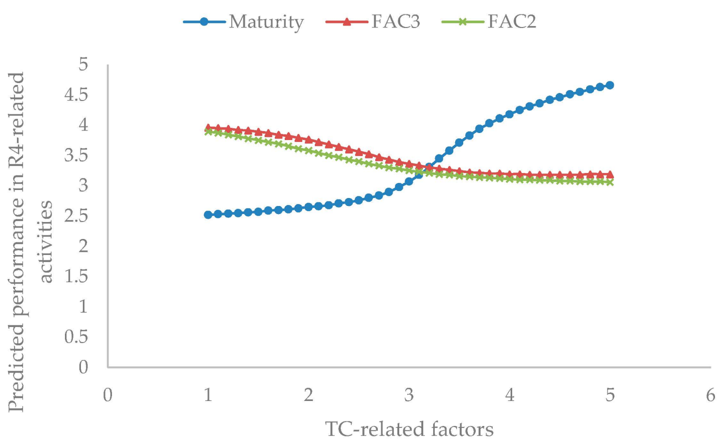

Figure A2. Effects of maturity, FAC3, and FAC2 on performance in R4-related activities.

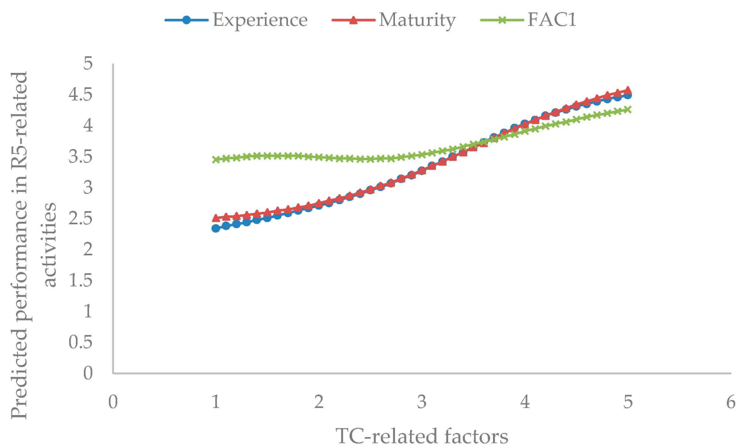

Figure A3. Effects of experience, maturity, and FAC1 on performance in R5-related activities.

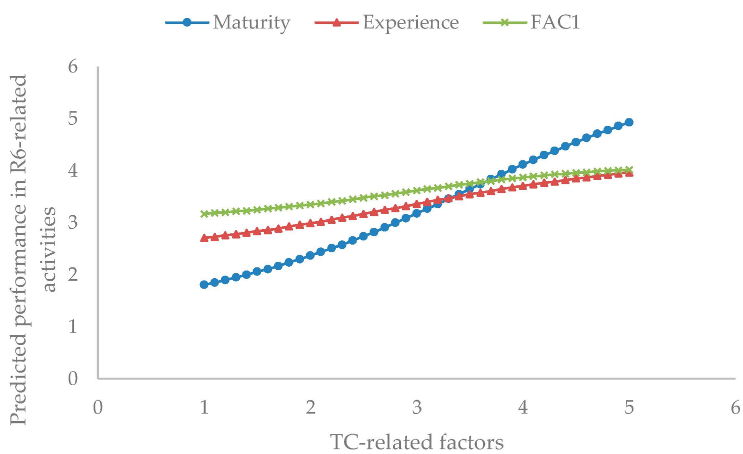

Figure A4. Effects of maturity, experience, and FAC1 on performance in R6-related activities.

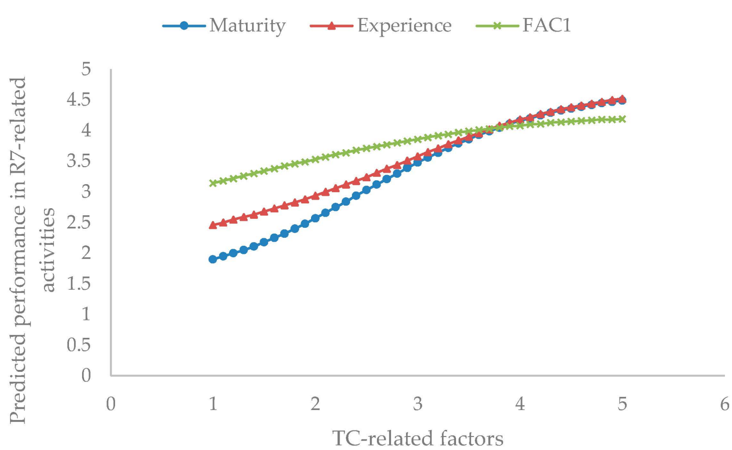

Figure A5. Effects of maturity, experience, and FAC1 on performance in R7-related activities.

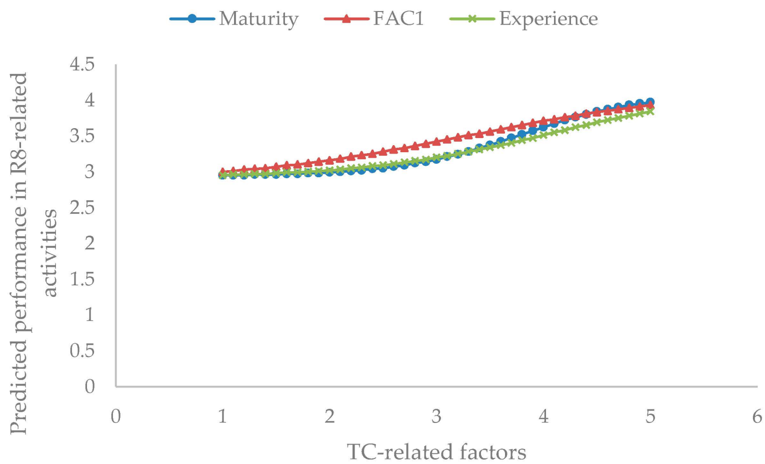

Figure A6. Effects of maturity, FAC1, and experience on performance in R8-related activities.

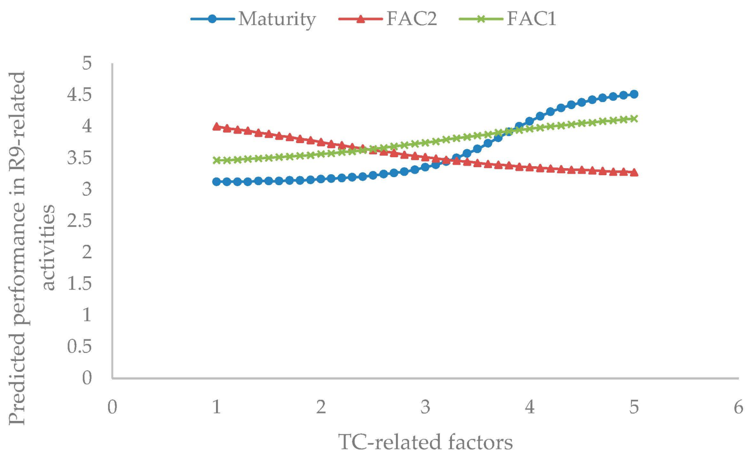

Figure A7. Effects of maturity, FAC2, and FAC1 on performance in R9-related activities.

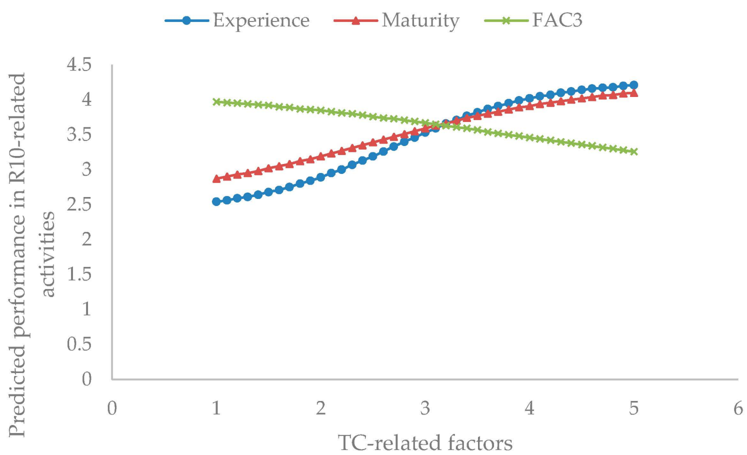

Figure A8. Effects of experience, maturity, and FAC3 on performance in R10-related activities.

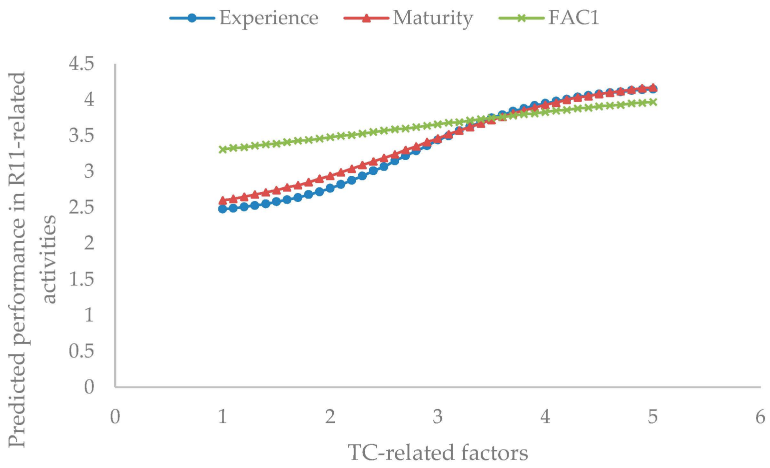

Figure A9. Effects of experience, Maturity, and FAC1 on performance in R11-related activities.

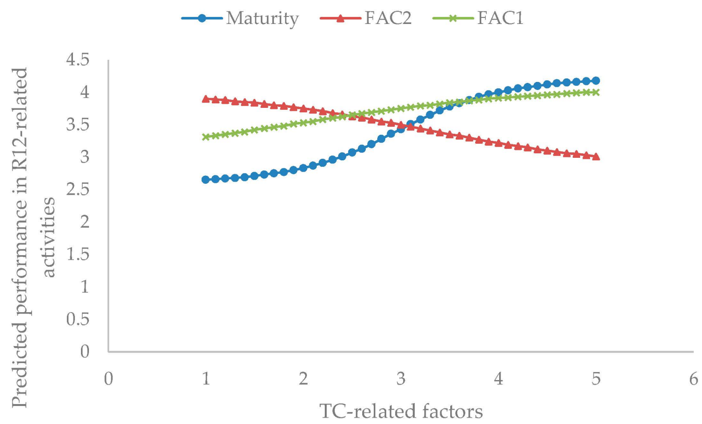

Figure A10. Effects of maturity, FAC2, and FAC1 on performance in R12-related activities.

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