Mathematics

AIMS Mathematics, 9(3): 5708–5721.
DOI: 10.3934/math.2024277
Received: 13 November 2023
Revised: 08 January 2024
Accepted: 25 January 2024
Published: 30 January 2024

http://www.aimspress.com/journal/Math

Research article

Mathematical modeling of intellectual capital asymmetric information game in financial enterprises

Bei Yuan*

School of Economics and Business, Heilongjiang University, Harbin 150080, China

* **Correspondence:** Email: 2022008@hlj.edu.cn.

Abstract: As a knowledge-intensive financial enterprise, intellectual capital can play a significant driving role in enhancing the value of financial enterprises. Especially in the current unstable and complex international financial market, it is necessary for financial enterprises to actively consider the advantages of intellectual capital to shape their competitive edge and maximize profit value. However, it is also important to consider the issue of asymmetric information within the financial system, particularly the attitudes and behaviors in the strategic interactions between governments and financial enterprises. Therefore, this paper took the strict logical structure and analytical method of game theory as an effective analytical tool to solve the problem of asymmetric information in the economy and to use the asymmetric information game method to construct a mathematical model of intellectual capital in order to cope with the mistrust in the game process. Based on game theory, this paper systematically analyzed the factors influencing intellectual capital and constructed mathematical models of game theory for adverse selection ex-ante and moral hazard ex-post, analyzing strategic behavior. The research results indicated that, from the perspectives of market reactions and financing constraints, there is an issue of information asymmetry between the government and financial enterprises. The paper also presents viable strategic recommendations for alleviating information asymmetry and achieving coordinated allocation of information resources between government and enterprises.

Keywords: intellectual capital; financial enterprises; asymmetric information; market reaction; financing constraints
Mathematics Subject Classification: 03-XX

1. Introduction

In recent years, intellectual capital, as a typical intangible asset, has been regarded as an important driving force to highlight the economic value of enterprises in the era of knowledge economy. Intellectual capital for enterprise value creation is particularly prominent in financial enterprises because, as knowledge-intensive enterprises, they face a more complex and turbulent operating environment, which requires them to keep pace with the updating of science and technology to cope with the unpredictability and uncertainty of the environment. The academic community has not formed a unified view of the concept of intellectual capital. The intellectual capital referred to in this paper denotes the sum of intellectual elements that are indispensable for a firm to create value and enhance competitive advantages, including human capital, structural capital, and relational capital [1–3]. Human capital constitutes the intangible assets accumulated by employees and managers through continuous learning and practice. Structural capital is the mechanism for enterprise members to use existing knowledge and skills to create enterprise performance, usually attached to the organizational structure, institutional norms, corporate culture, etc., which is the basis for the functioning of human capital. Relational capital represents the investments made by a firm to maintain relationships with stakeholders such as consumers, governments, financial institutions, investors, and partners during economic activities, reflecting the closeness of the ties with these stakeholders [4–7]. The three dimensions of intellectual capital are actually the different embodiments of knowledge and capabilities in the growth process of an enterprise, providing the source and impetus for its development as the value driver of an organization. With the advent of the digital economy era, knowledge-intensive enterprises are compelled to seek more reliable sources and improve productivity and competitive advantages by focusing on knowledge capital that is difficult to imitate.

In the relevant literature, intellectual capital has been found to be successful in contributing to the economic wealth creation of financial enterprises [8]. Increased investment in intellectual capital by financial enterprises has been able to increase firm productivity as measured by asset turnover (ATO) and employee productivity (EP); there is a significant positive correlation between efficiency in the use of intellectual capital and the profitability of financial enterprises; and the higher the quality of intellectual capital of financial enterprises, the better they are able to fulfill the social needs [9–12]. Upon reviewing and summarizing the literature on intellectual capital, it is evident that scholars have conducted in-depth analyses from micro perspectives, such as how intellectual capital promotes the development of financial enterprises [13–15]. However, the macro perspective of intellectual capital of financial enterprises to promote the development of financial markets is still to be explored, and few people have carried out research from the internal and external comprehensive environment on the specific path mechanism of the role of intellectual capital. Therefore, this paper contends that studying the pathways by which intellectual capital from both the external and internal environments contributes to the enhancement of a financial enterprise's value can address the gaps in current research and is of inherent value. From the external environment, the sustainable development capabilities of current financial enterprises are demonstrated by their focus on environmental sustainability and active promotion of green finance and sustainable investments. Internally, companies should comprehensively take into account their social image, environmental protection, corporate value, and strategic development. Changes in both internal and external

environments have spurred the demand for intellectual capital among financial enterprises, making it a key driving factor for enhancing their sustainable development capabilities and thereby gaining competitive advantages. In order to cope with this environment, financial enterprises need to rely on patents, technology and other intellectual capital to realize the development of sustainable capacity, which in turn leads to the enhancement of enterprise value. First, financial enterprises aim to showcase their unique intellectual capital strengths to the market, establish their prestige, and thus garner more trust from investors. Intellectual capital play a role in information conveyance at this juncture, reducing information asymmetry and enhancing the credibility of financial corporations. Second, as the influence of intellectual capital expands and permeates throughout the resource structure of the company, the attention and convergence of stakeholders correspondingly rise. Investors seek to identify the best investment opportunities through analysis of intellectual capital. Investment in intellectual capital can, to some extent, prevent financial enterprises from using consumer information for speculative behaviors, shifting consumer attention towards the contributions made to intellectual capital, thereby moderately increasing the corporate value of financial enterprises.

Building on prior research, this study contributes by considering the intrinsic relationships between variables in a cost-benefit model, establishing a mathematical model of intellectual capital asymmetric information, logically deducing the game between disclosing parties and information acquirers, and theoretically analyzing the mathematical model from a market response and financing constraint perspective. The intellectual capital asymmetric information model is as follows:

(1) input intellectual capital → enhancing investor confidence → increasing stock price → enhancing firm value;

(2) input intellectual capital → alleviating financing constraints → reducing financing costs → enhancing firm value.

This helps address information asymmetry between financial firms, investors, and the government. The paper contributes to the understanding of the dynamic decision-making mechanism of ex-ante adverse selection and ex-post moral hazard game in financial enterprises from several aspects. First, there is information asymmetry between business operators and owners, and this paper explores the problem of adverse selection and moral hazard due to agency conflict based on principal-agent theory. Second, there is information asymmetry between the government and the management of the enterprise, which leads to difficulty establishing political ties with the enterprise and the low motivation of the enterprise's intellectual capital investment. Based on signaling theory, the disclosure of corporate intellectual capital helps to reduce ex-ante adverse selection and motivates enterprises with capital investment to establish ties with the government. Once again, there is information asymmetry between enterprises and investors, which may lead to misinterpretation of the information released by investors about enterprises, resulting in inappropriate changes in stock prices caused by the release of false intellectual capital information by enterprises, leading to changes in the value of the enterprise and triggering moral hazard. Finally, the information asymmetry between enterprises and financing institutions may lead to financing institutions not being able to fully grasp the information of enterprises and not being willing to provide financial support for enterprises, causing adverse selection and putting enterprises in financing difficulties.

The remainder of the paper is structured as follows: Section 2 introduces the intellectual capital asymmetric information game model. Sections 3 and 4 refine the game model from different perspectives, with Section 3 as a sub-model from the market reaction perspective and Section 4 a

sub-model constructed from the financing constraint perspective. Section 5 concludes the study.

2. Mathematical modeling of intellectual capital asymmetric information games

2.1. Premise assumptions of the mathematical model

According to the principal-agent theory, the separation of ownership and operation of listed companies leads to agency conflicts between managers and shareholders of the company [16]. Due to the information asymmetry between managers and owners, owners have insufficient information and operators have information about the operation of the enterprise; therefore, the owners of the enterprise are easily deceived by the managers of the enterprise, which leads to the decision-making of the enterprise is not aimed at maximizing the value of the enterprise. Intellectual capital can effectively reduce the information asymmetry between enterprise shareholders and operators, which can bring about the enhancement of enterprise value. According to game theory, the game objects are committed to choosing actions that are more favorable to themselves. For the government, if enterprises take the initiative to disclose their intellectual capital, it reduces the cost of information collection, which is favorable to the government's decision-making. For the enterprise, the intellectual capital input of the enterprise is equivalent to the enterprise input factor, which can bring output. If it can establish contact with government departments, it is favorable to the production and operation of enterprises. There are additional costs to the company if it makes capital investments and establishes political connections. Therefore, based on the perspective of maximizing the benefits of both sides, it can form the basic conditions for the establishment of the game model. First, based on the theory of resource exchange, the survival and development of financial enterprises require necessary resources from the government and thus have a dependence on government resources [17]. At the same time, the government has a supervisory function over financial enterprises. The intellectual capital input of financial enterprises can reduce the supervision cost of the government. According to information asymmetry theory, information asymmetry leads to "moral hazard" and "adverse selection". According to principal-agent theory, the principal-agent problem can be transformed into the principal designing an incentive strategy to motivate the agent to engage in actions conducive to enhancing its efficiency [18]. The agent will be committed to choosing the action that maximizes its utility. Based on this, this paper argues that a game model can be constructed between financial enterprises and the government based on game theory and that this model can be used to study the impact of intellectual capital on the value enhancement of financial enterprises. Model construction faces the following constraints:

(1) Incentive compatibility constraint: The government can obtain actions that maximize its expected utility only if financial firms maximize their utility.

(2) Participation constraint: A financial firm chooses to participate in an action only if the utility of doing so exceeds the expected utility of not participating in any action.

To facilitate model construction, this paper makes the following assumptions:

(1) One of the economic consequences of the intellectual capital input of financial enterprises is the enterprise value, which is affected by some exogenous random variables μ in addition to the intellectual capital input of financial enterprises. According to the input-output model, the intellectual capital of the enterprise can be considered as the capital element of the enterprise, which can bring about the enhancement of the output value, so we establish a logical relationship, that is, the capital input of the enterprise brings about the enterprise value appreciation. Due to the large number of factors affecting the relationship between inputs and outputs, this paper introduces a random variable.

(2) *k* denotes the coefficient of value growth per unit of financial firm's intellectual capital input enhancement. The higher the input, the higher the value of the firm, that is, $V = kX + \mu$. μ denotes a random variable obeying a normal distribution with mean 0 and variance σ^2. That is $N: (0, \sigma^2)$.

According to the input-output model, there should be a positive link between the inputs and outputs of a firm, that is, the higher the capital inputs, the greater the value-added it brings. So, this paper introduces the value growth coefficient k.

(3) The investment of intellectual capital by financial enterprises has costs, including the cost of publicizing the intellectual capital; the cost of materials; and covering the relevant intermediaries, lawyers' legal fees, and appraisal fees. According to the cost theory, the capital investment of the enterprise is not gratuitous; it needs to be reflected in the form of cost expenditure. So, in this paper, the capital investment is reflected in the variable *c* and the cost-benefit model is constructed.

2.2. Mathematical modeling construction

(1) Costs of financial enterprises

$$c = m + bx^2. \tag{1}$$

Intellectual capital inputs of financial firms include fixed costs *m*, denoting shareholder costs such as intermediary fees and appraisal fees. However, the intellectual capital input of financial firms is limited by multiple source channels. And with the expansion of source channels, costs grow exponentially, showing an increasing cost scale. *b* denotes the cost coefficient incurred per unit of financial firm's intellectual capital input.

(2) Proceeds from financial enterprises

$$V = (kx - m - bx^2)(1 - p). \tag{2}$$

where $(kx - m - bx^2)$ denotes the utility of the financial firm, that is, the difference between the value appreciation and the cost of the financial firm. However, since based on the theory of resource exchange, financial firms need to pay a corresponding cost, *p* denotes the coefficient of efficiency improvement of the government due to the value appreciation caused by the intellectual capital inputs of financial firms, and $p(kx - m - bx^2)$ is the benefit of the government, which is also a part of the cost that financial firms need to pay to build up their political resources.

(3) Cost to government

The government has a vital supervisory role over financial enterprises, which are pivotal components of the economy. If these companies proactively disclose relevant information about their intellectual capital, a critical aspect of their business, it can significantly help the government better understand their intellectual capital and functioning, leading to more informed decision-making. This, in turn, could reduce the costs of government investigations and contribute to a more efficient regulatory environment.

$$c = n - sx. \tag{3}$$

Here, *n* denotes the fixed cost of government supervision of financial firms including personnel income, *s* represents the coefficient of cost reduction due to increased intellectual capital inputs of financial firms, and *p* denotes the coefficient of increase in benefits to the government due to the appreciation in value of financial firms from innovation of their intellectual capital. The benefits to the government encompass both direct revenue gains and indirect social welfare improvements.

$$Vg = p(kx - m - bx^2) - n + sx. \tag{4}$$

2.3. Derivation of the model analysis

According to the incentive compatibility constraint, it is only necessary to examine the actions that financial firms will take that are desired by the government when their utility is maximized. The specific mechanistic issues are shown below:

$$\text{MAX: } V = (kx - m - bx^2)(1 - t). \tag{5}$$

If $\frac{\partial V}{\partial x} = 0$, then $x = \frac{k}{2b}$.

It can be seen that when each unit of intellectual capital of financial enterprises needs to pay a larger cost coefficient to improve, the level of intellectual input of financial enterprises will be lower. This also indicates that if the quality of intellectual capital inputs of financial enterprises needs to pay more than expected when improving, the quality of intellectual capital inputs of financial enterprises will be reduced. At the same time, the effect of improving the quality of intellectual capital inputs per unit will be stronger, so that the growth of enterprise value is more significant. This also shows that the investment of intellectual capital of financial enterprises is directly proportional to the value of the enterprise.

Note that this equation also needs to satisfy a precondition (i.e., the participation constraint) as shown in Eq (6), where ϖ denotes the firm's retained utility when it does not make an intellectual capital investment:

$$V = (kx - m - bx^2)(1 - p) \geq \varpi. \tag{6}$$

We can maximize the profit by substituting $x = \frac{k}{2b}$ into Eq (2).

$$V = (kx - m - bx^2)(1 - p) = (1 - p)(\frac{k^2}{4b} - m) \tag{7}$$

.

We can find the government's maximized profit by substituting $x = \frac{k}{2b}$ into Eq (4).

$$Vg = p(\frac{k^2}{4b} - m) - n + \frac{sk}{2b} \tag{8}$$

and considering that the government's return function is a monotonically increasing function (i.e., government return increases along with government utility), the government formulation coefficient at this time cannot increase infinitely, otherwise, the financial enterprises will choose not to take any action. Therefore, in order to maintain a more stable level of returns, it is necessary to take more account of the wishes of financial enterprises.

We can find the range of the government utility improvement coefficient by substituting $x = \frac{k}{2b}$ into Eq (6), so the utility improvement coefficient can only incentivize financial firms to participate in intellectual capital investment under the following conditions:

$$p < 1 - \frac{4b\varpi}{k^2 - 4bm}. \tag{9}$$

To summarize, we can tell $x = \frac{k}{2b}$ and $p < 1 - \frac{4b\varpi}{k^2 - 4bm}$, the value of financial firms as shown

below:

$$Vg = \varpi. \tag{10}$$

In summary, we find that if the government's utility enhancement coefficient is too high, the probability that financial enterprises will make intellectual capital investments will be lower, and there is a critical value. If the government's utility enhancement coefficient is lower than this critical value, the investment of intellectual capital by financial enterprises will bring growth in enterprise value, that is, the enhancement of each unit of intellectual capital by financial enterprises will result in the enhancement of the growth effect of enterprise value, which will increase the willingness of financial enterprises to make intellectual capital investments. Therefore, under the two constraints, there is a positive correlation between intellectual capital investment and enterprise value of financial enterprises.

3. Sub-models in the market response perspective

3.1. Premise assumptions of the mathematical model

Based on subsection 2.1, this paper argues that the game model of financial enterprises and the government under the perspective of market reaction can be constructed based on game theory and the model establishment needs to satisfy the incentive compatibility constraints and participation constraints. By introducing consumer behavior into game analysis, this paper can study the market response that intellectual capital inputs can bring about, thus generating value-added effects. In order to study the impact of intellectual capital investment on the value of financial enterprises under the perspective of market reaction, this paper puts forward the following hypotheses:

(1) The value of a financial firm is not only related to the quality of the firm's intellectual capital input x but also to the random variable μ.

(2) k denotes the coefficient of value growth due to the improvement of intellectual capital investment in a unit of financial firm. The value of firms $V = kX + Xz + \mu$. μ denotes a random variable obeying a normal distribution with mean 0 and variance σ^2. That is, $N: (0, \sigma^2)$. z denotes the value growth caused by the increase in investor motivation due to the higher quality of disclosure.

(3) Intellectual capital investment in financial firms is not free.

3.2. Construction of mathematical models

(1) Costs of financial enterprises

$$c = m + bx^2. \tag{11}$$

The cost of intellectual capital for financial firms includes fixed costs m, indicating some shareholder costs such as intermediary fees and appraisal fees. However, the intellectual capital of financial firms is limited by multiple source channels. And with the expansion of source channels, the cost increases exponentially, thus showing an increasing cost scale. b denotes the cost coefficient incurred per unit of financial firms' intellectual capital.

(2) Proceeds from financial enterprises

$$V = (kx + xz - m - bx^2)(1 - p), \tag{12}$$

where $kx + xz - m - bx^2$ represents the utility of financial firms, that is, the difference between the value added by financial firms and their costs. However, based on the theory of resource exchange, financial firms need to pay a corresponding cost, and $p(kx + xz - m - bx^2)$ is the government's benefit and part of the cost that financial firms need to pay to build up their political resources.

(3) Costs of government oversight

$$c = n - sx, \tag{13}$$

where *n* is the fixed cost of government supervision of financial firms including personnel income, *s* denotes the cost reduction due to higher intellectual capital inputs by financial firms, and *p* denotes the benefit to the government from the coefficient of improvement in government effectiveness due to the appreciation in value caused by intellectual capital innovations by financial firms:

$$Vg = p(kx + xz - m - bx^2) - n + sx. \tag{14}$$

3.2. Analysis of model derivation

Considering the incentive compatibility constraint, it is sufficient to focus only on the scenario where the financial firm, in its best interests, maximizes its utility before taking any action desired by the government. This mechanism, outlined below, highlights how the financial firm operates within the bounds of governmental regulations and incentives.

$$MAX: V = (kx + xz - m - bx^2)(1 - p). \tag{15}$$

If $\frac{\partial V}{\partial x} = 0$, then $x = \frac{k+z}{2b}$.

This shows that when the coefficient of the cost of giving required to increase the intellectual capital investment of a unit company is larger, the lower the level of its willingness to disclose. This also indicates that if the company's intellectual capital enhancement requires the company to pay more cost than expected, then the company's external transmission effect will be lower. At the same time, the enhancement of the unit intellectual capital investment of financial firms makes the value growth effect of financial firms stronger. This also indicates that the intellectual capital investment of financial firms is directly proportional to the value of the firm. At the same time, intellectual capital investment leads to a stronger investor market response.

Note that this equation also needs to satisfy the participation constraint as shown in the following equation, where ϖ denotes the retained utility of the financial firm when it does not make intellectual capital investments:

$$V = (kx + xz - m - bx^2)(1 - p) \geq \varpi. \tag{16}$$

We can maximize our profit by substituting $x = \frac{k+z}{2b}$ for (12).

$$V = (kx + zx - m - bx^2)(1 - p) = (1 - p)(\frac{(k+z)^2}{4b} - m). \tag{17}$$

We can find the profit that the government maximizes by substituting $x = \frac{k+z}{2b}$ into (14).

$$Vg = p(\frac{(k+z)^2}{4b} - m) - n + \frac{s(k+z)}{2b}. \tag{18}$$

The government's payoff function exhibits a monotonically increasing trend, implying that an elevated governmental utility corresponds to an enhanced governmental pay off. However, the governmental coefficient is constrained from rising indefinitely, or else financial firms might opt to not act at all. Consequently, to ensure the stability of returns, it is of paramount importance to consider the willingness of financial firms.

We can find the range of the government's utility improvement coefficient by substituting $x = \frac{k+z}{2b}$ into (16), so the utility improvement coefficient can only incentivize financial firms to engage in intellectual capital investment under the following conditions:

$$p < 1 - \frac{4b\varpi}{(k+z)^2 - 4bm}. \tag{19}$$

In conclusion, the analysis reveals that the market reaction of financial firms can exert a notable positive influence on the firm's overall value. Moreover, this market reaction can be perceived as a pivotal determinant, functioning as a crucial conduit influencing the quality of intellectual capital and, by extension, firm value within the realm of financial institutions. This study is conducive to analyzing how listed companies can incentivize consumers to purchase products and services in order to add value, starting from consumer behavioral decisions. It is found that if it is possible to achieve positive market incentives through signaling by releasing information on intellectual capital, it can contribute to the value addition of enterprises.

4. Sub-models in the perspective of financing constraints

4.1. Premise assumptions of the mathematical model

Based on subsection 3.1, this paper argues that a game model of financial enterprises and the government under financing constraints can be constructed using game theory. The modeling must also satisfy incentive compatibility constraints and participation constraints. This paper introduces the behavior of financial institutions into the game model, which is able to study the word-of-mouth effect of financial firms brought about by intellectual disclosure, thus realizing value-added. In order to facilitate the construction of the model, this paper puts forward the following assumptions:

(1) Firm value is affected by the intellectual capital input of financial firms x and the exogenous random variable μ.

(2) Intellectual capital inputs by financial firms are subject to a consideration.

(3) The intellectual capital investment of financial enterprises is to get rid of financing difficulties, the profit of this project is L, the amount of financing required is H, the interest rate of debt financing is r, and the intellectual capital investment of financial enterprises can bring the profit of $v = kx + L - Hr$. In addition, the financing interest rate of financial firms is affected by the intellectual capital input, and the higher the intellectual capital input, the lower the interest rate of financial firms.

4.2. Modeling

(1) Costs of financial enterprises

$$c = m + bx^2. \tag{20}$$

The cost of intellectual capital input for financial enterprises includes a fixed cost m. However, the intellectual capital input of financial enterprises is limited by multiple source channels. As the source channels expand, the cost grows exponentially, thus exhibiting an increasing cost scale. *b* denotes the cost coefficient incurred per unit of financial firm's intellectual capital input.

(2) Proceeds from financial enterprises

$$V = kx + \delta x + L - Hr. \tag{21}$$

where $L - Hr - m - bx^2$ represents the utility of financial firms, that is, the difference between the value added and the cost of financial firms. However, since $p(L - Hr - m - bx^2)$ is based on the theory of resource exchange, it is a corresponding cost that financial firms need to pay, that is, the price that financial firms pay to build up their political resources, which can also be seen as a benefit to the government. In order to be closer to the real situation, this paper considers that the intellectual capital investment also leads to a reputation effect, assumed to be δ. This term is denoted as δx.

(3) Costs of government oversight

$$c = n - sx. \tag{22}$$

where *n* is the fixed cost of government supervision of financial firms including the income of personnel, *s* denotes the reduction in costs due to higher intellectual capital inputs by financial firms, and *p* denotes the benefit to the government from the coefficient of increase in the government's benefits due to the appreciation in value caused by intellectual capital innovations by financial firms:

$$Vg = p(kx + \delta x + L - Hr - m - bx^2) - n + sx. \tag{23}$$

4.3. Analysis of model derivation

The incentive compatibility constraint requires us to study when the financial firm maximizes its utility prior to undertaking the desired government action. The mechanism problem is illustrated below:

$$\text{MAX:}\ V = (1 - p)(kx + \delta x + L - Hr - m - bx^2). \tag{24}$$

If $\frac{\partial V}{\partial x} = 0$, then $x = \frac{k + \delta}{2b}$.

It is evident that if the intellectual capital input required by financial enterprises surpasses the anticipated costs, the quality of the intellectual capital input of financial enterprises is lowered. Additionally, the more pronounced the effect of financial enterprise value growth per unit of intellectual capital investment of financial enterprises, the stronger it becomes. This not only underscores the significance of intellectual capital investment in financial enterprises but also indicates that the value of the enterprise is directly proportional to its intellectual capital investment.

Note that this equation also needs to satisfy the participation constraint as shown in the following equation, where ϖ denotes the retained utility of the financial firm when it does not make intellectual capital investments:

$$\mathrm{V} = (\mathrm{kx} + \delta\mathrm{x} + \mathrm{L} - \mathrm{Hr} - \mathrm{m} - \mathrm{bx}^2)(1 - \mathrm{p}) > \bar{\omega}. \tag{25}$$

We can maximize the profit by substituting $x = \frac{k + \delta}{2b}$ into (21).

$$V = (kx + \delta x + L - Hr - m - bx^2)(1 - p) = (1 - p)\left(\frac{(k+\delta)^2}{4b} - m + L - Hr\right). \quad (26)$$

We substitute $x = \frac{k+\delta}{2b}$ into (23) to find the profit that the government maximizes.

$$Vg = p\left(\frac{k^2}{4b} - m + L - Hr\right) - n + \frac{s(k+\delta)}{2b}. \quad (27)$$

The government's payoff function is monotonically increasing, that is, the higher the government's utility, the greater the government's payoff. However, the government's coefficient cannot be increased indefinitely; otherwise, financial enterprises might choose not to take any action. Consequently, for the level of returns to be more stable, it is important to take into account the willingness of financial enterprises.

We can find the range of the government's coefficient of utility improvement by substituting $x = \frac{k+\delta}{2b}$ into (25), so that utility can incentivize financial enterprises to engage in intellectual capital investment only under the following conditions:

$$p \leq 1 - \frac{4b\bar{\omega}}{(k+\delta)^2 - 4bm + 4b(L-Hr)}. \quad (28)$$

Therefore, the value of a firm is enhanced when financial enterprises obtain financing at a lower interest rate. The lower the interest rate of financing for financial enterprises, the more indirectly it will impact and enhance the value of the firm. The investment of firms' intellectual capital facilitates the reputational effect. To summarize, the financing constraints of financial enterprises are one path through which the intellectual capital inputs of financial enterprises affect the value of the firm. This study is conducive to analyzing how listed companies can obtain financing from the formal financial market in order to add value, starting from financial institutions' decisions. It is found that if it is possible to increase the word-of-mouth effect of the company through the release of intellectual capital information, it can contribute to the value addition of the company through the signaling effect.

5. Conclusions

This paper explores the impact of a company's intellectual capital on its value from the perspective of mathematical modeling. Building on a comprehensive synthesis and systematization of existing literature, both domestic and international, the study first delineates the connotation and composition of intellectual capital and company value. It then chooses scientific measurement methods. Proceeding further, the paper inquires into the role relationship between intellectual capital and company value, doing so from the multifaceted standpoints of the capital market. To quantify and substantiate this relationship, the study employs a cost-benefit model. From this analysis emerge cogent insights. Intellectual capital, encompassing intangible assets like patents, trademarks, and copyrights, significantly impacts a company's market value. This relationship, as the study underscores, is contingent upon factors such as the capital market's disposition.

(1) From the perspective of consumers, the intellectual capital investment of financial enterprises helps to reduce the information asymmetry between financial enterprises, the government, and consumers and promotes the purchase of financial products by consumers and the profitability of

financial enterprises. The increase in the difference between the coefficient of reduction of the intellectual costs of the financial enterprise and the coefficient of intellectual capital investment of the financial enterprise, and the increase in the retained earnings of consumers and the intellectual capital of the financial enterprise are monotonically increasing [19]. This means that if the cost reduction of the financial enterprises through the introduction of intellectual resources is greater than the amount of money spent by the financial enterprises on the investment of intellectual capital, then consumers will be more motivated to buy the products and the retained earnings of consumers will be higher.

(2) From the supplier's perspective, the investment in intellectual capital by financial enterprises helps reduce the information asymmetry between the enterprises, the government, and suppliers, which encourages suppliers to offer favorable pricing and enhances the profitability of the enterprise [20–22]. In addition, positive evaluations of government regulation of financial enterprises can enhance the enterprise's standing with suppliers, facilitate cooperation, and increase enterprise value. This paper confirms that intellectual capital has a significant impact on the value of the company and that some elements of intellectual capital have an impact on the behavior of financial companies. This is mainly manifested in the fact that when analyzing the behavior of financial enterprises, the intellectual capital of financial enterprises should be taken into account as an influencing factor, and information about changes in the preferences of suppliers should be taken into account.

(3) From the perspective of the capital market, intellectual capital investment in financial enterprises helps to reduce the information asymmetry between financial enterprises, the government, and investors. It can also promote investor confidence and enhance the profitability of financial enterprises. The positive evaluation of the government's regulation of financial enterprises is equivalent to the favorable information of the enterprises, which promotes the influx of investors to form the agglomeration effect, so that the value of the financial enterprises is increased [23–25]. Financial companies should emphasize intellectual capital construction and maintenance so intellectual capital becomes the primary source of company value.

In summary, this study contributes to financial enterprises by promoting investment in intellectual capital, thereby influencing the decisions of market participants and government entities. It facilitates the integration of information resources, reduces information asymmetry, and promotes the enhancement of corporate value. However, there are limitations in this paper, which is due to the fact that this paper mainly uses mathematical model derivation to prove the impact of intellectual capital on enterprise value and does not refine intellectual capital into three major categories of human capital, relational capital, and structural capital in the measurement of intellectual capital. In the future research, we can appropriately refine the intellectual capital and further explore the mechanism of the enterprise's intellectual capital on the enhancement of enterprise value by constructing a model.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Acknowledgments

This work was supported by the Youth Program of Philosophy and Social Science Research Planning of Heilongjiang Province (23GLC052).

Conflict of interest

The authors declare no conflict of interest.

References

1. P. Nesegil, The effect of intellectual capital efficiency on financial performance: a research on participation banks, *J. Life Econ.*, **8** (2021), 281–287.
2. D. T. Nguyen, T. D. Q. Le, S. H. Tran, The moderating role of income diversification on the relationship between intellectual capital and bank performance evidence from Viet Nam, *Cogent Bus. Manag.*, **10** (2023), 2182621. https://doi.org/10.1080/23311975.2023.2182621
3. J. Bananuka, Intellectual capital, isomorphic forces and internet financial reporting: evidence from Uganda's financial services firms, *J. Econ. Adm. Sci.*, **36** (2019), 110–133. https://doi.org/10.1108/JEAS-03-2018-0042
4. K. C. T. Duho, Intangibles, intellectual capital, and the performance of listed non-financial services firms in West Africa: a cross-country analysis, *Merits*, **2** (2022), 101–125. https://doi.org/10.3390/merits2030009
5. P. N. Tran, D. H. Vo, Do banks accumulate a higher level of intellectual capital? Evidence from an emerging market, *J. Intellec. Cap.*, **23** (2020), 439–457. https://doi.org/10.1108/JIC-03-2020-0097
6. M. T. H. Majumder, I. J. Ruma, A. Akter, Does intellectual capital affect bank performance? Evidence from Bangladesh, *LBS J. Manag. Res.*, **21** (2023), 171–185. https://doi.org/10.1108/LBSJMR-05-2022-0016
7. P. Prasojo, W. Yadiati, T. Fitrijanti, M. Sueb, Exploring the relationship between intellectual capital and maqasid sharia-based performance: the moderating role of sharia governance, *J. Islamic Mark.*, **14** (2023), 2130–2146. https://doi.org/10.1108/JIMA-07-2021-0226
8. P. N. Githaiga, Income diversification and bank risk-taking: the moderating role of intellectual capital, *Cogent Bus. Manag.*, **9** (2022), 2149142. https://doi.org/10.1080/23311975.2022.2149142
9. M. A. S. Mollah, M. A. Rouf, The impact of intellectual capital on commercial banks' performance: evidence from Bangladesh, *J. Money Bus.*, **2** (2022), 82–93. https://doi.org/10.1108/JMB-07-2021-0024
10. N. Niccolò, Intellectual capital: the missing link in the corporate social responsibility-financial performance relationship, *J. Intellect. Cap.*, **23** (2022), 420–438. https://doi.org/10.1108/jic-02-2020-0038
11. L. A. M. Chowdhury, T. Rana, M. Akter, H. Mahfuzul, Impact of intellectual capital on financial performance: evidence from the Bangladeshi textile sector, *J. Account. Organ. Chan.*, **14** (2018), 429–454. https://doi.org/10.1108/JAOC-11-2017-0109
12. D. B. Tran, D. H. Vo, Should bankers be concerned with Intellectual capital? A study of the Thai banking sector, *J. Intellect. Cap.*, **19** (2018), 897–914. https://doi.org/10.1108/JIC-12-2017-0185
13. H. S. Mohammad, I. Bujang, Performance of Malaysian financial firms: an intellectual capital perspective using MVAIC model, *Asian Econ. Financ. Rev.*, **9** (2019), 752–765. https://doi.org/10.18488/journal.aefr.2019.97.752.765

14. Y. Yang, Do aggressive pro forma earnings-reporting firms have difficulty disclosing intellectual capital? Australian evidence, *J. Intellect. Cap.*, **19** (2018), 875–896. https://doi.org/10.1108/JIC-03-2017-0051
15. G. Ginesti, A. Caldarelli, A. Zampella, Exploring the impact of intellectual capital on company reputation and performance, *J. Intellect. Cap.*, **19** (2018), 915–934. https://doi.org/10.1108/JIC-01-2018-0012
16. M. A. Ibarra Cisneros, F. Hernandez-Perlines, Intellectual capital and Organization performance in the manufacturing sector of Mexico, *Manag. Decis.*, **56** (2018), 1818–1834. https://doi.org/10.1108/MD-10-2017-0946
17. F. Bertani, L. Ponta, M. Raberto, A. Teglio, Silvano Cincotti, The complexity of the intangible digital economy: an agent-based model, *J. Bus. Res.*, **129** (2021), 527–540. https://doi.org/10.1016/j.jbusres.2020.03.041
18. S. U. Rehman, H. Elrehail, A. Alsaad, A. Bhatti, Intellectual capital and innovative performance: a mediation-moderation perspective, *J. Intellect. Cap.*, **23** (2021), 998–1024. https://doi.org/10.1108/JIC-04-2020-0109
19. H. Hong, J. D. Kubik, J. A. Scheinkman, Financial constraints on corporate goodness, *NBER Working Paper*, 2012.
20. T. Garanina, J. Dumay, Forward-looking intellectual capital disclosure in IPOs: implications for intellectual capital and integrated reporting, *J. Intellect. Cap.*, **18** (2017), 128–148. https://doi.org/10.1108/JIC-05-2016-0054
21. F. Caputo, M. D. Giudice, F. Evangelista, G. Russo, Corporate disclosure and intellectual capital: the light side of information asymmetry, *Int. J. Manag. Financ. Account.*, **8** (2016), 75–81. https://doi.org/10.1504/IJMFA.2016.076668
22. W. Widarjo, R. Rahmawati, B. Bandi, A. K. Widagd, Underwriter reputation, intellectual capital disclosure, and underpricing, *Int. J. Biol. Sci.*, **18** (2017), 227–244. https://doi.org/10.33736/ijbs.480.2017
23. F. Caputo, M. D. Giudice, F. Evangelista, G. Russo, Corporate disclosure and intellectual capital: the light side of information asymmetry, *Int. J. Manag. Financ. Account.*, **8** (2016), 75–97. https://doi.org/10.1504/IJMFA.2016.076668
24. J. Chouaibi, A. Kouaib, Impact of shareholder' identity on intellectual capital performance: evidence from Tunisian manufacturing companies, *Int. J. Manag. Financ. Account.*, **7** (2016), 246–267. https://doi.org/10.1504/IJMFA.2015.074903
25. A. Limijaya, Y. Hutagaol-Martowidjojo, E. Hartanto, Intellectual capital and firm performance in Indonesia: the moderating role of corporate governance, *Int. J. Manag. Financ. Account.*, **13** (2021), 159–182. https://doi.org/10.1504/IJMFA.2021.117772

AIMS Press