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Optimum Risk/Reward Sharing Framework to Incentivize Integrated Project Delivery Adoption

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Abstract: The major benefit of integrated project delivery (IPD) is the involvement of stakeholders at the early stage of the project so that they can all contribute to project development. They would also work cooperatively towards the project goals that they have jointly developed. Moreover, IPD has not taken the market as promised by the aforementioned benefits due to two principal concerns. First, the conventional risk/reward sharing that has been developed for the principal-agent type of relationship has been used. Second, the reward has not been tailored to reflect the stochastic nature of the risks involved. This study proposes a novel risk/reward sharing framework that would alleviate these two concerns. Employing stochastic cooperative game theory and prospect theory as conceptual lenses, a more realistic risk/reward sharing framework is developed for IPD projects. The use of Pareto optimality enables the proposed framework to arrange incentives optimally with due regard to the risk propensity of the contracting parties. Setting the notional sharing approach as a fair starting point, the framework further introduces transfer payments to ensure fairness and retain optimum sharing at the same time. Both features would facilitate the structuring of multi-win sharing incentive to be incorporated with integrated project delivery. The operation of the proposed framework is illustrated by applying it to a real case. Wider adoption of IPD can be expected when the two principal concerns of IPD arrangements are addressed.

Keywords: Risk/reward sharing incentive; Integrated project delivery; Stochastic cooperative game theory; Prospect theory
Introduction

Construction projects using traditional project procurement methods such as fixed price contracts are prone to adversarial contracting behaviour due to inherent conflicts of interest (Thomsen et al. 2009). Convoluted decision-making processes add to communication bottlenecks (Egan 1998). Integrated project delivery (IPD) that uses a multi-party contracting arrangement has been used to bring all participating parties to work together from inception to completion. IPD therefore engenders closer integration and collaboration among members of project teams (Choi et al. 2019, Manata et al. 2021, Franz et al. 2017). IPD has demonstrated superior project performance over the competitive delivery approach (Choi et al. 2019; Mesa et al. 2016). For example, successful applications of IPD have been reported in the USA (Cohen 2010, Fischer et al. 2017, Mesa et al. 2016), Canada (Ibrahim et al. 2020, Cheng 2016), Australia (Walker et al. 2015) and the UK (Davies et al. 2009). Moreover, design and build remains the mainstream procurement strategy used in most construction markets. One concern of using IPD is the challenge in engendering collaboration of the extended project team (Schroeder 2014). In this regard, IPD projects should embrace arrangements to align the interests of the project participants with the objectives of the project (American Institute of Architects (AIA) National and AIA California Council 2009). It is advocated that a tailored risk/reward sharing incentive (RRSI hereafter) can be used to foster cooperative behaviour among the owner, designers, main contractor and key trade contractors (Cheng 2016, Cohen 2010, Mesa et al. 2019). Ideally, IPD risk/reward sharing (RRS hereafter) will incentivize joint efforts of all the participating parties (Lahdenperä 2012, El-adaway et al. 2017) so that the project can be more efficiently designed, built and operated (Franz et al. 2013, Laurent and Leicht 2019, Whang et al. 2019).

RRS is also identified as gainshare/painshare, wherein the participants will share the reward (i.e., gain) or loss (i.e., pain) according to the attainment or otherwise of the predetermined targets.
(AIA National and AIACC 2009). Most RRS in non-IPD contexts only involve the employer and the main contractor (Lahdenperä 2012, Ashcraft 2011). However, IPD RRSI should take into account the multi-party involvement whereby different kinds of expertise and talents can be brought to the project as early as the inception stage. IPD RRSI encourages individual excellence but also contributes to the common good of the project (Abdirad and Dossick 2019, Su et al. 2021, Choi et al., 2019). Furthermore, RRS-bonded project teams are more resilient in facing challenges (Cheng 2016). However, some barriers against the use of RRSI in IPD projects were reported (Ma et al. 2022a). While sharing risk and reward among multiple parties can incentivize superior project performance, it may invite its own risks (Thomsen et al., 2009, Ballard et al., 2015). The high level of uncertainty associated with the execution of the project makes the determination of the sharing ratios of risk/reward extremely challenging. Taking on risks beyond one’s capabilities would have an irreversible negative impact on the participants (Thomsen et al., 2009, Pishdad-Bozorgi and Srivastava 2018). When the final cost exceeds the target cost and the risk pool members fail to make any profit, the IPD project is recognized as a failure (Ballard et al. 2015). Thus, risk-averse contracting organizations would refrain from “betting on the wrong horse” and would be reluctant to subscribe to RRSI. Moreover, it is expected that the owner would set the target cost low, while the non-owners would have the opposite view (Ross 2003). Unrealistic high or low cost targets are relationally non-conducive (Ma et al. 2022b) and would amass sceptics against IPD.

Nevertheless, total avoidance of IPD will seriously affect the market share of a contracting organization (Cheng 2016), not to say the business of the IPD project owners. Due to the loss aversion effect, some participants perceive the profit obtained through involvement in the IPD RRSI to be lower than the margin in a fixed price contract (Cheng 2016). Moreover, the prevailing practice of retaining most of the money set aside in the risk pool until substantial completion makes
profits remote (Liu et al. 2013). It may give rise to cash flow issues. Some contracting organizations may opt to limit the number of IPD projects at any one time (Cheng 2016, p84).

This study proposes a novel method to optimize RRSI by minimizing the risk perceived by the risk pool members to an acceptable level. The proposed method aims to provide an optimum RRSI solution that is fair, stable, and acceptable for each agent. The authors use the “Pareto optimality” concept from stochastic game theory and define the “optimum risk/reward sharing solution” as the sharing solution that can provide each agent with the highest perceived benefit (Borm and Suijs 2002). The measurement for each agent’s share of the risk/reward is through the value function embedded in prospect theory (Tversky and Kahneman 1992). The study makes academic and practical contributions to improving the design of IPD RRSI to alleviate concerns about adopting an IPD-based procurement.

Literature Review

Characteristics of Risk/Reward Sharing in IPD

This study adopts the definition of integrated project delivery (IPD) suggested by Cheng et al. (2016): “IPD is the contractual project delivery method used by these project teams that created shared risk/reward structures, fiscal transparency, and release of liability”. IPD has evolved through capturing the benefits of project alliancing (Lahdenperä 2012). Initiated in the oil and gas industry (Knott 1996), the concept of project alliancing was adopted by the Australian construction industry in the late 1990s. The first Australian building project using project alliancing was the National Museum of Australia (Walker et al. 2002). The RRSI used in these alliancing projects only involved the owner and the main contractor (Walker et al. 2002). Moreover, the absence of a fair risk/reward allocation structure has been criticized (Haque et al. 2004). As a result, the project
alliancing participants had expressed their concern about the unsatisfactory structure of RRSI (Ross 2003).

The key distinguishing feature of IPD from other project delivery methods is the multi-party contract (Lahdenperä 2012). Unlike the discrete and transactional contractual strategies used with traditional procurement methods, IPD contracts are highly relational (Lichtig 2006). With contractual provisions such as liability waiver, open book and consensus decision-making (Dal Gallo et al. 2009, ConsensusDOCS 2007, AIA 2009), the participants are encouraged to have mutual trust and good faith to achieve real collaboration in the best interests of the project. Moreover, IPD contracts have been designed to support target value design (TVD) within the lean philosophy framework (Zimina et al. 2014). Throughout the TVD process, a diversity of expertise and insights can be integrated to optimize the design to the budget (Jung et al. 2012). As such, the construction cost can be reduced, and value for money for the owner can be achieved (Zimina et al. 2014).

Based on TVD, target cost is collaboratively developed by the IPD project team members and then it functions as a benchmark for risk and reward (Jung et al. 2012). In target cost contracts, IPD ties compensation to the achievement of project goals with an RRSI mechanism (Liu et al. 2013). For the compensation structure, there are typically three components (or three limbs, termed by Ross 2003 and Love et al. 2011). The first component is the reimbursed cost, consisting of the direct project costs and project overheads. Regardless of the project outcomes, this part of the cost would be reimbursed to the non-owner participants. The second component is fee, including the corporate overhead and project profit. The second component is also called the risk pool by some IPD practitioners (Ballard et al. 2015, Cheng 2016), as it is 100% at risk and the actual payable fee is based on the project outcomes. The third component is the RRS arrangement, i.e., sharing ratios of risk and reward (Love et al. 2011). Moreover, to stimulate innovations, any amount of project
contingency left is encouraged to be shared among the participants of the RRSI (Liu et al. 2013, Thomsen et al. 2009).

In such an RRSI arrangement, even profit-driven participants would need to work together to achieve project results that are collectively optimal to all participants (Fischer et al. 2017). Cheng (2016) reported notable savings obtained from a project-based equipment sharing arrangement. The savings therefrom would contribute to the profits for all participants. Likewise, any innovation or collaboration that would give project savings will benefit all participating parties. Since profits are at stake, they will be more active in expressing their opinions and offering solutions for problems faced by the project. The project team is collectively more resilient when extra efforts are rendered by the members (Zhu and Cheung 2022). The use of incentives to improve project performance is not new (Meng and Gallagher 2012, Whang et al. 2019). However, how to appropriately apply this incentivization in IPD projects would require a method to determine RRS ratios that are accepted as optimal by the project participants (Love et al. 2011, Hosseinian and Carmichael 2013, Su et al. 2021). Several optimization approaches have been reported in this regard. First, the optimal sharing ratio is determined based on the assumptions of principal-agent theory (PAT) (Hosseinian et al. 2020, Chang 2014, Wang and Liu 2015). PAT prioritizes maximizing the owner’s utility and asserts that the contractor will rationally work for their utility maximization regardless of the sharing ratios. The second approach seeks to address the risk-sharing arrangement by analysing real option valuations (Boukendour and Hughes 2014). This modelling method is mainly applied in Public-Private-Partnership projects. Quantifying the options, such as the guarantees from the host government from the perspective of real option (Liu et al. 2017), it can provide a good benchmark for risk allocation between two parties, i.e., the host government and private organization. The third approach uses game theory as the conceptual basis. As such, evolutionary game (Zheng et al. 2017), Nash equilibrium (Medda 2007, Zhang and Li
2014), and cooperative game (Pishdad-Bozorgi and Srivastava 2018, Teng et al. 2017, Melese et al. 2017) have been used to explain the motive for cooperation which is affected by risk allocation between agents.

There are three concerns if the aforementioned approaches are applied in IPD. First, PAT treats the owner as the buyer of the project. Moreover, in IPD projects, the owner actively and continuously participates throughout the project to identify the value and prioritize the alternatives. The owner is in fact an indispensable contributor instead of simply a service buyer (Cheng et al. 2012, Cheng 2016). It is therefore inappropriate to organize IPD RRS from a principal-agent relationship. Instead, cooperative game theory may have greater contextual similarities. IPD participants would work cooperatively to create extra value for the project. Second, in considering outcome uncertainty, the implicit assumptions of the reported studies are that decision-makers behave according to the prediction of expected utility theory (Al-Harbi 1998, Wang et al. 2018, Hosseinian et al. 2020). Although expected utility theory can provide a very tractable framework (Ramos et al. 2014, Barberis 2013), it has been found that human decisions often deviate from rational courses (Hauser and Urban 1979). Furthermore, expected utility theory does not differentiate the loss and gain (Farooq et al. 2018), i.e., the risk and reward in IPD projects, resulting in identical treatment for both loss and reward. In contrast, prospect theory differentiates risk and reward in predicting an individual’s choice, thereby providing a more realistic perspective (Barberis 2013). The third is the oversimplification in treating the outcome as deterministic irrespective of the uncertainty faced by the project (Teng et al. 2017). The occurrence of risks and hence outcomes is stochastic in nature (Elghaish et al. 2021). Hence, stochastic cooperative game theory that takes into account the outcome uncertainty would fit better with IPD risk events (Borm and Suijs 2002). It can therefore be summarized that there is a knowledge gap in modelling multiple agents’ risk-handling behaviours in IPD projects. This study applies the conceptual lenses of
stochastic cooperative games and prospect theory to model such behaviours. Accordingly, an optimal RRS framework for IPD projects is proposed. With improved RRS, wider use of IPD can be expected.

Theoretical Background

Cooperative Game Theory

Game theory was initiated by von Neuman and Morgenstern (1944) to explain some economic behaviour and has attracted numerous applications (Barron 2013). Game theory addresses the problems of multi-person decisions by predicting the likely actions that the players would take and the resulting payoffs in a commercial situation with the assumption that players are rational. Furthermore, game theory considers two classes of games: non-cooperative and cooperative. The former posits that a decision-making individual or party would treat his counterpart as a competitor, while the latter deals with a group of decision-makers who are collaborators to accomplish their common goals (Song and Panayides 2002). Essentially, the concepts of the cooperative game are used to solve two key problems: (i) what is the benefit in forming a coalition, and (ii) how to allocate the benefits arising from the cooperation among members of a coalition (Barron 2013; Meinhardt 2015, Peleg and Sudhölter 2007, Driessen 2013). In cooperative games, one well-known allocation solution is called the “core”. The core consists of the allocations that satisfy every coalitional member in the sense that the benefit the member receives is higher than or equal to the benefit that the member can obtain on their own or by joining any other coalition. The allocations that belong to the core can ease the members’ willingness to leave and contribute to a stable coalition (Meinhardt 2015). Using the “core” concept, the RRS is developed under the framework of cooperative game theory (Barron 2013).
The key working of IPD is that the project team members will cooperate to achieve the project goals by committing to an RRSI. The interactions between the IPD owner and non-owner parties can be framed as a cooperative game. Both the owner and non-owners of an IPD project can benefit through cooperation and collaboration. The owner’s expectations can be met or exceeded with less cost by using IPD (Mesa et al. 2019), while the non-owner parties can gain 20% to 25% more profit by joining the risk pool (Cheng 2016, p84). When the risk pool members work together to achieve the target cost goal, project savings are shared among them, leading to increased profit. As a result, the behavioural strategies of IPD contracting parties have the salient features of a cooperative game. Therefore, cooperative game theory was used to model the RRS among IPD contracting parties.

**Prospect Theory**

Tversky and Kahneman (1992) proposed cumulative prospect theory as a descriptive model to explain and predict individuals’ choice-making under risk. In particular, through a variety of psychological experiments, three main features were found when individuals make decisions under risk (Kahneman and Tversky 1979). First, unlike expected utility, which is measured with reference to wealth, the prospect value function \( v \) is a measure of wealth deviation from a reference point (see Figure 1) (Kahneman and Tversky 1979, Tversky and Kahneman 1992). Second, decision-makers are risk averse when making choices in the gain domain, whereas they are risk seeking when making choices in the loss domain (Kahneman and Tversky 1979, McDermott et al. 2008). Third, the slope of risk seeking for losses is steeper than that of risk aversion for gains. According to the experiments conducted by Kahneman and Tversky (1979), the slope of the loss function is typically twice as steep as the slope of the gain function, which is referred to as loss aversion.
The outcome of a prospect is evaluated via a value function \( v(x_i) \), which reflects the prospect value of the outcome. Risk aversion for gains (concave) and risk seeking for losses (convex) is revealed from the S-shaped value function (Kahneman and Tversky 1979), as shown in Figure 1.

![Prospect value function and expected utility function](image)

**Figure 1. Illustration of prospect value function and expected utility function**

The risk and reward of the future IPD project characteristically correspond to the loss and gain, respectively. Specifically, gain is the monetary gain arising from cost underruns, early completion and other fulfilled project goals, and loss refers to the reduced monetary value caused by failed project goals, e.g., cost overruns and delay. As expected, utility theory is unable to differentiate risk and reward (see Figure 1) (Farooq et al. 2018), prospect theory can overcome this inadequacy. Furthermore, the ideal condition is having completely rational IPD contracting parties. In reality, this is not possible (Li and Cheung 2019). Pragmatically, the behaviour choice of decision-makers is subjected to bounded rationality and can be influenced by many psychological factors. In this respect, prospect theory that takes into account an individual’s decision-making preferences is more akin to actual happenings (Barberis 2013).
Research Approach

Stochastic Approach

Most of the allocation approaches assume that the cost or revenue to be shared is deterministic. However, not all eventualities and their risks can be foreseen so that respective allocations can be made ex ante. Considering the allocation solution for uncertain outcomes, stochastic cooperative game theory (Suijs et al. 2012) was applied in this study. The most appealing value of stochastic cooperative game is that it can explicitly include the risk preferences of decision-makers. Any response to risks, from taking to avoiding, are manifestations of these preferences (Suijs 2003, 2012). In a stochastic game, the random benefits can be represented by a deterministic number, also known as the certainty equivalent. Using the concept of certainty equivalent, a stochastic game can be reduced to a game with deterministic outcomes. The “core” in the stochastic cooperative game therefore refers to the allocations that the certainty equivalent of the future random benefit that every coalitional member perceives is at least as much as the member can obtain on their own or by joining any other coalition. With the capability to capture the individual’s risk preferences and approach stochastic outcomes, the stochastic approach embedded in a stochastic game (Suijs 2012) is used in this study.

However, one important point that should be noted is that some assumptions in stochastic cooperative game theory are implicitly based on expected utility theory (Suijs and Borm 1999, Suijs 2003), the principal axioms of which are found to be incompatible with the decision-maker’s choice behaviour (Hauser and Urban 1979). Thus, to tackle this incompatibility, prospect theory is used in this study to measure stochastic payoffs to reflect the practical psychological state of IPD-based contracting.
### Notations in Optimum RRSI Framework

<table>
<thead>
<tr>
<th>Notations</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Grand coalition</td>
</tr>
<tr>
<td>S</td>
<td>Coalitional team formed by the IPD contracting parties</td>
</tr>
<tr>
<td>≥</td>
<td>“Is preferred to,” for example, ( x \geq y ) means “( x ) is preferred to ( y )”</td>
</tr>
<tr>
<td>( N_n )</td>
<td>Set of non-owner parties</td>
</tr>
<tr>
<td>( N_o )</td>
<td>Set of owner party/parties</td>
</tr>
<tr>
<td>( C_i )</td>
<td>Compensation for the non-owner party ( i )</td>
</tr>
<tr>
<td>( X_S )</td>
<td>Stochastic payoff generated by the coalitional team ( S )</td>
</tr>
<tr>
<td>( X_S^{IPD} )</td>
<td>Stochastic IPD outcome generated by team ( S )</td>
</tr>
<tr>
<td>( X_S^{non-IPD} )</td>
<td>Stochastic outcome generated by team ( S ) when using non-IPD method</td>
</tr>
<tr>
<td>( v_i(x) )</td>
<td>Prospect value of payoff ( x )</td>
</tr>
<tr>
<td>( v_i(X_S^{IPD}) )</td>
<td>Prospect value of stochastic outcome ( X_S^{IPD} ) for the agent ( i )</td>
</tr>
<tr>
<td>( v_i(X_S^{non-IPD}) )</td>
<td>Prospect value for stochastic outcome ( X_S^{non-IPD} ) for agent ( i )</td>
</tr>
<tr>
<td>( m_i(X_S^{IPD}) )</td>
<td>Certainty equivalent of stochastic outcome ( X_S^{IPD} ) for agent ( i ), equal to ( v_i^{-1}(X_S^{IPD}) )</td>
</tr>
<tr>
<td>( m_i(X_S^{non-IPD}) )</td>
<td>Certainty equivalent of stochastic outcome ( X_S^{non-IPD} ) for agent ( i ), equal to ( v_i^{-1}(X_S^{non-IPD}) )</td>
</tr>
<tr>
<td>( \alpha_i )</td>
<td>Coefficient of gain concavity for agent ( i )</td>
</tr>
<tr>
<td>( \beta_i )</td>
<td>Loss convexity coefficient for agent ( i )</td>
</tr>
<tr>
<td>( \lambda_i )</td>
<td>Loss aversion coefficient</td>
</tr>
<tr>
<td>( d_i )</td>
<td>Transfer payment for agent ( i ), positive transfer payment represents that ( i ) needs to transfer payment to others and negative transfer payments means that ( i ) receives payment from others</td>
</tr>
<tr>
<td>(</td>
<td>d_i</td>
</tr>
<tr>
<td>( r_i )</td>
<td>Sharing ratio for agent ( i )</td>
</tr>
<tr>
<td>( r'_i )</td>
<td>Notional sharing ratio for agent ( i )</td>
</tr>
<tr>
<td>( \hat{r}_i )</td>
<td>Optimum sharing ratio for agent ( i )</td>
</tr>
<tr>
<td>( G_i )</td>
<td>Gain prospect value perceived by agent ( i )</td>
</tr>
<tr>
<td>( TC )</td>
<td>Target cost</td>
</tr>
<tr>
<td>( x_{AC} )</td>
<td>Actual cost</td>
</tr>
<tr>
<td>( L_i )</td>
<td>Loss prospect value perceived by agent ( i )</td>
</tr>
<tr>
<td>( f(x_{AC}) )</td>
<td>Probability distribution function of the project actual cost</td>
</tr>
<tr>
<td>( \Delta r_{jk} )</td>
<td>Share of risk/reward that agent ( k ) buys from agent ( j )</td>
</tr>
<tr>
<td>( S_b )</td>
<td>Set of agents who buy the share of risk/reward</td>
</tr>
<tr>
<td>( S_s )</td>
<td>Set of agents who sell the share of risk/reward</td>
</tr>
</tbody>
</table>
Optimum Risk/Reward Sharing Framework

Each agent is willing to be involved in an IPD project only if the perceived profit of the RRSI outcome is no less than that of a non-IPD outcome. This is the baseline expectation of using IPD. The notional RRS method is used as the starting point for optimization. By notional RRS, the owner is allocated 50% of the risk/reward, and the sharing ratio for the non-owner parties is proportional to their compensation fee (Love et al. 2011), which can be expressed as

\[ r_i = \begin{cases} 0.5, & i \in S \cap N_o \\ 0.5 \frac{C_i}{\sum_{i \in S \cap N_o} C_i}, & i \in S \cap N_n \end{cases} \]

(1)

where the set of non-owner parties, i.e., design consultants, main contractor, and trade contractors, is denoted by \( N_n \), the owner party is denoted by \( N_o \), \( S \) refers to the coalitional team formed by the IPD contracting parties and \( C_i \) represents the compensation fee for the non-owner party \( i \).

The subsequent paragraphs first discuss whether the notional RRS approach can satisfy the baseline expectations for IPD participants. The proposed optimum RRSI framework development is then presented.

The Baseline of Risk/Reward Sharing Incentive

According to the core concept, to maintain coalition stability, coalition members should be better off than working on their own or joining any other coalition. Therefore, it is necessary to adopt the RRSI according to the baseline that an agent who is inclined to be involved in IPD incentives would perceive the profit gained from using IPD not to be lower than the agent’s typical profit when using the non-IPD method, e.g., design-bid-build (DBB). Otherwise, the agent would not commit to the
incentive or simply stay away from the project. Taking DBB as an example, the major difference between DBB and IPD is that when using DBB, instead of sharing risk/reward, it is typically the main contractor and owner taking the risks, while the architect takes zero risk for the cost performance contractually (Darrington and Lichtig 2010). Table 2 gives the risk allocation pattern in different project delivery methods. The baseline is therefore zero for the architect. For the main contractor, the baseline concerns protecting the contractor’s interest by defining that the certainty equivalent of the prospect value of using IPD is not lower than that derivable from the non-IPD method. The certainty equivalent refers to a monetary value of utility when the outcome is uncertain. The baseline of the owner concerns protecting his interest by defining that the certainty equivalent of the prospect value of using IPD is not lower than that of using the non-IPD method. Each agent should have a higher or equal certainty equivalent of prospect value when using IPD than when using the non-IPD method, which can be expressed as

$$m_i(v_i^{IPD}) \geq m_i(v_i^{non-IPD}), \text{ for all } i \in N_o \cup N_n$$

(2)

where $v_i^{IPD}$ refers to the prospect value for agent $i$ when using the IPD method, $m_i(v_i^{IPD})$ is the pertinent certainty equivalent for agent $i$, $v_i^{non-IPD}$ is the prospect value for agent $i$ when the non-IPD method is used and $m_i(v_i^{non-IPD})$ is the pertinent certainty equivalent for agent $i$.

Notwithstanding that the notional RRS is often identified as literally fair, the agents’ baseline expectations of using IPD may not be satisfied by applying the notional sharing approach. This commonly occurs when risk-averse agents take a large share of risk/reward (Cheng 2016, p93), especially when the outcome is highly uncertain. If the baseline expectations cannot be met, the agents resist joining the RRSI. In this study, the proposed optimum RRS model not only enables fair sharing of the risk/reward but also satisfies the baseline.
Table 2 Comparison of risk allocation for different delivery methods

<table>
<thead>
<tr>
<th>PDM</th>
<th>Coalition $S$</th>
<th>Risk allocation</th>
<th>Prospect value</th>
</tr>
</thead>
</table>
| DBB    | $\{1,2,3\}$  | The risk is allocated between owner and main contractor, denoted by $[r_1, r_2, 0]$ | $v^1_{DBB} = v_1(r_1 X^S_{DBB})$  
$v^2_{DBB} = v_2(r_2 X^S_{DBB})$  
$v^3_{DBB} = 0$                                                     |
| CM at risk | $\{1,2,3\}$  | The risk is allocated between owner and main contractor, denoted by $[r_1, r_2, 0]$ | $v^1_{CM} = v_1(r_1 X^S_{CM})$  
$v^2_{CM} = v_2(r_2 X^S_{CM})$  
$v^3_{CM} = 0$                                                     |
| DB     | $\{1,2,3\}$  | The risk is allocated between the owner and a single entity who is responsible for design and build, denoted by $[r_1, r_{[2,3]}]$ | $v^1_{DB} = v_1(r_1 X^S_{DB})$  
$v^2_{DB} = v_{[2,3]}(r_{[2,3]} X^S_{DB})$  
$v^3_{CM} = 0$                                                     |
| IPD    | $\{1,2,3\}$  | The risk is shared among the contracting parties, denoted by $[r_1, r_2, r_3]$     | $v^1_{IPD} = v_1(r_1 X^S_{IPD})$  
$v^2_{IPD} = v_2(r_2 X^S_{IPD})$  
$v^3_{IPD} = v_3(r_3 X^S_{IPD})$                                      |

Note: 1, owner; 2, main contractor; 3, architect; PDM: project delivery method

Framework Development

The proposed optimal IPD RRSI framework is developed as a stochastic cooperative game (Suijs et al. 1999) with the application of prospect theory (Kahneman and Tversky 1979). Stochastic cooperative game theory considers the players as contracting parties, the characteristic function value as the monetary equivalent of risk and reward, and the coalition as the group of contracting parties. In addition, prospect theory can portray the possible gain and loss by subjective utility. It is assumed that all IPD contracting parties are subjective utility maximisers. This means that an agent prefers a certain RRS to the other if the subjective utility of that exceeds the subjective utility of the others. The power utility function is used to describe the risk propensity of the contracting parties, as it is the most commonly used parametric form in empirical and theoretical applications of prospect theory (Liu et al. 2019), as shown below
\[ v_i(x) = \begin{cases} x^\alpha, & x \geq 0, \alpha_i > 0 \\ -\lambda_i (-x)^\beta, & x < 0, \beta_i > 0, \lambda_i > 1 \end{cases} \] (3)

where \( \alpha_i \) is the coefficient of gain concavity for player \( i \), \( \beta_i \) refers to the loss convexity coefficient, and \( \lambda_i \) represents the loss aversion coefficient.

Let \( X_s \) describe the future stochastic payoff for the coalitional team \( S \) formed by the contracting parties. According to Suijs et al. (1999), a game with stochastic payoffs can be defined as a tuple \( (N_o \cup N_n, (X_s)_{S \in N_o \cup N_n}, (\succ_i)_{i \in N_o \cup N_n}) \), where \( N_o \cup N_n \) represents the owner and non-owner parties, and \( \succ_i \) describes the preferences of agent \( i \) over the set of stochastic payoffs with finite expectation. According to Suijs et al. (1999), the allocation of stochastic payoff \( X_s \) to the coalitional members can be represented by the pair of \( (d_i, r_i) \) for each agent \( i \in S \). \( r_i \) is the allocation ratio for each agent \( i \in S \) and \( d_i \) can be understood as the transfer payment between agent \( i \) and the other agent \( j \in S, j \neq i \).

Accordingly, the optimum sharing of stochastic IPD outcome (denoted by \( X_s^{IPD} \)) can be represented by the pair of \( (d_i, \hat{r}_i) \) for each agent \( i \in S \). Herein, \( \hat{r}_i \) refers to the optimum sharing ratio for \( i \), and \( d_i \) refers to the payment that the contracting party \( i \) should transfer to other parties for the difference between the notional \( r_i \) and optimum sharing ratio \( \hat{r}_i \). If the optimum sharing ratio is different from the notional one, the concept “transfer payment” is used to make up for the difference between the notional and optimum sharing ratios (Suijs and Borm 1999, Melese et al. 2017).

There are three steps to follow to obtain an optimum RRS (Figure 2 refers): (i) quantify the risk (loss) and reward (gain) for the agents with subjective utility, (ii) obtain the optimum RRS
ratio $\hat{r}_i$ for the agent $i \in S$ by maximizing the certainty equivalent, and (iii) calculate the transfer payment $d_i$ for each agent $i \in S$ according to the difference between notional ($r_i'$) and optimum ($\hat{r}$) sharing ratios, as described in the remainder of this section.

<table>
<thead>
<tr>
<th>Purposes</th>
<th>Optimum RRSI ($\hat{r}_i, d_i$) for each agent $i$</th>
<th>Notional RRSI $[r_1', r_2', \ldots, r_n']$</th>
</tr>
</thead>
<tbody>
<tr>
<td>To measure the risk and reward in a pragmatic way</td>
<td>Step 1: Quantification of risk (pain) and reward (gain) based on Prospect Theory</td>
<td>-50% allocated to owner</td>
</tr>
<tr>
<td></td>
<td>-Prospect pain value. $AC &gt; TC$</td>
<td>-Proportional to compensation for non-owners</td>
</tr>
<tr>
<td></td>
<td>-Prospect gain value. $AC \leq TC$</td>
<td></td>
</tr>
<tr>
<td>To obtain an optimum RRSI</td>
<td>Step 2: Optimum allocation of risk/reward $[\hat{r}_1, \ldots, \hat{r}_i, \ldots, \hat{r}_n]$ based on Stochastic CGT -Pareto optimal allocation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Affected by the risk preference of the agent $i$, and the outcome uncertainty</td>
<td></td>
</tr>
<tr>
<td>To obtain an optimum and fair RRSI</td>
<td>Step 3: Transfer payments $[d_1, \ldots, d_i, \ldots, d_n]$ among contracting parties</td>
<td>To ensure a fair RRSI</td>
</tr>
<tr>
<td></td>
<td>-Transfer payment of the owner $d_1$ concerns the difference between $\hat{r}_1$ and $r_1'$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Transfer payment of the contractor $d_2$ concerns the difference between $\hat{r}_2$ and $r_2'$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Transfer payment of the architect $d_3$ concerns the difference between $\hat{r}_3$ and $r_3'$</td>
<td></td>
</tr>
</tbody>
</table>

$\hat{r}_i$: optimum sharing ratio for contracting party $i$

$r_i'$: notional sharing ratio for contracting party $i$

$d_i$: transfer payment for contracting party $i$

$AC$: actual cost

$TC$: target cost

Figure 2. The three-step model development
Step 1: Quantification of Risk (Loss) and Reward (Gain)

Prospect theory suggests that the individual or party usually reflects sensitivity depending on the states of the outcomes with respect to the reference point (Tversky and Kahneman 1992). The reference point can be decided by the current or expected outcome (Barberis 2013). In this study, the concept of the reference point (Kőszegi and Rabin 2007, 2009) that people use to measure gain and loss is their held expectations in the recent past about outcomes. Thus, the expected outcome, i.e., the target cost, is defined as the reference point herein. To be more specific, when the actual cost is less than the target cost, the project outcome is perceived as the gain by the agent; when the actual cost exceeds the target cost, the project outcome is perceived as the loss.

Let the prospect gain value and prospect loss value for agent \( i \) be denoted by \( G_i \) and \( L_i \), respectively. According to the analysis above, the prospect values can be defined as follows.

Definition 1. If the actual cost is less than or equal to the target cost (\( x_{AC} \leq TC \)), then the prospect gain value for agent \( i \) whose sharing ratio is \( r_i \) can be defined as

\[
G_i = \int_0^{TC} (r_i (TC - x_{AC}))^{\alpha_i} f(x_{AC})dx_{AC}
\]

where \( TC \) and \( x_{AC} \) represent the target cost and actual cost of the project, respectively, \( f(x_{AC}) \) refers to the probability distribution function of the project actual cost, and \( \alpha_i (0 \leq \alpha_i \leq 1) \) is the coefficient describing the gain concavity for agent \( i \).

Definition 2. If the actual cost exceeds the target cost (\( x_{AC} > TC \)), then the prospect loss value for agent \( i \) whose sharing ratio is \( r_i \) can be defined as

\[
L_i = -\lambda_i \int_{TC}^{\infty} (-r_i (TC - x_{AC}))^{\beta_i} f(x_{AC})dx_{AC}
\]
where $\lambda_i (\lambda_i > 1)$ represents the loss aversion coefficient ( $\lambda_i > 1$ describes the pronounced asymmetry of the value function, i.e., subjective utility in the loss region is steeper than in the gain area), and $\beta_i (0 \leq \beta_i \leq 1)$ is the coefficient describing the loss convexity for agent $i$.

Therefore, the prospect value for agent $i \in S$ whose sharing ratio is $r_i$ can be presented as

$$
v_i(r_iX_S) = \int_0^{TC} (r_i(TC - x_{AC}))^{\alpha_i} f(x_{AC})dx_{AC} - \lambda_i \int_{TC}^{+\infty} (-r_i(TC - x_{AC}))^{\beta_i} f(x_{AC})dx_{AC}$$  \hspace{1cm} (6)

**Step 2: Optimum Sharing of Risk/Reward**

Pareto optimality can be achieved if it is impossible to improve the certainty equivalent of one agent without the loss of another agent (Suijs 2012, Zhang and Li 2014). According to Suijs et al. (1998), an allocation solution is Pareto optimal if and only if this allocation maximizes the sum of certainty equivalent for the contracting parties. Because $d_i$ is a deterministic payment, the certainty equivalent of $d_i$ is $d_i$ per se. Furthermore, as the transfer payments are performed within team $S$, $\sum_{i \in S} d_i$ is zero. The sum of the certainty equivalent of the stochastic payoff received by the contracting parties therefore equals

$$
\sum_{i \in S} m_i (d_i + r_iX_S)
= \sum_{i \in S} d_i + \sum_{i \in S} m_i (r_iX_S)
= \sum_{i \in S} m_i (r_iX_S)
$$  \hspace{1cm} (7)

where $m_i(r_iX_S)$ represents the certainty equivalent of stochastic payoff $r_iX_S$ for agent $i \in S$. $m_i(r_iX_S)$ can be obtained by the inverse function of a value function, i.e., $v_i^{-1}(r_iX_S)$. 

20
According to Eq. (7), maximizing the value of \( m_i(d_i + r_i X_S) \) can be understood as the problem of maximizing \( \sum_{i \in S} m_i(r_i X_S) \). Moreover, according to Eq. (2), each agent holds the baseline expectation that the certainty equivalent of the prospect value of using IPD should be equal to or higher than that of using the non-IPD method, e.g., \( m_i(r_i X_S^{IPD}) + d_i \geq m_i(X_S^{non-IPD}) \) for \( i \in S \). Hence, the optimum sharing of risk/reward incentives is further deduced as follows:

\[
\max \sum_{i \in S} m_i(r_i X_S) \tag{8}
\]

such that

\[
\sum_{i \in S} r_i = 1 ;
\]

\[
r_i > 0, \text{ for all } i \in S ;
\]

\[
m_i(r_i X_S^{IPD}) + d_i \geq m_i(X_S^{non-IPD}), \text{ for all } i \in S .
\]

**Step 3: Transfer Payments among Contracting Parties**

The proposed optimum RRS ratio (denoted as \( \hat{r}_i \) for agent \( i \in S \)) takes into account the risk preference of agent \( i \in S \). Moreover, the notional RRS ratio (denoted as \( r'_i \) for agent \( i \in S \)) is considered a relatively fair sharing incentive and set as the starting point for optimization. To ensure fairness and maintain optimum sharing at the same time, the transfer payment (denoted as \( d_i \)) is introduced here to bridge the difference between \( \hat{r}_i \) and \( r'_i \). Hence, when the optimum sharing ratio is different from the notional one, the best RRSI is to share the risk/reward in the optimum ratios with transfer payments for the exchange of shares of risk/reward among the agents.
There are several methods to determine the amount of $d_i$. Suijs et al. (1998) applied the zero utility principle to identify $d_i$. Moreover, Suijs (2012) also suggested using other risk premium concepts, e.g., the net premium principle, to determine $d_i$. The principle of zero utility is to ensure that the utility of an agent remains unchanged after sharing the risk. The net premium principle is to calculate the “risk” for sharing based on the expected outcome. Thus, these premium principles provide transfer payments that are either too high or too low for the agent who shares risk. In this study, the concept of a risk sharing zone (Melese et al. 2017) is adopted, as this concept can help achieve a win–win deal for the agents.

To illustrate the working of the concept, consider that agent 1 transfers some share of the risk/reward to agent 2. According to Melese et al. (2017), the best sharing rule for agent 1 would be the one that maximizes 1’s certainty equivalent subject to the constraint that 2’s certainty equivalent should not be less than his certainty equivalent of notional share, i.e.,

$$d_2 + m_2(\hat{r}_2 X_S) \geq m_2(r_2 X_S).$$

Meanwhile, agent 2 tries to negotiate for a higher price, ensuring that agent 1’s certainty equivalent should not be less than his certainty equivalent of notional share, i.e.,

$$d_1 + m_1(\hat{r}_1 X_S) \geq m_1(r_1 X_S).$$

Noting that only agents 1 and 2 are involved in the exchange of risk/reward share, \(\hat{r}_1 - r_1 = -(\hat{r}_2 - r_2)\) and \(d_1 = -d_2\). Hence, the zone of transfer payment, subject to optimum sharing, is given as

$$m_2(r_2 X_S) - m_2(\hat{r}_2 X_S) \leq -d_1 = d_2 \leq m_1(\hat{r}_1 X_S) - m_1(r_1 X_S)$$

(9)

Let the two agents’ scenario be extended to multiple agents’ and denote the set of agents who buy and sell the share of risk/reward as $S_b$ and $S_s$, respectively. For $k \in S_b$, $\hat{r}_k \geq r_k$, the zone of transfer payment $d_k$ can be expressed as
\[ \sum_{j \in S_s} ((m_j(r_j)X_s) - m_j((r_j - \Delta r_{jk})X_s)) \leq |d_k| \leq \sum_{k \in S_s} ((m_k(\hat{r}_k)X_s) - (m_k(\hat{r}_k - \Delta r_{jk})X_s)) \]  

(10)

As \( d_k \leq 0 \), Eq. (10) can also be expressed as

\[ \sum_{j \in S_s} ((m_k(\hat{r}_k - \Delta r_{jk})X_s) - (m_k(\hat{r}_k)X_s)) \leq d_k \leq \sum_{j \in S_s} (m_j((r_j - \Delta r_{jk})X_s) - (m_j(r_j)X_s)) \]  

(11)

where \( \Delta r_{jk} \) is the share of risk/reward that agent \( k \) buys from agent \( j \in S_s \), \( \hat{r}_k \) is the optimum sharing ratio for agent \( k \), and \( r_j \) represents the notional sharing ratio for agent \( j \).

For \( j \in S_s \), \( \hat{r}_j \leq r_j \), the zone of transfer payment \( d_j \) can be expressed as

\[ \sum_{k \in S_k} ((m_j(r_j)X_s) - m_j((r_j - \Delta r_{jk})X_s)) \leq d_j \leq \sum_{k \in S_k} ((m_k(\hat{r}_k)X_s) - (m_k(\hat{r}_k - \Delta r_{jk})X_s)) \]  

(12)

Case Illustration

In this section, the working of the proposed RRSI is illustrated through a case study. The optimum RRSI solution of the IPD case is provided and compared to the notional RRSI. The case comparison demonstrates the value of an optimum RRSI (see Table 2). Furthermore, a comparative statics is conducted to examine the impacts of model parameters (i.e., risk preferences and outcome uncertainty) on the optimum RRSI of different cooperating parties (including optimum sharing ratios and the transfer payments) (see Figure 3 and Figure 4). The comparative statics results indicate the model reliability.

A real IPD case reported in Cheng (2016) was used in this study. Specifically, the main parameter values defining IPD project performance are derived from an IPD project named Akron Children’s Hospital, Kay Jewelers Pavilion, located in Akron, Ohio, USA. Moreover, the parameter values defining the risk preference of the agents come from the empirical studies
conducted by Abdellaoui (2000) and Abdellaoui et al. (2007). Akron Children’s Hospital is a successful IPD case, and sufficient data on its project performance have been reported by Cheng (2016). Moreover, a tripartite IPD contract was used in Akron Children’s Hospital; thus, the focus of this case study is on the three key contracting parties, i.e., owner, main contractor, and architect. The key cost information is as follows:

- The target cost was initially set to be 182.225 (million dollars).
- As the final cost was 175.048 (million dollars), the cost outcome is set to be normally distributed on (175, 20); and
- The compensation fee for design consultants and main contractor was 1:9. Proportional to the compensation fee, the notional sharing ratio for the owner, main contractor and architect is [0.5, 0.45, 0.05].

In addition, as the market cost of this project was 200 (million dollars) and it is considered that the market cost equals the cost when the traditional delivery method was applied, the cost outcome was set to be normally distributed on (200, 30) if DBB was used. Furthermore, the risk sharing ratio for the owner, main contractor and architect is assumed to be [0.2, 0.8, 0] if DBB is used.

In Abdellaoui (2000) and Abdellaoui et al. (2007), a novel and simple method, called parameter-free elicitation method, was used to elicit the individual utility function. The parameter-free elicitation method only needs a few choices and can efficiently obtain the reliable parametric estimations. A power utility function was assumed in his study, which is consistent with this study. According to Abdellaoui (2000), the median estimates of $\alpha$ and $\beta$ were 0.89 and 0.92, respectively. For loss aversion, the loss aversion $\lambda$ estimate obtained by Abdellaoui et al. (2007) was 1.98.
Moreover, the interquartile range (IQR) of \( \lambda \) is [1.19, 2.34] (Kahneman and Tversky 1979), and \( \alpha \leq 1, \beta \leq 1 \). Therefore, the values of \( \alpha \), \( \beta \) and \( \lambda \) within the IQR were randomly derived as the default value for each agent in this study. The random numbers were computationally generated using a uniform random sampling method.

Therefore, the values of \( \alpha \), \( \beta \) and \( \lambda \) within IQR were randomly derived as the default value for each agent in this study. Specifically,

- Owner’s gain coefficient \( \alpha_1 = 0.91 \), loss coefficient \( \beta_1 = 0.92 \), loss aversion index \( \lambda_1 = 1.92 \).
- Main contractor’s gain coefficient \( \alpha_2 = 0.88 \), loss coefficient \( \beta_2 = 0.90 \), loss aversion index \( \lambda_2 = 1.82 \).
- Architect’s gain coefficient \( \alpha_3 = 0.85 \), loss coefficient \( \beta_3 = 0.93 \), loss aversion index \( \lambda_3 = 2.15 \).

**Notional Risk/Reward Sharing for the IPD Project**

Python3.9 was used to calculate the certainty equivalent of prospect values when using notional and optimum RRSIs (see the code files in the Supplementary Material). According to Eq. (1), Eq. (3) and Eq. (6), the baseline (i.e., using a non-IPD method, DBB) for the owner, main contractor and architect is (-4.5, -16.9, 0). This means that if the non-IPD method is used, with the same compensation paid to the main contractor and architect from the owner and cost budget, the reward obtained by the owner and main contractor would be negative, which is -4.5 and -16.9, respectively; the architect would have zero reward. The certainty equivalent when using notional allocation is (0.259, 0.290, -0.009). It is worth noting that the certainty equivalent of the prospect value for the architect is negative, lower than the baseline expectation. Apparently, the notional sharing
incentive cannot satisfy the baseline expectation for the architect, although the profits perceived by
the owner and contractor have been improved by using IPD. As expected, the architect would be
resistant to joining the RRSI with a notional sharing approach.

**Optimum Risk/Reward Sharing for the IPD Project**

Grid search optimization was applied to obtain the optimum RRS ratios for the owner, contractor
and architect (see Supplementary Material). According to Eq. (8), the optimum sharing vector for
the owner, main contractor, and architect equals \( R' = [0.363, 0.632, 0.005] \). Based on Eq. (11) and
Eq. (12), the transfer payments among the contracting parties can be obtained. For the convenience
of the simulation, the midpoint of the transfer payment zone was used herein to calculate the
transfer payment for each agent. Consistent with the optimum sharing ratio, the transfer payments
for the owner, main contractor and architect are -0.065, 0.072, and -0.007 million, respectively.
Practically, the optimum RRSI is to decrease the main contractor’s compensation and increase the
architect’s compensation, which are 0.072 and 0.007 million, respectively, while decreasing the
owner’s payment to the contractor and architect by 0.065 million; the owner, main contractor and
architect share 36.3%, 63.2% and 0.5% of the final project monetary value, respectively, regardless
of project savings or overruns.

**Case Comparison**

Table 3 compares the certainty equivalent of the prospect values for the three agents when the
notional and optimum sharing incentives are adopted. For the architect, the certainty equivalent of
the prospect value shifts to positive from negative after adopting the optimum sharing ratio. It
demonstrates that adopting the optimum RRSI is an effective strategy to ease the team members’
reluctance to enter into the sharing agreement. Meanwhile, the optimum RRSI can also incrementally change the certainty equivalent for the owner and main contractor. As the certainty equivalent represents the perceived profit, the optimum RRSI can therefore increase the willingness to use IPD for all contracting parties.

Table 3 RRSI and certainty equivalent of prospect values

<table>
<thead>
<tr>
<th>Coalition</th>
<th>IPD (notional RRSI)</th>
<th>IPD (optimum RRSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>{1,2,3}</td>
<td>{1,2,3}</td>
</tr>
<tr>
<td>Sharing ratios</td>
<td>[0.5, 0.45, 0.05]</td>
<td>[0.363, 0.632, 0.005]</td>
</tr>
<tr>
<td>Transfer payments (Million $)</td>
<td>[0,0,0]</td>
<td>[-0.065, 0.072, -0.007]</td>
</tr>
<tr>
<td>Certainty equivalent of prospect value $m_i(d_i + r_iX^IPD_s)$ for each agent</td>
<td>(0.259, 0.290, -0.009)</td>
<td>(0.262, 0.309, 0.012)</td>
</tr>
</tbody>
</table>

Note: 1, owner; 2, main contractor; 3, architect.

**Comparative Statics**

The comparative statics aims to compare the optimum sharing ratios and transfer payments of different contracting parties after changes in risk preference-related parameters (see Figure 3) and outcome uncertainty (see Figure 4). The specific impacts of these parameters are analysed and discussed below.

Figure 3 shows the effect of behavioural parameters on the optimum sharing ratios and transfer payments. In Figure 3a, it can be seen that the owner’s optimum sharing ratio $\hat{r}_1$ decreases as the owner’s loss aversion coefficient $\lambda_1$ increases, while the optimum sharing ratio of the architect $\hat{r}_3$ and contractor $\hat{r}_2$ show an upwards trend with the increase of $\lambda_1$. Taking a closer look at the changes in $\hat{r}_1$, it can be seen that $r_1$ remains almost unchanged for $\lambda_1 < 1.75$ or $\lambda_1 > 2.05$. This may
imply that when the owner’s loss aversion coefficient $\lambda_1$ is very low, most of the risk/reward should be distributed to him and only a very small share should be allocated to his partners; the sharing ratios stay constant when $\lambda_1$ is very low or very high. Moreover, the effect of $\beta_1$ changes on the optimum sharing ratios shows a similar trend with the changes of $\lambda_1$ (see Figure 3c), while $\alpha_1$ changes cause an opposite trend in sharing ratios (see Figure 3b).

Figure 3a also shows that the owner’s transfer payment $d_1$ increases with the increase of $\lambda_1$, while the main contractor and architect’s transfer payments, i.e. $d_2$ and $d_3$ show an opposite trend for $\lambda_1 < 1.98$. Then, the owner’s transfer payment $d_1$ has a slight decrease for $\lambda_1 \geq 1.98$, although his optimum sharing ratio is constantly decreasing. One explanation is that as $\lambda_1$ increases, the sharing of risk/reward becomes “negative equity” for the owner, and the trade price for the risk/reward share (i.e., transfer payment) drops as expected. In addition, the effect of $\beta_1$ changes on the transfer payments shows a similar trend with the changes of $\lambda_1$ (see Figure 3c), while $\alpha_1$ changes cause an opposite trend in transfer payments (see Figure 3b).
Figure 3. Effect of behavioral parameters on RRSI: (a) effect of $\lambda_i$ changes on the optimum sharing ratios and transfer payments; (b) effect of $\alpha_i$ changes on the optimum sharing ratios and transfer payments; (c) effect of $\beta_i$ changes on the optimum sharing ratios and transfer payments.
In Figure 4, it can be seen that the owner’s optimum sharing ratio $\hat{r}_1$ decreases with the increase of outcome uncertainty $\sigma$, whereas the optimum sharing ratios for the main contractor $\hat{r}_2$ and architect $\hat{r}_3$ increase as $\sigma$ increases. Moreover, the transfer payment for the owner $d_1$ does not show a constant upward trend with the decrease of his optimum sharing ratio $\hat{r}_1$, yet the transfer payment for the main contractor $d_2$ does not show a constant downward trend with the increase of his optimum sharing ratio $\hat{r}_2$. This can be explained by the probability distribution functions of the actual outcome. As the outcome uncertainty increases, the loss area stretches and the gain area shrinks, with the mean of the final cost remaining unchanged. The loss aversion effect may lead to negative prospect value when the gap between the loss and gain areas becomes narrower. In this case, the sharing of risk/reward becomes “negative equity”, and the transfer payment decreases as expected.

![Graph showing trend of optimum sharing ratios and transfer payments](image)

Figure 4. The trend of optimum sharing ratios and transfer payments when $\sigma$ increases

Interestingly, it is worth noting that when the transfer payment approaches zero, the optimum sharing ratio is close to the notional sharing ratio (see the blue dashed lines in Figure 3 and Figure
4). For example, when $\lambda_1 = 1.9$ (see the blue dashed lines in Figure 3a), the owner’s (i.e., agent 1) transfer payment approaches zero, and consistently, his optimum sharing ratio converges to the notional numbers (i.e., $r_1 = 0.5$, $r_2 = 0.45$, $r_3 = 0.05$). The blue dashed lines in Figure 3b and Figure 3c also consistently point to the same parameter value of $\alpha_1$ (i.e. $\alpha_1 = 0.912$) and $\beta_1$ (i.e. $\beta_1 = 0.918$), respectively. This is a projected result because the transfer payment reflects the differences between the optimum and notional sharing ratio. The result also supports the reliability of the model.

**Discussion and Management Implications**

This study shows that agents are reluctant to use the IPD incentive if the notional RRSI is applied. This observation is explained from a novel perspective by using the baseline to measure their perceived profit. It is advocated that the notional RRSI may not satisfy the baseline for the agents. Because of the loss aversion effect, i.e., the individual’s decisions have an irrational bias towards being overly averse to risk, and the prospect values of involvement in the IPD RRSI may be lower than when they use the traditional method, even though IPD is more profitable (Cheng 2016). Therefore, they are hesitant to use IPD.

This has demonstrated the value of the optimum RRSI, i.e., that it can satisfy the baseline expectations and consequentially incentivize agents to adopt IPD procurement. The starting point of the proposed optimum sharing framework is a commonly used and recommended incentivization, i.e., the notional RRSI that provides 50:50 shares to the owner and non-owner groups and divides the RRS among non-owner parties according to the cost structure (Hall and Bonanomi 2021). This is different from the other models that simply maximize the sum of utility and suggest the sharing ratios only according to the agents’ behavioural parameters (such as risk
preferences and effort cost). That is, our optimum RRSI captured “fairness” by grounding on the notional sharing rule. Furthermore, by transferring part of the RRS to the risk-tolerant agent from the risk-averse agent with payments (see Figure 2 and Eq. (11) and Eq. (12)), especially when the outcome is highly uncertain, both agents’ perceived profit and further willingness to be involved in the sharing agreements would be increased. Therefore, another strength of this optimum sharing framework is that the introduction of “transfer payment” can help take advantage of “Pareto optimality” without disregarding “fairness”. The case illustration demonstrated that the optimum RRSI not only buys in IPD sceptics, but also incentivizes IPD proponents by improving the certainty equivalent of all parties.

This study has also discovered the correlation between the optimum RRSI (sharing ratios and transfer payments) and the behavioural parameters (i.e., the loss aversion coefficient \( \lambda \), the gain concavity coefficient \( \alpha \), and loss convexity coefficient \( \beta \) (see Figure 3)), as well as the outcome uncertainty \( \sigma \) (see Figure 4). The comparative statics results suggest that if the agent (normally the risk-tolerant agent) prefers a higher RRS, he can select the agent who is relatively risk-averse (characterized by a higher loss aversion coefficient (\( \hat{\lambda} \)), a lower coefficient of gain concavity (\( \hat{\alpha} \)), or a higher coefficient of loss convexity (\( \hat{\beta} \)) as his partner. Furthermore, if the risk-tolerant agent aspires for a higher RRS without additional payment for the trade of risk/reward, he can endeavour to set the sharing ratios when the outcome is highly uncertain. Taking the contractor (a relatively risk-tolerant agent compared to the owner and architect) in the illustration as an example, he should try to determine the sharing ratios at the earlier project stage. This is because the contractor can negotiate for a high RRS along with increased compensation, which is only possible when the uncertainty is relatively high (see \( \sigma \geq 24 \) in Figure 4). On the other hand, if the risk-averse agent expects additional payment for the exchange of RRS, he should try to set the sharing ratios when
the outcome is relatively certain. As shown in Figure 4, when \( \sigma \in [15, 24] \), the owner’s RRS is relatively high and transfer payment is negative, which means that he can have less payment to the non-owner parties. The owner as a relatively risk-averse agent compared to the contractor in the illustration, therefore, should seek to set the sharing ratios when the design is substantially complete. These findings are useful for developing effective strategies (how and at what time to set the sharing ratios) for IPD users to craft a satisfactory RRS arrangement.

The results offer different perspectives from the findings of previous studies, e.g., Hosseinian and Carmichael (2013) and Suijs (2003), who concluded that the optimal risk sharing ratio is independent of outcome uncertainty. The novel suggestion is derived from approaching different theoretical lenses in addressing risk/reward sharing. Previous studies have used expected utility theory to simulate individual choice behaviour with the assumption that decision-makers are totally rational. Instead of following expected utility theory, the focus of this study looks into the psychological effects of outcome uncertainty by applying descriptive prospect theory. This approach is in agreement with the studies of Boukendour and Hughes (2014), Melese et al. (2017) and Hosseinian et al. (2020), who pointed out the correlation between outcome uncertainty and optimum sharing.

**Limitations and Further Research**

The caveat of this study is the probability weights assumed for the working of prospect theory. Future research can be directed towards developing other quantification models by incorporating other theoretically sound probability weights. It is also worth noting that this research considers only the cost of the project as an outcome indicator. The work can be extended to other project success criteria. Another limitation is that most decisions are made jointly at the project level as well as at the firm level in an IPD context, whereas the prospect theory assumption of individual
utility does not directly apply to organizations. Therefore, it is recommended to elicit group utility reflecting the risk preferences of organizations to replace individual utility in future studies. Moreover, a real elicitation process of IPD players’ value function describing their risk preferences would enshrine the practical application of the proposed model. Additionally, the implicit assumptions of the study are that the transfer payment embedded in the optimum RRSI solution is possible and that the IPD project outcome is predicative. To operationalize the optimum RRSI framework, future studies can examine the feasibility of this innovative RRSI solution and evaluate IPD project outcomes, in addition to value function elicitation.

This study investigates risk sharing in the construction industry. Future studies can apply the optimum RRSI framework to other fields, e.g., cooperation in the insurance or production industry. Moreover, the main idea of our optimum RRSI framework is to reallocate the risk in terms of the players’ risk preferences and transfer payments given the difference between optimum and notional RRS. The notional sharing approach that captured the principle of fairness can be replaced by any allocation solution concept (e.g., Shapley value) as long as it is considered fair and applicable.

**Conclusion**

Establishing an effective and stable RRSI for IPD is vital for project success, as it can stimulate cooperative behaviours and hence outcomes. However, previous attempts at RRS models do not reflect the fact that the owner is actively and continuously engaged in the IPD team. Additionally, the methods used to model the outcome uncertainty did not consider the stochastic nature of project outcomes from future IPD projects. The assumption of rational economic individuals is also not consistent with the decision-maker’s behaviour in the real world. This study proposes an alternative approach in factoring behaviour consideration in the formulation of RRS. The conceptual lenses
are stochastic cooperative game theory and prospect theory. It implicitly takes into account the collaborative nature of the IPD project team and assumes that all contracting parties are subjective utility maximisers in a situation that involves uncertainty. Setting the notional RRSI as a fair starting point, the proposed optimum RRSI consisted of two parts, i.e., optimum sharing ratio and transfer payment. A case illustration is provided to further explain how the model can be used to help IPD practitioners achieve a multi-win RRSI. The numerical analyses show the following:

- The optimum RRSI can incrementally change the perceived profit of all contracting parties compared to the notional RRSI.
- The optimum sharing ratios of the optimum RRSI solution depend on the risk preferences of contracting parties and the level of outcome uncertainty.
- The transfer payments of the optimum RRSI solution are associated with the risk preferences, level of outcome uncertainty and notional RRS portions.

This study offers a novel and practical approach to design RRSI for use in IPD projects. The proposed method introduces the behaviour analysis method and examines IPD participants’ choice behaviour under risk. Furthermore, the proposed RRSI framework also takes care of the stochastic nature of project outcomes. The use of the “transfer payment” concept ensures that the optimum RRSI derived from “Pareto optimality” does not compromise fairness. Taken together, the research is useful for the formulation of more acceptable RRSI and the selection of more suitable IPD partners, thereby promoting the use of IPD. The adoption of IPD can be enhanced if the RRSI is considered by the parties as optimal.
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