GAME THEORY BASED UNDERSTANDING OF DYNAMIC RELATIONSHIPS BETWEEN PUBLIC AND PRIVATE SECTORS IN PPPS

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The relationships between public and private sectors in public private partnership (PPP) projects can be visualised as structured across different layers: activity layer, resource layer and actor layer. However, these relationships are dynamic and will change when the principal parties face particular problems or encounter serious issues during the long life cycles of most PPP projects. A game theory based approach for understanding such dynamic relationships is developed in this study. In this approach, the dynamic relationships between public and private sectors are analysed as a cooperative game, from risk allocation and financial negotiation to project operation. Variables which influence this relationship are identified from an international questionnaire survey; and will be incorporated into the final game theory based model. This paper presents an approach and corresponding methodology for conceptualising and understanding the behavioural dynamics of the main parties in PPPs. It also provides a theoretical foundation for research on relationships in PPPs.

Keywords: dynamic relationship, game theory, PPPs.

BACKGROUND AND INTRODUCTION

The recent resurgence of PPPs has precedents in previous centuries where private capital was injected into public infrastructure for railroads in USA and water supply in France (Kumaraswamy and Morris, 2002). As a procurement method for public infrastructure projects, PPP spread to many countries, in terms of greater involvements of the private sector over the past few decades. However, the drivers for adopting PPPs also gradually shifted from chasing private funds for public projects, to 'second generation' PPPs which focus on greater efficiency and value for money (Kumaraswamy *et al.*, 2007).

There are many successful infrastructure PPP projects in Mainland China. The first BOT (Build-Operate-Transfer, which is taken as one form of PPP) project in Mainland China was the Shajiao B Power Station. Hong Kong SAR has also developed mega infrastructure PPP projects, which include 3 cross harbour tunnels, Hong Kong Disneyland and the Asia World Expo convention centre near the new airport.

Compared with the conventional project procurement approach which is marked by cost overruns and delays, PPP/PFI projects are usually completed within time while capital expenditure may only slightly exceed budget, given the strong in-built,

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incentives and controls. According to UK research (HM Treasury, 2003), over 60 PFI projects, 89% were delivered on time or early; while all PFI projects in the Treasury sample were delivered within public-sector budgets. However, PPP projects generally have a longer term contract between public and private sectors, and a wider range of project stakeholders. Moreover, the PPP procurement process is much more complex, and the cost of tendering is higher than in the conventional procurement method. These characteristics demand better risk allocation between partners in PPP projects, and a high level of diligence to establish the business case (Grimsey and Lewis, 2004), as well as much stronger cooperative relationships between public and private organisations (Kumaraswamy *et al.*, 2007).

The objective of this paper is to examine basic relationship dynamics between the public and the private sectors in infrastructural PPP ventures. The dynamics of such relationships can be considered to develop progressively, over each stage of the bargaining process between the two main PPP game players: from (a) selecting the preferred bidder, (b) negotiating with the preferred bidder, and (c) supervising the selected private partner. This bargaining process will be conceptualised in this paper, as a game theory based framework. The objective is to analyse through a game framework, the behaviour of the players when the principal parties face particular problems or encounter serious issues during the long life cycles of most PPP projects. The different attitudes and behaviours of the parties are seen to be fundamental to the development of the afore-mentioned dynamic relationships.

DYNAMIC RELATIONSHIPS BETWEEN PUBLIC AND PRIVATE SECTORS

Business or inter-company relationships are complex. All inter-company relationships simultaneously exhibit conflict and cooperation, with guile and self-seeking elements (Turnbull *et al.*, 1996). It shows that each relationship can also be regarded as a part of a broader network of interdependent relationships. Any single relationship can not be viewed in isolation, but as a part of the larger whole. Any business enterprise, no matter how small, has to maintain relations with several other actors and some other relationships contribute or influence the development of each relationship (Håkansson and Snehota, 1995).

Previous research has examined relationships among PPP participants. Kumaraswamy *et al.* (2007) proposed that 'relationally integrating' larger PPP Teams can help to generate more successful integrated teamworking, joint risk management, sustainable relationships and a longer-term focus; compared with the 'classical contracting approaches' of traditional contracts that usually generate segregated teams, adversarial contracts, a blame culture and a short-term focus, and are in turn blamed for poor performance levels. Julian *et al.* (2006) have researched into how to manage trust and relationships in PPP, and pointed out that PPP can increase efficiencies at some micro management levels, but may not be able to establish trust. Grimsey and Lewis (2004) developed a framework which can assess ongoing business viability of the contractor to meet requirements for the term of contract. Some research has also been done on how relationships are managed between private sector organisations within the concession, and between private organisations and public sector clients (Kay *et al.*, 2008; Smyth and Edkins, 2007) .

In an infrastructure PPP project, the government enters into a business relationship with the public service provider, who is private company. Being a long term relationship, this must be strong enough to be sustainable. The relationship between

private sector and public sector is also a part of the larger network. The network may consist of direct and indirect relationships between all stakeholders of the PPP project, from government departments, private companies, consulting companies, contractors, banks and insurance companies to the general public, including end users and others affected. Some of them are easy to identify, while others are not. But it is essential to identify these complex relationships and their potential influence, especially the core relationship between public and private sector in a PPP project.

However, these relationships are also identified as necessarily dynamic in this research, since they change when the main parties face particular problems or encounter serious issues during the long life spans of most PPP projects. The overall research exercise, of which part is reported in this paper, also identifies 'variables' which comprise and contribute to building blocks and conditions for a successful partnership, and their influences on the overall relationship between public and private sectors. These core variables were identified through an international questionnaire survey. However, these particular survey results are scheduled to be published separately in the near future.

RESEARCH APPROACHES

Apart from the questionnaire survey mentioned above, the research approach adopted for this theoretical framework-building component of the study is based on game theory. Game theory can be defined as "the study of mathematical models of conflict and cooperation between intelligent rational decision-makers" (Barron, 2007). Among economic theories, game theory has been successfully applied to many important issues, such as negotiations, finance, and imperfect markets (Ho, 2006).

Concepts and processes in a PPP scenario can also be described in the language of 'gaming' (Scharle, 2002). The main players are the public sector (government) and private sector (PPP Project Company), if modelled as a two player cooperative game. Ho (2006) developed a model for financial renegotiation in PPP projects and its policy implications from a game theory perspective. Medda (2006) studied the allocation of risks in PPP transportation projects using a game theory approach. Ho (2005) also modelled a bid compensation decision process as a non-cooperative static game. That model aimed to study the impacts of bid compensation and to develop appropriate bid compensation strategies, whereas the cooperative game model in this paper focuses on the dynamic relationships between the main parties in PPP projects.

Akintoye *et al.* (2004) also applied game theory in PPPs, especially in the phases before and after a preferred bidder is selected. The present study will focus on the entire relationship development process between public and private sectors, from the primary risk allocation, to tenderer selection, and project operation; applying game theory to explain the 'rational' behaviours of both public and private parties.

The following sections outline basic concepts of game theory that can be related to the PPP tendering procedure, risk allocation and project operation (performance supervision). These are key stages/phases in the long life cycle of infrastructure PPP projects. Both public and private parties would have several choices (of strategies) and must make choices during each of the above mentioned stages/phases. The concept of 'Nash Equilibrium' (Neumann and Morgenstern, 1944) will be applied here to explain their preferable choices (strategies), considering the project condition, external environment and preferable choices (strategies) of the other party, and how the choices made could influence the relationships between public and private sectors.

OVERVIEW OF GAME THEORY

A game involves a number of players N, a set of strategies for each player, and a payoff that quantitatively describes the outcome of each 'play' of the game in terms of the amount that each player wins or loses. A strategy for each player can be very complicated because it is a plan, determined at the start of the game that describes what a player will do in every possible situation. There are two types of game: two person non-cooperative game and cooperative game. A cooperative game involves two individuals/players whose interests are neither completely opposite nor completely coincident (Barron, 2007). In a cooperative game, there exists binding agreements between players, but this is not so in non-cooperative games. Given the PPP scenario, a cooperative game approach will be used for modelling and analysing the dynamic relationships between players.

In game theory, Nash Equilibrium represents the 'best response' of each player to a particular choice of strategy by the other player(s) (Neumann and Morgenstern, 1944). Table 1 indicates a classical game model called 'the Prisoner's Dilemma'.

Table 1: A Payoff Matrix in the classical 'Prisoner's Dilemma'

	Prisoner B Stays Silent	Prisoner B Betrays
Prisoner A Stays Silent	Each serves 6 months (-0.5, -0.5)	Prisoner A: 10 years Prisoner B: goes free (-10, 0)
Prisoner A Betrays	Prisoner A: goes free Prisoner B: 10 years (0, -10)	Each serves 5 years (-5, -5)

The Prisoner's Dilemma has a single Nash Equilibrium: both players will choose to betray (-5, -5).

MODELLING THE GAME SCENARIOS IN PPP

The following assumptions are made in formulating the PPP game theory models:

Public sector 'behaviour' is predictable, and its characteristics are generally known because of the general government regulations, transparency and accountability.

It is difficult to predict the behaviour of the private sector, which aims to maximise their profit under different circumstances. We may assume two categories of private companies: 'cooperative type' and another 'uncooperative type'. Which type a private company will choose to be, is determined by how much profit/overall utility they can receive. Also, a private company can choose to cooperate at first, but may change to 'uncooperative type'.

The public sector utility function is related to both economic benefits and social benefits and their inter-relationships, while the private sector utility function is assumed to only relate to economic benefits. This assumption neglects for purpose of this study, increasing attention paid to 'corporate social responsibility' issues by private companies. Taking a cynical new, this may be considered a simplification that assumes such professed ideals are merely paying lip-service to, or linked to the 'business case' for incorporating such apparently altruistic goals.

This research focuses on the relationships between the main public and private parties in the proposed basic framework. Other PPP project participants, like financiers, insurance companies or general public will be considered to be part of the project conditions and external environment in the game theory framework.

General Payoff Matrix for PPP Projects

In a PPP scenario, taking x to represents the Public Sector, and y to represents the Private Consortium (SPV), the following Payoff Matrix can be formulated in general, where m,n indicate the possible choices or strategies that each project party can make.

x, y	0	1	2	$\cdots$	n
0	(x_0, y_0)	(x_0, y_1)	(x_0, y_2)	$\cdots$	(x_0, y_n)
1	(x_1, y_0)	(x_1, y_1)	(x_1, y_2)	$\cdots$	(x_1, y_n)
2	(x_2, y_0)	(x_2, y_1)	(x_2, y_2)	$\cdots$	(x_2, y_n)
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
m	(x_m, y_0)	(x_m, y_1)	(x_m, y_2)	$\cdots$	(x_m, y_n)

(x_i, y_j) means the payoffs of both public (x_i) and private sectors (y_j), if the public sector chooses strategy i while private sector selects strategy j.

$i = 0,1,\cdots,m$. $j = 0,1,\cdots,n$.

The Nash Equilibrium in this matrix can be identified through a numerical approach. For two-person cooperative games where players have more than two strategies, if the first payoff number, in the pair of the cell, is the maximum of the column of the cell and if the second number is the maximum of the row of the cell, then the cell represents a Nash equilibrium (Barron, 2007). For example, the initial Nash Equilibrium could be (x_1, y_0), (x_2,y_1), (x_n, y_2). However, if the project condition and outside environment changes, the values of both parties' payoffs will change correspondingly. This will trigger dramatic changes of the Nash Equilibrium, which means both public and private sector will have 'updated' preferable choices (strategies).

The selection of key public sector participants, setting of the rules, selection of private sector players and timing of their involvements are taken as part of the 'PPP game'. Some players enter sub-games: developers hire designers and contractors, financing institutions establish a sponsoring consortium, public authorities set up a specific public company, etc. At a macro level there are at least three phases in PPP projects development procedures: soliciting, contracting and implementing (Scharle, 2002).

The PPP infrastructure project game scenario unfolds as the procurement proceeds. In this research, we divide the procurement process into 4 main phases and corresponding models, as shown in Figure 1; of which this paper focuses on the Primary Risk Allocation Model and Supervision Model.

Primary Risk Allocation Model

Although primary risk allocation is decided unilaterally by the client, when he/she chooses the PPP route and contract type, the Primary Risk Allocation Model can be used to explain this initial risk allocation strategy of the public sector. This model conceptualises risk allocation as a game where the client would simulate in advance the options of 'take' or 'transfer' risk between itself and the private party on many basic issues, risks and their consequences (payoffs). The client could assume that both public and private parties will be co-operative and thus aim for win-win outcomes (as in Akintoye *et al.*, 2004).

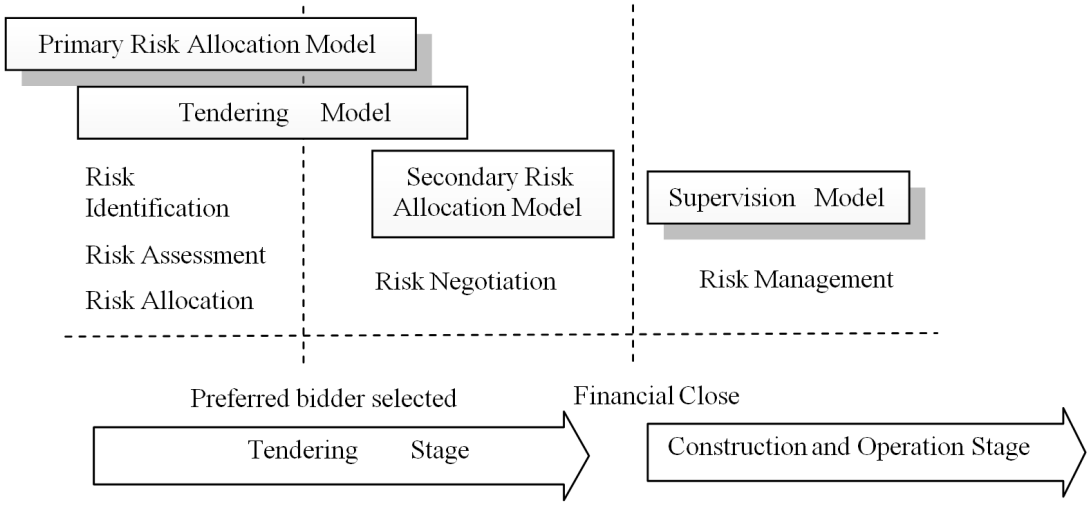

Figure 1: Summary Framework of PPP Infrastructure projects Procurement Models

For the above general simulations, the basic payoff matrix is conceptualised as follows:

x, y	*Take*	*Transfer*
Take	(x_0, y_0)	(x_0, y_1)
Transfer	(x_1, y_0)	(x_1, y_1)

As before, x represents the Public Sector, while y represents the Private Consortium (SPV). In this basic scenario, the public and private sectors only have two strategies to deal with the risk items during the primary risk allocation phase, i.e. take or transfer.

(x_0, y_0), means both public and private parties are expected to be willing to take the risk. The risk can then be managed jointly (Joint Risk Management) or solely by one party through negotiation.

(x_1, y_1), means both public and private parties are expected to be unwilling to take the risk. The risk may then be transferred to a third party like insurance company; otherwise it would be managed jointly (Joint Risk Management) through negotiation.

(x_1, y_0), (x_0, y_1), means that the risk is expected to be managed by one party solely.

In carrying out the above simulation, the client can use the general principle that risks should be allocated to those parties who are best able to manage them. This is because if one party can better manage that risk, the payoff will larger and that party is more willing to take the risk. The strategy they choose depends on their respective payoffs, which is ultimately determined by the project conditions and external environment. The outcome from the above simulation would feed into the primary procurement strategy and hence tender document calling for private partners.

Given space limitations, rather than describe all these subsequent models as conceptualised in Figure 1, this paper next focuses on a summary of the envisaged 'Supervision Model'. However, it may be noted that the 'Tendering Model', would involve a different and more structured game scenario, while the 'Secondary Risk Allocation Model' conveys the 'negotiation game' between the public party and the preferred bidder when negotiating the final points/grey areas/final adjustments before 'financial close' and signing the final PPP contract.

Supervision Model

Once the contract has been signed between the government and service provider, their relationship is more like an Agent-Principal relationship. The private company, acts as an agent of government, and provides public services to the community. The government, as the principal, has to supervise the performance of the private company according to applicable regulations and construction specifications stated in the contract.

When the main parties in this game face particular problems or serious issues during the long life cycles of PPP infrastructure projects, these will influence the utility functions of both public and private sector, and change their payoffs. This will then cause dramatic changes of the Nash Equilibrium, leading both public and private sector to change their preferable choices (strategies). For example, if the market needs are underestimated for a toll road, the public sector may consider building a new road to cater for the extra flow. This will become a competitor to the existing PPP road. Alternatively, if demand is overestimated, the private company usually has to bear the market risk according to the concessionaire contract, but the project may be refinanced in some cases e.g. for some landmark projects, or there could be a toll adjustment or compensation mechanism.

CONCLUDING OBSERVATIONS

The present study explores the behavioural dynamics of the main parties in PPPs from a game theory perspective. It also provides a theoretical foundation for deeper research on relationships in PPPs. Applying the gaming perspective in PPP issues seems to help to visualise and enhance 'fair play' for both parties. The models proposed in this paper are basic/'first order' and therefore simplified. If including influences from many internal and external factors, like political stability, social opposition, and PPP legislation etc, more work needs to be done on incorporating those factors into these models.

The main difficulty/limitation of this research is the determination of the values of payoffs for both parties. The payoffs may not be uni-dimensional but two-dimensional, or even multi-dimensional. For example, the payoffs in the Primary Risk Allocation Model do not only relate to the benefit if the risk is under control, but also relate to the loss if the risk cannot be managed. Another example is the payoff of the public sector, since its utility function relates to both economic benefits and social benefits. These lead to the difficulty of finding the Nash Equilibrium in the payoff matrix even if an absolute state of equilibrium exists in theory.

Future research is needed on the stability of the equilibrium, to explain the sustainability of relationships between public and private sector. This is an important area that is worth exploring for both uplifting and sustaining the success of PPPs in general.

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