Government incentive impacts on private investment behaviors under demand uncertainty

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A B S T R A C T  
This paper elaborates the impacts of government incentives on the private investment behaviors including the choices of investment timing, capacity, and price under demand uncertainty. The results suggest that revenue guarantee, concession period extension, lump-sum subsidy, and unit subsidy can induce timely investment. Revenue guarantee and concession period extension have limited impacts on the choices of capacity and price. Lump-sum subsidy leads to a smaller capacity and a higher price, while unit subsidy leads to a larger capacity and a lower price when comparing to the choices by a monopoly without government incentives.

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1. Introduction

Estimates of global infrastructure needs soar as high as US$ 3 trillion per annum (Dickinson, 2010). Government budgets are unable to fulfill the infrastructure demand, leaving an enormous gap of $1 to 1.5 trillion annually between demand and supply in global infrastructure (Airoldi et al., 2013). To close the infrastructure investment gap, many governments have embraced public-private partnerships (PPPs) to leverage private sectors’ financial resources and expertise for providing public infrastructure and service (Osei-Kyei and Chan, 2015). Build-operate-transfer (BOT) is a main type of PPPs, in which a private sector constructs, operates, and maintains an infrastructure facility for a specific concession period, and transfers the ownership to the host government at the end of the concession (Bao et al., 2015).

Modeling the private sector’s investment behaviors and characterizing the impacts of government incentives is a vibrant topic in the realm of PPP research. Despite previous research efforts, the private sector’s investment timing decision has not been well considered in conjunction with the choices of capacity and price under demand uncertainty with various government incentive mechanisms. The lack of consideration on investment timing and uncertainty is a main knowledge gap, which hinders the complete characterization of investment behaviors and incentive impacts. In absence of a sharp understanding on the investment behaviors and incentive impacts, the private sector may implement a suboptimal investment strategy, and the government may end up with undesired project outcomes due to inappropriate types and sizes of incentives.

This study aims to address the above knowledge gap by attaining two objectives. The first objective is to prove conjectures on the private sector’s optimal choices of investment timing, capacity, and price under uncertainty in a BOT project. The second objective is to characterize the impacts of government incentives including revenue guarantee, concession period extension, and subsidies on the private investment behaviors. The remainder of this paper is organized as follows. Section 2...
reviews relevant studies and underscores the knowledge gap. Section 3 builds on the real option theory and optimization techniques to explore the investment behaviors and incentive impacts, followed by a numerical study in Section 4. In Section 5, the research findings and their implications are discussed, and the limitations and future research directions are pointed out. Section 6 concludes the paper by highlighting important remarks.

2. Literature review

Many studies have examined the investment behaviors and government incentives. Xiao et al. (2007) studied the competition among private roads and found that oligopolistic competition yields higher tolls and smaller capacities than the social optima. Wu et al. (2011) proved that the level of service, represented by the volume-capacity ratio, offered by the profit-maximizing firm on a private toll road is the same as that provided by a welfare-maximizing authority. Guo and Yang (2009) proposed a strategy for the government to obtain a socially optimum BOT contract, in which the government requires a minimum demand and allows the private sector to select the road capacity, toll charge, and concession period.

Tan et al. (2010) elucidated the properties of Pareto-efficient BOT contracts and analyzed the behaviors of private investors under various regulations using a bi-objective programming approach. They proved that price-cap, rate-of-return, and capacity regulations are inefficient while demand and markup charge regulations are efficient in leading to Pareto-optimal outcomes. Qiu and Wang (2011) showed that a BOT contract with a price regulation during the concession period and a license extension after the concession period can achieve full efficiency.

Wang and Pallis (2014) used game theory to design incentive mechanisms for port concession contracts, in which a performance-based concession fee is required to align the interests of port authority and terminal operator. Tian and Huang (2015) investigated the impacts of capacity and toll choices of a BOT project on the distribution of benefits among the private sector, road users, and government. Noruzolaiæe et al. (2015) developed analytical models to investigate the capacity and pricing choices of two congestible airports under three privatization scenarios: public-private duopoly, private-private duopoly, and private monopoly.

Feng et al. (2015) lamented the lack of attention on modeling the impacts of government guarantees on investment behaviors. They modeled the impacts of minimum traffic guarantee, minimum revenue guarantee, and price compensation guarantee on the choices of toll rate, road quality, and capacity by a private monopoly. They fixed two variables at a time and then investigated how the other variable will change when the private sector is endowed with a government guarantee. Feng et al. (2016) employed a relational contract approach to derive the optimal government subsidy plan for quality improvement in a private toll road project. They demonstrated that the government subsidy is feasible in improving quality when the discount factor is sufficiently high, while the marginal cost of public funds is sufficiently low. Shi et al. (2016) explored the optimal choice of capacity, toll, and government guarantee for a BOT road project under both symmetric and asymmetric cost information. They concluded that the government guarantee can serve as an instrument to induce a private sector to report its actual cost information.

Efforts have been made to incorporate uncertainties into models. Tan and Yang (2012) considered the demand uncertainty and studied the flexibility of a BOT contract that involves the choices of concession period, road capacity, and toll rate with ex-post adjustments. Niu and Zhang (2013) investigated the impacts of demand uncertainty on the BOT contract design by solving a bi-objective problem with three decision variables: capacity, toll, and concession period. Xu and Moon (2013) presented a principal-agent model to determine the concession period for a BOT project with stochastic revenue and cost. Xiao et al. (2013) modeled the impacts of demand uncertainty on airport capacity choices. Their study showed that for both profit-maximizing and welfare-maximizing airports, the demand uncertainty will not change the optimal capacity choice if the demand variation is low and the capacity cost is high. Otherwise, the optimal capacity is smaller when a deterministic mean demand is considered.

Tan and Tan (2014) proposed an ex-post toll adjustment procedure to achieve Pareto-efficient outcomes for a BOT toll road project with a predetermined road capacity and an unknown demand function. In the model developed by Yang and Fu (2015), an airport operator chooses both the airport charge and the service quality to maximize its profit, and a regulator chooses a price cap or a penalty payment to maximize the expected welfare. They analytically compared the ex-ante price cap and the ex-post light-handed airport regulation in the presence of demand uncertainty. Chen and Liu (2016) proposed a model, where two port operators first choose their facility investment levels, and then determine their cargo-handling amounts and service prices. They used a two-period game to investigate the simultaneous investment decisions by the risk-averse port operators under demand uncertainty.

The real option theory has rapidly gained momentum in analyzing investment problems (Dixit, 1993; Décamps et al., 2006; Azevedo and Paxson, 2014, and Huismann and Kort, 2015). Gao and Driouchi (2013) incorporated Knightian uncertainty into the real option to examine the timing decision in rail transit infrastructure investment. Lv et al. (2014) presented a method based on real option to determine the concession period for a BOT project. Li et al. (2015) used a real option approach to answer two questions in transit technology investment under urban population volatility, i.e. what transit technology should be selected and when it should be introduced. Power et al. (2016) examined different strategic options including buyout and revenue sharing in highway concessions using the real option theory.

The literature review reveals a major knowledge gap, i.e. the investment timing decision by the profit-maximizing private sector has not been well considered with the capacity and price decisions under demand uncertainty, and the impacts of
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