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Is transportation infrastructure cost recoverable under the risk of disasters?

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A B S T R A C T

This study examines cost recoverability, or whether or not the expected revenue from the optimal congestion toll exceeds the cost of optimal investment in transportation infrastructure, when its capacity is uncertain owing to significantly large disasters whose loss cannot be hedged, either by any saving or insurance. The government controls the degree of reliability of the entire transportation system by combining two types of infrastructure, namely, unstable infrastructure, whose capacity decreases when a disaster occurs, and stable infrastructure, whose capacity is constant regardless of the occurrence of disaster. Under the assumption of risk-averse preferences of households, the theorem of cost recovery does not hold even if the congestion toll is controlled in a completely flexible manner, given any incidents. The optimally designed unstable (stable) infrastructure is (not) cost recoverable because the benefit of investment mitigating the risk premium in social welfare is not covered by the revenue of the congestion toll. We also show that if the transportation cost is specified by a linear function, The entire transportation infrastructure is not cost recoverable, if price elasticity of transport demand is less than one, as many empirical studies have shown.

1. Introduction

Transportation infrastructure always faces the risk of disasters such as earthquakes, storms, and floods. After a large disaster, it takes significant time for infrastructure facilities to recover, ranging from several months to several years, and the disaster area suffers a significant loss in production and income during the period. Although risk caused by disasters is unfavorable, it is too significant for individuals to hedge through insurance or deposits, even if we only consider monetary loss. Therefore, considering the value of these risks and developing a sufficiently reliable transportation system for disasters is an important task for the government.

While damage as a result of disaster can be directly mitigated by some adaptive investment, such as break water for climax and robust structure, developing multiple routes and facilities, is also an effective measure to enhance reliability of the entire transport network. It is well known that nearby infrastructure with high resiliency provides backup facilities when one infrastructure becomes unavailable as a result of disaster [1]. Hence, the planner has to invest in abundant capacity of stable or resilient infrastructure, to respond to cases of disaster, and this is the focus of this paper.

There are several recent studies evaluating the effect of disaster on infrastructure and investigating socially optimal investment in transportation infrastructure, given multiple different future scenarios on disaster and the probability of them occurring (e.g., Mojtahedi et al., 2017; Faturechi and Miller-Hooks, 2014; Xiao et al., 2015). Further, a few studies consider the development of

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[1] For example, when the earthquake in Japan and the following tidal wave seriously destroyed roads and airports on the Pacific Ocean coast, inland roads and airports promptly recovered their facilities to substitute destroyed infrastructure.

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reliability of the transport network with multiple roads, as well as adaptive investment (e.g., Asadabadi and Miller-Hooks, 2017). Although the central concern of past studies has been the cost and social benefit of investments, planners have another practical concern regarding infrastructure development, which is the so-called cost recovery or self-financing, articulated by the question of whether investment cost is covered by revenue in the form of user charges, or not. A novel theorem for cost recovery by Mohring and Harwitz (1962) shows that the construction cost of optimal capacity is exactly equal to the revenue of congestion toll, and there is a large body of literature to show extensions and counter examples of the theorem (e.g., Small, 1999; Arnott and Kraus, 1995; Bichsel, 2001; Kidokoro and Zhang, 2017). There is growing concern around cost recovery because privatization of transport infrastructure, such as airports and highways, is a worldwide tidal wave, and recently, even public planners have required self-financing and reduction of subsidy. To answer those concerns, we mainly focus on "cost recoverability", or whether the investment cost of infrastructure is exactly equal to or less than its revenue of optimal congestion toll, rather than just the "exact" cost recovery as mentioned by Mohring and Harwitz (1962).

This study considers the problem of cost-recoverability in the situation that there is a risk of disasters and the capacity of the infrastructure is designed so as to provide optimal backup facilities for the others. First, we investigate cost recoverability of each infrastructure focusing on its resilience, which describes difference in role within entire transportation network to mitigate risk of disaster. From this analysis, we can identify which infrastructure yields profit (or deficit), and how revenues should be transferred among them for developing transportation network with optimal reliability. Furthermore, our second question is whether the transfer between infrastructure facilities is sufficient to cover the aggregated investment cost of the entire infrastructure. Otherwise, subsidy from outside the transport sector is required. We then investigate the possibility of self-financing of each individual infrastructure and the entire transportation system.

Several studies consider the theorem with uncertainty in transport demand and facilities. The most related studies are Lindsey (2009) and Lindsey and De Palma (2014), who showed that despite uncertain shocks in demand and infrastructure facilities, strict cost recovery holds in expected value terms if the toll is fully flexible (i.e., allowing the first best pricing by observing each shock) [2]. Furthermore, Arnott and Kraus (1998) considered the accumulation of transportation capital for uncertain growth in transportation demand. They speculated that strict cost recovery holds in present value terms if information on future demand is complete and the toll is flexible over time. This is proved by Lindsey and De Palma (2014).

On the contrary, this study focuses on uncertainty in transportation facilities combined with risk-averse preferences of households toward uncertainty in income, although Lindsey (2009) and Lindsey and De Palma (2014) assume risk-neutral social welfare. Our assumption of risk-averse preference is essential while considering significant but rarely occurring disasters like the earthquake in Japan in 2011. In the next few decades, some countries might experience disasters while others may not. Once people encounter a disaster, they suffer significant loss of income and lifetime utility which is not completely hedged by their savings and insurance [3]. This is why we should not evaluate the value of transport infrastructure only with expected social surplus. Risk premium should also be considered. On the contrary, if the focus is on a frequently-occurring event, such as daily change in weather, as in past studies, accumulated consumer surplus will converge to the expected value during a certain length of time, and then, we can assume risk-neutral social welfare.

Furthermore, this study is also related to studies on cost recovery of multiple transport infrastructure. Although Yang and Meng (2002) proved that the cost recovery theorem holds for each substitutable route, they did not consider the risk and provision of backup facilities among them, while we consider both. By considering two infrastructure, we can investigate how their stability, or the role in the entire transportation system, matters its cost-recoverability. This is completely new question not investigated in past studies.

We consider a situation in which the economy can possibly face a disaster that partially destroys infrastructure and increases transportation costs. Since firms input both, transportation services and labor for production, a decrease in transportation facilities due to disasters also decreases the productivity of the firms, and wages paid to households. We also assume that households are risk-averse, and hence, dislike risk in income in the future. Hence, the government should consider the risk premium in social welfare, as well as the expected income, while developing a transportation system. We assume a government that constructs two congestible forms of infrastructure, namely, unstable infrastructure whose capacity decreases when a disaster occurs, and stable infrastructure whose capacity is a constant, regardless of incidents. The stability of the entire transportation system is, therefore, a policy variable that is controlled by a combination of these two infrastructures. [4] We also assume flexible congestion tolls, which differ in terms of infrastructure and observed incidents. Therefore, the government can change the congestion toll observing the disaster.

The primary focus of this study is cost recoverability in terms of expected revenue, called *ex-ante* cost recoverability, as well as past studies. We show that strict cost recovery does not hold owing to the risk-averse preference even when the government can flexibly change the congestion toll observing the situation. This is because the benefit of investment to mitigate risk premium is not covered by the expected revenue of the congestion toll. Therefore, we also show that stable infrastructure is not cost recoverable because it contributes to the reduction of risk, while the completely unstable one is cost recoverable. In other words, cost

[2] Correct information on each shock is essential so that the cost recovery holds. Kraus (1982) shows that demand uncertainty distorts the strict cost recovery theorem in expected value terms if the congestion toll and investment have to be determined, given the uncertainty surrounding the information on demand. Lindsey (2009) also showed that a flexible toll cannot achieve cost recovery if planners receive only a probabilistic signal of demand shocks.

[3] Note that there is no insurance in reality to cover all losses caused by disasters.

[4] Planners can develop completely reliable infrastructure by investing only in stable infrastructure.