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Regulation of Privatized Public Service Systems

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Abstract

To alleviate the financial shortage for public service provision, a government agency may jointly finance, own, and run a service system with a private firm (in the manner of a joint venture) or delegate service provision to the firm subject to regulation in service price or wait time. We model the service system as a queueing system in which customers are heterogeneous in service valuation and sensitive to price and delay. While the government aims to maximize social welfare, the firm's goal is to maximize profit. Hence, the joint venture has the objective of a mix of profit maximization and social welfare creation. Under the regulation, two types of interaction between the government and the firm, that is, sequential move (in the absence of the government's myopic adjustment) and simultaneous move (in the presence of myopic adjustment), are considered. We find that while wait time regulation is more efficient than price regulation in the presence of myopic adjustment, the relationship is reversed in the absence of myopic adjustment. Somewhat surprisingly, price regulation with myopic adjustment may backfire. However, in some instances, the government must take a large share in a joint venture to achieve the same performance under price regulation without myopic adjustment. Our work uncovers whether the government adopts myopic adjustment plays a critical role in choosing the regulation instrument.

Keywords

Public service, queueing system, regulation, joint venture, game theory

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1 Introduction

Public services such as healthcare, emergency services, and public transportation are provided by a government to people living within its jurisdiction, either directly through the public sector or by financing the provision of such services (McGregor Jr et al., 1982). As the population increases and the aging problem becomes more significant, the demand for public services is increasing over time, which requires large financial investments in public infrastructures. To reduce the tremendous financial pressure, many governments seek partnerships with the private sector.

The joint venture, as one form of public–private partnership (PPP), is a common mechanism governments use to address financial constraints for service provision. For instance, in January 1997, Huaxin, a company in Henan Province of China, invested in a public hospital, which became the first PPP hospital in China.[1] The Hong Kong Financial Secretary Corporation, on behalf of the Hong Kong government, sold 23% of its stake in the Mass Transit Railway (MTR) Corporation in a public offering in June 2000; the MTR Corporation then became the MTR Corporation Limited and was listed on the stock exchange of Hong Kong in October 2000. By inviting a private firm to be on board, the government jointly owns and operates the project with the private firm. The private firm thus has bargaining power for decision-making in the project. As argued by Luo and Kaul (2019), PPPs and other hybrid arrangements are better suited to deal with social problems concerning high information asymmetry and a high potential

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for innovative solutions. However, the private firm's for-profit interest usually runs counter to that of the government and the general public.

In addition to the joint venture, the governments may allow private service providers to offer public services. This is known as privatizing public services and is commonly seen in sectors such as healthcare and transportation. Government agencies represent the general public, whereas private service providers are usually profit-driven. The conflict of interest between the government and private service providers may lead to undesired consequences. For instance, the toll for using one privately operated tunnel in Hong Kong (Western Harbor Crossing) is high, so the realized daily traffic volume is only 57% of its designed capacity, while the daily traffic volume of one public tunnel (Cross-Harbor Tunnel) is ∼147% of its designed capacity.[2] As a result, privatized public services are usually regulated (in terms of price or service quality) by the government (see, e.g., Joskow, 2014). In fact, when a private corporation runs as a monopoly, regulation is typically necessary to prevent abuse of monopoly power. In practice, price and wait time (a key indicator of service quality) are the two most commonly used regulation instruments in public service systems, such as healthcare, public transportation, and tunnel and highway tolls.[3] For example, the service price of the Elderly Transport Service in Hong Kong, ranging from HK$15 to HK$70 depending on the journey distance,[4] is much lower than the market price. As another example, the mandated service level of accident-and-emergency centers in England is that no more than 5% of patients have to wait longer than 4 h from the time of entering the center (Jiang and Sodhi, 2019). In Jiangsu Province of China, the queue length in highway toll systems is required to be < 200 m (which is approximately equivalent to a wait time regulation); if this target is exceeded, cars must be offered free of charge. Governments may prefer a hands-on approach to regulating privatized public services. However, such an approach could be pushed back by private firms, especially when they are partners to help address governments' capital shortfall in service development and provision. Instead, governments tend to only partially regulate firms; see, for example, De Fraja and Iozzi (2008) on quality regulation, Costa-Font et al. (2014) on price regulation, and Benjaafar et al. (2022) for an example of on-demand service platforms for which the labor wage is regulated, but the service price is not. In view of those practices, we focus on governments' partial regulation in price or service quality, but not on both.[5]

Such a partial regulation has a critical impact on society. Inappropriate regulation instruments may even lead to inefficiency, in the sense that social welfare is lower with regulation than without. For example, if the service price is capped at a very low level, the service system can become overly crowded; see Besley and Coate (1991) for such an example in healthcare systems. If the wait time is set too short, the private service provider may respond by charging a high price, thereby serving only a small number of customers. Thus, it is critical to choose the right type and level of regulation. Furthermore, as pointed out by Stiglitz (1998), "it [i.e., the government] always has the possibility of changing its mind." The reason for such a possibility could be the change of the decision environment or other short-sightedness, for example, to gain more votes in an election. For example, the Chinese government intervened and set prices on 32 occasions between 1998 and 2013. Each time, the average price reduction across therapeutic categories equaled 20% (Fang, 2015). As another example, the municipal government of Guangzhou, China, changed the toll standard of Huanan Expressway three times in 2003, 2012, and 2020. The private operator of Huanan Expressway publicly complained about the mandated toll reduction in 2012.[6] Thus, "the government is likely to be an unreliable partner even if the industry were to agree to price controls and other regulations" (Frank, 2003). The private firm then may react to the regulation adjustment by adjusting unregulated elements of its operation. If the government is simply to adapt to the change in the environment, its regulation adjustment will induce the firm to be adaptive correspondingly. However, if the government's adjustment is for short-sighted purposes, the government adjusts the regulation after observing the actual performance of the privately run public system even when the decision environment does not change. In this case, because the firm will react in its own interest, the resulting welfare of the system could be lower. Over time, if the government myopically adjusts the regulation several times, the government is gaining in the short-term right after the adjustment but may be worse off over the long run. Therefore, whether the government will adjust the regulation for short-sighted purposes over time could have a significant impact on the regulation efficiency and the selection of a regulation instrument.

We study the following research questions: Is regulation an efficient way to improve welfare? Which type of regulation, price or wait time, is more efficient? If the government adjusts the regulation for short-sighted purposes over time, how would the results change? How does the price or wait time regulation perform compared with a joint venture? To answer these questions, we consider a system in which a private firm provides a type of public service to a population of price- and delay-sensitive customers with heterogeneous service valuations, in the manner of a joint venture or regulation. The firm can potentially decide the service capacity and price, or equivalently, the price and wait time, to maximize its profit. The government's incentive is to maximize social welfare, that is, the sum of the firm's profit and customer surplus. When a public service is run in a joint venture, the objective is a mix of profit maximization and social welfare maximization. Consistent with intuition, the resulting social welfare increases with the government's project share or, equivalently, the capital that the government invests.

Motivated by practical examples in healthcare and toll systems, we then consider two types of regulation: price and wait time. The move of the government and the firm can be sequential or (effectively) simultaneous, depending on whether the government will adjust the regulation for short-sighted purposes over time. Hereafter, we refer to such a short-sighted adjustment as a myopic adjustment. In the absence of myopic adjustment, the interaction between the government and the firm under regulation is modeled as a Stackelberg game, with the government moving first to announce the regulated price (respectively, wait time) followed by the firm's best response to the wait time (respectively, price) decision. In the presence of myopic adjustment, the equilibrium of interaction over time is captured by a Nash game.

Our analysis reveals that both price and wait time regulation are effective in the absence of the government's myopic adjustment, in the sense that they increase social welfare compared with no regulation. Indeed, by enforcing a lower price (respectively, shorter wait time) than that without regulation, consumer surplus increases under regulation, although the firm's profit may decrease. Hence, social welfare can be boosted by appropriately choosing a regulated price or wait time as long as the government will not adjust the regulation over time. Moreover, we find that price (a monetary regulation instrument) is more efficient than wait time (an operational regulation instrument). This is due to the firm's flexibility in complying with the wait time regulation: the firm can increase either the service capacity or the service price (such that fewer customers are served) or both. Note that increasing the service price decreases consumer surplus and social welfare (as we have shown that the customers' and the government's interests are aligned). By contrast, under price regulation, the firm can only adjust its capacity. As a result, the firm's incentive to increase the capacity is weaker under wait time regulation than under price regulation, and hence, price regulation is more effective.

However, in the presence of myopic adjustment, the ranking of the two regulatory schemes is reversed: wait time regulation is now more efficient. This result also indicates that the myopic adjustment has a stronger (negative) impact under price regulation than under wait time regulation. In the presence of myopic adjustment, the conflict of interest between the government and the firm means that the government will lower the regulated price whenever it revisits its decision myopically. The firm, however, responds by reducing the service capacity out of its profit-driven interest. In equilibrium, the firm earns zero profit with the least operational service capacity. When the government instead regulates the wait time, it shortens the wait time for the customers' sake, which will push the firm to expand the service capacity but decrease the firm's profit. Nevertheless, the firm can take advantage of pricing to profitably comply with the regulation by increasing the service price, which will reduce the number of customers it serves. Hence, the conflict of interest between the government and the firm is alleviated under wait time regulation. Moreover, the firm's pricing power sustains the incentive to expand the service capacity. Hence, in equilibrium, the service capacity is larger under wait time regulation than under price regulation. Meanwhile, because the price under price regulation is extremely low (under which the firm receives zero profit), the number of customers the firm serves is larger than under wait time regulation. As a result, the system is very congested under price regulation, thereby leading to lower social welfare. Somewhat surprisingly, price regulation can backfire: when the market size is sufficiently large, the system is very congested with low capacity; the social welfare thus can be lower than it would be without regulation. With no regulation, the firm charges a higher price but has the incentive to invest in capacity.

Finally, we compare the performances of the regulations and the joint venture. The joint venture can avoid the possible backfire of price regulation with myopic adjustment. Furthermore, our numerical study shows that to achieve the same social welfare when the government regulates the service price without myopic adjustment, the government should take a large share under the joint venture when the market size is relatively large or/and the cost parameters such as the unit service cost, capacity cost, and delay cost are relatively small.

2 Literature Review

Extensive studies exist about the government's regulation of corporate projects and operations. Monetary regulation such as price regulation (see, e.g., Greenberg and Murphy, 1985), taxation/toll (see, e.g., Krass et al., 2013), and subsidy (see, e.g., Cohen et al., 2019), are particularly common in practice. Regulation with other instruments can be regarded as quality regulation. For instance, the government may impose a requirement on a product, service, or project characteristics, such as quality (see, e.g., Melumad and Ziv, 2004), reliability (see, e.g., Gao et al., 2021), and hospitals' readmission rate (see, e.g., Zhang et al., 2016). In the context of service systems, wait time or queue length is one of the commonly used quality indicators. Shang and Liu (2011) investigate firms' competitive behavior in industries where customers are sensitive to both promised delivery time and quality of service measured by the on-time delivery rate. In this paper, we study practically motivated price and wait time regulation and compare their efficiency in public service systems.

Our paper is closely related to the literature on regulation and comparison of welfare-maximizing and profit-maximizing solutions in service (or production) systems with congestion. This literature dates back to the celebrated work by Naor (1969). The author uses an M/M/1 queue, where the queue length is observable and customers are homogeneous, to model a toll system and shows that the welfare-maximizing toll is lower than the revenue-maximizing one, thereby implying that the toll should be regulated downwards for welfare maximization. For an M/M/1 service system, Huang and Chen (2015) show that revenue maximization and welfare maximization lead to different pricing strategies when customers perform anecdotal reasoning, whereas the two objectives are equivalent in the fully rational benchmark. Haviv and Oz (2018) suggest a classification of regulation schemes based on a few desired properties and use it to categorize schemes from the existing literature and propose a novel regulation scheme that possesses all of the properties. In these papers, the (monopolistic) firm's capacity is exogenously given. Considering an M/M/1 service system where the queue length is unobservable and customers have different service values, Mendelson (1985) studies the pricing and capacity decisions made to maximize social welfare and profit. In a decentralized setting, Liu et al. (2007) study a decentralized supply chain consisting of a supplier and a retailer facing price- and lead time-sensitive demands, analogous to our system consisting of the government and a service provider facing price- and delay-sensitive customers. The authors find that the inefficiency due to decentralization is strongly influenced by market and operational factors. Decision-makers in these papers are profit-seeking, whereas, in our decentralized system, the private sector is profit-seeking while the government seeks to maximize overall welfare. Moreover, in contrast to those papers, we are interested in how the various regulation schemes perform and how the regulation efficiency changes when the interaction between the private sector and the government changes from a sequential move to a simultaneous move. As far as we know, these two questions have not been studied in this stream of literature on service systems.

The equilibrium concept of regulation in the absence and presence of the government's myopic adjustment in our paper turns out to coincide with those in the Stackelberg and Nash games, respectively. Thus, our work is related to the literature that discusses the impact of the decision sequence on outcomes in games with public and private organizations. De Fraja and Delbono (1989) analyze a situation in which one public firm and multiple private firms compete in setting quantities of a homogeneous commodity, and show that social welfare is higher when the public firm moves first, compared with a simultaneous move. Poyago-Theotoky (2001) makes an extension by introducing an output subsidy offered by a public firm to all firms. In addition to considering different decision sequences, our paper takes into account the operational-level system congestion and different regulation schemes for each decision sequence. Thus, we show not only how decision sequences affect social welfare for a given regulation scheme in systems with congestion but also how the preferred regulation scheme changes as the decision sequence changes.

Our paper is also related to the literature on privatized public service systems, many of which study two-tier service systems in the healthcare context. In these systems, the public service systems are partially privatized by introducing private service providers. De Vericourt and Lobo (2009) consider a healthcare system in which the paying hospital's revenue is used to support the free hospital's operations and identify the optimal resource and capacity allocation policy. Guo et al. (2014) study a similar self-financing two-tier service system in a queueing model. They first derive the optimal price and capacity of the toll system and then show that expanding the free system's capacity can actually increase congestion for all customers, thereby exhibiting the Downs–Thomas paradox. Andritsos and Aflaki (2015) analyze the capacity competition in a two-tier system and show that providing a larger subsidy to the for-profit hospital can increase the waiting time in the nonprofit hospital. Hua et al. (2016) study the competition and coordination issues in a situation where the public SP is partially subsidized by the profits of the private SP. Qian et al. (2017) compare the efficiency of conditional and unconditional subsidy schemes in two-tier healthcare systems. Our paper differs from these papers in two aspects. First, the government or public party in our paper does not compete with the private service provider but influences its decisions by regulation. Second, we do not consider subsidy policies (belonging to monetary regulations) as we focus on the situation where the government lacks sufficient capital. In other words, we examine a new direction for managing the public service system. Considering the lack of capital, Zhou et al. (2023) propose to change the ownership of the public service provider to increase the social welfare of a two-tier system. The (partial) privatization of the public service provider in their paper leads to the joint venture mode, while our paper compares the performance of the regulation and joint venture. Moreover, compared with Zhou et al. (2023), we also consider the capacity decision of the system, which captures the long-run effect of the government's policy.

3 The Model

Consider the scenario in which a government provides a type of public services, such as healthcare, highways, or tunnels. To develop a tractable model for the complex service system, we approximate it by an M/M/1 queueing system, see, for example, Wang et al. (2019), Xu et al. (2020), and Armony et al. (2021). Suppose that potential customers arrive according to a Poisson process with rate Λ. The customers are price- and delay-sensitive. We assume that the queue length in the service system is unobservable to the customers, and they form and use (the belief about) the expected wait time when evaluating the waiting cost associated with the option of joining the service system, see, for example, Yang et al. (2018); Wang et al. (2019), and Araman et al. (2019). If a customer joins the system, he or she obtains a service value v, which is a random draw from a uniform distribution on the interval $[0, a]$, and suffers an expected waiting cost in proportion to the expected wait time w; see Benjaafar et al. (2022) for the same assumptions on customer valuation and waiting disutility. As a robustness check, we consider nonuniform distributions and show that the main results continue to hold in E-Companion E.1 (Supplemental material). The customer's expected net utility for joining the system is $v - p - hw$, where $p > 0$ is the service price and $h > 0$ is the delay cost per unit of time (also known as delay sensitivity). The utility of balking and taking an outside option is normalized to 0 for all customers without loss of generality. Apparently, given the equilibrium expected wait time w, those customers who have $v \geq p + hw$ will join the system, yielding the effective arrival rate

$$\lambda = \Lambda \int_{\min\{p+hw,a\}}^{a} \frac{1}{a} \, \mathrm{d}v = \Lambda \left(1 - \frac{hw}{a} - \frac{p}{a}\right)^{+}, \qquad (1)$$

where $x^{+} = \max\{x, 0\}$. Throughout the paper, unless otherwise stated, we focus on the scenario with $(hw/a) + (p/a) \leq 1$ such that $\lambda \geq 0$, because the project performance with $(hw/a)+(p/a) > 1$ is the same as that with $(hw/a)+(p/a) = 1$. Intuitively, the effective demand is decreasing in the service price p and the expected wait time w. For ease of exposition, we denote by $V(\lambda)$ the total service value per unit of time associated with the effective arrival rate; that is,

$$V(\lambda) = \Lambda \int_{p+hw}^{a} \frac{v}{a} \, \mathrm{d}v = a\lambda \left(1 - \frac{\lambda}{2\Lambda}\right). \qquad (2)$$

The service provider incurs a given cost c per customer served and a cost γ per unit of capacity, per unit of time (see, e.g., Allon and Federgruen, 2007). For convenience, we refer to c and γ as the unit service cost and capacity cost. The service price p and the service capacity μ are decision variables of the service provider, from which the expected wait time (in the M/M/1 queueing system) $w = 1/(\mu - \lambda)$ is a derived measure. Note that for any given p, there exists a one-to-one mapping between μ and w. Hence, we can treat p and w as the decision variables, although the capacity cost is directly related to μ. We use w as a decision variable in order to align with the two regulation measures mentioned thereinafter.

In the following, we introduce several performance indicators of the system. Let Π denote the profit per unit of time. Then, we can write

$$\Pi = \lambda(p - c) - \gamma\mu = \lambda(p - c - \gamma) - \frac{\gamma}{w}, \qquad (3)$$

where the last equality follows from $\mu = \lambda + 1/w$. The total customer surplus per unit of time, denoted by CS, equals the total service value $V(\lambda)$ minus the total cost of joining, including the monetary cost and waiting cost, which yields

$$\mathrm{CS} = V(\lambda) - (p + hw)\lambda = V(\lambda) - a\left(1 - \frac{\lambda}{\Lambda}\right)\lambda = \frac{a\lambda^2}{2\Lambda}. \quad (4)$$

The second equality follows from (1), and the last equality follows from (2). Finally, social welfare per unit of time is defined as the sum of the profit and the total customer surplus,

$$\mathrm{SW} = \Pi + \mathrm{CS} = V(\lambda) - \lambda(hw + c + \gamma) - \frac{\gamma}{w}, \qquad (5)$$

where the last equality follows from (3). From (5), social welfare equals the total service value $V(\lambda)$ minus the sum of the total expected waiting cost $h\lambda w$, the total service cost $c\lambda$, and the total capacity cost $\gamma(\lambda + 1/w)$.

To ensure that the service provider is sustainable, a non-negative profit should be achievable. That is, the return of capacity investment should be sufficiently large, which effectively requires a sufficiently large market size. We make the following assumption throughout this paper.

ASSUMPTION 1. $\Lambda \geq \Lambda_0 \equiv 27ah\gamma/(a - c - \gamma)^3$, *or equivalently,* $\Theta \equiv \Lambda/\Lambda_0 \geq 1$.

By definition, we refer to Θ as the market scale factor, and a higher value of Θ implies a larger market size.

The service system runs for a long time, and the system parameters may change over time. Because each party in the systems has full information about the parameters, their decisions can be adaptive to the parameter changes. For simplicity, we assume that the system parameters are constant over time.

3.1 The Benchmark Scenarios

The government can build the service system and provide the service by itself. However, the government lacks sufficient capital for capacity expansion. To address this situation, the government invites a private firm to jointly finance, own, and operate the service system. This operating mode is known as a joint venture. We assume that the private firm has sufficient capital. Under the joint venture, the private firm joins the board, as in the examples of the MTR Corporation in Hong Kong and the hospital in Henan province of China. Thus, the board of the public service provider consists of government agents who advocate for social welfare and the representatives of the private shareholders who advocate for profit. Hence, both private and public shareholders have an influence on decision-making. The bargaining among the public and private agents results in a compromise between maximizing welfare and maximizing profit (Matsumura, 1998; Fujiwara, 2007; Fan et al., 2020; Zhou et al., 2023). Let β measure the social responsibility weight the government exerts on the service provider's decision-making. The problem under the joint venture can be formulated as follows:

$$\max_{p,w} \; \beta\mathrm{SW} + (1 - \beta)\Pi \quad \text{s.t. } \Pi \geq 0, \; \mathrm{SW} \geq 0. \qquad (\mathrm{B})$$

Here, we assume that both the firm and government do not have outside options, so their disagreement points for the joint venture are 0. Such a treatment has been widely adopted in literature (see, e.g., Peters, 1986; Nagarajan and Bassok, 2008; Baron et al., 2016; Shang and Cai, 2022). If the firm has sufficient capital, it may have an outside option yielding a positive profit. We consider such a situation (where the firm's participation constraint is replaced by $\Pi \geq \pi_0$) and study the impact of π_0 in E-Companion E.2 (Supplemental Material). Recall that $\mathrm{SW} = \Pi + \mathrm{CS}$. Thus, $\Pi \geq 0$ implies $\mathrm{SW} \geq 0$, and we can drop $\mathrm{SW} \geq 0$ in Model (B).

For the joint venture, the objective function is a weighted sum of profit and social welfare. Such an objective of moving

Table 1. Equilibrium in joint venture ($K \equiv h\gamma/(a-c-\gamma)$).

Condition	$\beta \le \beta_0$	$\beta > \beta_0$
Price p^B	$\frac{1-\beta}{2-\beta}(a-c-\gamma)(1-\Phi^B)+c+\gamma$	$(a-c-\gamma)\Phi^B+c+\gamma$
Effective arrival rate λ^B	$\frac{1}{(\Phi^B)^2}\frac{K^2}{h\gamma}$	
Profit Π^B	$\left(\frac{1-\beta}{(2-\beta)(\Phi^B)^2}-\frac{3-2\beta}{(2-\beta)\Phi^B}\right)K$	0
Social welfare SW^B	$\left(\frac{3/2-\beta}{(2-\beta)(\Phi^B)^2}-\frac{7/2-2\beta}{(2-\beta)\Phi^B}\right)K$	$\left(\frac{1}{2(\Phi^B)^2}-\frac{1}{\Phi^B}\right)K$

Note: $\Theta \ge 1$.

beyond profit maximization (Cachon et al., 2020) is consistent with the mixed mission of those firms certified as "B Corporation" in the U.S., which requires a sufficient portion of "social and environmental performance" in a firm's agenda.[7] We thus refer to the scenario with the joint venture as Scenario B. In practice, the value of β reflects the project share the government holds.

PROPOSITION 1 (OPTIMAL SOLUTION UNDER JOINT VENTURE). *(i) Under joint venture, the equilibrium price p^B and the resulting effective arrival rate λ^B, profit level Π^B, and social welfare SW^B are presented in Table 1. Moreover, the equilibrium wait time satisfies $w^B = \Phi^B((a-c-\gamma)/h)$, where Φ^B is characterized as follows:*

- *If $\beta \le \beta_0$, Φ^B is the unique root to $\Theta(1-\Phi) = 2-\beta/27\Phi^2$ in the range $\Phi \in (0, (1/3)\Theta^{-1/3}]$.*
- *If $\beta > \beta_0$, Φ^B is the unique root to the equation below in the range $\Phi \in (0, (1/3)\Theta^{-1/3}]$,*

$$\Theta(1-2\Phi) = \frac{1}{27\Phi^2}. \qquad (6)$$

(ii) Under the optimal solution in Scenario B, if $\beta \le \beta_0$, the effective arrival rate λ^B and social welfare SW^B are increasing in β, whereas the profit Π^B is decreasing in β; if $\beta > \beta_0$, they are invariant to β.

Consistent with our intuition, when the government's weight is low, as it increases, the increasing focus on welfare maximization drives the public service provider to serve more customers at the cost of profitability. However, when the government's weight is sufficiently large, the firm's participation constraint is binding, that is, $\Pi = 0$, and the service provider's objective is equivalent to maximizing social welfare. As the objective function becomes irrelevant to the weight, there is no need for the government to increase its weight anymore.

In the following, we consider two special cases in which the weight β takes extreme values. When the government does not take any share, that is, $\beta = 0(< \beta_0)$, the service provider's objective becomes profit maximization so that the joint venture corresponds to (full) *privatization*. When the government takes all share, that is, $\beta = 1(> \beta_0)$, the joint venture corresponds to *nationalization* with an objective of social welfare maximization. Because the service provider acts as a planner of the decentralized (respectively, centralized) system, we refer to privatization (respectively, nationalization) as Scenario D (respectively, Scenario C).

COROLLARY 1 (OPTIMAL SOLUTION UNDER NATIONALIZATION AND PRIVATIZATION). *The optimal service price p^i and the resulting effective arrival rate λ^i, profit level Π^i, and social welfare SW^i, $i = C, D$ are presented in Table 2. Moreover, the resulting wait time satisfies $w^i = \Phi^i((a-c-\gamma)/h)$, where Φ^i is characterized as follows:*

- *Φ^C is the unique root to (6) in the range $\Phi \in (0, (1/3)\Theta^{-1/3}]$,*
- *Φ^D is the unique root to $\Theta(1-\Phi) = 2/27\Phi^2$ in the range $\Phi \in (0, (1/3)\Theta^{-1/3}]$.*

We note from Corollary 1 that the profit is exactly zero under Scenario C. That is, social welfare is maximized when the service provider earns no profit. This is consistent with the observation that a nonprofit usually generates the highest possible social welfare, see, for example, Kaul and Luo (2018). This result highlights the conflict of interest between the government and the private firm. Furthermore, according to Proposition 1, it follows that the optimal service price, wait time, and the firm's resulting profit level are lower under nationalization than under privatization, while the resulting effective arrival rate, customer surplus, and social welfare are higher under nationalization. That is, $p^C \le p^D$, $w^C \le w^D$, $\Pi^C \le \Pi^D$, $\lambda^C \ge \lambda^D$, $CS^C \ge CS^D$, and $SW^C \ge SW^D$.

We illustrate the main findings of Proposition 1 and Corollary 1 in Figure 1. As the government's weight increases from 0 to β_0, it turns Scenario D to be closer to Scenario C such that social welfare increases (while the profit decreases). However, maintaining a larger share requires the government to invest more assets, which may not be practical in the government's financial situation.

Table 2. Equilibrium under benchmark scenarios ($K \equiv (h\gamma/(a-c-\gamma))$.

Scenario	C	D
Price	$(a-c-\gamma)\Phi^C + c + \gamma$	$(a+c+\gamma-\Phi^D(a-c-\gamma))/2$
Effective arrival rate λ^i	$\frac{1}{(\Phi^C)^2}\frac{K^2}{h\gamma}$	$\frac{1}{(\Phi^D)^2}\frac{K^2}{h\gamma}$
Profit Π^i	0	$\left(\frac{1}{2(\Phi^D)^2} - \frac{3}{2\Phi^D}\right)K$
Social welfare SW^i	$\left(\frac{1}{2(\Phi^C)^2} - \frac{1}{\Phi^C}\right)K$	$\left(\frac{3}{4(\Phi^D)^2} - \frac{7}{4\Phi^D}\right)K$

Note: $\Theta \geq 1$.

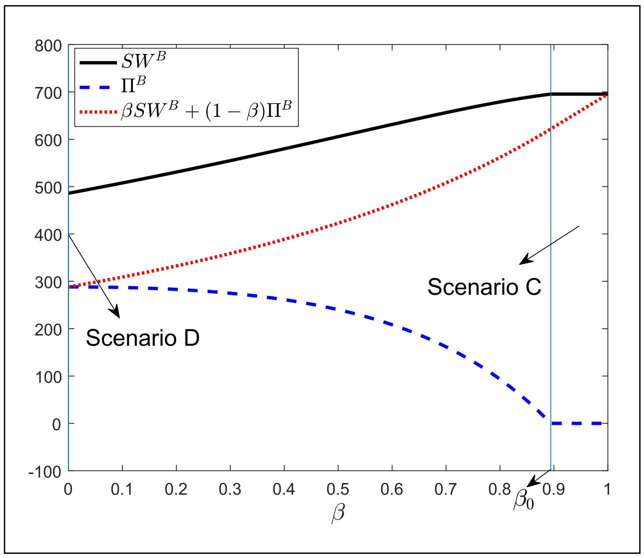

Figure 1. The equilibrium social welfare and profit in the benchmark scenarios (B, C, and D): $\gamma = 30$, $a = 120$, $h = 30$, $\lambda = 50$, $c = 20$.

4 Price and Wait Time Regulations

In this section, we consider an alternative operating mode for the capital-constrained government, that is, privatization with regulation, to deliver public service. Without the government's permission, the private firm cannot operate in the public service market. Hence, as a return for delegating the service provision to the private firm, the government can regulate the firm's operations to mitigate the misalignment of their interests. Consider the scenario in which the government contracts with a private firm. The firm finances, builds, and owns the service system and operates it, whereas the government imposes regulations in the contract. We consider a contract in which the government specifies a price floor p or a maximum (expected) wait time w. Due to the conflict of interests between the government and the private firm, the firm will operate just to achieve the regulatory specifics. Thus, imposing a cap on the price or wait time is equivalent to determining the specification itself. We provide a detailed analysis for such equivalence in E-Companion C (Supplemental Material). Throughout this paper, we refer to the "wait time" as the "sojourn time" in the system to get through the whole process, for example, passing through the tunnel. If the regulation deals with the delay before customers get served, given that there is a one-to-one correspondence between the delay and the sojourn time, an equivalent regulation can be imposed on the latter. Note that instead of specifying a wait time in the contract, the government may specify a service level at which the probability of meeting a time guarantee t must be above a certain level, say α. This requirement, however, is equivalent to the requirement about the wait time in our setup.[8] We use the subscript "P" (respectively, "W") to indicate the scenario in which the regulation instrument is the price p (respectively, the wait time w).

The government may adjust the regulation over time. The reason for such adjustments is two-fold. First, the system parameters can be time-varying. That is, the value of the parameters may change over time. In this case, it is optimal for the government to adjust the regulation term. We refer to this type of adjustment as responsive adjustment. Second, the government may adjust the regulation term for short-term purposes such as earning votes in an election. We refer to this type of adjustment as myopic adjustment. Apparently, the responsive adjustment is beneficial to the government and the public. In contrast, the public may or may not benefit from the myopic adjustment. Hence, we are interested in the impact of myopic adjustment in this paper. Note that our assumption of constant system parameters facilitates us to highlight this impact of myopic adjustment because the responsive adjustment is unnecessary when the system parameters do not change over time.

4.1 Regulation Without Myopic Adjustment

In the absence of myopic adjustment, the government does not change its decision over time, and in response, the firm does not change its decision either. Thus, we can model the interaction between the government and the firm as a (one-shot) Stackelberg game. Because the government has stronger bargaining power in public service provision than the firm, it is natural to assume that the government acts as a Stackelberg leader, whereas the firm acts as a follower; see, for example, Guan and Zhuang (2015). Such a Stackelberg game also reflects that the government has commitment power when it does not implement myopic adjustment. In the next section, we study the scenario in which the government implements myopic adjustment. We indicate the regulation without myopic adjustment by superscript "S," as we model it as a Stackelberg game. For convenience, we use "SP" and "SW" to denote the price and wait time regulation without myopic adjustment, respectively.

4.1.1 Price Regulation Without Myopic Adjustment (SP). In this regime, the government first sets the service price p. Given the service price p, the firm sets the expected wait time w to maximize $\Pi(w,p)$. Based on the firm's best response to the expected wait time, the government's decision problem is

$$\max_{p} \ \mathrm{SW}(w_f(p),p) \quad \text{s.t.} \begin{cases} w_f(p) = \arg\max_w \Pi(w,p), \\ \Pi(w_f(p),p) \geq 0. \end{cases} \tag{SP}$$

In particular, the constraint $\Pi(w_f(p),p) \geq 0$ is the nonnegative profit constraint to ensure that the firm has the incentive to participate in the project.

4.1.2 Wait Time Regulation Without Myopic Adjustment (SW). Given the expected wait time w regulated by the government, the firm sets the service price p to maximize $\Pi(w,p)$. Based on the anticipation about the firm's pricing decision, the government's decision problem is

$$\max_{w} \ \mathrm{SW}(w,p_f(w)) \quad \text{s.t.} \begin{cases} p_f(w) = \arg\max_p \Pi(w,p), \\ \Pi(w,p_f(w)) \geq 0. \end{cases} \tag{SW}$$

We solve the equilibrium of the two Stackelberg games as follows.

Proposition 2 (Equilibrium in Regulation Without Myopic Adjustment). *In the absence of the government's myopic adjustment, under the two regulation scenarios (i.e., $j = P, W$), the equilibrium price p_j^{S} and the resulting effective arrival rate λ_j^{S}, profit level Π_j^{S}, and social welfare $\mathrm{SW}_j^{\mathrm{S}}$ are presented in Table 3. Moreover, the equilibrium wait time satisfies $w_j^{\mathrm{S}} = \Phi_j^{\mathrm{S}}((a-c-\gamma)/h)$, where Φ_j^{S} is characterized as follows:*

- *If $1 \leq \Theta \leq \Theta'(= (2^{-1/3} + 2^{7/6})^3/27 \approx 1.039)$, Φ_P^{S} is the unique solution to (6) in the range $\Phi \in [(1/3)\Theta^{-1/3}, (1/2))$; if $\Theta > \Theta'$, Φ_P^{S} is the unique solution to $\Theta(1-\Phi) = (1/27\Phi^2)(1 + (2/27\Theta\Phi^3))$ in the range $\Phi \in (0, (2^{1/6}/3)\Theta^{-1/3})$.*
- *If $1 \leq \Theta \leq \Theta''(= (256/243) \approx 1.054)$, Φ_W^{S} is the unique solution to*
$$\Theta(1-\Phi)^2 = \frac{4}{27\Phi} \tag{7}$$
in the range $\Phi \in (0, \Phi^{\mathrm{D}}]$; if $\Theta > \Theta''$, Φ_W^{S} is the unique solution to $\Theta(1-\Phi) = 4/81\Phi^2$ in the range $\Phi \in (0, ((243/4)\Theta)^{-1/3})$.

When the market size is small, that is, $1 \leq \Theta \leq \Theta'$ in SP or $1 \leq \Theta \leq \Theta''$ in SW, the firm's participation constraint is binding, which implies that the government's optimal decision is to leave no money on the table for the firm. By contrast, when the market size is large enough, the government's optimal decision is such that the firm earns a positive profit. Moreover, $\Theta'' > \Theta'$ implies that there exists a larger primitive set for the firm to obtain positive profit when the government regulates the price rather than the wait time. We provide the intuition behind it as follows. When the government regulates the wait time, the firm can decide on the capacity and the price. However, when the government regulates the price, the firm would

Table 3. Equilibrium in regulation without myopic adjustment ($K \equiv \frac{h\gamma}{a-c-\gamma}$).

Scenario	SP		SW	
Condition	$1 \leq \Theta \leq \Theta'$	$\Theta > \Theta'$	$1 \leq \Theta \leq \Theta''$	$\Theta > \Theta''$
Service price p_j^{S}	$\frac{a-c-\gamma}{27\Theta(\Phi_P^{\mathrm{S}})^2} + c + \gamma$		$\frac{a+c+\gamma-\Phi_W^{\mathrm{S}}(a-c-\gamma)}{2}$	
Effective arrival rate λ_j^{S}	$\frac{1}{(1-2\Phi_P^{\mathrm{S}})\Phi_P^{\mathrm{S}}}\frac{K^2}{h\gamma}$	$\frac{2}{27\Theta(\Phi_P^{\mathrm{S}})^5}\frac{K^2}{h\gamma}$	$\frac{2}{(1-\Phi_W^{\mathrm{S}})\Phi_W^{\mathrm{S}}}\frac{K^2}{h\gamma}$	$\frac{2}{3(\Phi_W^{\mathrm{S}})^2}\frac{K^2}{h\gamma}$
Profit Π_j^{S}	0	$\left(\frac{2}{(27\Theta)^2(\Phi_P^{\mathrm{S}})^7} - \frac{1}{\Phi_P^{\mathrm{S}}}\right)K$	0	$\left(\frac{1}{3(\Phi_W^{\mathrm{S}})^2} - \frac{4}{3\Phi_W^{\mathrm{S}}}\right)K$
Social welfare $\mathrm{SW}_j^{\mathrm{S}}$	$\frac{1}{2(1-2\Phi_P^{\mathrm{S}})}K$	$\frac{2}{(27\Theta)^3(\Phi_P^{\mathrm{S}})^{10}}K + \Pi_P^{\mathrm{S}}$	$\frac{1}{2\Phi_W^{\mathrm{S}}}K$	$\left(\frac{1}{2(\Phi_W^{\mathrm{S}})^2} - \frac{3}{2\Phi_W^{\mathrm{S}}}\right)K$

Note: $\Theta'' > \Theta' > 1$.

follow the regulated price and can decide on the capacity only. The price regulation is more direct to influence the firm's capacity investment. As a consequence, the government can afford less stringent regulation under SP than under SW. However, it is not necessary that the firm earns more profit under SP than under SW, as confirmed in the following theorem.

THEOREM 1 (PERFORMANCE OF REGULATIONS WITHOUT MYOPIC ADJUSTMENT). *We compare the equilibrium performances of Scenarios C, D, SP, and SW as follows:*

1. *(Wait time)* $\max\{w^C, w^S_W\} \leq w^D \leq w^S_P$. *Moreover,* $w^S_W < w^C$ *if and only if* $\Theta < 125/81$.
2. *(Service price)* $\max\{p^C, p^S_P\} \leq p^D \leq p^S_W$. *Moreover,* $p^S_P < p^C$ *if and only if* $\Theta < \Theta_0 (\approx 1.1367)$.
3. *(Effective arrival rate)* $\lambda^D \leq \min\{\lambda^S_P, \lambda^S_W\} \leq \max\{\lambda^S_P, \lambda^S_W\} \leq \lambda^C$. *Moreover,* $\lambda^S_P \leq \lambda^S_W$ *if and only if* $\Theta \leq \Theta_1 (\approx 1.084)$.
4. *(Firm's profit)* $\Pi^C \leq \min\{\Pi^S_P, \Pi^S_W\} \leq \max\{\Pi^S_P, \Pi^S_W\} \leq \Pi^D$. *Moreover,* $\Pi^S_W \leq \Pi^S_P$ *if and only if* $\Theta \leq \Theta_2 (\approx 1.137)$.
5. *(Social welfare)* $SW^D \leq SW^S_W \leq SW^S_P \leq SW^C$.
6. *(Customer surplus) The comparison of the equilibrium customer surplus follows the same order as the equilibrium effective arrival rate.*

Recall from (4) that the total customer surplus increases in the effective demand. Thus, the comparison of the total customer surplus follows the same order as that of the equilibrium effective arrival rate. Compared with the regulation scenarios, nationalization (i.e., Scenario C) and privatization (i.e., Scenario D) are two extremes. In the extreme case of nationalization, for the sake of the general public, the government would sacrifice the private firm's profit to improve customer surplus. Hence, under nationalization, the firm's profit is the lowest, while the effective demand and social welfare are the highest. At the other extreme of privatization, the firm cares only about profit, thereby leading to the highest profit, the lowest effective demand (and consumer surplus), and the lowest social welfare of all scenarios. In between the two extremes, regulation attempts to protect social welfare by moderating the firm's self-interested behavior.

As we can see, under SP (respectively, SW), the government's regulation caps the price (respectively, wait time), that is, $p^S_P \leq p^D$ (respectively, $w^S_W \leq w^D$), but the firm reacts by increasing the unregulated wait time (respectively, price), that is, $w^S_P \geq w^D$ (respectively, $p^S_W \geq p^D$). With regard to the equilibrium effective demand and the firm's profit, the comparison of monetary and operational regulations, that is, SP and SW, depends on the market size. Though the firm may not always prefer one type of regulation over another, Theorem 1 shows that the government will always prefer SP over SW. To explain this result, we note that the firm needs to make two decisions: price and capacity. When the government regulates the price, the firm can decide on the capacity only. Thus, by choosing the price, the government is able to influence the firm's capacity investment. By contrast, when the government regulates the wait time, the firm can make both price and capacity decisions. Thus, to meet the wait time requirement, the firm may increase the price (to admit fewer customers into the system) rather than the capacity. Specifically, plugging $w = 1/(\mu - \lambda)$ into (1) yields $w = (1 - \mu/\Lambda - p/a + \sqrt{(1 - \mu/\Lambda - p/a)^2 + 4h/(a\Lambda)})/(2h/a)$, from which the firm can choose any pair of service price and capacity as long as the value of $(\mu/\Lambda) + (p/a)$ meets the requirement associated with the wait time regulation. For instance, the firm can choose a smaller capacity coupled with a higher price or a larger capacity coupled with a lower price. This flexibility weakens the government's influence on the firm's capacity investment for social welfare since the firm's and the government's objectives are not aligned. As a result, wait time regulation is not as effective as price regulation in terms of incentivizing expansion of the system capacity, and thus, price regulation results in higher social welfare in the one-shot interaction between the government and the firm. Moreover, such flexibility under wait time regulation brings more profit to the firm than under price regulation when the market size is sufficiently large. This is because the firm could leverage flexibility by building less capacity, charging a higher service price, and serving fewer customers under wait time regulation than under price regulation when the market size is large enough.

COROLLARY 2. *Suppose that the government does not implement myopic adjustment. Compared with wait time regulation, price regulation achieves a win–win situation for the firm and government when* $\Theta < \Theta_2$, *and achieves a win–win–win situation for the firm, customers, and government when* $\Theta_1 < \Theta < \Theta_2$.

Implied from Theorem 1, Corollary 2 confirms that in the absence of myopic adjustment, price regulation can mitigate the conflict of interest between the government and the firm. Moreover, by Theorem 1(6), when the market size is large enough (i.e., $\Theta > \Theta_1$), even customers can benefit more from price regulation than wait time regulation due to the lower service price, despite longer wait (see Theorem 1(1) and (2)). As a result, the government's price regulation is more likely to receive support from the firm and customers when the government does not implement myopic adjustment.

4.2 Regulation With Myopic Adjustment

As mentioned, when the government adjusts the regulation for short-sighted purposes, the firm can react to change its decision. This may result in disappointing consequences for both parties over the long run. Even so, as long as the firm does not react very quickly, the government can achieve and maintain short-term gains via the regulation adjustment for a certain period of time. However, firms do take time to learn,

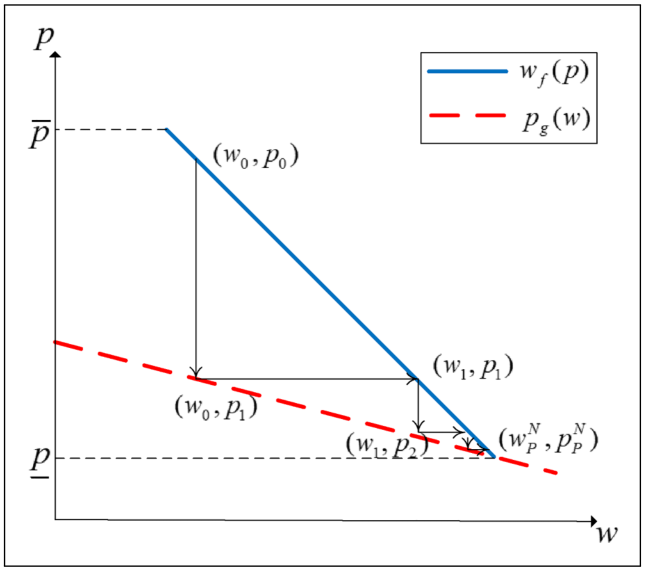

Figure 2. Dynamics in the presence of the government's myopic adjustment.

design, and implement reactive schemes in response to regulation adjustments, that is, myopic adjustment does occur in practice, see, for example, Stiglitz (1998) and Frank (2003), for practical observations and discussions. In response to the firm's reaction, the government may find it beneficial to adjust the regulation term again, which triggers the firm's subsequent decision change. This process evolves until no party can be better off by deviating from its own decision. Such an equilibrium concept is exactly captured by Nash equilibrium. In practice, only a few rounds of best responses could lead to an outcome very close to the Nash equilibrium. Therefore, we would focus on the notion of Nash equilibrium for the regulation scenario with myopic adjustment.

To see how the Nash equilibrium forms, we plot the firm's best response to the government's regulation in p, $w_f(p)$, and the government's best response to the firm's action in w, $p_g(w)$, in Figure 2. In particular, in this NP example, if the regulated price is either too low or too high, that is, $p \notin [\underline{p}, \overline{p}]$, the firm will quit. The equilibrium under SP is a point chosen by the government from the firm's best-response curve $w_f(p)$ to maximize social welfare. We denote the SP equilibrium as (w_0, p_0) in the figure, that is, $(w_0, p_0) = (w_P^S, p_P^S)$. However, given the firm's choice of wait time w_0, the government finds it better to lower the price to p_1 (according to its best-response function), thereby increasing the social welfare for that moment. Then, the firm reacts by increasing the wait time from w_0 to w_1. This dynamic process evolves and converges to a situation where no party can be better off deviating from its own decision, that is, the intersecting point of $p_g(w)$ and $w_f(p)$. We denote this point as (w_P^N, p_P^N), where superscript "N" indicates the regulation with myopic adjustment as a Nash game.

Over repeated interactions, the Nash equilibrium can be achieved. However, if the government adjusts the regulation only once, the equilibrium, as a result of the firm's reaction, will be (w_1, p_1). In E-Companion D (Supplemental Material), we compare the performance of this equilibrium to that of (w_P^S, p_P^S). Overall, the myopic adjustment process will eventually lead to a lose–lose situation for the government and the private firm, thus indicating that myopic adjustment harms the regulation's efficiency. As explained, the government may myopically adjust the regulation twice or more as the authority finds it beneficial to do so before the Nash equilibrium is eventually achieved. For exposition, we focus on the scenario where the Nash equilibrium is achieved in the remainder of this paper. This scenario demonstrates the worst-case impact of myopic adjustment on regulation efficiency and shows the importance of not pursuing short-sighted objectives, that is, the power of commitment. Therefore, we formulate the best-response problems as follows.

4.2.1 Price Regulation With Myopic Regulation (NP). Given the wait time w chosen by the firm, the government's decision problem is as follows:

$$\max_p \ \mathrm{SW}(w,p) \quad \text{s.t. } \Pi(w,p) \geq 0, \tag{NP-G}$$

where the constraint $\Pi(w,p) \geq 0$ is to ensure the firm's participation, and otherwise, the private firm quits, and the government ends up with $\mathrm{SW}(w,p) = 0$. Notably, $\Pi(w,p) \geq 0$ implies $\mathrm{SW}(w,p) \geq 0$ because $\mathrm{SW}(w,p) \geq \Pi(w,p)$. Given the service price p set by the government, the firm's decision problem is

$$\max_w \ \Pi(w,p). \tag{NP-F}$$

4.2.2 Wait Time Regulation With Myopic Regulation (NW). Given the service price p chosen by the firm, the government's decision problem is

$$\max_w \ \mathrm{SW}(w,p) \quad \text{s.t. } \Pi(w,p) \geq 0. \tag{NW-G}$$

Given the expected wait time w set by the government, the firm's decision problem is

$$\max_p \ \Pi(w,p). \tag{NW-F}$$

We solve the equilibrium of the two Nash games as the intersection of the best responses.

PROPOSITION 3 (EQUILIBRIUM IN REGULATION WITH MYOPIC ADJUSTMENT). *In the presence of the government's myopic adjustment, under the two regulation scenarios (i.e., $j = P, W$), the equilibrium price p_j^{N} and the resulting effective arrival rate λ_j^{N}, profit level Π_j^{N} and social welfare $\mathrm{SW}_j^{\mathrm{N}}$ are presented in Table 4. Moreover, the equilibrium wait time satisfies $w_j^{\mathrm{N}} = \Phi_j^{\mathrm{N}}((a - c - \gamma)/h)$, where Φ_j^{N} is characterized as follows:*

Table 4. Equilibrium in regulation with myopic adjustment ($K \equiv h\gamma/(a-c-\gamma)$).

Scenario	NP	NW	
Condition	$\Theta \geq 1$	$1 \leq \Theta \leq \Theta'''$	$\Theta > \Theta'''$
Service price p_j^{N}	$\frac{a-c-\gamma}{27\Theta(\Phi_P^{\mathrm{N}})^2}+c+\gamma$	$\frac{a+c+\gamma-\Phi_P^{\mathrm{N}}(a-c-\gamma)}{2}$	
Effective arrival rate λ_j^{N}	$\frac{1}{(1-2\Phi_P^{\mathrm{N}})\Phi_P^{\mathrm{N}}}\frac{K^2}{h\gamma}$	$\frac{2}{(1-\Phi_W^{\mathrm{N}})\Phi_W^{\mathrm{N}}}\frac{K^2}{h\gamma}$	$\frac{1}{2(\Phi_W^{\mathrm{N}})^2}\frac{K^2}{h\gamma}$
Profit Π_j^{N}	0	0	$\left(\frac{1}{4(\Phi_W^{\mathrm{N}})^2}-\frac{5}{4\Phi_W^{\mathrm{N}}}\right)K$
Social welfare $\mathrm{SW}_j^{\mathrm{N}}$	$\frac{1}{2(1-2\Phi_P^{\mathrm{N}})}K$	$\frac{1}{2\Phi_W^{\mathrm{N}}}K$	$\left(\frac{3}{8(\Phi_W^{\mathrm{N}})^2}-\frac{11}{8\Phi_W^{\mathrm{N}}}\right)K$

Note: $\Theta''' > \Theta'' > \Theta' > 1$.

- *If* $\Theta \geq 1$, Φ_P^{N} *is the unique root to (6) in the range* $\Phi \in [(1/3)\Theta^{-1/3}, 1/2)$.
- *If* $1 \leq \Theta \leq \Theta'''(= (125/108) \approx 1.157)$, Φ_W^{N} *is the unique root to (7) in the range* $\Phi \in (0, \Phi^{\mathrm{D}}]$, *where* Φ^{D} *is given by Proposition 1; if* $\Theta > \Theta'''$, Φ_W^{N} *is the unique root to* $\Theta(1-\Phi) = 1/27\Phi^2$ *in the range* $\Phi \in (0, (1/3)(4\Theta)^{-1/3})$.

Recall that under Scenario C, the optimal service price that maximizes social welfare is sufficiently low that the firm's profit is zero. Thus, we conjecture that the government will always undercut the price to pursue its short-sighted objective, that is, to maximize the short-term social welfare, under NP. Indeed, we show in the E-Companion (Supplemental Material) that for any given wait time, social welfare decreases with the regulated price in the parameter space that ensures $\Pi \geq 0$. Hence, the government will keep reducing the regulated price until the Nash equilibrium is reached so that the firm's participation constraint is binding, that is, $\Pi_P^{\mathrm{N}} = 0$. By contrast, when the government regulates the (expected) wait time, the optimal wait time for any given service price does not necessarily result in zero profit for the firm. Hence, under NW, the equilibrium may not bind the firm's participation constraint, and the firm earns a positive profit when the market size is large enough, that is, $\Theta \geq \Theta'''$.

THEOREM 2 (PERFORMANCE OF REGULATIONS WITH MYOPIC ADJUSTMENT). *We compare the equilibrium performances of Scenarios C, D, NP, and NW as follows:*

1. *(Wait time)* $w_W^{\mathrm{N}} \leq w^{\mathrm{C}} \leq w^{\mathrm{D}} \leq w_P^{\mathrm{N}}$.
2. *(Service price)* $p_P^{\mathrm{N}} \leq p^{\mathrm{C}} \leq p^{\mathrm{D}} \leq p_W^{\mathrm{N}}$.
3. *(Effective arrival rate)* $\lambda^{\mathrm{D}} \leq \lambda_W^{\mathrm{N}} \leq \lambda_P^{\mathrm{N}} \leq \lambda^{\mathrm{C}}$.
4. *(Firm's profit)* $\Pi^{\mathrm{C}} = \Pi_P^{\mathrm{N}} = 0 \leq \Pi_W^{\mathrm{N}} \leq \Pi^{\mathrm{D}}$.
5. *(Social welfare)* $\max\{\mathrm{SW}^{\mathrm{D}}, \mathrm{SW}_P^{\mathrm{N}}\} \leq \mathrm{SW}_W^{\mathrm{N}} \leq \mathrm{SW}^{\mathrm{C}}$. *Moreover,* $\mathrm{SW}^{\mathrm{D}} < \mathrm{SW}_P^{\mathrm{N}}$ *if and only if* $\Theta < \Theta_3(\approx 1.22)$.
6. *(Customer surplus) The comparison of the equilibrium customer surplus follows the same order as the equilibrium effective arrival rate.*

Like regulations without myopic adjustment, regulations with myopic adjustment have a direct effect on the targeted instrument and a side effect on the unregulated one: $p_P^{\mathrm{N}} \leq p^{\mathrm{D}}$ and $w_P^{\mathrm{N}} \geq w^{\mathrm{D}}$ under NP, and $w_W^{\mathrm{N}} \leq w^{\mathrm{D}}$ and $p_W^{\mathrm{N}} \geq p^{\mathrm{D}}$ under NW. Recall the conflict of interest between the government and the firm. When the government pursues its short-sighted objective, it always finds it better to lower the regulated price (so that the firm earns zero profit), thereby forcing the firm to serve as many customers as possible, while the firm responds by reducing the service capacity;[9] in equilibrium, the firm makes zero profit (i.e., $\Pi_P^{\mathrm{N}} = 0$) with the least operational service capacity over time; see Figure 2 for an illustration. Moreover, as a result of the low service capacity and the low regulated service price, the resulting wait time is extremely long. When the government regulates the wait time, a more stringent requirement incentivizes the firm to increase the service capacity on the one hand and to increase the service price on the other hand, to make up for the increased capacity cost. In equilibrium, the firm expands the service capacity to a level higher than that under privatization while possibly taking advantage of a high service price to make a positive profit.

Both regulation schemes have a positive effect on the effective arrival rate and customer surplus (with a lower price in NP and a higher service capacity in NW). However, the impact from NW is weakened by the increased price such that $\lambda^{\mathrm{D}} \leq \lambda_W^{\mathrm{N}} \leq \lambda_P^{\mathrm{N}}$. From (5), we see that each joining customer suffers from an increase in the wait time at the same degree (as measured by h). In contrast, the increase in the total service value due to the rise in the effective demand brings diminishing returns. Therefore, NW, which does not increase the effective demand too much but caps the wait time, results in higher social welfare compared with NP. Moreover, it is somewhat surprising to observe that NP may backfire:[10] the associated social welfare is lower than that under privatization.

This counter-intuitive result, again, is due to the aggressive increase in the effective demand (induced by a low regulated price), which makes the system congested, more so when the market size is sufficiently large, that is, $\Theta > \Theta_3$. This result cautions the government that price regulation with myopic adjustment does not necessarily improve social welfare and can cause the system to perform worse than with no regulation at all. Interestingly, we show in E-Companion E.2 (Supplemental Material) that a larger reservation profit of the firm can mitigate the degree of backfire.

COROLLARY 3.

(i) Among Scenarios D, NP, and NW, no one scenario leads to a win–win–win situation for the firm, customers, and government over another.

(ii) Scenario NW achieves a win–win situation for the firm and government over Scenario NP.

(iii) Compared with Scenario D, Scenario NP leads to a lose–lose situation for the firm and government when $\Theta > \Theta_3$.

Corollary 3 highlights that neither price nor wait time regulation Pareto dominates the other for the government, firm, and customers in the presence of the government's myopic adjustment. Moreover, price regulation with myopic adjustment may result in lower social welfare and lower profit for the firm than privatization. Thus, the government's myopic adjustment may reduce the efficiency of price regulation over the long run.

THEOREM 3.

(i) In the presence of myopic adjustment, regulation efficiency, and the firm's profit decrease, regardless of the regulation instrument, that is, $\mathrm{SW}_j^{\mathrm{N}} \le \mathrm{SW}_j^{\mathrm{S}}$ *and* $\Pi_j^{\mathrm{N}} \le \Pi_j^{\mathrm{S}}$, $j = P, W$, *and the advantage to the government of regulating price versus wait time is reversed:* $\mathrm{SW}_W^{\mathrm{S}} \le \mathrm{SW}_P^{\mathrm{S}}$ *and* $\mathrm{SW}_P^{\mathrm{N}} \le \mathrm{SW}_W^{\mathrm{N}}$.

(ii) The (negative) impact of myopic adjustment is more significant under price regulation than under wait time regulation, that is, $\mathrm{SW}_W^{\mathrm{S}} - \mathrm{SW}_W^{\mathrm{N}} \le \mathrm{SW}_P^{\mathrm{S}} - \mathrm{SW}_P^{\mathrm{N}}$.

As confirmed by Theorem 3, regulation efficiency (in terms of maximizing welfare) decreases in the presence of the government's myopic adjustment. It may not be surprising that the government is worse off when pursuing short-sighted objectives, but surprisingly, the private firm also gets hurt in this situation. This is because the government needs to keep adjusting its actions in order to improve social welfare, which means it keeps undercutting the firm's profit. Moreover, regulation efficiency decreases more under price regulation than under wait time regulation, so the government prefers price regulation in the absence of myopic adjustment and wait time regulation in the presence of myopic adjustment. To better understand this phenomenon, it is helpful to remember that there exists a conflict of interest between the government and the firm, as revealed in Scenario C, and that when the government regulates the wait time, the firm has one more degree of freedom in deciding on its service capacity. In the absence of myopic adjustment, the government, as the Stackelberg leader, can better influence the firm's decision about capacity investment when regulating the price, whereas its influence is weaker under wait time regulation because the firm will use the extra degree of freedom in its operational capacity to improve its profit, thereby undercutting social welfare. However, in the presence of myopic adjustment, when the government regulates the price, social welfare maximization drives the government to reduce the price invariably, while the firm reacts by decreasing capacity investment over time, thereby leading to a prisoner's dilemma in which the firm earns zero profit and social welfare is the lowest among Scenarios SP, SW, NP, and NW ($\mathrm{SW}_P^{\mathrm{N}} \le \mathrm{SW}_W^{\mathrm{N}} \le \mathrm{SW}_W^{\mathrm{S}} \le \mathrm{SW}_P^{\mathrm{S}}$). This result provides an explanation for the emerging trend of relaxing control over pricing in PPP projects in China.[11] When the government regulates the wait time, the private firm's extra degree of freedom in setting service capacity mitigates the conflict of interest. As a result, the firm has more incentive to increase capacity, leading to a boost in social welfare. To summarize, which regulation instrument works better depends on whether the government will implement myopic adjustment. Furthermore, the firm's extra degree of freedom in complying with wait time regulation makes the equilibrium outcomes less sensitive to myopic adjustment. This implies that wait time regulation may be a good choice if the government is unsure whether myopic adjustment will be implemented over time.

4.3 Regulations Versus Joint Venture

In the following, we compare the performance of the joint venture and regulations. Combining Proposition 1 and Theorems 1 and 2, we have the following results.

COROLLARY 4 (REGULATIONS VERSUS JOINT VENTURE). *(i) There exist two thresholds,* $0 < \beta_W^{\mathrm{S}} \le \beta_P^{\mathrm{S}} < 1$, *such that* $\mathrm{SW}_j^{\mathrm{S}} > \mathrm{SW}^{\mathrm{B}}$ *if* $0 < \beta < \beta_j^{\mathrm{S}}$, *and* $\mathrm{SW}_j^{\mathrm{S}} \le \mathrm{SW}^{\mathrm{B}}$ *if* $\beta_j^{\mathrm{S}} \le \beta \le 1$, *where* $j = P, W$.

(ii) For $\Theta \in (1, \Theta_3)$, *there exist two thresholds,* $0 < \beta_P^{\mathrm{N}} \le \beta_W^{\mathrm{N}} < 1$, *such that* $\mathrm{SW}_j^{\mathrm{N}} > \mathrm{SW}^{\mathrm{B}}$ *if* $0 < \beta < \beta_j^{\mathrm{N}}$, *and* $\mathrm{SW}_j^{\mathrm{N}} \le \mathrm{SW}^{\mathrm{B}}$ *if* $\beta_j^{\mathrm{N}} \le \beta \le 1$, *where* $j = P, W$. *For* $\Theta \ge \Theta_3$, $\mathrm{SW}_P^{\mathrm{N}} < \mathrm{SW}^{\mathrm{B}}$ *always holds, and there exists* $\beta_W^{\mathrm{N}} \in (0, 1)$ *such that* $\mathrm{SW}_W^{\mathrm{N}} > \mathrm{SW}^{\mathrm{B}}$ *if* $0 < \beta < \beta_W^{\mathrm{N}}$, *and* $\mathrm{SW}_W^{\mathrm{N}} \le \mathrm{SW}^{\mathrm{B}}$ *if* $\beta_W^{\mathrm{N}} \le \beta \le 1$.

With a sufficiently high weight on social welfare, the joint venture achieves greater social welfare than it would under a specific regulation scheme. However, such significant control of the joint venture project typically requires the government to invest sufficient assets, whereas regulation does not. It is worthwhile noting that when the market size is large enough

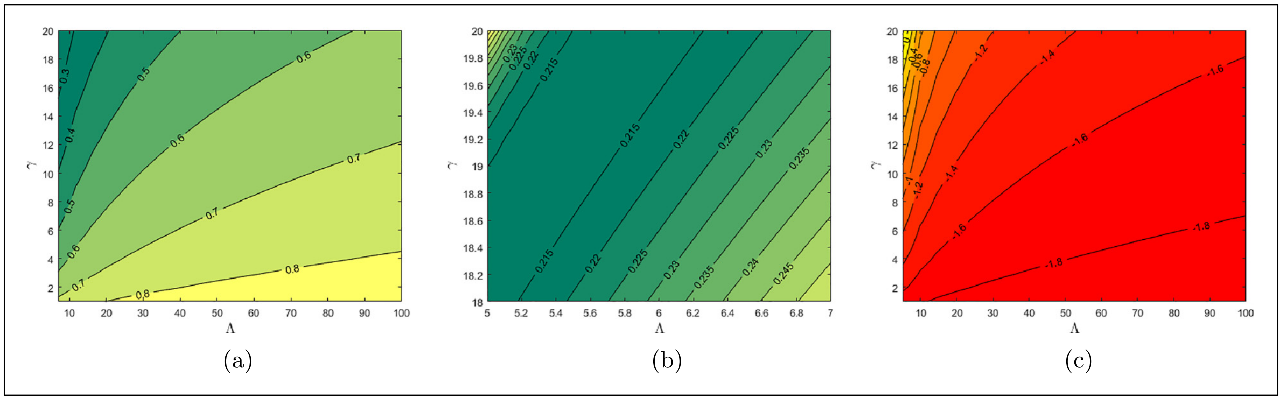

Figure 3. RI versus Λ and h: $a = 100$, $c = 15$, $h = 30$. (a) Scenario SP-Case 1; (b) Scenario SP-Case 2; (c) Scenario NP.

(i.e., $\Theta > \Theta_3$), price regulation in the presence of the government's myopic adjustment backfires, but the joint venture always leads to greater social welfare than full privatization without any regulation. Corollary 4 also shows that the thresholds above which the joint venture achieves higher social welfare than would occur under price or wait time regulation change places from not having myopic adjustment to having it.

5 Numerical Study

5.1 Sensitivity Analysis

In this subsection, we explore how system parameters, such as the potential market size Λ, the maximal service valuation a, the service capacity cost rate γ, the service cost per customer c, and the customers' delay sensitivity h, affect the performance of different regulation schemes and joint venture. To better indicate the efficiency of different schemes, we use the following indicator, which is referred to as the relative improvement and denoted by RI:

$$\mathrm{RI} = \frac{x - \mathrm{SW}^{\mathrm{D}}}{\mathrm{SW}^{\mathrm{C}} - \mathrm{SW}^{\mathrm{D}}}, \quad \text{where} \quad x \in \{\mathrm{SW}_P^{\mathrm{S}}, \mathrm{SW}_W^{\mathrm{S}}, \mathrm{SW}_P^{\mathrm{N}}, \mathrm{SW}_W^{\mathrm{N}}, \mathrm{SW}^{\mathrm{B}}\}.$$

By definition, RI measures the efficiency of regulation and joint venture based on the privatization and nationalization scenarios as the bottom line and ceiling. It is easy to see that $\mathrm{RI} \leq 1$ and $\mathrm{RI} < 0$ whenever regulation backfires.

Figures 3(a) and (b) illustrate how Λ and γ affect RI in Scenario SP. The two figures show that RI is not monotonic in the parameters under Scenario SP: in a wide range of the parameters, RI is increasing in Λ while decreasing in γ; in a narrow parameter subspace, RI, however, is decreasing in Λ while increasing in γ (see Figure 3(b)). Note that the nonmonotonicity of RI under Scenario SP does not indicate that $\mathrm{SW}_P^{\mathrm{S}}$ is nonmonotonic in Λ or γ because not only $\mathrm{SW}_P^{\mathrm{S}}$ but also SW^{C} and SW^{D} contribute to RI. In fact, we have checked that $\mathrm{SW}_P^{\mathrm{S}}$ is monotonic in the value of system parameters. In other scenarios (i.e., Scenarios SW, NP, NW, and B), our numerical study shows that RI shares the same monotonicity in each parameter across those scenarios, though we have omitted the details here. Taking Scenario NP as an example: RI is decreasing in Λ while increasing in γ; see Figure 3(c). Our numerical study has also examined the impact of other parameters. We find that the market parameters, Λ and a, play a similar role in affecting RI; similarly, all the cost parameters, c, γ, and h, play a similar role, with the monotonicity of RI in the cost parameters being the reverse of that in the market parameters. Moreover, surprisingly, our numerical study shows that the monotonicity of RI in the system parameters under Scenario SP is different from that under other scenarios in many instances. Under the joint venture, we have another parameter, β, which is the weight given to welfare maximization by the decision-maker. We have already shown that SW^{B} increases in β. It then follows that RI in Scenario B increases with β, though, for brevity, we do not demonstrate this in the figures.

5.2 The Weight in Joint Venture

As mentioned, the performance of Scenario B hinges on the value of β, which is mainly determined by the share in the project the government holds. In a numerical study, we investigate how large β should be under Scenario B to produce the same social welfare as regulations do. We run a large number of numerical instances. The representative examples are illustrated in Figure 4. Through the numerical study, we observe that the required value of β for price regulation without myopic adjustment is monotonic in the parameters, whereas this is not true for other regulation scenarios. For instance, the required value of β in SP is decreasing in c, whereas it is unimodal in c in other regulation scenarios; see Figure 4(a) for the illustration. As another example, the required value of β in SP is increasing in Θ (or equivalently, Λ), whereas it is unimodal in Θ (Λ) in other regulation scenarios; see Figure 4(b) for the illustration. Note that by definition, a higher value of Θ implies a smaller value of c and vice versa. This explains the symmetric patterns in the two figures. Moreover, we have confirmed

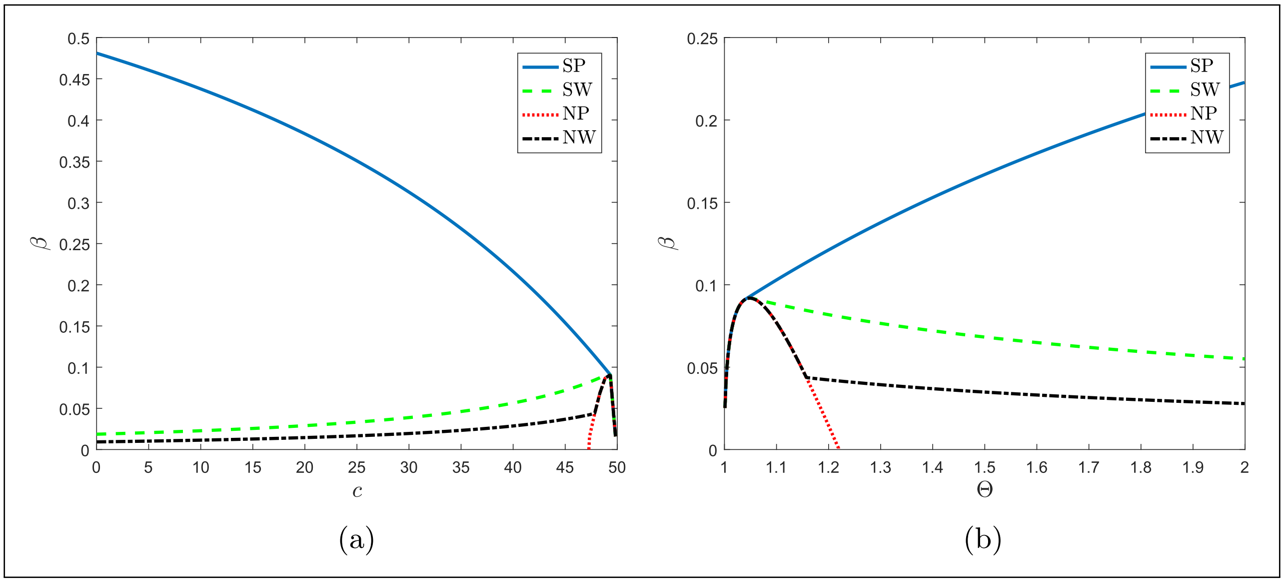

Figure 4. The value of β for $SW^B = SW^i_j$, $i = S, N$, $j = P, W$: $a = 120$, $h = 10$, $\gamma = 30$. (a) when c varies with $\Lambda = 15$; (b) when Θ varies with $c = 20$.

that the impact of h and γ is similar to that of c. For brevity, we focus on the impact of Θ as displayed in Figure 4(b) in the following discussion.

First, because social welfare in Scenario B increases in β, several analytical results are confirmed in Figure 4(b): SP outperforms SW; NW outperforms NP; NP backfires when Θ is sufficiently large. Second, we observe that all regulation scenarios perform the same when Θ is small enough. Indeed, when Θ is small enough, given that the project's self-sustaining constraint must be satisfied, the decision space for welfare maximization is rather tight, and as a result, different regulation scenarios result in the same welfare level. Furthermore, it is interesting to observe that by taking only a small share (about 10%), the government can obtain greater social welfare under Scenario B than it can under Scenarios SW, NP, and NW. However, compared with Scenario SP, the required share increases in Θ, and the required share can be very large when Θ is relatively large.

In E-Companion A (Supplemental Material), we provide two practical examples, toll tunnels and outpatient clinics in Hong Kong, to demonstrate the efficiency of regulation and the joint venture. The two examples have different cost structures. The service capacity cost is relatively high for the clinic example but low for the tunnel example. The examples show that given that the system is very congested under privatization, for example, when the service capacity cost is high enough (as in the clinic example), Scenario B (i.e., the joint venture) outperforms all possible regulatory schemes even when the government takes only a small share (as small as 9.973%) in the project. Heavy congestion is often observed in healthcare systems. Our result thus suggests that investing in private healthcare systems, even with a small share, could go a long way by benefiting the public a lot. However, in the tunnel example, where the service capacity cost is relatively low and the market size is relatively large, the government needs to take an 87.685% share of the project in Scenario B to achieve the same social welfare obtained in Scenario SP.

6 Conclusion

We first illustrate the conflict between the government's objective of maximizing social welfare and the firm's objective of maximizing profit. Joint venture can mitigate this conflict by combining these two objectives. However, it requires more capital investment for the government to increase the resulting social welfare. Then, we examine two regulation instruments designed to mitigate the conflict. Compared with no regulation at all, price regulation caps the service price, but it results in a longer expected wait time; wait time regulation decreases the expected wait time, but it leads to a higher service price. The firm's profitability is hurt by regulation, and social welfare does not necessarily increase: when price regulation is adopted and the government pursues the short-sighted social-welfare-maximizing objective by myopic adjustment over time, social welfare may not benefit from regulation. Government must recognize this when choosing a method of regulation: in the presence of myopic adjustment, price regulation leads to a prisoner's dilemma for the government and the firm. However, price regulation (respectively, wait time regulation) is to the government's advantage in the absence (respectively, presence) of myopic adjustment. Our result also implies that a higher throughput may reduce the welfare of the system. Thus, it could be helpful if the government regulates the number of customers who can access the system, for example, by limiting the number of customers who can be served in a day.

Finally, we compare the performances of the regulations and joint venture and show that, in some instances, the joint venture outperforms all the regulation schemes, even when the government takes only a small share in the project. In contrast, in other instances, the government must take a large share in a joint venture to achieve the same performance under price regulation without myopic adjustment.

Our paper has some limitations. First, we assume that customers are homogeneous in delay sensitivity. One may consider a scenario in which delay sensitivity is heterogeneous across customers, or a customer's delay sensitivity is related (e.g., proportional) to her service valuation. Second, our model does not take market uncertainty into account. For instance, the potential market size could be stochastic, following some distribution. Lastly, we do not study the regulation performance in a competitive environment with two or more service providers, which would be interesting. We leave exploring these directions to future research.

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Supplemental Material

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Notes

1. http://news.sina.com.cn/c/h/2006-10-08/115411180613.shtml (accessed February 2024). Google Translate: https://translate.google.com/website?tl=en&nui=1&u=http://news.sina.com.cn/c/h/2006-10-08/115411180613.shtml&sl=zh-CN.
2. https://www.legco.gov.hk/research-publications/english/1617issh23-road-harbour-crossings-20170322-e.pdf (accessed February 2024).
3. In addition to price and wait time, capacity can be regulated but may be difficult to contract for because of the lack of precise information on capacity cost. In contrast, price and wait time are relatively easy to measure and contractible. Hence, capacity regulation seems less popular.
4. https://www.rehabsociety.org.hk/transport/eab/elderly-transport-service/ (accessed February 2024).
5. In our setting, when both price and service quality are regulated, the problem becomes trivial in the sense that the firm has no control at all, and the market outcomes become completely predetermined by the government.
6. https://news.ifeng.com/c/7fcIchuffR7 (accessed February 2024). Google Translate: https://translate.google.com/website?tl=en&nui=1&u=https://news.ifeng.com/c/7fcIchuffR7.
7. https://bcorporation.net/ (accessed February 2024).
8. In an M/M/1 queueing system, the sojourn time W is exponentially distributed so that the service reliability requirement of $Pr(W \leq t) \geq \alpha$ is equivalent to $\mathbb{E}[W] \leq t/-\log(1-\alpha)$.
9. For instance, in the example presented in E-Companion A.1 (Supplemental Material), tunnel operators can decide the number of opened lanes.
10. In E-Companion E.1 (Supplemental Material), we show that NW may backfire as well when the service valuation is not uniformly distributed.
11. https://www.sohu.com/a/241928867_480400 (accessed February 2024). Google Translate: https://www-sohu-com.translate.goog/a/241928867_480400?_x_tr_sl=auto&_x_tr_tl=en&_x_tr_hl=en-US&_x_tr_pto=nui.

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