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Bottleneck congestion and distribution of work start times: The economics of staggered work hours revisited

Yuki Takayama [a,*]

[a]Graduate School of Engineering, Tohoku University, 6-6-06 Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan

Abstract

Since the seminal work of Henderson (1981), a number of studies examined the effect of staggered work hours by analyzing models of work start time choice that consider the trade-off between negative congestion externalities and positive production externalities. However, these studies described traffic congestion using flow congestion models. This study develops a model of work start time choice with bottleneck congestion and discloses the intrinsic properties of the model. To this end, this study extends Henderson's model to incorporate bottleneck congestion. By utilizing the properties of a potential game, we characterize equilibrium and optimal distributions of work start times. We also show that Pigouvian tax/subsidy policies generally yield multiple equilibria and that the first-best optimum must be a stable equilibrium under Pigouvian policies, whereas the second-best optimum in which policymakers cannot eliminate queuing congestion can be unstable.

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1. Introduction

Urban traffic congestion is caused by concentrated demand for travel around the start of the workday, because firms in central business districts (CBDs) generally have fixed work schedules and workers start work at the same time. Introducing staggered work hours (SWH) is a transportation demand management (TDM) measure for alleviating peak congestion. It is widely recognized but rarely implemented, because it may reduce intra-firm communication and productivity (Wilson, 1988). That is, SWH reduces positive production externalities (temporal agglomeration economies) alongside the negative congestion externalities (temporal agglomeration diseconomies). Therefore, considering the trade-off between congestion and productivity is essential when we examine the effect of TDM measures for reducing peak congestion.

Since the seminal work of Henderson (1981), a number of studies have developed models of work start time choice that consider traffic congestion and productivity effects; these studies will be discussed in Section 1.1. By examining the equilibrium and optimal distributions of work start times and optimal congestion tolls, these studies provide insights into TDM measures. However, analytical difficulties inevitably arising in models with agglomeration economies and diseconomies (i.e., nonconvexities) limit these studies. Foremost among their limitations is that they describe traffic congestion using flow congestion models, which are inappropriate for dealing with peak congestion.

* Corresponding author. Tel.: +81-22-795-7419; Fax: +81-22-795-7418.
E-mail address: takayama@civil.tohoku.ac.jp

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Second, although their models have multiple equilibria, these studies address only a subset—e.g., cases where work starting times are continuously distributed or completely clustered—and do not examine their stability. Therefore, the equilibrium distribution of work start times may be unstable and may never emerge in their models. Third, Akamatsu et al. (2014) shows that if we consider models with positive and negative externalities, social optima can be unstable equilibria under Pigouvian policies, and a non-optimal stable equilibrium will exist. Therefore, although previous studies (e.g., Arnott, 2007) investigate the properties of optimum congestion tolls, social optimum may not be achieved under their congestion tolls.

This study shows that the *potential function approach*, which utilizes properties of a potential game, overcomes these limitations and clarifies the intrinsic properties of a model of work start time choice with bottleneck congestion. This paper first develops a model with production effects and bottleneck congestion by combining Henderson (1981)'s model and the standard bottleneck model (Vickrey, 1969; Hendrickson and Kocur, 1981; Arnott et al., 1990). Similar to models in Peer and Verhoef (2013) and Gubins and Verhoef (2014), ours assumes that workers make long-run decisions about work start times and short-run decisions about day-specific work arrival times. In the short-run, workers choose arrival times and take work start times as a given; in the long-run, they choose work start times indirectly through their choice of employer. We then show that the short-run equilibrium is uniquely determined, whereas the long-run equilibrium is not unique.

This study examines the local stability of long-run equilibrium by viewing it as a Nash equilibrium of a potential game (Sandholm, 2001). The model of the long-run choice of work start time admits a potential function, and the set of long-run equilibria coincides exactly with the set of Karush–Kuhn–Tucker points for the maximization problem of the potential function. Further, all local maximizers of the potential function are locally stable long-run equilibria. We can therefore characterize long-run equilibria and their stability by the shape of the potential function.

After characterizing the long-run equilibria and their stability, this study investigates the properties of the first-best and second-best optimal distributions of work start times and their stability under Pigouvian policies. The first-best optimum is defined as the global maximizer of the social welfare function (workers' total utility), and the second-best optimum is that under the condition whereby policymakers cannot control workers' short-run decisions; that is, the queue at the bottleneck cannot be eliminated. Thus, differences between optimum and stable equilibria are clarified by comparing the shapes of the social welfare function and the potential function. Furthermore, stability of the first-best and second-best optima under Pigouvian policies is analyzed by the potential function approach. This analysis discloses that the first-best optimum must be a stable equilibrium under Pigouvian policies, whereas the second-best optimum can be unstable.

1.1. Related Literature

Theoretical studies of SWH and its variants have appeared since the benchmark study by Henderson (1981). Henderson (1981) assumed that all workers in a city commute from a common residential area to a common CBD along a single congestible road and that the productivity of a worker at a point in time depends on the number of workers at work at that time. These two assumptions yield both traffic congestion and productivity effects in his model. He then analyzed the equilibrium and optimal distributions of work start times. Wilson (1992) and Arnott et al. (2005) extended Henderson (1981) by introducing workers' choices of residential location and firm heterogeneity, respectively. Arnott (2007) generalized Henderson's model and analyzed optimal congestion tolls. Henderson (1981) and these subsequent studies, however, described traffic congestion using a flow congestion model.

Mun and Yonekawa (2006) and Fosgerau and Small (2014) were the most successful in considering both production effects and peak-period traffic congestion.[1] Mun and Yonekawa (2006) formulated a peak-period congestion based on the standard bottleneck model and developed a model that describes firms' and workers' choices to adopt fixed or flextime schedules.[2] They showed that a situation in which all firms adopt flextime never emerges as equilibrium and that multiple equilibria could exist. However, due to analytical difficulties, they examined the stability of equilibria only by numerical examples.

[1] Sato and Akamatsu (2006) also extended the standard bottleneck model to incorporate the productivity effect. Although they provided a rigorous framework, their analysis was limited to a particular set of equilibria, such as cases where work start times are completely clustered and staggered.

[2] Yoshimura and Okumura (2001) proposed a similar model and numerically examined the optimal distribution of work start times.