Doctoral Abstract

A Study on Structural Changes in Cities: Spatial and Temporal Agglomeration Mechanisms of Economic Activities

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Background

Traffic congestion is a major issue in most cities worldwide. For example, in 2021, the average American driver lost 36 hours and spent $564 due to congestion. Nationally, traffic congestion in the U.S. cost drivers about 3.4 billion hours and $53 billion (Pishue, 2021).

The main reason for traffic congestion is that traffic capacity is less than traffic demand. For recent years, economists have been advocating transportation demand management (TDM) measures to deal with urban traffic congestion. As shown in Figure 1, there are two broad types of TDM measures:

1) Reduction in road traffic demand (by using public transit to reduce road traffic demand).

2) Reduction in spatial and temporal agglomeration of traffic demand (e.g., staggered work hours, flextime, and road pricing).

However, as noted by Takayama (2015), TDM measures that alleviate traffic congestion during peak hours by adjusting traffic demand (i.e., reducing temporal clustering) are not necessarily socially desirable in the long-run. To accurately evaluate the long-run effects of TDM measures on structural changes in cities, we investigate the mechanism of each type of TDM measures.

First, we focus on the measures of reduction in road traffic demand. Since road traffic demand changes over time, here we discuss effects of measures for road traffic demand reduction on temporal distribution of economic activities. So far, a number of studies (e.g., Takayama, 2015; Li et al., 2020) on departure time choice model have succeeded

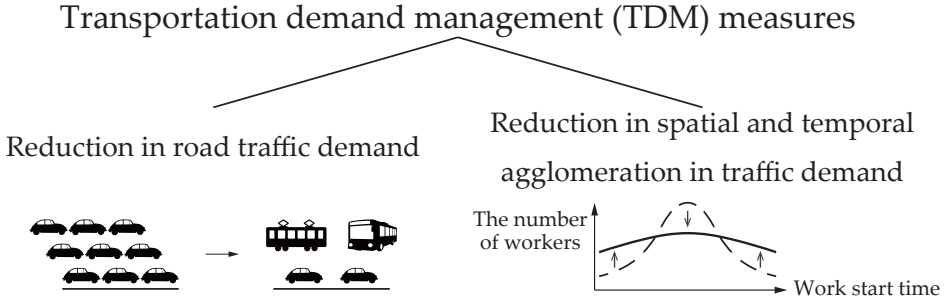

FIGURE 1: Types of TDM measures.

in developing dynamic frameworks that can adequately describe peak-period congestion. However, frameworks used in most studies cannot properly address urban transit systems because most of them only consider solo-driving commuting and ignore public transport which can significantly reduce road traffic demand and alleviate peak congestion.

Although studies on departure time choice and mode choice that considering public transport have been developed in recent years, most of these studies failed considering the effects of scale economies which is an important characteristic of public transport sector, or assumed that fares for public transport are only set at optimal levels (cf. Introduction of Part I).

Second, we focus on the measures of reduction in spatial and temporal agglomeration of economic activities. It is readily that huge traffic demand that causes traffic congestion (negative congestion externalities) is mainly due to the agglomeration of firms in central business districts (CBDs) and the same work start time (WST) workers have. These phenomena of the spatial and temporal concentration of firms and workers are caused by positive production externalities. Hence, economists also advocate another TDM measures — reducing spatial and temporal agglomeration of economic activities. This type of TDM measures aims to deal with urban traffic congestion by changing the balance of positive and negative temporal externalities. That is, these TDM measures reduce positive temporal externalities (temporal agglomeration economies) alongside negative temporal externalities (temporal agglomeration diseconomies).

In fact, the implementation of TDM measures affects not only temporal distribution of traffic demand but also spatial distribution of economic activities. For example, changes in the distribution of WSTs affect urban land use patterns because traffic demand of peak hours and congestion situations will be changed. Moreover, changes in urban land use patterns affect WSTs distribution because origins and destinations of traffic demand and congestion situations will also change. Thus, it is important to consider the interaction between spatial and temporal distributions of economic activities. However, no study has yet investigated desirable spatial and temporal distributions by considering both spatial and temporal externalities (cf. Introduction of Part II).

In this dissertation, we have analyzed how how commuters choose their departure times

and commuting modes under different regulations, and how commuters choose where they reside and their WSTs under equilibrium and after policy implementation.

Main Contributions

The main scientific contributions of this dissertation are summarized hereafter.

1. *Verification of long-term effects of reduction in road traffic demand*

   Part I of the dissertation develops the first departure time choice and mode choice model considering scale economies in public transport and investigating the properties of equilibria under different public transport fare regulations (marginal cost regulation/ average cost regulation/without regulation).

   Note that we analyze urban public transport into two types: rail transit, reduces traffic demand by separating a portion of commuters from road traffic; and carpooling, which which shares the road with automobiles and reduces traffic demand by increasing the number of commuters in an automobile. Rail transit and carpooling are analyzed in Chapter 2 and 3, respectively.

   We show that if average cost regulation is implemented simultaneously with the development of public transport, the number of public transport commuters will not increase and equilibrium commuting costs will not change; if average cost regulation is implemented when public transport operators are monopolistically competitive, public transport commuters will increase and equilibrium commuting costs will decrease. We demonstrate that this result holds regardless of whether public transport is assumed to be rail transit or carpooling.

2. *Verification of long-term effects of reduction in spatial and temporal agglomeration of economic activities*

   Part II of the dissertation is the first to investigate the spatial and temporal agglomeration mechanisms of economic of activities while considering urban spatial structure as an open city (Chapter 4) and multi-city (Chapter 5).

- Chapter 4 shows that greater interaction among different WSTs rural-to-urban migration (spatial agglomeration), and the increase in urban population does not necessarily improve social welfare.
- Chapter 5 shows that the greater the interaction among different cities, the more clustered the WSTs distribution, and greater interaction among different WSTs leads to intercity population concentration (spatial agglomeration). The equilibrium spatial (temporal) distribution may be less (more) agglomerated than at the optimum.

Dissertation Outline

This dissertation consists of 6 chapters that are briefly described in the following paragraphs (see also Figure 2). The main 4 chapters (excluding Chapter 2, 3, 4, and 5) are organized into 2 parts.

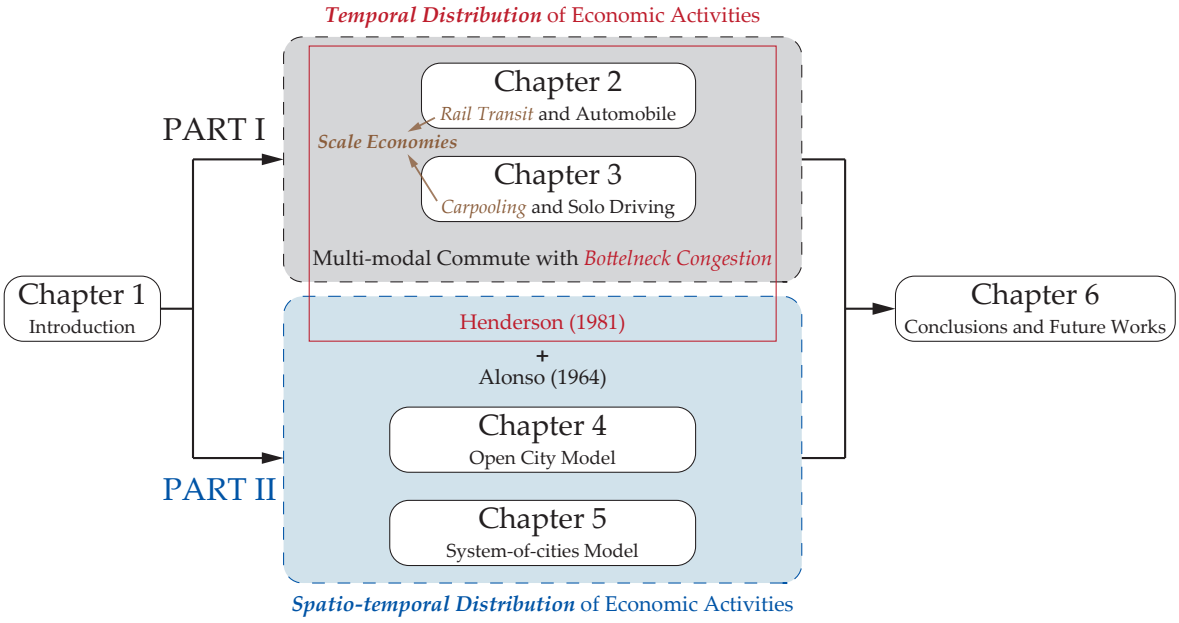

FIGURE 2: Organization of the dissertation.

Part I includes Chapters 2 and 3 that investigate long-term effects of reduction in road traffic demand. In this part, we consider multi-modal commute with bottleneck congestion

in rail transit and carpooling, respectively, by considering scale economies in these public transports.

Part II investigate long-term effects of reduction in spatial and temporal agglomeration of economic activities In this part, we verify the long-term effects in different urban structures (open city and multiple cities) by considering spatial and temporal agglomeration economies and diseconomies.

Note that each chapter is a complete stand-alone research article including an abstract, introduction, methodology, results, and conclusions with its own (mathematical) notations.

This dissertation is organized in more detail as follows.

Chapter 1 is the introduction that summarizes the theoretical background and the purpose of the present dissertation.

Chapter 2 develops a model of multi-modal commute with bottleneck congestion and scale economies in rail transit. To this end, we incorporate the models of de Palma et al. (2017) and Tabuchi (1993) into the standard bottleneck model (Vickrey, 1969). We then show the properties of equilibria when the regulator sets rail fares equal to the marginal cost or average cost and when there is no regulation on rail fares. By comparing these equilibria, we clarify the impacts of the regulations on the number of rail commuters and commuting costs.

Chapter 3 develops a model of multi-modal commute with bottleneck congestion and scale economies considering both carpooling and solo driving. Similar to Chapter 2, we show the properties of equilibria when the regulator sets carpooling fares equal to the marginal cost or average cost and when there is no regulation on carpooling fares. Then by comparing these equilibria, we clarify the impacts of the regulations on the number of carpooling commuters and commuting costs.

Chapter 4 investigates the mechanisms of spatial and temporal agglomeration of economic activities by introducing spatial structure (open city and multiple residential locations) into a model of WST choice (Henderson, 1981). By using the properties of the potential game, we characterize equilibrium and optimal distributions of population and WSTs.

Chapter 5 investigates the mechanisms of spatial and temporal agglomeration of economic activities in the context of a different urban structure (multi-city and multiple residential

locations in each city) from that of Chapter 4. Then, by using the properties of the potential game, we characterize equilibrium and optimal distributions of intercity and intracity populations and WSTs.

Finally, **Chapter 6** concludes the dissertation by summarizing the main findings, contributions and some directions for future work.

Overall, this dissertation contributes to proceed systematic understanding of mechanisms behind TDM measures, and more accurate evaluation of the long-run effects of various TDM measures on structural changes in cities, so that traffic congestion can be alleviated more effectively.

Key Words: *bottleneck congestion, modal split, scale economies, spatial and temporal agglomeration economies, open city model, system-of-cities model, potential game*

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令和　4年　8月　5日

学位論文審査報告書（甲）

1．学位論文題目（外国語の場合は和訳を付けること。）

A study on structural changes in cities: Spatial and temporal agglomeration mechanisms of economic activities

（都市構造変化に関する研究：経済活動の時間・空間集積メカニズム）

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3．審査結果の要旨（600～650字）

提出された学位論文（以下，本学位論文）に対して，審査委員の全員が口頭試問等を行うとともに，論文の内容について精査した．また，令和４年８月５日に行われた口頭発表後に，審査委員会を開催した．そのなかで，論文提出者が第一著者である査読付き論文が参考論文に含まれていること，学位論文および副論文が英語で執筆されているとともに，副論文に含まれる国際会議の論文に関する発表・質疑応答を英語で実施していることから英語能力があることを確認した．そして，その後の協議の結果，以下のように判定した．本学位論文では，都市経済学・交通計画分野で蓄積された都市交通・土地利用に関する数理モデルを適切に統合するとともに，進化ゲーム理論の知見を活用しながら，系統的にそのモデル特性を解明している．さらに，その結果から，交通需要マネジメントを中心とした都市交通政策がもたらす長期的な効果（e.g., ピーク時の交通渋滞，公共交通需要，都市空間構造の変化）を明らかにしている．そのうえで，都市交通政策が期待通りの効果をもたらさない可能性があること，その状況への適切な対応策に関する知見を得ることに成功している．以上の研究成果は学術的に有用かつ価値が高いものであることから，本審査委員会は本学位論文が博士（工学）に値すると判断した．

4．審査結果　(1) 判　　定（いずれかに○印）　（合　格）・　不合格

(2) 授与学位　　博　士（　工学　）