ON THE EFFECTS OF THE ELECTRONIC ROAD PRICING PLAN IN THE JAKARTA METROPOLITAN AREA

A DISSERTATION
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY IN PUBLIC ECONOMICS

Muhammad Halley Yudhistira

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I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

(Yoshitsugu Kanemoto) Principal Adviser

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List of Abbreviation

ADTS	Average Daily Travel time Saving
ALS	Area License Scheme
BPR	Bureau of Public Roads
Bappenas	Badan Perencanaan Nasional (National Planning Agency)
CBD	Central Business District
CMEA	The Coordinating Ministry of Economic Affairs the Republic of Indonesia
CV	Compensating Variation
DATT	Daily Average Travel Time
ERP	Electronic Road Pricing
EV	Equivalent Variation
GNSS	Global Navigation Satellite System
IHCM	Indonesia Highway Capicity Manual
IU	In-vehicle Unit
JaPTRAPIS	Project for the study on Jabodetabek Public Transportation Policy Implementation Strategy
JICA	Japan International Cooperation Agency
JMPA	Jakarta Metropolitan Priority Area

JUTPI	Jabodetabek Urban Transportation Policy Integration
LCCS	London Congestion Charging Scheme
LTA	Land Transport Authority
MSA	Metropolitan Statistical Area
MT	The Ministry of Transportation the Republic of Indonesia
MTTS	Monetary Travel Time Saving
MUI	Marginal Utility of Income
PCU	Passenger Car Unit
RPS	Road Pricing Scheme
SBD	Sub-central Business District
SCCS	Stockholm Congestion Charging System
SITRAMP	Study on Integrated Transportation Master Plan for Jabotabek
TfL	Transport for London

Abstract

In this dissertation, I investigate the effects of introducing electronic road pricing (ERP) in the Jakarta Metropolitan Area (JMA) by using the spatial general equilibrium (SGE) model. The ERP charges all car and motorcycle users who pass the boundary of the central business district (CBD). In transport economics, this type of road pricing is commonly referred to as the cordon pricing. The plan itself has entered the legislative process since the central government enacted Government Regulation (PP) No. 32/2011 on Traffic Management and Engineering. The regulation provides a legal framework within which the Jakarta local government may execute the ERP plan. At the same time, there is a continuous debate at the national level on whether the gasoline subsidy in Indonesia should be reduced to create more funds for social and development spending. Reducing the gasoline subsidy implies an increase in the gasoline price, which is similar to the gasoline tax practices that are found in developed countries. It is also interesting to compare the performance of the cordon toll to that of the gas tax policy in reducing congestion and generating welfare gain.

Based on the work of Anas and his co-authors, I analyze the effects of road tolls by using the SGE model to accommodate the assumption of the polycentric city of the JMA. The SGE model includes a multicentric city feature as well as the interactions among workers, producers, and the government. The JMA is divided into ten zones

and three subregions, i.e. the CBD, the sub-central business district (SBD), and the suburbs, which serve as both working and residential zones. Production takes place in all zones, where the final goods are heterogeneous across zones. Workers are divided into three groups exogenously and cannot upgrade into the higher group, and vice versa. They consume final goods, land, and leisure to maximize their utility subject to the annual income. Given the possible consumption bundles, workers choose the best home-to-work choice that would maximize their utility. Given their home-to-work choice, workers must commute and shop by using the available transport modes (the car, the motorcycle, and the public bus) and route choices. The residents minimize the generalized travel cost, which consists of the monetary travel cost and the travel time cost, by choosing a mode-route arrangement. The model incorporates the endogenous per car equivalent unit (PCU) due to the heterogeneous traffic flow. The crowding cost of the public bus is introduced as a positive function of bus ridership and a time multiplier parameter. The latter variable is defined as the marginal rate of substitution of the travel time between the congested and the base levels. Interactions among producers, workers, and the government are reflected in three different markets, i.e. the labor, the land, and the final goods markets. The equilibrium endogenously determines the land, the employment, and the final goods allocations between the producers and the workers, as well as among all prices.

Using the aforementioned SGE model, I investigate the welfare effects of the CBD cordon toll of the JMA. Initially, the CBD cordon toll as proposed by the Japan External Trade Organization (JETRO) is simulated: 15 thousand rupiah (1.5 USD) for the private car users and 5 thousand rupiah (0.5 USD) for the motorcycle users. Other simulated cases are developed by widening the cordon ring or charging the private car users only. Two scenarios for a wider cordon are the SBD cordon and the step-tolling CBD+SBD cordon. The results show that the welfare gain is 225.7 thousand rupiah or approximately 0.48 percent of the gross annual income, while the gain for wider cases is 60-75 percent higher. The welfare gain, however, is lower if the time multiplier parameter is higher, which prevents road users from switching to the public bus, and in turn, reduces the congestion level less. Doubling the base parameter of the time multiplier results in a 0.3-0.4-percent decrease in congestion reduction and a 4.5-6.1-percent decrease in welfare gain.

A simpler cordon toll scheme that focuses on charging private car users may attain a higher gain than the tolling of both private modes. The car tolling yields a wider generalized cost between the car and the other modes than tolling both the car and the motorcycle. As a result, it drives more car users to switch to the use of motorcycles, which is faster than the use of public buses, and thus generates higher daily travel time saving than the tolling of both cars and motorcycles. Yet, the higher the toll, the less the gap is between the tolling of all private modes and that of the car only. For each additional toll, the private-based cordon toll drives out more private mode users than those driven out by the car-based cordon toll. Beyond 60 thousand rupiah of the cordon toll, the gain under the private-based toll becomes higher.

I evaluate the welfare effects of the gasoline tax as an alternative anti-congestion policy and compare the results to those of the CBD cordon toll. Two scenarios are considered. First, the gas tax affects all transport modes, including the bus fare. I refer to this scenario as the general gas tax policy. Second, the gas tax is assumed to have no direct effect on the bus fare to the extent that the fare remains constant. This scenario is then referred to as the policy mix. Because the gas tax policy captures more road users and serves as a distance-based road tax regardless of the private modes, an increase of 25 percent in the gas price ensures that the general gas tax policy obtains a similar level of welfare gain as the private CBD cordon toll. The policy mix provides better results than the general tax policy since it reduces more congestion and provides higher travel time saving. An increase of 22 percent in the gas price under the policy is sufficient for obtaining the welfare gain under the private CBD cordon toll. The policy mix creates a wider gap of the generalized travel cost between the private modes and the public bus, and hence allows more car and motorcycle users to switch to the public bus than those allowed by the general tax policy.

In the long run, the road pricing changes not only the workers' transportation behaviors, but also their commuting arrangements. I investigate how the road tolls influence the residents' choices of residential and/or working locations. Three road toll scenarios are then considered, i.e. the cordon toll, the area toll, and the gasoline tax. In general, the area toll is similar to the cordon toll, except that the area toll also levies the interzonal trips of the designated area. Two equilibrium regimes related to the workers' behavior are considered: the flexible home-to-work choice and the fixed residential choice.

Under the flexible regime, the results of the cordon toll confirm the findings of previous studies, which have asserted that the cordon tolls may lead to a more dispersed city if the cordoned area is small enough. Nevertheless, the dispersion effects can be minimized as long as a sufficient discount is offered to the CBD residents, as seen in the cases of the area toll. The gas tax policy rather creates a more compact urban form, as a direct toll-avoidance response of the workers is a reduction of the commuting distance. Interestingly, the car-based cordon scenarios lessen the effects, or even contradict the results, of the private-based cordon scenarios. Under the car CBD cordon toll, the concentration effect is present. The reason is that, although the private- and the car-based CBD cordon cases allow relatively similar travel time saving in the CBD zone, the latter yields significantly less expected annual monetary travel cost, and in turn, achieves a positive net gain and invites more residents to live in the CBD.

Meanwhile, the fixed residential choice regime allows workers to exploit fully the flexible job location choice by anticipating the increase of the generalized travel cost.

The results, however, show that, in general, the curvature of employment changes does not differ significantly from the results under the flexible residential location choice, except for those concerning the general gas tax policy. Employment in the CBD decreases while the opposite occurs under the flexible home-to-work choice regime. Since 53 percent of the total residents live in the suburban zones, the dispersion result occurs as some suburban workers alternate their working places from the CBD and the SBD zones to the suburban zones.

This research contributes to better understanding of the effects of road toll policies when the traffic flow is heterogeneous and the public transport uses the same road networks as the other private modes. The simulation results suggest some policy choices from which the JMA authority may select an appropriate road toll scheme for the road congestion reduction of Jakarta.

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Chapter 1

Introduction

1.1 Research Background

The Jakarta Metropolitan Area (JMA) is the biggest urbanized area in Indonesia, as well as one of its central area of economic activities. The estimated gross regional domestic product was 512 trillion rupiah in 2009, which is equivalent to 23 percent of the national gross domestic product (GDP). Furthermore, the recent population census revealed that the JMA population in 2010 reached 28 million people, or as much as 11.8 percent of the national population. Table 1.1 presents some basic numbers of the JMA. The Central Jakarta district is labeled as the central business district (CBD) of the JMA. The performance of the CBD is astonishing because even with less than one percent of the total land of the JMA, it produces approximately 19 percent of the JMA's total GDP, mainly from its service sectors. In addition, the GDP per capita that the CBD earns is fivefold of that earned by the JMA. The CBD is also much denser than the other districts: it is 1.3 times denser than Jakarta

Table 1.1: Basic Figures of the JMA

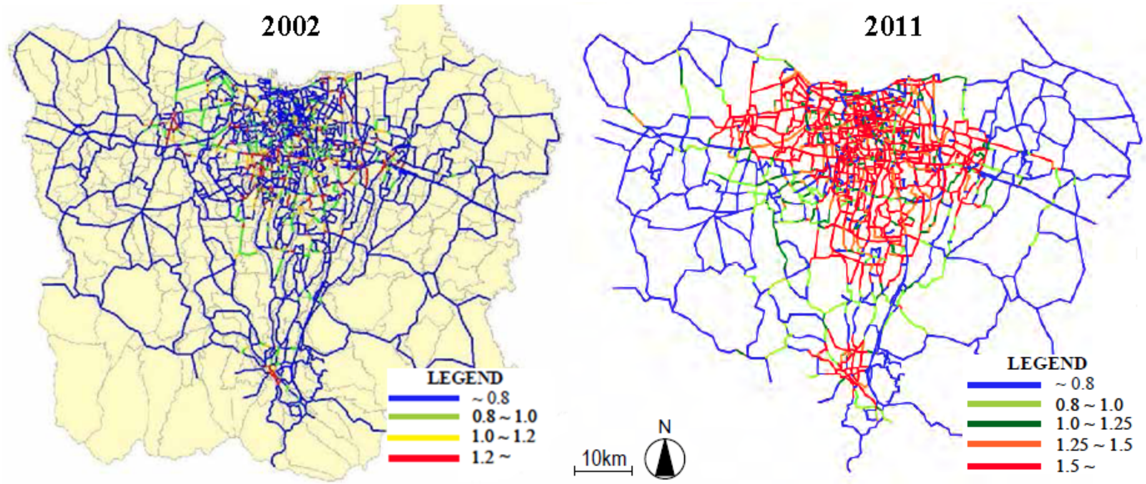
	GDP per capita*	Size (km^2)	Residential Density(thousand/km^2)	
			Population	Worker
Jakarta	82.1	653.6	14.7	6.6
CBD	222.6	48.1	18.8	8.5
Suburban	18.8	5,850.3	3.3	1.2
JMA	42.3	6,503.9	4.3	1.8
Indonesia	27.1	1,904,569.6	0.1	

*in million rupiah
Sources: Indonesia Bureau of Statistics (2013a), DKI Jakarta Bureau of Statistics (2012), Banten Bureau of Statistics (2011), West Java Bureau of Statistics (2011).

overall, and more than 5 times denser than the suburban zones, which renders it the busiest region in the JMA, or even Indonesia.

One of the most complicated problems in the Jabodetabek area, which is one of the most urbanized areas in the world, is the urban traffic congestion. Urban travel demand is excessively concentrated in the CBD, especially in the Sudirman-Kuningan Golden Triangle area. The Study on Integrated Transportation Master Plan for Jabotabek (SITRAMP) conducted by the National Planning Agency (Bappenas) and the Japan International Cooperation Agency (JICA) reported that the Volume/Capacity (V/C) ratio in 2002 had almost reached its capacity. The travel speed had been as low as 34.8 km per hour. As no significant improvement had been achieved by 2011, the congestion level worsened, and the average travel speed decreased further to 24.6 km per hour in 2011. As seen in Figure 1.1, high private motorization has significantly worsened road congestion within the last decade. Almost all major links had already exceeded beyond their capacity in 2011. Road links in the core of Jakarta had reached excess capacity, as indicated by the wide coverage of the red lines. The SITRAMP's estimation of the accumulated loss due to this congestion is approximately 65 trillion rupiah, which consists of additional vehicle operating costs and longer travel times.

Figure 1.1: Volume/Capacity Ratio in 2002 and 2011

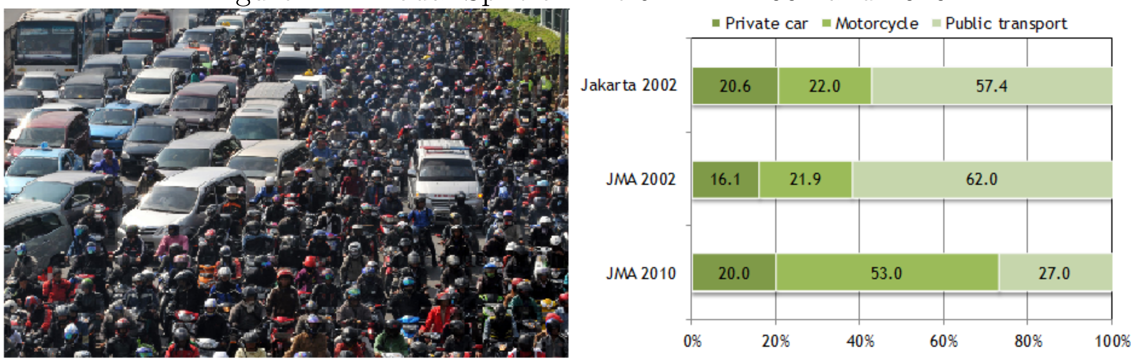


Source: SITRAMP (2004) and JAPTraPIS (2012)

Extreme unbalanced growth between roadway and private transport ownership is one of the main sources of road congestion in Jakarta. As presented in Figure 1.2, the modal split is relatively even between the private and the public transport modes. The private car and the motorcycle accounted for 20.6 and 22.0 percent, respectively, in 2002, and the rest was for public transports, mainly the public bus. However, this figure appears to show a persistent favor of private modes since the dramatic growth of private transport, especially motorcycles, throughout the past decade. Low public transport service quality combined with economic acceleration has strongly driven motorization in the JMA in the last decade. In 2010, 73 percent of the JMA trips were dominated by private modes, especially motorcycles. The left-hand side of Figure 1.2 illustrates the current conditions of a congested road in the JMA road links.

Considering the significant economic loss due to the urban traffic congestion, Jakarta's local government has undertaken some work to improve the situation. In

Figure 1.2: Modal Split of The JMA in 2002 and 2010



Source: SITRAMP (2004) and JUTPI (2012)

terms of the transportation demand management (TDM) policy in the CBD, the local government has implemented the “3 in 1” policy. In the morning and afternoon peaks, only cars with at least three passengers can pass the area. However, the SITRAMP pointed out the several drawbacks of this policy: 1) the increase in traffic demands on the parallel streets during peak hour; 2) the increase in jockey practices; and 3) the lack of collected revenue. In light of these drawbacks compared to the relatively small benefit, the local government is considering some alternative policies to replace the “3 in 1” policy.

One proposed plan for the replacement of the “3 in 1” policy is to implement electronic road pricing (ERP) in the CBD, particularly in the extended Jakarta Golden Triangle Area (the Sudirman-Thamrin corridor). The execution of this scheme is aimed for 2016; until then, the technical scheme is being reviewed. The idea is to charge every road user a fixed toll when the user enters a specified cordon surrounding a specific area of a city in which traffic is the most congested (Mun et al., 2003). This scheme, which is often called cordon pricing, is preferable because it raises the revenue stream for the local government and is relatively feasible to implement. At the same time, its main objective to reduce the traffic congestion can still be achieved even under the second-best condition. Cordon tolling policy and its variances have been effectively implemented in several big cities, some of which will be discussed in the following sections.

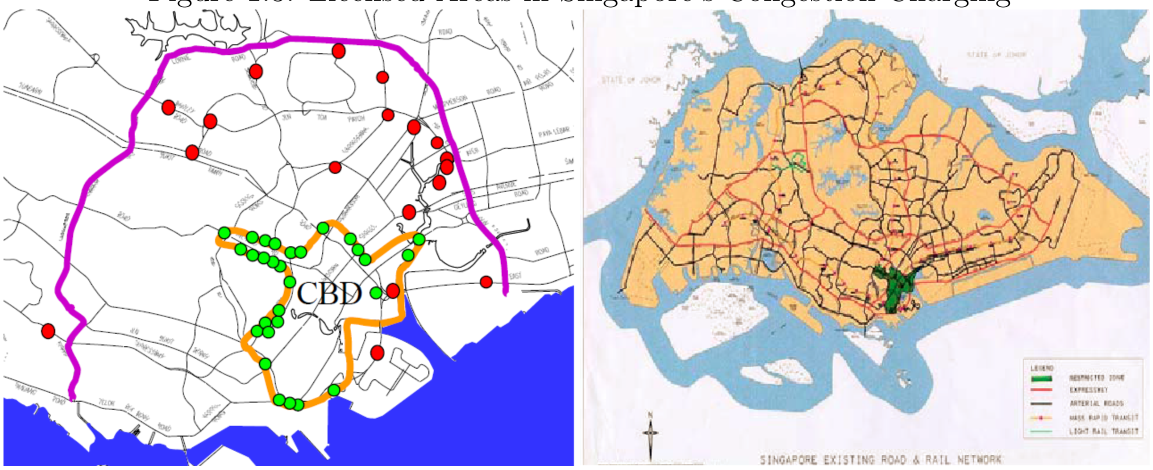
1.2 Implementation of Cordon Pricing Around the World

Various road pricing schemes have been widely implemented in some major cities in the world. There is even a case, i.e. Singapore, that has already started the road pricing in 1970s. In a recent study, Noordegraaf et al. (2014) compared six road pricing cases, including Singapore, London, Stockholm, several Norwegian cities, Hong Kong and Edinburgh. This section will cover a deeper description on Singapore, London, and Stockholm road pricing schemes because these examples closely resemble the practice of cordon tolling.

1.2.1 The electronic cordon pricing of Singapore

The history of the road pricing implementation in Singapore can be traced back to 1975 with the implementation of the ALS, which was a system that required road users to show a paper area license upon entering the restricted zone during peak hours (7.30 to 10.15 AM), except on Sundays and holidays. As reflected in the name, the ALS manually charged the road users that traveled to the downtown area, which covered approximately 7.5 km2 of the business district in the southern part of Singapore (Figure 1.3). Later, it was extended to the evening peak, and in 1994, the operating hours were further extended to 7.30 AM to 6.30 PM in order to

Figure 1.3: Licensed Areas in Singapore's Congestion Charging



Source: Chin (2010), Menon and Guttikunda (2010)

overcome the inter-peak period (Santos et al., 2004). In June 1995, another paper-based road pricing scheme, called the RPS, was initiated for other expressways to reduce expressway congestion and allow the road users to familiarize themselves with the two road pricing combination (Goh, 2002). In 1998, the ALS and the RPS were abolished and replaced by ERP. The system itself is now fully electric with the use of sensor-based payment. Several gantries have been erected on all of the roads near the restricted zone; the vehicles that wish to enter this zone must install an In-vehicle Unit (IU) filled by a smart card. The fees are deducted from the smart card electrically through a radio sensor in the gantries.

The pricing system of Singapore's ERP is rather complicated; the details are available on the Land Transport Authority (LTA) website and summarized in Table 1.2. The system varies across modes, times, and networks. The variety across the modes derives from the per car equivalent unit (PCU) for each mode while the time-fee variations are based on the peak-load congestion. The highest charge applies from 8.35 to 8.55 AM for entry into the busiest gantry. Interestingly, the implementation of a new system, called graduated ERP, has started since February 2003. The idea

Table 1.2: Charges in Singapore's ERP

Charge (in Singapore $)	Category
Full exempt	Police cars, ambulances, and fire engines
0.50 – 6.00	Passenger cars, light goods vehicles, taxis
0.25 – 2.50	Motorcycles
0.75 – 9.00	Heavy goods vehicles and small buses
1.00 – 12.00	Very heavy goods vehicles and big buses

Source: summarized from http://www.onemotoring.com.sg/

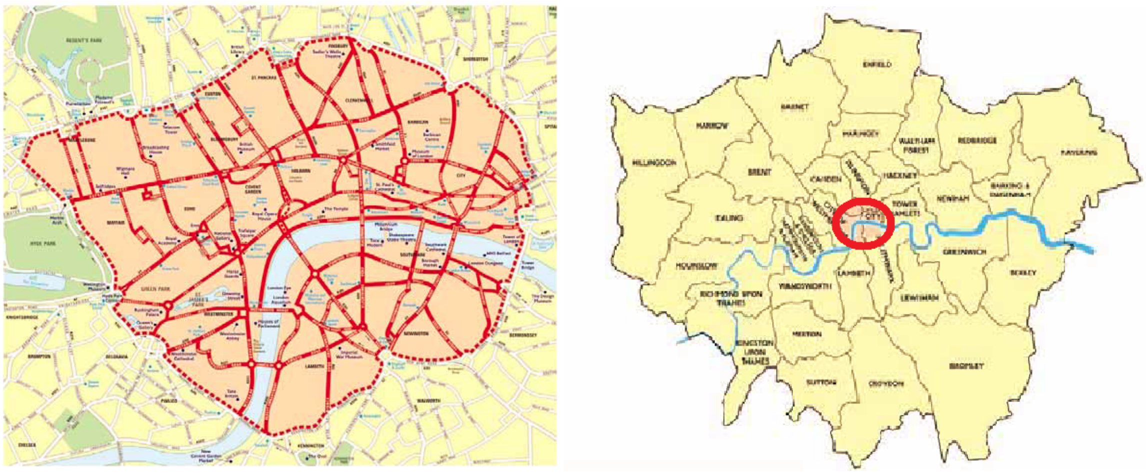
of this system is to discourage road users from slowing down or speeding up to avoid higher charges (Santos et al., 2004). In general, it applies a higher ERP rate to the first five minutes of the following time period, and a lower ERP rate to the last five minutes of the same time period. For example, the initial fee for motorcycles is S$1.50 between 8 and 8.30 AM; it then increases to S$3.00 between 8.30 and 9.00 AM. Graduated ERP maintains the rate at S$1.50 from 8 to 8.30 AM, S$2.25 from 8.30 to 8.35 AM, S$3.00 from 8.35 to 8.55 AM, and S$2.00 from 8.55 to 9.00 AM.

The LTA is now preparing a new generation of ERP called ERP II. The main idea is to integrate the system with the Global Navigation Satellite System (GNSS) to design the ideal distance-based charge. It will closely resemble the first-best congestion pricing, which is a function of the travel distance.

1.2.2 The London congestion charging

London's congestion pricing is commonly referred to as the London Congestion Charging Scheme (LCCS), which was developed in 1960 as a response to the decrease of speed in the central area, which dropped from 12.7 mph to 8.6 mph in 2002 (Leape, 2006). The system was designed in 2003 by Transport for London (TfL). The concept itself has been developed since 1999, as written in the Greater London Authority Act. Since then, preparation and socialization have been undertaken in the form of notices, leaflets, newspapers, and broadcasts. Consultation exercises involving the business

Figure 1.4: Licensed Area in London's Congestion Charging



Source: TfL (2006)

and the community have been held to perfect the system, which covers 21 km2 or 1.3 percent of Greater London, and is active between 7 AM and 6 PM from Monday to Friday (Figure 1.4). Weekend and other public holidays are free of charge.

The LCCS differs from Singapore's ERP in two ways in terms of the charging system. First, the local government generously offers a significant discount for particular road users, as presented in Table 1.3. It targets all private car users that drive into the licensed area. The charge was initially £5, but has increased to £8 since 2005. The charge can be paid on the day of or on the day after by midnight. A charge of £10 is levied instead for the next-day payment. The full exemption applies for public transport, motorcycles, and other special vehicles (military, low-carbon, or local government vehicles). To avoid resistance from the residents of the central zone, the local government offers a 90-percent discount and a £10-registration per year for

Table 1.3: Exemptions and Discounts

Charge	Category
£8/10	Private car from outside licensed area
Fully exempt	Motorcycles, mopeds and bicycles
	Emergency vehicles
	Public service vehicles with 9 or more seats licensed as buses
	Vehicles used by disable persons that are exempt from VED
	Licensed London taxis and mini-cabs
100% discount with	Certain military vehicles
free registration	Local government service vehicles (e.g. refuse trucks, street maintenance)
	Vehicles with 9 or more seats not licensed as buses (e.g. community minibuses)
100% discount with	Vehicles driven for or by individuals or institutions that are blue-badge holders
a one-off £10 registration	
100% discount with	Alternative fuel vehicles – requires emission saving 40% above Euro IV standards
£10 registration per year	Roadside assistance and recovery vehicles
	(e.g. motoring organizations such as the Automobile Association)
90% discount with	Vehicles registered to residents of the central zone
£10 registration per year	

Source: Santos (2008)

their vehicles. The LCCS is also relatively simpler in pricing than the ERP, since it does not vary in time and location (Santos, 2008).

1.2.3 The Stockholm congestion charge

Stockholm is also a city that provides another good example of the implementation of a second-best road pricing, namely, the Stockholm Congestion Charging System (SCCS). Before its full implementation, a trial was held from August 2005 to July 2006. The system itself covers 30 km-square of the inner-city zone (mostly the CBD), as shown in Figure 1.5. The charging system is electric, which is similar to those of the other cases, and involves 18 control points surrounding the city of Stockholm.

The SCCS focuses on charging passenger cars to and from the cordoned zone, and the charge itself varies within the day, which essentially render the SCCS a simple combination of the LCCS and Singapore's ERP. The morning peak time is from 7.30 to 8.29 AM while the afternoon peak time is from 4.00 to 5.30 PM with 20 Sweden kroner per passing. The payment system is a prepaid system that uses the on-board unit for direct debit payment. Recharging can be done in convenience shops

Figure 1.5: Stockholm Ring

Source: IBM (2006)

Table 1.4: Charges in the Stockholm Ring

Charge (in SEK)	Category
Full exempt	Taxis, buses, alternative-fuel cars, foreign cars, motorcycles
10 – 20	Passenger cars

Source: Jonas Eliasson and Hugosson (2008), IBM (2006)

or through bank transfers (Jonas Eliasson and Hugosson, 2008). The full exemption applies for public transports, buses, and low-emission cars (Table 1.4). Interestingly, there is a free-charge bypass link, named the Essinge bypass, which connects the southern and the northern parts of the cordoned area, due to the strong rejection of this system from surrounding municipalities.

1.3 Electronic Road Pricing Plan in the JMA

Learning from the success of the road tolling policy around the world, the local government of Jakarta starts to consider applying a certain road toll scheme as part of the Proposed ERP plan in the JMA as depicted in Figure 1.6. The proposal of the JMA cordon plan can be traced back since early 2000 as SITRAMP suggested electronic road pricing as an alternative traffic demand management replacing the ineffective "3 in 1" policy. The target area is pretty much similar with "3 in 1" zone with some expansion covering major businesses and commercial centers, namely the Mangga Dua area, Ciliwung riverside, extension from Kota, the Monas area, Tomang - Slipi (S. Parman) roadside, Sudirman -Thamrin corridor, H.R. Rasuna Said corridor, Gatot Subroto roadside, Gunung Sahari-Kramat Road side, and the Blok M (Kebayoran) area. The potential cordoned area in general can be illustrated in Figure 1.6 that locates in the center of JMA networks. Considering all potential zones to be covered, SITRAMP proposes 6 alternatives from the narrowest to widest ring with two alternative tolls (i.e. 15 and 25 thousand rupiah) on the private car, depending on which zones to be included. Nevertheless, the Monas area, Sudirman-Thamrin corridor, H. R. Rasuna Said corridor, Gatot Subroto, and Prof Dr. Satrio roadside remain included due to their importance in business activity.

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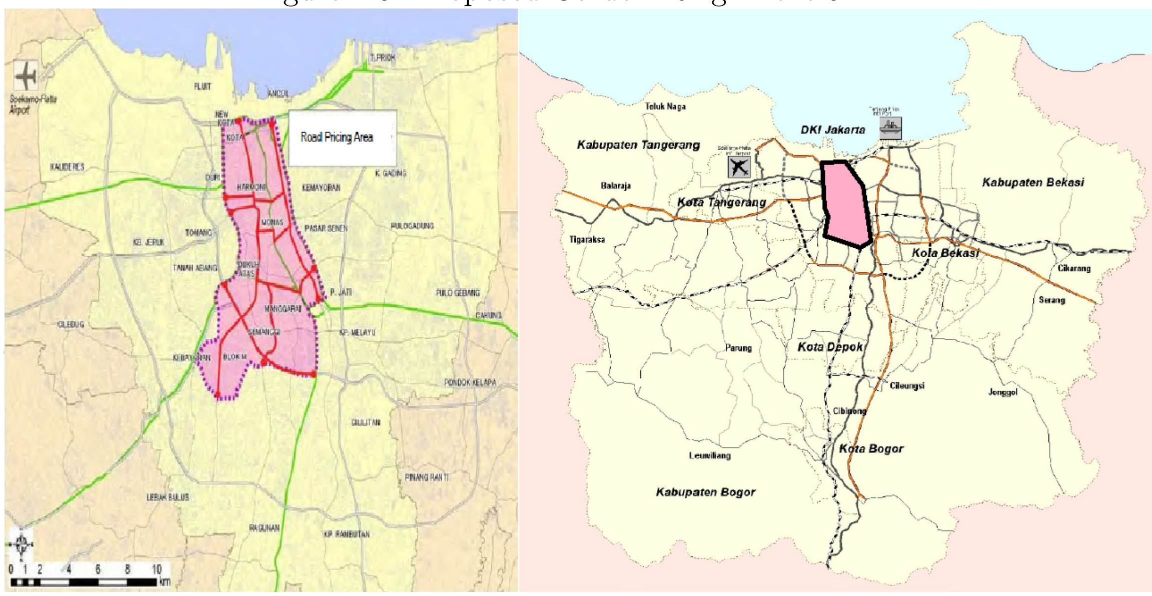
A report by the Japan External Trade Organization (JETRO) in 2007 solely focused on discussing the feasibility of the JMA's CBD cordon pricing. The pricing strategy is now different because it includes motorcycles as another charged transport mode; it now levies 15 and 5 thousand rupiah on the private car and the motorcycle, respectively. Despite a relatively strong resistance from the people, this change is more sensible due to the rapid growth in motorcycle use since 2000. Drawn from a small survey, about 70 percent of the respondents are against the charging of motorcycles due to various reasons. It is also estimated that 1.2 trillion rupiah as fixed costs and 66.6-158.3 billion rupiah per annum for operating costs would be required, depending on the technology and the size of the cordoned zone. The adopted technology is similar to that of Singapore's ERP in the use of gantries and the identification of licensed modes by the sensor systems on top of the gantries.

Due to worsening traffic congestion in recent years, the implementation of the CBD cordon toll may occur in the near future. Recent developments of the CBD cordon toll policy have entered the formulation of the legal standard. The central government has signed Government Regulation (PP) No. 32/2011 for Traffic Management and Engineering, which is a necessary step for implementing ERP in Jakarta's CBD. This regulation ensures a brief guidance for the local government that would include all technical and regulatory aspects of the ERP policy.

Figure 1.6: Proposed Cordon Ring in the JMA



Source: SITRAMP (2004) and JETRO (2008)

1.4 Economic Impacts of Cordon Tolling

The main focus of this thesis is a welfare analysis of the cordon pricing in the CBD zone of the JMA. The goal is to investigate how cordon pricing in the JMA improves the welfare of the JMA residents, and to examine the magnitude of the improvement. Welfare gain is then monetized in Indonesian rupiah to draw a more explicit comparison. Welfare distribution effects are also examined to determine the parties that benefit the most from the system on one hand, and those that benefit the least, on the other. Considering the construction of a cordon toll system that is supported by all stakeholders may lead to positive results.

In the literature on the welfare impact of cordon tolling, there are mixed results concerning the welfare impacts. Mun et al. (2003) pioneered the theoretical cordon-pricing model under the monocentric city assumption. Along with Verhoef (2005), who worked with a different setup despite his use of the same monocentric city case, Mun et al. found a high performance of the cordon toll that is relative to that of the first-best distance-based road toll. Measured in percentages of the first-best cases, the cordon toll can theoretically provide a 90-percent welfare gain under the first-best case. Once the monocentric city assumption relaxes, the welfare improvement of the cordon toll drops substantially, as confirmed by Mun et al. (2005); Fujishima (2011). The latter study obtained a 50-percent gain of the cordon toll compared to that of the first-best case. With more complex models that depict the Chicago Metropolitan Statistical Area (MSA), Anas and Hiramatsu (2013) obtained 65 percent of the gain from the Pigouvian tax by tolling all major roads.

The SITRAMP also provided a cost-benefit analysis for implementing the CBD cordon toll in the JMA with the use of 2002 as the base year. There are six proposed rings with two pricing cases. The benefit is measured in the form of savings in vehicle operating costs (VOC) and passenger traveling time cost (TTC). It took a moderate cordon ring and car toll charge (8 thousand rupiah) to obtain a benefit of 390 billion rupiah in 2007. Approximately 41 percent of the total benefit (around 160 billion rupiah) was from TTC savings and the rest was in the form of VOC savings. In terms of Jakarta's nominal GDP, it accounted for 0.7 percent. In 2008, the JETRO provided a study that solely focuses on the JMA cordon tolling. By using the SITRAMP model, it proposes different pricing strategies by charging 15 and 5 thousand rupiah for car and motorcycle users, respectively, to anticipate the regional income growth and the significant increase of motorcycle users.

This thesis develops a model called spatial general equilibrium (SGE), which tackles some drawbacks in the SITRAMP and the Jabodetabek Urban Transportation Policy Integration (JUTPI) study. First, my model involves the economic behavior of all economic agents, i.e. the workers, the producers, and the government. The workers' (or the producers') behavior is explicitly set to maximize their utility, given the income constraint (or the perfect competition assumption). Workers need to commute, and the home-to-work commuting arrangement is chosen based on the logit approach. Therefore, there is a set of available home-to-work choices along with the probability that each home-to-work arrangement may be chosen. The highest probability belongs to the home-to-work choice that gives the highest utility. In contrast, the SITRAMP and the JUTPI study relied on the classic gravity origin-destination (O-D) model. Second, in this study, the welfare gain is calculated based on the equivalent variation (EV), which is more accurate than the monetary values of travel time saving (MTTS) and other savings (e.g. gasoline consumption reduction) calculated by the JETRO, since EV-based welfare gain incorporates not only benefits in the form of the MTTS and VOC, but also the cordon toll that is paid by the passengers. Third, our model incorporates the two new features in recent transportation studies that were not explicitly modeled in the JUTPI study and the SITRAMP, or even the other SGE models, i.e. the endogenous PCU and the crowding cost of public transport. Lastly, the SITRAMP and the JUTPI models assume that the road toll does not change workers' home-to-work arrangement. In this SGE model, the road toll alters workers' preferences not only in the transport modes but also in the home-to-work choices.

There are several key outcomes from the simulation results. The average annual welfare gain of the JETRO scenario is 227 thousand rupiah, which is equal to 0.5 percent of the total annual income. Surprisingly, a charge of 15 thousand rupiah for car users and a lack of charges for motorcycle users yield a 10-percent higher annual welfare gain as a result of the higher travel time saving. The high performance results of car tolling remain persistent for the wider cordon cases. The reason for this may be that, despite the fact that less road users are charged, car tolling produces a wider generalized travel cost gap between the car and the motorcycle than that produced by tolling both the car and the motorcycle. Hence, the car tolling drives out more car users and reduces the congestion level more. This magnitude, however, becomes weaker as the toll level gets higher, and beyond 60 thousand rupiah of the toll, the tolling of both the car and the motorcycle obtains a higher annual welfare gain. In the road pricing changes not only the workers' transportation behaviors, but also their commuting arrangements. The results of the cordon toll confirm the findings of previous studies, which have asserted that the cordon tolls may lead to a more dispersed city if the cordoned area is small enough. Interestingly, the car-based cordon scenarios lessen the effects, or even contradict the results, of the private-based cordon scenarios. Under the car CBD cordon toll, the concentration effect is present. Although the private and the car CBD cordon tolling allow relatively similar travel time saving in the CBD zone, the latter scheme yields significantly less expected annual monetary travel cost, and in turn, achieves a positive net gain and invites more CBD residents.

1.5 Structure of the Dissertation

This dissertation consists of six chapters. Following the introductory chapter, the second chapter discusses the details of the model framework, including the urban structure and the behavior of the economic agents. The next three chapters comprise the main discussions. The third chapter simulates the cordon toll level as proposed by the JETRO report that refers to the CBD cordon tolling. Counterfactual cases that use the SBD zones as the cordoned areas are also presented for comparison. The fourth chapter discusses the policy of a gas price increase as an alternative anti-congestion policy, and compares its performance with that of the CBD cordon toll. Chapter 5 mainly discusses the location effects. In the long run, the cordon toll affects not only the residents' transportation behavior but also their decisions regarding their living and working locations. The last chapter sums up all of the discussions into brief policy implications.

Chapter 2

The Model

2.1 Introduction

The focus of the research on the effects of cordon pricing in transport economics has perhaps just recently and, in general, evolved from a monocentric city to a polycentric urban form. The study by Mun et al. (2003) marks the development of the theoretical models of cordon pricing under a monocentric city case. In a different setup, despite the same monocentric city assumption and the explicit treatment of labor market equilibrium, Verhoef (2005) analyzed several second-best road toll schemes, including the cordon toll. In a more recent study, Lara et al. (2013) also built a monocentric model and used the region of Paris as a calibration target. Despite their different setup, both found that no close form could be mathematically derived to obtain the optimal cordon pricing and location, and thus allow them to rely on the simulation. The study by Mun et al. (2003), on the other hand, marks the development of the study of cordon pricing under a polycentric city. In order to obtain a non-monocentric city, they first assumed a long narrow city, as Vickrey (1969) had done, in which the O-D trips in equilibrium are distributed along points in the city in such a way that the marginal private benefit is equal to the private travel cost.

Recent cordon tolling studies under the polycentric city assumption have significantly relied on the framework proposed by Anas and his co-authors in their various papers (e.g. Anas and Kim (1996); Anas and Xu (1999); Anas and Rhee (2006)). To establish a multicentric city form, Anas' model relies on the property of a logit model. As the first step, a city is divided into several zones, each of which is feasible as a working/living zone or for both purposes. There are at least two economic agents: a worker and a producer who interact with one another in the city. A representative commuter chooses an optimal bundle of consumption goods and/or other goods that differs across an O-D home-to-work pair. Given the various optimal bundles of goods available, the model derives the probability of choosing an O-D pair to maximize the commuter's utility, which follows the logit assumption. In the labor demand side, production takes place in each zone and requires a labor hour as one of the inputs. A relatively simple application in road pricing can be found, for example, in Eliasson and Mattsson (2001); Fujishima (2011). With a more complex and realistic model, Anas and Liu (2007); Anas and Hiramatsu (2012, 2013) developed a simulation model for the Chicago Metropolitan Area.

This dissertation employs a multicentric city model to portray the JMA urban system, and hence follows some of the regularities in Anas' SGE model. The JMA is divided into several zones that serve as both working and living zones. Residents are divided into three groups exogenously and cannot upgrade into the higher group, and vice versa. Given his/her chosen home-to-work O-D pair, residents must commute and shop by using the available transport modes in the congested road networks. Production takes place in all zones in a differentiated manner to the extent that final goods are heterogeneous across zones. The following extensions are made to differentiate our model from the other models in order to gain further insight on transportation behavior, particularly in the case of the JMA. First, the PCU level is endogenous as a function of the congestion level, rather than exogenously determined. Arasan and Arkatkar (2011) asserted that PCU values must endogenously depend on traffic volumes, particularly under heterogeneous traffic flows. Second, the total capacity of the public bus is fixed; therefore, additional bus users will lead to more crowded public buses. In contrast, all SGE models with a public transport feature (mostly trains) assume an elastic public transport supply. This can be misleading in the short run because an expansion of the capacity cannot be done in a short period. Last, as a result of the higher use of public transports, bus users will experience the disutility of crowded public transport[1]. In this study, I adopt the results from Haywood and Koning (2013) to render the cost as a function of the average ridership. These extensions, although seemingly less innovative, can be crucial and significant for adjusting the simulation results. Further details are provided in Section 2.2. The calibration procedures are presented in Section 2.3. Section 2.3 presents the results of the benchmark city.

2.2 Structure of The Model

This section will mainly describe the underlying model that is used to depict the JMA economy. It first describes the division of the JMA into several zones. A discussion on the ways through which the economic agents behave and interact in the

[1] Li and Hensher (2011) summarized the existing studies that have estimated the cost of discomfort from the use of public transport.

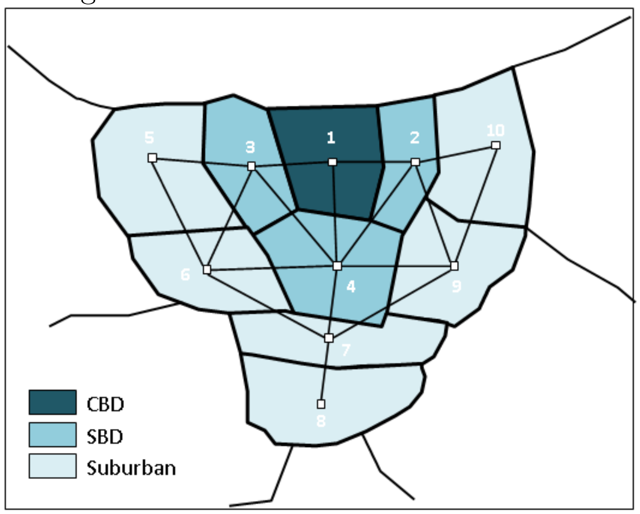
economy, as well as the modeling of the transport sectors then follows. The last part of this section describes the equilibrium conditions.

2.2.1 Urban structure

The model divides the JMA into ten zones, the distribution of which consists of one central business district (CBD), three sub-central business districts (SBD), and six suburban zones. Each region, i, endows a fixed land area, A_i, with a diameter, $d_i = 2(\frac{A_i}{pi})^{0.5}$, that may differ across regions. These regions are allocated into three main purposes: residences, productions, and roads. Each zone is interconnected with intracity and intercity road networks. The quality of roads is assumed to be homogenous within a region, but varies among regions. Road allocation in each zone, K_i, is exogenously determined, yet others are endogenously distributed under no-toll equilibrium, including land rent. Given the no-toll equilibrium result, land allocation is fully exogenous once the road toll is introduced under short-run equilibrium. There is no room for workers to consume more (or less) land size after the policy intervention. Zones are linked by the exogenous road system networks with distance, d_{ij}, and some $i - j$ arrangements can have more than one value of distance, d^o_{ij}, due to route alternatives. For example, d_{23} can involve road systems in the CBD (Zone 1) or take a detour by traversing another SBD (Zone 4). Firms produce final goods for workers' consumption by using land and all types of workers under a competitive environment. Hence, producers face a zero-profit condition, and the producer price is set to the equivalent of the average cost. The commodities are homogeneous within the zone but vary across zones. Differentiated final products enable workers to enjoy a higher utility from their varied tastes.

The economy consists of three agents: the producers, the workers, and the government, as represented in Figure 2.2. Producers require labor inputs from the workers and land inputs from the government to produce heterogeneous final goods across

Figure 2.1: The JMA's urban structure

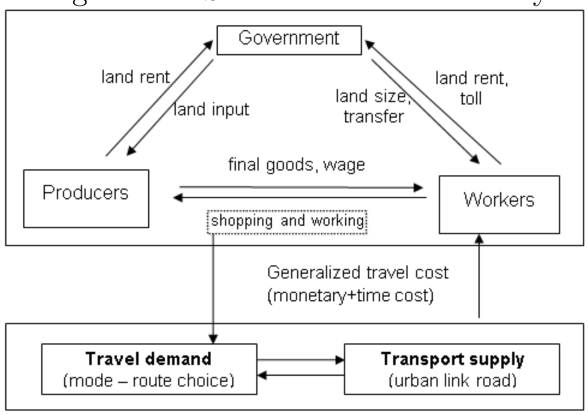


regions. Workers provide labor supplies measured in hours, are obliged to commute from their home to the workplace, given their choice of home-to-work arrangement, by using either the car, the motorcycle, or the bus[2], depending on their modal choice endowment, and receive wages per hour from the producers. All types of households can freely choose their residential and working zones, given their home-to-work choice restrictions. Such restrictions are needed, since in reality there are certain home-to-work arrangements that may not be available in the JMA network due to the significantly longer commuting time. Workers also have to complete shopping trips to buy final good composites. Since all trips are conducted via road links, workers as the sole users of the roads face a certain level of road congestion that extends their travel time. Depending on the toll mechanism, workers' trips are subject to a certain level of road toll that is paid to the government. In addition, workers face toll charges under the condition that their home-to-work choice under no-toll equilibrium,

[2]The model ignores railways as one of the alternative modal choices, since railway users are relatively small; according to the SITRAMP (2004), they account for approximately 3 percent of the total trips.

as well as their land size consumption, remain unchanged. Meanwhile, the government is assumed to be the landowner that pools all land rent, and then distributes it evenly through a lump-sum transfer to the workers.

Figure 2.2: Structure of the economy



In this economy, the interaction among the producers, the workers, and the government is reflected in three different markets, i.e. labor, land, and commodities. In equilibrium, market mechanisms endogenously determine land, employment, production, and all vector prices. Following the SGE framework (e.g. Anas and Xu (1999); Anas and Rhee (2006); Tscharaktschiew and Hirte (2012)), idiosyncratic tastes in worker utility create a mixed land use between residential and production purposes, which would more likely lead towards a multicentric city formation. This assumption more appropriately reflects the JMA's urban structure, as well as those of other urbanized areas in the world. The following subsection will briefly explain the behavior of each agent, starting with the workers.

2.2.2 Workers' behavior

2.2.2.1 Utility maximization and location choice under status-quo equilibrium

There are N workers available, and these fall into one of three groups based on skill, i.e. the low-, middle-, and high-skilled groups. Given his f type, each worker has utility-maximizing behavior, as expressed by

$$\max_{\mathbf{z},h} U_{ij}^{f}(\mathbf{z},h,e,\theta,\varepsilon,\nu) = \delta_1 \ln(\sum^{k} \chi(z_{ijk}^{f})^{\delta_3})^{\frac{1}{\delta_3}} + \delta_2 \ln h_{ij}^{f} + \delta_4^{f} \ln\left(e_{ij}^{f} - \bar{e}\right) + \theta_i + \varepsilon_i^{f} + \nu_{ij}^{f} \quad (2.1)$$

The utility function in Equation 2.1 has two parts: the systematic and the idiosyncratic tastes. The systematic term is a well-defined utility representation as a function of final goods consumption, z, land lot consumption, h, and leisure, e. The last systematic component can be defined as the leftover time from the yearly working time, Ds_{ij}^{f}, and the time spent on commuting, shopping, and the disutility of using the crowded public bus, respectively, which can be written as $e_{ij}^{f} = \bar{S} - D\bar{s}^{f} - \Gamma_{ij}^{f} - \urcorner_{ij}^{f}$. There is a threshold for leisure, $\bar{e}$, which is the minimum leisure for resting that results from multiplying the minimum daily resting hour by the total working days. Due to the exogenous leisure time, the utility function is maximized with respect to the composite goods and the lot size. Optimal decision for the composite goods is a function of the delivered and the composite prices, but these prices do not include the travel time costs of shopping.

The constant elasticity of substitution (CES) form of the sub-utility vector composite goods indicates that people love a variety in their consumption of different zonal-specific final goods. Under this utility function setup, δ_1 and δ_2 are the proportions of the total final goods and land lot consumption, respectively, out of the total income. δ_4^f is the parameter for leisure. Meanwhile, δ_3 is the elasticity of substitution of the final goods, which reflects the spatial taste variety as pointed out by Dixit and Stiglitz (1977). As $\delta_3 \to 1$, the final goods become the perfect substitution among others, and as a response, workers will fully consume a specific good with the lowest generalized price. In contrast, $\delta_3 \to \infty$ lets a respective worker consume all available types of final goods equally, regardless of their generalized price. A basket of final goods consumption is defined such that , $\chi\left(z_{ijk}^f\right) = z_{ijk}^f$ if shopping trips $i - k$ are available, and 0, if otherwise.

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Expected commuting time depends on the home-to-work arrangement while shopping time is proportional to the number of final goods consumed. Denoting g_{ij}^f as an average travel time of an $i - j$ return trip of a type f worker, the total travel time that includes the time required for both commuting and shopping is $\Gamma_{ij}^f = D\bar{g}_{ij}^f + \varkappa \sum^k \bar{g}_{ik}^f z_{ijk}^f$. The first term indicates the commuting time cost for a return trip multiplied by the available working days in a year. The second term specifies the annual shopping time cost that is proportional to the amount of final goods consumed.

The idiosyncratic taste of $\varepsilon_j^{ty} + \nu_{ij}^f$ is unobserved and assumed as following the Gumbell distribution. I have two components in the idiosyncratic taste that forms a nested logit-type decision of the home-to-work choice. θ_i is a specific constant that varies across regions but is homogeneous among the SBDs and the suburban zones. This parameter is introduced so that the calibration target of residential density is met. θ_i is set such that it has the highest value for the SBD, followed by the CBD, and then the suburban zones.

Expected commuting time depends on the home-to-work arrangement while shopping time is proportional with the number of final goods consumed. Denoting g_{ij}^f as an average travel time of an $i - j$ return trip of worker's type f, the total travel time which includes for both commuting and shopping, is $\Gamma_{ij}^f = D\bar{g}_{ij}^f + \varkappa \sum^k \bar{g}_{ik}^f z_{ijk}^f$. The first term indicates the commuting time cost for return trip times available working days in a year. The second term specifies annual shopping time cost that is proportional to the amount of final goods consumed. The idiosyncratic taste $\varepsilon_j^{ty} + \nu_{ij}^f$ is unobserved and assumed to follow Gumbell distribution. We have two components in the idiosyncratic taste that forms nested logit type decision of home-to-work choice. θ_i is a specific constant which varies across regions but homogeneous among SBDs and suburban. This parameter is introduced in order to meet our calibration target on residential density. θ_i is set such that it has the highest value for SBD, followed by the CBD, and the suburban zones.

A representative worker earns his money by spending an exogenous amount of hours on working on a daily basis, s_{ij}^f, in one of the possible zones, and receives wages per hour, w_j^f. Another source of income is transfer payment, Δ. The monetary income is exhausted for the full consumption of the final goods, z, the renting of a land lot, h, and the payment of the monetary travel costs for the commuting $\left(D\bar{G}_{ij}^f\right)$ and the shopping trips $\left(\varkappa \sum^{k} \left(\bar{G}_{ik}^f\right) z_{ijk}^f\right)$. It consists of gasoline consumption (for private modes) or fee charges (for the public bus) and tolls (if any). Thus, the workers' income constraint can be written as

A representative worker earns his money by spending an exogenous amount of hour for working on a daily basis s_{ij}^f in one of possible zones and receives per hour wage w_j^f. Another source of income is transfer payment Δ. The monetary income is exhausted to fully consume final goods z, rent land lot h and pay the monetary travel cost for the commuting $\left(D\bar{G}_{ij}^f\right)$ and the shopping trips $\left(\varkappa \sum^{k} \left(\bar{G}_{ik}^f\right) z_{ijk}^f\right)$. It consists of gasoline consumption (for private modes) or fee charge (for the public bus) and toll (if any). Thus, workers' income constraint can be written as

$$I_{ij}^f \equiv D\bar{s}w_j^f + \Delta - D\bar{G}_{ij}^f = \sum^{k} \left(p_k + \phi\bar{G}_{ik}^f\right) z_{ijk}^f + r_i h_i \tag{2.2}$$

Workers' utility maximization is achieved by a maximized Equation 2.1 that is subject to Equation 2.2 with respect to (w.r.t.) z and h. For a given $i-j$ arrangement with I_{ij}^f as the net income after paying the monetary commuting travel cost, $\bar{G}_{ij}^f$, the optimal final goods and land consumption are determined by

$$z_{ijk}^f = \frac{\delta_1 I_{ij}^f (\tilde{p}_{ijk}^f)^{\frac{1}{\delta_3 - 1}}}{\sum^k (\tilde{p}_{ijk}^f)^{\frac{\delta_3}{\delta_3 - 1}}} \quad \forall k \tag{2.3}$$

$$h_{ijk}^f = \frac{\delta_2 I_{ij}^f}{r_i} \tag{2.4}$$

From optimal final goods and land lot consumption, the systematic part of the indirect utility function is

$$V_{ij}^{f}\left(I_{ij}^{f},\tilde{p}^{f},r,e_{ij}^{f}\right)=\ln I_{ij}^{f}-\frac{\delta_1\left(\delta_3-1\right)}{\delta_3}\ln\left[\sum^{K}\tilde{p}_{ijk}^{f\,\frac{\delta_3}{\delta_3-1}}\right]-\delta_2\ln r_i+\delta_4^{f}\ln\left(e_{ij}^{f}-\bar{e}\right)+\theta_i \tag{2.5}$$

Given the available home-to-work choices, the probability of a representative worker choosing an $i-j$ arrangement follows the nested logit framework under regularity, as explained by Ben-Akiva and Lehman (1985)[3]. At the first stage, a worker chooses his residential zone, and based on his chosen workplace, he chooses the working zone. The probability that an $i-j$ home-to-work arrangement is chosen is $\Lambda_{ij}^{f}=\hat{\Lambda}_{j|i}^{f}.\tilde{\Lambda}_{i}^{f}$, where the first term is the probability of a type f worker working in the j-th zone, which is conditional on living in the i-th zone, while the second term is the probability of a chosen residential zone, i. This can be justified, as Manning (2003) argued that homes are less mobile than jobs, which means that the former is likely to be more inelastic than the latter. Since the scale parameter of the upper nest must be lower or equal to the lower nest, according to Ben-Akiva and Lehman (1985), the best way to accommodate it as well as the previous elasticity issue is to put the residential and employment zone choices in the upper and lower nests, respectively. $\mathbf{J_f}$ represents the set of all possible working places, and $\mathbf{D_n}$ represents the set of all possible residential zones. I define $\mathbf{J_{nf}}$ as the subset of the employment zone in $\mathbf{J_f}$, which is feasible if he/she lives in i. Thus, both terms of the home-to-work choice arrangement are calculated by

[3]It comprises three assumptions on error component. First, ε_i^f and ν_{ij}^f are independent. Second, ν_{ij}^f is independent and identically follows the Gumbel distribution under scale parameter λ_2. Last, ε_i^f is such that $\max_{i\in\mathbf{J_{nf}}} U_{ij}^f$ also follows the Gumbel distribution under scale parameter λ_1

$$\tilde{\Lambda}_i^f = \Pr\left[\max_{i \in \mathbf{J_{nf}}} U_{ij}^f \geq \max_{i' \in \mathbf{J_{n'f}}} U_{ij'}^f\right] = \frac{\exp(\lambda_1 \daleth_j^f)}{\sum\limits_{i' \in \mathbf{D_n}} \exp(\lambda_1 \daleth_{j'}^f)} \tag{2.6}$$

$$\hat{\Lambda}_{j|i}^f = \Pr\left[U_{ij} \geqslant U_{i'j}, \forall j' \in \mathbf{J_{nj}}, j' \neq j\right] = \frac{\exp(\lambda_2 V_{ij}^f)}{\sum\limits_{j' \in \mathbf{J_{nf}}} \exp(\lambda_2 V_{i'j}^f)} \tag{2.7}$$

where $\daleth_j^f = \frac{1}{\lambda_2} \ln \sum\limits_{j' \in \mathbf{J_{nf}}} \exp(\lambda_2 V_{i'j}^f)$. Based on the work of Kanemoto (2011), $\daleth_j^f$ can be defined as the expected value of the maximum utility from the employment zone choices in the residential zone, i. Aside from the value of the utility of each possible home-to-work choice, behaviors in the two equations above are also determined by the scale parameters of λ_1 and λ_2. As $\lambda \to 0$, the utility value of each choice will be neglected and the probability of choosing a residential/working zone will be uniform across choices. In another extreme case, $\lambda \to \infty$ allows a residential/working zone that provides the highest utility to be chosen with a probability of one.

2.2.2.2 Utility maximization after policy introduction

Under the no-toll condition, all markets are assumed to be in equilibrium, and the workers maximize their utility and choose the location choice, as described in the preceding discussion. Once the local government implements a road toll policy, a respective worker cannot flexibly alter his/her decision, as in no-toll equilibrium. Amundsen (1985) argued that the consumption of housing services has to stay constant for some period and is suboptimal to relative prices and income. On the other side, there are various studies that emphasize the substantial costs of job searching in cities (e.g. see Patacchini and Zenou (2006)). Therefore, changing these aspects would not be smoother than altering transport behavior, which could change more immediately. This implies that, in the very short run, people do not change these factors; rather, they alternate their decisions with others in response to the road toll. The new short-run utility maximization formulation can be written as follows:

$$\max_{\mathbf{z}} U(\mathbf{z}, h, e, \theta, \varepsilon, \nu) = \delta_1 \ln(\sum^{k} {z_k}^{\delta_3})^{\frac{1}{\delta_3}} + \delta_2 \ln \overline{h} + \delta_4 \ln(e) + \theta_i + \varepsilon_j + \nu_{ij}$$

$$s.t.\, \tilde{I}^{SR} = I^{SR} - R\bar{h} = \sum \tilde{p}_k z_k$$

This formulation implies that the workers consider the land lot consumption as fixed, as in no-toll equilibrium, and because land rent is exogenous for the workers' decision nest, the land consumption spending is fixed. By taking first order conditions (FOCs) with respect to the final goods consumption, I find that

$$z_k = \tilde{I}^{SR} \frac{\left(\tilde{p}_k^{SR}\right)^{\frac{1}{\delta_3 - 1}}}{\sum\limits^{l} \left(\tilde{p}_l^{SR}\right)^{\frac{\delta_3}{\delta_3 - 1}}} \quad \forall k$$

Thus, suppressing identifiers, the indirect systemic utility function is defined as

$$\tilde{V} = \delta_1 \ln \tilde{I}^{SR} - \frac{\delta_1 (\delta_3 - 1)}{\delta_3} \ln \left[\sum^{l} \left(\tilde{p}_l^{SR}\right)^{\frac{\delta_3}{\delta_3 - 1}} \right] + \theta_i + \delta_2 \ln \overline{h} + \delta_4 \ln e$$

2.2.2.3 Mode-route decision

Modeling transport demand solely focuses on the workers. This assumption perhaps oversimplifies reality because producers also give a certain amount of contribution to transport demand. However, I believe that this simplification can still be justified due to at least two reasons. First, the measurement of the welfare gain is based on the workers' side, while other agents' behaviors are kept as simple as possible without loss of any fundamental assumptions. Second, although producers contribute to transportation demand, particularly with regards to heavy vehicles, the main sources of transport demand are the workers[4]. Other assumptions are the lack of a trip chain and the lack of the choice of time in conducting a trip.

To perform both commuting and shopping trips, a worker chooses a combination of mode-route choice to minimize the generalized travel cost. Each mode-route generalized travel cost consists of the monetary cost, the time cost, and the crowding cost of the public bus. Monetary cost comprises of gasoline consumption cost and road toll (if applicable). Bus charges vary across origin-destination-routes, or $i - j - o$. Gasoline consumption per km varies across modes and is a function of the travel speed in each traversed zone.

The $i - j - c - o$ time cost is defined as the travel time needed from i to j by mode, c , and route, o, which are evaluated by values of time. For any $i - j$ link, the travel time per km is an increasing function of the number of trips and a decreasing function of the land allocation for roads. Therefore, additional trips traversing zone i lead to a higher congestion level and provide additional externality to other road users. The distance of an $i - j$ trip depends on its nature, whether it is an intrazonal or an interzonal trip. One-way intrazonal trips are assumed to traverse half of the respective zone's width, while one-way interzonal trips must traverse half of the width of all zones passed in such an assignment, including the origin and the destination areas. A simple example is an interzonal trip from the Depok suburb (Zone 7) to the CBD (Zone 1), which passes through South Jakarta's SBD (Zone 4) and spends half

[4]The SITRAMP reported that, in 2002, pick-ups and trucks together accounted for percent of the total trips in the JMA.

of the width of three zones as defined in its link. Meanwhile, the value of travel time is defined as $\rho_{ij}^{f} = \frac{\frac{\partial V_{ij}^{f}}{\partial e_{ij}^{f}}}{\frac{\partial V_{ij}^{f}}{\partial I_{ij}^{f}}} = \frac{\delta_4^f I_{ij}^f}{e_{ij}^f - \bar{e}}$.

The last component of the generalized travel cost arises only for the public bus use in the form of crowding disutility. I pick the average ridership as the proxy for the crowding variable. The crowding cost is an increasing function of the average ridership, which means that a greater number of people inside the public bus will create a greater level of discomfort. The crowding cost also increases as travel time gets longer because the passengers must endure a longer period of discomfort.

I define C_{ijco}^{f} as the generalized travel cost from zone i to j for a respective f-skilled worker's choice of transport mode, c, and traverse of route, o. Thus, the generalized travel cost is calculated by

$$C_{ijco}^{f} = \underbrace{\rho_{ij}^{f} g_{ijco}\left(c, \mathbf{d_{ijo}}, \tilde{\mathbf{F}}_{\mathbf{ijo}}, \mathbf{K_{ijo}}\right)}_{time\,cost} + \underbrace{\tau_{ijco}}_{toll} + \underbrace{\varrho_{ijco}\left(c, \mathbf{d_{ijo}}, \tilde{\mathbf{F}}_{\mathbf{ijo}}, \mathbf{K_{ijo}}\right)}_{monetary\,cost} + \underbrace{\rho_{ij}^{f}\psi_{ijco}^{f}(c, \iota_c)}_{cost\,of\,discomfort} + \hbar_{ijco}^{f} + \epsilon_{ijc} + \varpi_{ijco} \tag{2.8}$$

where the last two terms are random terms needed to form a nested logit model for the mode-route choice. $\tilde{\mathbf{F}}_{ij}$ and $\mathbf{K_{ij}}$ are the respective vectors of the generalized number of trips and the land allocation for roads, whose elements belong to every zone traversed in the $i - j - o$ arrangement. The first term in the left-hand side of Equation 2.8 is the travel time in hours evaluated by the values of travel time for each skill group with an $i - j$ home-to-work arrangement. The second term is the road toll. The value and cordon location are determined exogenously. In Chapter 3, the road tolls considered are the three types of cordon ring (the CBD, the SBD, and the step-tolling SBD+CBD) and the two variants (tolling all private modes or cars only). The third part is the monetary cost of gasoline consumption as a function of the travel distances, the zonal congestion level, and the lands for road allocations. The last part is the cost of discomfort from the use of the crowded public bus. The cost essentially measures the disutility from the addition of one more passenger to the public bus. The disutility is then evaluated by the travel time equivalence, in the manner of Haywood and Koning (2013). A constant, $\hbar^f_{ijco}$, is introduced in order to meet the calibration target of the modal split for each worker group. The detailed explanation of all of these components will be provided in the following section.

The mode-route decision is derived from a nested logit procedure, in which a favorable transport is chosen in the first place, followed by the route of the second stage. All skill levels can access the three types of transport mode, i.e. the car, the motorcycle, and the bus. Route-traversing assignment is exogenously determined, and an $i-j$ trip contains at most two route alternatives[5]. Let Θ^f_c be a set of possible transport modes for f-skilled workers and O_e be a set of all of the possible alternative routes that connect the $i-j$ O-D link. Let M^f_{co} be further denoted as a subset of routes that are feasible in the $i-j$ link. Thus, the probability of choosing the mode-route arrangement of Φ^f_{ijco} is determined by

$$\tilde{\Phi}^f_{ijc} = \Pr\left[\max_{c\in\mathbf{\Theta^f_{co}}} - C^f_{ijco} \geq \max_{c\in\mathbf{\Theta^f_{c'o}}} - C^f_{ijc'o}\right] = \frac{\exp(\lambda_3 \Upsilon^f_{ijc})}{\sum\limits_{c'\in\mathbf{\Theta^f_c}} \exp(\lambda_3 \Upsilon^f_{ijc'})} \tag{2.9}$$

$$\hat{\Phi}^f_{ijo|c} = \Pr\left[-C_{ijco} \geqslant -C_{ijco'}, \forall o \in \mathbf{\Theta_{co'}}, o' \neq o\right] = \frac{\exp(-\lambda_4 C^f_{ijco})}{\sum\limits_{o'\in\mathbf{O_e}} \exp(-\lambda_4 C^f_{ijco'})} \tag{2.10}$$

$$\Phi^f_{ijco} = \tilde{\Phi}^f_{ijc}.\hat{\Phi}^f_{ijo|c} \tag{2.11}$$

[5]Under $10X10$ origin-destination trip possibilities, I consider 40 percent of it to have two route alternatives

where $\Upsilon^f_{ijc} = \frac{1}{\lambda_4} \ln \sum_{o' \in \mathbf{M_{co}}} \exp(-\lambda_4 C^f_{ijco'})$ is the logsum variable or the inclusive value of the transport mode, c (Kanemoto (2011)). In this context, the inclusive value represents the expected value of the minimum two-way generalized travel cost from the routes in nest . The result from Equation 2.11 completes the calculation of the average annual travel time, the monetary time cost, and the disutility of the public bus of the $i - j$ arrangement, as follows:

$$\bar{\Gamma}^f_{ij} = \sum_{c'} \sum_{o'} \Phi^f_{ijco} g_{ijco} \left(d_{ijo}, \tilde{\mathbf{F}}_{\mathbf{ijo}}, \mathbf{K_{ijo}} \right) \tag{2.12}$$

$$\bar{G}^f_{ij} = \sum_{c'} \sum_{o'} \Phi^f_{ijco} \left(\varrho_c \left(d_{ijo}, \varrho'_{\mathbf{ijc}} \left(g' \left(d_{ijo}, \tilde{\mathbf{F}}_{\mathbf{ijo}}, \mathbf{K_{ijo}} \right) \right) \right) + \tau_{ijco} \right) \tag{2.13}$$

$$\daleth^f_{ij} = \phi \sum_{o'} \Phi^f_{ij3o} \psi^f_{ij3o}(\iota) \tag{2.14}$$

2.2.3 Transport Supply

This section will explain how the traffic flows, travel times, gasoline consumption, PCU values, and cost of discomfort are determined. From the generalized travel cost in Equation 2.8, the travel time is a function of the zonal traffic flow in each of the zones traversed. To determine these numbers, recall that from the home-route choice in the location choice decision, the daily total traffic flows from zone i to zone j of the f-skilled worker are derived from $F^f_{ij} = N^f \left(\Lambda^f_{ij} + \frac{\varkappa}{D} \sum_k \Lambda^f_{ik} z^f_{ikj} \right)$, where z^f_{ikj} is the j-th final goods consumed by the f-skilled worker living in zone i and working in zone k. In other words, F^f_{ij} covers all of the trips from i to j for the commuting and shopping purposes. Thus, the amount of daily traffic flows from zone to zone with the use of mode c and route alternative o is $F_{ijco} = \sum_f \Phi^f_{ijco} . F^f_{ij}$.

From the daily traffic flows information, I define the daily zonal traffic flow F_{jc}^{z} as the number of trips that traverse zone j by using transport mode c. The simplest example is by determining the daily zonal traffic flow for Zone 8 (suburbs), which is obtained from the daily total traffic flow for and from Zone 8 with only one route alternative, or $F_{8c}^{z} = \sum_{i=1}^{10} F_{i8c1} + \sum_{j=1}^{10} F_{8jc1} - F_{88c1}$. Since all three transport modes have different sizes in nature, they are weighted by the PCU in order to obtain a generalized daily zonal traffic flow of $\tilde{F_{k}^{z}} = \sum_{c=1}^{c'} \frac{\varsigma_{c}^{k}}{\iota_{ck}} F_{kc}^{z}$, where ς_{c}^{k} and ι_{c} are the PCU value in zone k and the average ridership of mode c, respectively. The average ridership is exogenous for all modes and equilibrium conditions, except for the public bus. In no-toll equilibrium, the parameter for the average ridership is constant; given the number of trips via the public bus, the total number of buses is derived. This value is perfectly inelastic across the equilibrium. Hence, the additional public bus user will only raise the average ridership, and not the number of available public buses in the JMA.

Once the zonal traffic flows for each zone are determined, the zonal travel time per km, g'_{kc}, can be calculated. I follow the conical volume-delay function, as proposed by Spiess (1990), rather than the Bureau of Public Roads (BPR)-type function, such that $g'_{kc} = g'_{0kc}\left(2 + \sqrt{(\alpha_2)^2\left(1 - \frac{\tilde{F_{k}^{z}}}{\alpha_3 K_k}\right)^2 + (\alpha_4)^2} + \alpha_2\left(1 - \frac{\tilde{F_{k}^{z}}}{\alpha_3 K_k}\right) - \alpha_4\right)$, where $\alpha_4 = \frac{2\alpha_2 - 1}{2\alpha_2 - 2}$ and $\alpha_2 > 1$. One of its advantages over the BPR-type function lies in the fewer number of parameters to be calibrated. The conical function requires one parameter to be determined as $\alpha_4 = f(\alpha_2)$, while the BPR-type requires the calibration of two parameters. g'_{0kc} is the free-flow travel time per km of transport mode c in zone k. g'_{0kc} is highest for the private car, then the motorcycle and the bus. Furthermore, the function itself has properties of $\frac{\partial g'}{\partial \tilde{F^{z}}} < 0$ and $\frac{\partial g'}{\partial K} > 0$, or, generally speaking, the travel time per km is higher when more road users are traveling, and lower when more land is allocated for the road in the respective zone. A one-way, (i, j, c, o), travel time requires a half width of the distance of every traversed zone, while there is an additional constant for the bus user, $\hat{g}$. The constant time can be regarded as the waiting and the access times for the bus users from his/her home to the nearest station. For example, $g_{12c1} = \hat{g} + 0.5\,(d_1 g'_{1c} + d_2 g'_{2c})$[6].

The gasoline consumption per km varies across modes, and is a function of the travel speed per km in each traversed zone of g'. I adopt the gasoline consumption per km function in zone k, ϱ_{kc}, from the SITRAMP to follow a quadratic function to the extent that

$$\varrho'_{kc}\,(g') = \overline{\sigma}^c + \sigma_1^c(g'_k) + \sigma_2^c(g'_k)^2 \;\;, c \in \{1, 2\} \tag{2.15}$$

This function is calibrated for private modes only, i.e. autos and motorcycles, and does not apply for public transport mode (bus) fares, or $\sigma_{13} = \sigma_{23} = 0$. In other words, the bus fare is a sole increasing function of the distance. Let ϱ_{ijco} be the gasoline consumption for traveling from i to j with the use of mode c and route o, and let κ be the gasoline price per liter. Similar to the travel time arrangement, one-way gasoline spending requires a half width of the distance of the zone in the respective route. Thus, taking the route in the travel time function as the example, I find that $\varrho_{12c1} = 0.5\kappa\,(d_1\varrho'_{1c} + d_2\varrho'_{2c})$.

The PCU is assumed to be endogenous as a function of the level of each zone, rather than exogenously determined. Arasan and Arkatkar (2011) argued that, under a heterogeneous traffic flow, assuming fixed PCU values becomes more irrelevant because it is difficult for these various modes to follow the traffic lanes. Smaller modes like motorcycles or mopeds have more maneuvers to change their lateral positions than other modes. The level of maneuvers also depends on the traffic volume (V/C ratio). To obtain the numbers, Arasan and Arkatkar simulated a road link filled with several types of modes (two-wheelers, three-wheelers, cars, light commercial vehicles, buses,

[6] Complete notes on the travel time arrangement are available upon request.

trucks, bicycles, and tricycles) and calculated the PCU of each group with respect to the V/C ratio. Their resulting PCU function is

$$\varsigma_c^k = \bar{\varsigma}_c + \varsigma_c^1 \tilde{F}_k^z + \varsigma_c^2 \left(\tilde{F}_k^z\right)^2 + \varsigma_c^3 \left(\tilde{F}_k^z\right)^3 + \varsigma_c^4 \left(\tilde{F}_k^z\right)^4 \tag{2.16}$$

where the constant, $\bar{\varsigma}_c$, is the value of the PCU under fixed and exogenous assumptions.

Existing literature has presented several ways of quantifying the cost of the crowding discomfort from riding the public transport. Li and Hensher (2011) summarized the recent crowding valuation studies of the bus, the light rail, and the train. The discomfort was measured, in the form of the number of standing passengers, the proportion that is seated, the load factor, the probability of getting a seat, the probability of public transport occurrence, the walking and waiting times, or the desirability for increased seating capacity. The evaluation method was mostly divided into two ways: monetary value or time multiplier. The latter is defined as the marginal rate of substitution of the travel time between the congested and the base levels, which is usually the least congested state (Haywood and Koning (2013)). For example, consider the value of the time multiplier as 1.5. It implies that the bus passengers are indifferent towards spending a minute in the worst congested condition and the least congested state for 1.5 minutes. To model the discomfort of the bus users, I use the average ridership, which is more or less equivalent to the load factor, as the discomfort variable. I assume that the discomfort cost has the following function:

$$\psi_{ij3o}^f(\iota_3) = \bar{\psi} + \rho_{ij}^f \phi g_{ij3o} \frac{(\iota_3 - \bar{\iota}_3)}{\bar{\iota}_3} \tag{2.17}$$

The function of the crowding cost in 2.17 has several features. First, it uses the reference point of the average ridership $\bar{\iota}_3$ so that the discomfort cost increases (decreases) if the ridership is higher (lower) than the reference point. In other words, the cost of discomfort will be maintained as long as the average ridership keeps constant. The constant $\bar{psi}$ is introduced since I use this value for the calibration purpose under no-toll equilibrium. Second, the discomfort from additional ridership is increasing along with longer travel time and evaluated using time multiplier. At last, the number is multiplied by the value of time of each group to obtain its monetary value. Because higher type group always have higher values of time, the highest discomfort bus will always belong to the high-skilled group followed by the middle and low-skilled group.

2.2.4 The Producers' Behavior

Many competitive firms that produce homogeneous products exist in each zone, yet they differentiate across zones. Production technology follows the constant return of the Cobb-Douglas function that requires the land and all types of labor skills to produce the zonal-specific final commodities. With L_k as the aggregate land production input in zone k and M_k^f as the aggregate labor input of skill f in zone k, the production function of the zonal-specific final commodities, Y_k, becomes

$$Y_k = B_k L_k^{\eta_k} \prod_{f=1}^{F} \left(M_k^f \right)^{\mu_k^f} \tag{2.18}$$

where B_k is the Solow residual. SAssuming that the constant returns to scale, $\eta_k + \sum_{f=1}^{F} \mu_k^f = 1, k \in r$. Profit maximization strategy, along with a zero economic profit condition, gives the following conditions:

$$w_k^f = \frac{\mu_k^f Y_k}{M_k^f}, \ f \in F \tag{2.19}$$

$$R_k = \frac{\eta_k Y_k}{L_k} \tag{2.20}$$

$$p_k = \frac{(R_k)^{\eta_k} \prod^{F} \left(w_k^f\right)^{\mu_k^f}}{B_k \eta_k^{\eta_k} \prod^{F} \left(\mu_k^f\right)^{\mu_k^f}} \tag{2.21}$$

where $F = \{1, 2, 3\}$.

2.2.5 The Government Transfer

The economy works under public ownership. Revenue from land rent is evenly distributed to the residents. Likewise, since I do not model how the gasoline cost, the bus fare, and the toll revenue may be specifically allocated, all of these revenues are pooled and directly transferred to the residents. Thus, the transfer payment per worker can be calculated as

$$\Delta = \frac{1}{N} \left(\sum R_k \left(A_k - K_k\right) + \sum_f N^f \left(\sum_{ij} \hat{\Lambda}_{ij}^f \left[D\bar{G}_{ij}^f + \varkappa \sum^{k} \bar{G}_{ik}^f z_{ijk}^f \right] \right) \right) \tag{2.22}$$

where the first and the second terms in the bracket are the transfer associated from the land rent and the monetary revenue from the transportation sector, respectively. The monetary revenue itself consists of the revenues from commuting and shopping, respectively.

2.2.6 Market equilibrium conditions

2.2.6.1 No-toll equilibrium

In the absence of the road toll, the spatial equilibrium conditions in zone k that need to be satisfied can be expressed as follows:

$$\sum_f N^f \sum_j \Lambda^f_{kj} h^f_{kj} + L_k = A_k - K_k \tag{2.23}$$

$$D\bar{s}N^f \sum_i \Lambda^f_{ik} = M^f_k \quad \forall f \in \{1,2,3\} \tag{2.24}$$

$$\sum_f N^f \sum_{ij} \Lambda^f_{ijk} z^f_{ijk} = Y_k \tag{2.25}$$

Equation 2.23 reflects the land market equilibrium for each zone of k. On the right-hand side, the total net land available in zone k after subtraction by the exogenous road allocation is fully distributed for residential purposes and productions. Equation 2.24 summarizes the equilibrium for three groups of workers in each zone. For an k-skilled market in zone k, the total labor demand, which is on the right-hand side, from the producing firms in zone k must meet the total supply from the workers that is expressed on the left-hand side. Because the daily working hour is assumed as constant regardless of the zone and the worker's type, the labor supply in zone k is simply an aggregate of the number of f-skilled workers working in the respective zone. The last equation shows the equilibrium in the final goods. Due to a closed economy assumption (no export), final goods production in zone k is fully consumed by all workers in the economy.

Solving Equations 2.23-2.25 simultaneously will give the equilibrium results of the land rents, the wages with respect to the skill level of f, the final goods prices, and in turn, all of the endogenous goods allocation (land, employment, and final goods), given the workers' and the firms' maximization problems. With 10 zones and 3 skill levels, the equilibrium system deals with 50 non-linear equations, and therefore the analytical solution is almost impossible. Due to the Walras Law, the producer mill price in the CBD (Zone 1) is set as the numeraire.

2.2.6.2 Short-run environment

In this section, the toll policy will be analyzed under a short-run environment that is characterized by a worker's fixed home-to-work arrangement and a fixed land allocation. Anas and Hiramatsu (2012) used a similar setting in one of the short-run equilibriums to disaggregate the gasoline price elasticity. It implies that both the labor supply and the land demand will be fixed, which will lead to constant levels of final goods production in each zone. This result corresponds with those of a study by Eliasson et al. (2009) on Stockholm's congestion toll trial; this study argued that the impact on retail in the inner ring zone is insignificant. Based on this argument, the equilibrium conditions in Equations 2.23-2.25 are modified into the following:

$$\sum_f N^f \sum_j \bar{\Lambda}^f_{kj} \bar{h}^f_{kj} + \bar{L}_k = A_k - K_k \tag{2.26}$$

$$D\bar{s}N^f \sum_i \bar{\Lambda}^f_{ik} = M^f_k \ \ \forall f \in \{1, 2, 3\} \tag{2.27}$$

$$\sum_f N^f \sum_{ij} \bar{\Lambda}^f_{ijk} z^f_{ijk} = Y_k \tag{2.28}$$

where variables in $^-$ are obtained in no-toll equilibrium.

2.3 Model Calibration of No-Toll Equilibrium

Despite the limited real JMA parameters available, I calibrate the model to represent the JMA condition as realistically as possible. The unavailable JMA parameters are obtained from other studies, calibrations, and/or logical assumptions in order to meet the main calibration targets in Tables 2.1-2.2 as closely as possible. Land size for each area is obtained from the Regional Statistics of each respective zone. The CBD is represented by the Central Jakarta district while the sizes of the SBDs are calculated by evenly dividing the rest of Jakarta's land, except the Thousand Island municipality. The Thousand Island municipality is excluded from the system, as it is geographically separated from the Jakarta mainland. For the suburbs, it is assumed that 2400 km^2 (about 40 percent) of the total suburban areas is directly related to the JMA; this area is then evenly divided into six suburban zones for the sake of simplicity, as shown in Figure 2.1. In other words, only 46 percent of the total land available in the JMA is included in the model. There is no valid literature that clearly justifies the extent of the JMA economically, as, for example, the work of Kanemoto and Kurima (2011), which defined an urban metropolitan area of Japan. However, an inclusion of all of the areas would also be unrealistic, since there are substantial amounts of forests, estates, and hills in the suburban areas that should not be included. In addition, I believe that the economic activities in some regions of the suburbs are not directly linked with Jakarta, which means that the cordon toll would have a small impact on these regions. Information on the land allocation for roads in Jakarta derives from Jakarta's Regional Statistics publication. Real parameters for the land allocation for roads are available only for the zones that fall into the Jakarta province, i.e. the CBD and the SBDs, and are drawn from the Jakarta Bureau of Statistics (2012). Parameters for the SBDs are adapted from the road allocation of the West Jakarta, the South Jakarta, and the East Jakarta municipalities, respectively. Meanwhile, suburban zones are assumed to allocate 4 percent of their land for roads, which is less than those in the CBD and the SBDs. The real numbers of road allocations are not available in the respective regional publications.

Table 2.1: Calibration Targets on Urban Economy

Parameters		Target	Model	Source
Workers' residential density (thousands workers/km^2)	Suburban	1.24	2.05	[1]
	SBD	6.58	6.41	
	the CBD	8.46	8.66	
Average monthly wage rate (thousands rupiah)	Low-skill	681.8	650.0	[2]
	Middle-skill	1,769.9	1,769.9	
	High-skill	6,075.4	5,983.8	
Average monthly working hours		160	160	
Elasticity of location demand w.r.t. commuting time		(-0.6)-(-0.5)	(-0.1)	[3]
Elasticity of labor supply in the CBD w.r.t. the CBD wage		1.2-2.8	1.2	

Source:
[1]Indonesian Bureau of Statistics (2013a)
[2]Indonesian Bureau of Statistics (2012)
[3]Anas and Hiramatsu (2013)

As many parameters as possible for the workers' behavior are extracted from various sources, particularly from Indonesia's Central of Statistical Bureau (BPS) or adapted from other references. On top of that, I first assume percent of the total workers involved in the JMA. According to the recent population census in 2010, there are 11.5 million workers living in the JMA, and hence our structure is occupied by 9.2 million workers. The distribution exogenously follows the Jabodetabek Urban Transportation Policy Integration (JUTPI) study. On the utility function, the first two parameters, δ_1 and δ_2, are extracted from the Indonesia Socio Economic Survey (SUSENAS) in 2010, which was published by Indonesia Bureau of Statistics (2013b). It provided the consumption of final goods as well as housing as a proportion of the total expenditure. It was reported that the average spending on final goods and housing are approximately 80 and 20 percent, respectively, which give the values of δ_1 and δ_2, respectively. I follow the work of Anas and Rhee (2006) for the parameter of substitution.

The last part of the consumption behavior is the leisure parameter, δ_4^f. There are two measures of the values of time to be calibrated: the hourly values of the time for each skill and the percentages of the values of time with respect to the hourly wages. The JUTPI study estimated the hourly values of time with respect to skills and transport modes. I use this number to obtain the range of the values of time for each skill group. Small and Verhoef (2007) summarized the empirical studies on estimating the values of time, and asserted that these values vary widely, usually between 20-90 percent of the gross wage rate with an average of approximately 50 percent. Hence, the preferred target for the ratio of the average values of time over wages is within 50-60 percent. In order to meet this target, I calibrate δ_4^f, which varies across skills, to bring the average values of time, $\bar{\rho}^f$, close enough to favor 50 percent of the average gross wage rate. The next step is to calibrate the values of time in rupiah. The JUTPI study estimated the hourly values of time with respect to skills and transport modes. I use this number to obtain a range of the values of time for each skill group; it turns out that setting the targeted values of time to as much as 50 percent of the per hour wage is sufficient for meeting this target.

Dispersion parameters are calibrated to meet both the elasticity of the location demand w.r.t. the commuting time and the elasticity of labor supplies in the CBD w.r.t. the CBD wages. Calibration results from Anas and Hiramatsu (2012, 2013) are chosen as the target, and the parameters to be calibrated are both the dispersion parameters in the nested logit commuting choice behavior. Our model's ability to meet the target of the elasticity of location demand is relatively poor. However, I argue that the moving cost plays a more important role in the big cities of developing countries than in those of the developed countries. A residential density target is calculated from the population census of 2010 that reported the number of those employed for each regency and district in the JMA. I calibrate the additional constant term in the utility function to match these numbers. The results from the suburban zones are much higher than the target numbers, as there are fewer available workers to be considered in the model. The average working hour is exogenously determined, and derives from the National Employment Survey 2011 (Indonesia Bureau of Statistics, 2012). From the same source, I draw the monthly average gross rate for each skill, and then calibrate the values of μ_k^f to meet those figures as closely as possible. In addition, the values of μ_k^f are calibrated so that the average wage in the CBD is higher than that in the SBD, which is in turn higher than that in the suburbs.

Table 2.2: Calibration targets on Transport Behavior

Parameters		Target		Model	Source
Modal split (percent)	JMA	Car	20.0	19.9	[1]
		Motorcycle	53.0	53.2	
		Bus	27.0	26.9	
	Low-skill	Car	8.0	8.2	
		Motorcycle	56.0	56.6	
		Bus	36.0	35.2	
	Middle-skill	Car	22.0	22.7	
		Motorcycle	53.0	51.7	
		Bus	25.0	25.6	
	High-skill	Car	44.0	36.4	
		Motorcycle	43.0	52.2	
		Bus	14.0	11.4	
Volume-Capacity ratio ($\frac{F}{\alpha_2 K}$)		the CBD	$1.5-1.6$	1.53	[1],[2],[3]
		SBD	$1.5-1.6$	1.53	
		Suburban	$0.8-0.9$	0.88	
Average daily travel speed (kph)			$15-20$	19.7	[4]
Per liter gasoline price (thousand rupiah)			$4.5-8.0$	5.6	[8]
Shopping trips (% of total trips)			$1-6$	4.9	[2]
Bus fare (thousand rupiah)			$1-6$	$0.8-10$	[1]
Elasticity of travel demand for public transport w.r.t. fare			$0.0-(-0.8)$	-0.12	[5]
Elasticity of travel demand for auto w.r.t. gas price			$(-0.1)-(-0.3)$	-0.16	[6]
Cross elasticity of travel demand for bus w.r.t. gas price			$0.0-0.8$	0.15	[7]
Elasticity of route demand w.r.t. monetary travel cost			$(-0.2)-(-0.4)$	-0.4	[9]
Ratio average values of time over wage (percent)			35-84	50-60	[6]
Hourly values of time (thousands rupiah)	Low-skilled		1.6-2.1	2.2	[1]
	Middle-skilled		3.9-7.1	6.1	
	High-skilled		12.4-22.6	20.9	

Source:
[1] CMEA and JICA (2012)
[2] Bappenas and JICA (2004)
[3] CMEA and JICA (2012)
[4] MT and JICA (2012)
[5]Oum et al. (1992)
[6] Small and Verhoef (2007)
[7] Nowak and Savage (2013)
[8] GIZ (2013)
[9] Dwiyono (1997)

In the transport supply sector, the first target is the calibration of the modal split for each skill group as well as that for the total. As shown in Table 2.2, there is a positive income elasticity for the auto user, yet a negative income elasticity for the motorcycle and the bus demands. On the transport supplies side, I start from assuming the travel time per km function, in order to follow Spiess' (1990) conical travel time function of $g'_{kc} = g'_{0kc}\left(2 + \sqrt{(\alpha_2)^2\left(1 - \frac{\tilde{F}^z_k}{\alpha_3 K_k}\right)^2 + (\alpha_4)^2} + \alpha_2\left(1 - \frac{\tilde{F}^z_k}{\alpha_3 K_k}\right) - \alpha_4\right)$. Spiess (1990) argued that, for simulation purposes, this function is more efficient than the BPR-type function. Furthermore, conical function requires only one parameter to be calibrated, i.e. α_2, to obtain the whole function's expression. The performance is quite close to that of the BPR function if α_4 of BPR function is relatively low[7]. This function helps my calibration because there are limited parameters of travel time function available. To calibrate α_2, the value of the most recent average speed of the JMA is used. I adjust the average speed of 23.4 kph in the JMA in 2010, as reported by the JUTPI study, and prefer to have the average speed set in the range of $15 - 20$ kph. The purpose is to accommodate the fact that most trips in our model are commuting trips, which are essentially conducted during the morning and the evening peaks. Parameter g_{0ic}, which indicates the free flow travel time and varies across modes and zones, is adapted from the Indonesian Highway Capacity Manual (Ministry of Public Works, 1993). Capacity parameters, α_{2i}, are calibrated such that the V/C ratio, $\frac{F_i}{\alpha_{2i} K_i}$, meets the target. These numbers are carefully drawn from the V/C ratios of the JMA in 2011, as shown in Figure 1.1. In 2011, almost all of the road links in both the CBD and the SBD exceeded their capacity with a V/C ratio

[7] If the BPR function is defined as $g_{ic} = g_{0ic}(1 + \alpha_1(\frac{\tilde{F}_i}{\alpha_{2i} K_i})^{\alpha_3}$, then α_4 in the conical function corresponds to α_4 in the BPR function. A performance comparison between both functions is available in Appendix.

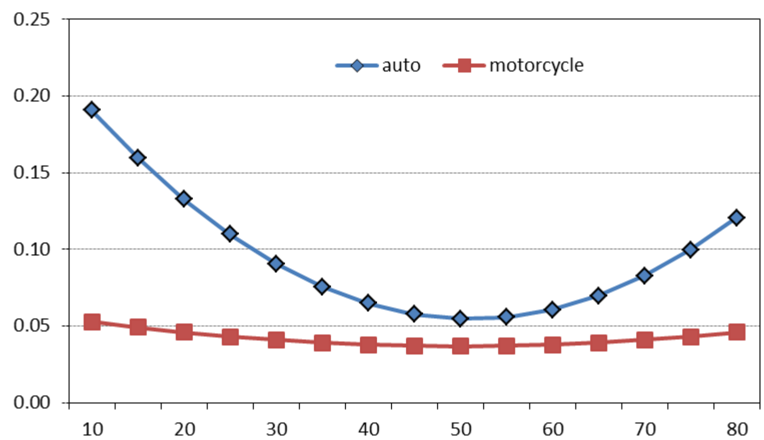
of more than 1.5. I set the target for the V/C ratio of both zones within the range of $1.5 - 1.6$. Meanwhile, since some suburban road links exhibit a high V/C ratio (>1.0), although most of them are less than 1.0, I set the suburban V/C ratio target within the range of $0.8 - 0.9$. I adapt the number from Eliasson and Mattsson (2001) for the bus constant access time. Lastly, gasoline consumption per km for cars and motorcycles is adapted from the SITRAMP. For simplicity, bus fare is charged to fully cover the bus' gasoline consumption. Reported by GIZ (2013), the values of the gasoline price vary from 4.5 to 7 thousand rupiah, depending on the type[8]; the model is calibrated so that the price is close to the lower-bound, as almost all road users use the unsubsidized gasoline.

Gasoline consumption for each type of private modes is obtained from the SITRAMP, and assumed to follow the quadratic function. Figure 2.3 shows that, in general, the gasoline consumption function of the car is always higher and more sensitive toward changes in the travel speed than that of the motorcycle. Minimum gasoline consumption for both private modes lies within the 50-55 km/h range. Before this range, more severe congestion requires more gasoline consumption per km, while beyond that level, a faster speed consumes more gasoline per km. Since the current average travel speed is 23.6 km/h, according to the JUTPI study, any improvement in the congestion level will yield the two benefits of faster travel time and lower gasoline consumption costs.

Endogenous PCU functions are adapted from Arasan and Arkatkar (2011) and assumed to follow a quadratic polynomial function. Figure 2.4 presents the functions for the car, the motorcycle, and the public bus. The constant value in the bus' PCU function is adjusted so that it has a similar number to that in the JUTPI study. Essentially, the JUTPI study reported three different PCU values that vary across bus

[8]In general, Indonesia's gasoline pricing consists of two different products: subsidized (premium) gasoline, which is cheaper, and unsubsidized (pertamax plus) gasoline.

Figure 2.3: Gasoline Consumption (lt/km) as Function of Travel Speed (kph)



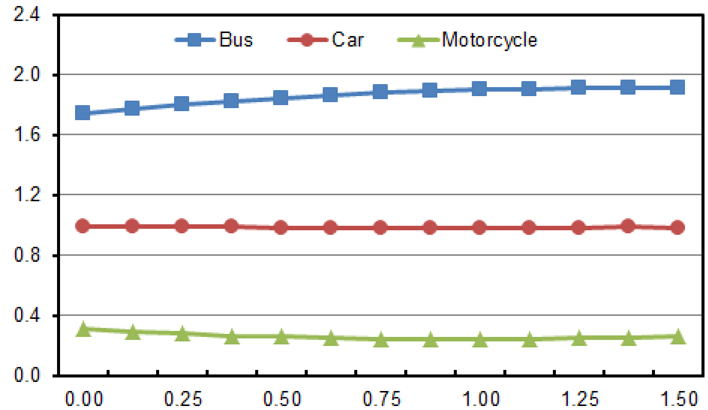
sizes. Thus, by using the average ridership under no-toll equilibrium as the reference, I pick the weighted average as the number.

Calibration for the cost of the bus discomfort function starts with setting the average ridership, $\bar{\iota} = 25.2$, and the constant, $\bar{\psi} = 0.025$, such that the calibration target in the modal split is met. The remaining parameter is ϕ. I also adapt the results from Haywood and Koning (2013), who estimated the crowding cost of the public train in Paris. The variable that I use to measure the crowding is passenger density (pass/m^2). In their study, Haywood and Koning (2013) proposed that $\phi = 0.11$.

2.4 Results of a Status-Quo City

Aside from the calibration results presented in the previous section, Table 2.3 summarizes the other results of a status-quo city, including the land rent, the wages, and the residential or employment density. Land rent in the CBD is significantly higher than those of the others, followed by that of the SBD and that of the suburban zones, respectively due to high marginal productivity. The CBD land rent is about

Figure 2.4: PCU Values of Each Mode as a Function of the V/C Ratio



Note: The X- and Y-axes indicate the values of the V/C ratio and the values of the PCU of each mode, respectively.

three times of the SBD rent and more than four times of the suburban rents. Wage rate is set through the production technology function so that the higher skilled group will enjoy a higher wage rate. For the wage rate across zones, there is no strict calibration target that needs to be met. Therefore, the result is sufficient as long as the wage does not significantly differ across zones and the CBD wage rate is higher than those of the others. Since a restriction in shopping trips results in less of a demand for suburban production, the wage level in the suburbs becomes the lowest among those of the others.

The aforementioned result of residential density implies that there is quite a fair split between the residents of Jakarta and those of the suburban areas. 48 percent of total residents live in Jakarta, 4.6 percent of them live in the CBD, and the rest are in the suburban zones. The employment pattern is rather concentrated in Jakarta, with 75 percent of the total workers. Jobs are greatly concentrated in the CBD, as reflected in its density, with 37.7 thousand workers per km2, which is equal to 20.5

Table 2.3: Results of A Benchmark City

	CBD (zone 1)	SBD (zone 2-4)	Suburban (zone 5-10)
Land rent (thousands Rupiah/m-sq/yr)	234.2	115.7	64.5
Wage rate (thousands Rupiah/month)			
Low-skill		650.0	
Middle-skill		1769.9	
High-skill		5983.8	
Average annual gross income (millions Rupiah)			
Low-skill		32.5	
Middle-skill		45.6	
High-skill		95.9	
Residential density (thousands/km-sq)	8.7	6.4	2.0
	4.7	**41.8**	**53.5**
Employment density (thousands/km-sq)	37.3	8.4	1.0
	20.3	**54.8**	**24.9**

Note: numbers in bold indicate percent residents/workers in respective zones.

percent of the total workers. Employment opportunity in the SBD is the largest in terms of the total shares, with 55.0 percent of the total workers employed.

2.5 The Sensitivity Analysis of Endogenous PCU, Inelastic Bus Capacity, and Crowding Cost of Public Bus

How do all three assumptions, i.e. an endogenous PCU, an inelastic bus capacity, and the crowding cost of the public bus, alter the simulation results? I compare the performance of the private CBD cordon toll three times such that in each simulation, one of these three assumptions is relaxed. Table 2.4 reports the simulation results of the private CBD cordon toll under various cases: in each of these cases, one of the three assumptions is relaxed. The results are then compared to those of the base case in which all assumptions are held. The magnitude is robust for other toll scenarios; for reporting purposes, only that of the private CBD cordon toll is presented.

Among three cases, assuming that the exogenous PCU and the elastic bus supply give lower results than those of the base case. In the case of the exogenous PCU, any change in the congestion level will not change the values of the PCU, while the

Table 2.4: Simulation result from relaxing some assumptions

	exogenous PCU	elastic bus supply	no crowding cost	all assumptions hold
Average daily travel time saving (minutes)	6.7	7.6	9.1	8.7
JMA congestion level (percent change)	-4.1	-4.6	-5.3	-5.1
Modal split (percent change)				
Car	-1.3	-1.3	-1.3	-1.2
Motorcycle	-0.9	-1.1	-1.1	-1.0
Public bus	2.2	2.4	2.4	2.2
CBD route avoidance (percent change)[1]	-11.2	-10.8	-10.9	-10.9
Average bus ridership (workers)	27.3	25.2	27.5	27.3
Annual EV per capita (thousand rupiah)2	171.4	202.9	243.3	225.7
	75.9	**89.9**	**107.8**	**100.0**

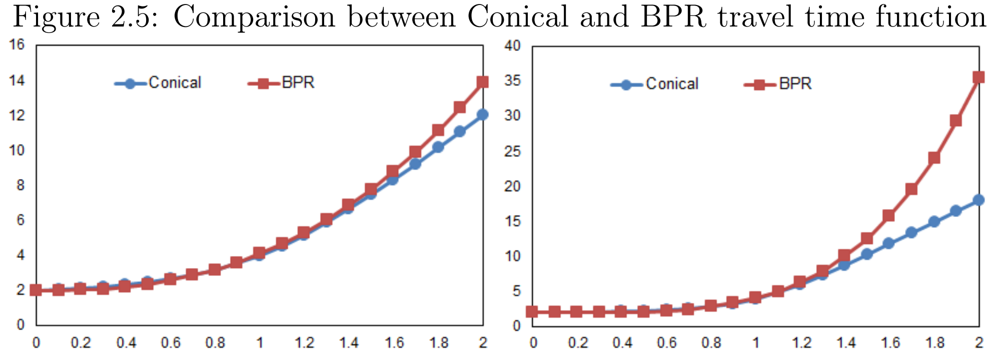
[1]Numbers in the CBD route avoidance are obtained from changes in the number of trips that traverse any route involving the CBD route, excluding those from or to the CBD.
[2]Numbers in bold indicate the percentages of the benefits w.r.t. the benefits under all assumptions held.

endogenous PCU, together with the average congestion level that is greater than one, implies that the decreasing congestion level will reduce the PCU of the private car and the public bus (see Figure 2.4). As a result, the exogenous PCU assumption reduces less congestion, provides less average daily travel time saving (ADTS) and annual EV per capita. The ADTS and the EV of the exogenous PCU are 75.9 and 75.3 percent of those in the case with full assumptions. Similarly, the elastic bus capacity supply means that an additional bus user will demand further use of the public bus to keep the ridership as constant. Because the bus uses the same network as the other road users, it also contributes to the congestion level as a whole, although it does this in a lesser degree than the car or the motorcycle. The ADTS and the benefits of relaxing this assumption are 89.8 and 88.9 percent of those in the case with full assumptions. Overlooking the assumption of the crowding cost of the public bus has the opposite effects because it invites more bus users. There will be an additional 0.2 percent of bus users if the crowding cost is zero. It will lead to greater congestion reduction, ADTS, ridership, and EV.

Appendix: A Comparison Between Conical and BPR Travel Time Function

Conical travel time function was first introduced by Spiess (1990). Its advantage over the usual BPR function lies in the fact that only one parameter needs to be estimated (calibrated), and therefore, the use of this function eases our calibration under limited real parameters. Despite its simplicity, the conical travel time function yields results that are close to those of the BPR function under a low value of α_4. Conversely, both functions will significantly differ from one another under a high value of α_4 and if $\frac{F}{\alpha_3 K} >> 1$. The BPR function severely punishes the over-congested link because α_4 enters the function as a power. Figure 2.5 illustrates the comparison of the two functions. The figures assume that the free flow is 50 kph, the link distance is 100 km, and $\alpha_3 = 1.05$ for the BPR function. Left and right figures are when $\alpha_4 = 2.5$ and $\alpha_4 = 4$, respectively. Under a low value of α_4, the difference is relatively small even after the V/C ratio reaches 2. The difference is about 1.9 hours or 14.5 percent of the average time. The gap is significantly wider for higher values of α_4. In such a case, the gap is 26.8 hours or 65.7 percent of the average time.

Figure 2.5: Comparison between Conical and BPR travel time function



Note: Figures on the left and the right correspond to $\alpha_4 = 2.5$ and $\alpha_4 = 4$, respectively. The X- and Y-axes represent the V/C ratio and the travel time in hours, respectively.

Chapter 3

Welfare Improvement of The Cordon Toll Policy

3.1 Introduction

This chapter focuses on assessing the welfare impacts of several possible cordon-pricing strategies on economic welfare. In particular, it examines the welfare gains and the magnitude of several possible types of cordon pricing in their improvement of economic welfare, as well as people's responses toward these tolls. Mun et al. (2003) defined cordon tolling as that which charges all road users a fixed toll whenever they pass the boundary of the designated area that is usually the central area of a city in which traffic is usually most congested. The cordon toll is a second-best road toll because it does not completely internalize all the congestion; rather, it focuses on reducing the congestion level of the cordoned area. In the real world, implementation of the cordon tolls or its variants can be found in several of the cities of developed countries, such as Singapore, London, and Stockholm. Thus, there are a handful of studies that have analyzed the performance of these policies. Santos and Verhoef

(2011) summarized four examples of congestion pricing practices, i.e. the United States (US), Singapore, London, and Stockholm cases. Meanwhile, there is a scarcity of studies on road pricing policies that use features of the typical cities of developing countries, most likely due to the lack of real world cases and available data. By using most of the features and parameters of the JMA, this study is perhaps one of the pioneering studies that have attempted to understand the impacts of road tolls on welfare from the point of view of a city of a developing country.

Whilst studies on the second-best road toll have been conducted for a couple of decades, perhaps since the work of Kraus (1989), researches on cordon pricing have just emerged recently following the development of the cordon practice in the real world (e.g. in Singapore and Oslo). Eliasson and Mattsson (2001) simulated the effects of the ring toll on the modal split and the location choice of households, workplaces, and shops. They calibrated the model by using the parameters of Swedish cities. Research by Mun et al. (2003) can be attributed as the first theoretical study that focused mainly on cordon pricing and its significant improvement of economic welfare. It pinned down the theoretical analysis of cordon pricing under a monocentric city with an exogenous and elastic trip demand. Verhoef (2005) extended the model by endogenizing the trip demand through a labor supply mechanism. Both studies suggested a surprisingly high performance from the cordon-pricing scheme; welfare gain under cordon pricing is about 90 percent of the first-best toll. However, both studies further argued that the gain may not be that high under a multicentric city structure. An exception is found in the study of Lara et al. (2013), who developed a monocentric model based on the work of Fujita (1989), and used the Paris region as the calibration target to explore the impact of the various forms of congestion pricing, one of which is the cordon toll, on welfare, urban form, transport volume, and emission and energy consumption. They found a relatively lower welfare gain from the cordon toll compared to the results of Mun et al. and Verhoef. It amounts to approximately 63 percent of the first-best toll. In addition, the gain is also lower than that under an optimal flat toll.

It has been shown that relaxing a monocentric city into a multicentric city assumption may reduce the efficiency of the cordon toll. Mun et al. (2005) showed that the multicentric city assumption cuts the efficiency of the cordon-pricing scheme, under the assumptions of a steep density gradient, an inelastic trip demand, and a larger road capacity. Fujishima (2011) investigated the welfare effects of the cordon-pricing scheme under a multicentric city by endogenizing the land for road allocation and allowing employment and population to diversify across locations. Using the spatial general equilibrium framework of Anas and Xu (1999), and setting the city of Osaka as the calibration target, he found that cordon pricing achieves about half of the efficiency gains of the first-best policy[1]. He also compared the performance of cordon charges to that of the London-type area pricing, and concluded that cordon pricing has an advantage when the city has many long-distance commuters; the area pricing is better if congestion is mainly caused by the residents of the central urban area. This result naturally comes from the urban structure of Osaka city, which consists of the CBD between two suburban areas. Anas and Hiramatsu (2013) developed a spatial computable general equilibrium for the Chicago MSA and simulated a $5 USD toll under several cordon ring scenarios. There are three cordon rings considered: the CBD, the city, and the city and the inner-suburbs cordon. They concluded that the CBD cordon increases the compensating variation (CV), while the other two cordon schemes provides the negative CV. However, by adding the other components of welfare, i.e. the toll revenue and the changes in real estate income, the city cordon obtains the highest welfare. Welfare gain per capita accounts for 52 percent of the $5 USD tolling of all major roads.

[1] Fujishima (2011)defines the first best policy as an optimal road tax under an optimal road investment

To analyze the welfare effects of the cordon toll on the JMA, I build a SGE model that follows some of the regularities in Anas' studies. However, our model differs from those of other similar studies, particularly in the transportation sector, through the following ways. First, the economy has three types of transport modes, i.e. the auto, the motorcycle, and the public bus, which generate more heterogeneous traffic flow. This extension is important in the sense that most studies have focused on autos as a sole private mode and railways as the alternative public transit (see Anas and Liu (2007); Fujishima (2011); Anas and Hiramatsu (2013)), and have assumed the PCU as constant. This assumption is close to the reality of most cases of cities in the developed countries whose modal splits are highly dominated by cars or railways. U.S. Census Bureau (2009); U.S. Census Bureau (2010) reported the recent survey on mode shares in the U.S. and revealed that the public transport mode shares and the walking shares account for approximately 5 and 3 percent on average, respectively, while the rest are car users. These figures are completely different from those in the case of Indonesia. Excluding non-motorized modes, the modal split is dominated by motorcycles (53 percent), followed by public transport (27 percent) and cars (20 percent), all of which use road links, since public transport mostly consists of buses (JUTPI, 2010). (Arasan and Arkatkar, 2011) argued that PCU can be endogenous as a function of the congestion level, particularly under the case of heterogeneous traffic flow. Second, I assume that the public bus capacity is constant to the extent that an additional bus user will not increase the number of public buses in operation, but rather raise the number of the average ridership. This assumption is usually not explicitly explained or modeled in other studies. It may not be problematic if the alternative public transport uses different lines than the other modes. Nonetheless, a failure to assume the state of the public bus supply would undermine the results. Last, the crowding disutility of the public bus is explicitly modeled as a function of the average ridership of the bus. Li and Hensher (2011)summarized all of the studies that estimated the crowding disutility of public transport (i.e. metro and rail) and found that the cost can be quite sizable. All extensions are developed under a constant land use distribution among the consumers, the producers, and the road networks, along with an inelastic home-to-work choice. These vectors are endogenous under no-toll equilibrium, yet exogenous under post-toll equilibrium. This setup allows us to set behavioral changes in the transport sector as the dominant source of welfare gain. Anas and Hiramatsu (2013) showed that an elastic housing demand and labor supply blunt the toll's impacts. These extensions will be our main contributions to the current literature on the welfare analysis of second-best road tolls.

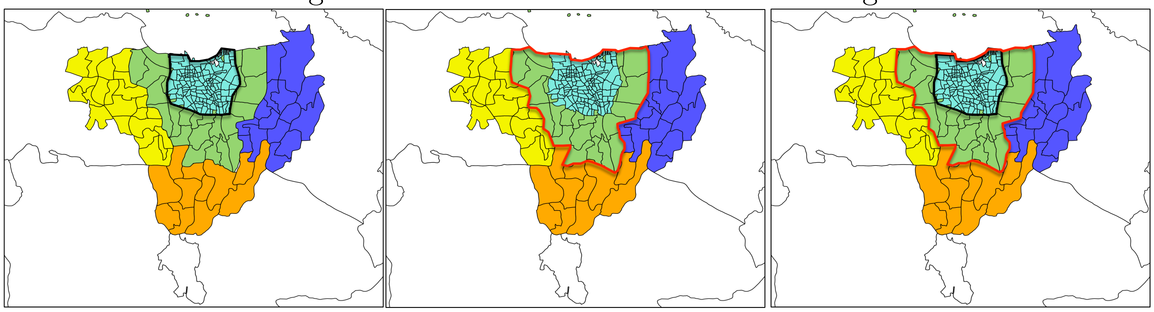
This chapter is organized as follows. Section 3.2 explains all considered cordon toll scenarios and how the JMA workers may respond. Section 3.3 presents the results of the transport behavior, the congestion reduction, and the welfare gain. It also examines the welfare distribution effects with respect to the workers' group, the residential zone, and the working zone. Section 3.4 provides the sensitivity analysis of three aspects: the crowding cost of the public bus, the discount for the CBD residents, and the iso-benefit curve. Section 3.5 concludes.

3.2 Toll Scenarios and Behavioral Adjustments

3.2.1 Toll scenarios

Three types of policy scenarios are considered. The first policy scenario is the CBD cordon toll that levies all targeted modes traversing the CBD zone. The second scenario is the SBD cordon that charges all private modes passing the SBD ring. It rules out all suburb-to-suburb trips that do not traverse the SBD, as well as all interzonal trips within the SBD, including the SBD-to-CBD trips. The last scenario is the two-tier SBD and CBD cordon toll. It is similar to the SBD cordon except

Figure 3.1: Three Scenarios of Cordon Ring



Note: Figures in order from left to right represent CBD, SBD, and SBD+CBD cordon schemes respectively. Positions of the ring are shown in black or/and red line. Light blue and green zone represents CBD and SBD zones respectively while others are for suburban zones.

that there is an additional toll for entering the CBD. Hence, the toll level differs if the private mode trips that originate from the suburbs traverse the SBD or the CBD. All scenarios are also evaluated under two options: charging all private modes (cars and motorcycles) or cars only. Figure 3.1 and Table 3.1 summarize the toll rings and charges for each scenario. The black ring represents only the cordon charges for entering the CBD (Zone 1). The red ring surrounds all three zones in the SBD so that all interzonal SBD trips involving the suburban zones are charged.

The toll level for each scenario is 15 thousand rupiah (1.5 USD) and 5 thousand rupiah (0.5 USD[2]) per passing for private cars and motorcycles, respectively, unless mentioned as otherwise. These numbers are drawn exogenously based on a simulation by the JETRO. In the case of the SBD+CBD cordon toll, there is an additional 0.5 USD (0.25 resp.) for the SBD-CBD trips. Hence, it differs from the SBD toll as the SBD toll charges nothing for such trips. Under three different cordon ring scenarios, the SBD+CBD cordon toll is expected to generate the highest benefit, followed by the SBD and the CBD cordon tolls, as this scenario expectedly captures more trips to be charged. These three scenarios are also evaluated under two cases: charging all private modes (cars and motorcycles) or cars only. Thus, the private (or the car)

[2]The exchange rate is simplified into 10 thousand rupiah per USD.

Table 3.1: Summary of the Toll Levels of Each Cordon Scenario

	Cordon tolls					
	CBD		SBD		SBD+CBD	
	private	car	private	car	private	car
Toll per crossing (thousand rupiah)						
Suburban trips bound for CBD						
Car	15	15	15	15	20	20
Motorcycle	5	-	5	-	7.5	-
Bus	-	-	-	-	-	-
Suburban trips bound for SBD						
Car	-	-	15	15	15	15
Motorcycle	-	-	5	-	5	-
Bus	-	-	-	-	-	-
SBD trips bound for CBD						
Car	15	15	-	-	5	5
Motorcycle	5	-	-	-	2.5	-
Bus	-	-	-	-	-	-

Note: Figures in order from left to right represent the CBD, the SBD, and the SBD+CBD cordon schemes, respectively. Positions of the rings are shown in black and/or red lines. Light blue and green zones represent the CBD and the SBD zones, respectively, while others are the suburban zones.

CBD cordon corresponds to the CBD cordon that charges both car and motorcycle (or car) users for traversing the CBD.

Benefit calculation is the most difficult part because there is no correct approach. Kanemoto (2011) showed that the correct way is to calculate the logsum difference in utility as evaluated by the marginal utility. In our case, it is calculated as $\triangle B^f = \frac{1}{\Omega^f}\left\{\frac{1}{\lambda_1}\ln\left(\sum_{j'\in\mathbf{J_f}}\exp(\lambda_1 \beth_{j'}^{f,1})\right) - \frac{1}{\lambda_1}\ln\left(\sum_{j'\in\mathbf{J_f}}\exp(\lambda_1 \beth_{j'}^{f,0})\right)\right\}$, where Ω^f is the marginal utility of income (MUI) for f-class workers, while 0 and 1 indicate the values before and after the policy. However, the equation requires constant MUI (Small and Rosen, 1981), while this dissertation employs the Cobb-Douglas function, which leads the MUI to differ across $i-j$ commuting arrangements and workers as well. Therefore, the several attempts that have been performed in other similar studies are undertaken to overcome this shortcoming. In addition to the EV and CV measurements, Anas and Rhee (2006) calculated the weighted average of the MUI across $i-j$, combined with the cases before and after the policy to obtain the consumer surplus. Fujishima (2011)followed Morisugi and Ohno (1995) by extracting the EV from the logsum of the lower nest. Similarly to Fujishima, Anas and Hiramatsu (2013) extracted the CV between the unemployed and the employed groups. Tscharaktschiew and Hirte (2010a,b) compared several attributes including the CV and the toll revenue to compare the advantages of a certain policy with those of others. In this study, I use the EV measurement because it is more relevant for conducting comparisons among a variety of road toll scenarios. The EV approach is more appropriate for this purpose because it controls the vector of prices, i.e. the status-quo prices (Varian (1992)). The EV is calculated such that $EV_{ij}^f = E_{ij}^f(\tilde{V}^1, \tilde{\mathbf{p}}^0, R^0, e^0) - E_{ij}^f(\tilde{V}^0, \tilde{\mathbf{p}}^0, R^0, e^0)$, where is E an expenditure function of indirect systematic utility, $\tilde{V}$, delivered price vector, land rent, and leisure. Superscripts 1 and 0 indicate the values after and before the toll, respectively. Given the indirect utility maximization setup in the short-run environment, the expenditure function is obtained by

$$\tilde{E}^{SR} = \exp\left[\frac{1}{\delta_1}\left\{\tilde{V} + \frac{\delta_1(\delta_3 - 1)}{\delta_3}\ln\left[\sum^{l}\left(\tilde{p}_l^{SR}\right)^{\frac{\delta_3}{\delta_3 - 1}}\right] - \theta_i - \delta_2 \ln \overline{h} - \delta_4 \ln(e)\right\}\right]$$

Thus, for a particular road toll, EV_{ij}^f is calculated as

$$EV_{ij}^f = \exp\left[\frac{1}{\delta_1}\left\{\tilde{V}_{ij}^{f,1} + \frac{\delta_1(\delta_3 - 1)}{\delta_3}\ln\left[\sum^{l}\left(\tilde{p}_{ijl}^{f,SR,0}\right)^{\frac{\delta_3}{\delta_3 - 1}}\right] - \theta_i - \delta_2 \ln \overline{h}_{ij}^f - \delta_4 \ln\left(e_{ij}^{f,0}\right)\right\}\right] - \exp\left[\frac{1}{\delta_1}\left\{\tilde{V}_{ij}^{f,0} + \frac{\delta_1(\delta_3 - 1)}{\delta_3}\ln\left[\sum^{l}\left(\tilde{p}_{ijl}^{f,SR,0}\right)^{\frac{\delta_3}{\delta_3 - 1}}\right] - \theta_i - \delta_2 \ln \overline{h}_{ij}^f - \delta_4 \ln\left(e_{ij}^{f,0}\right)\right\}\right] \tag{3.1}$$

with the average EV as $\overline{EV} = \frac{\sum N^f \sum \Lambda_{ij}^f EV_{ij}^f}{N}$.

In addition to the CV, a benefit measurement based on the MTTS is calculated. Since the values of time vary across regimes and workers' types, the average benefit is defined by $\overline{B} = \frac{1}{N}\overset{f}{\sum} N^f \left(\tilde{T}_0^f \overline{\rho}_0^f - \tilde{T}_1^f \overline{\rho}_1^f\right)$, where subscripts 1 and 0 indicate the values under toll and no-toll equilibriums, respectively. is the daily average travel time (DATT) including both the commuting and the shopping times, which is calculated by $\frac{\sum_f N^f \sum_{ij} \Lambda_{ij}^f (\tilde{T}_{ij}^{f,com} + D^{-1} \tilde{T}_{ij}^{f,sh})}{\sum_f N^f}$. Similarly, $\overline{\rho}^f$ is the average values of time with respect to the skill levels; it is obtained by $\overline{\rho}^f = \sum_i \sum_j \Lambda_{ij}^f \rho_{ij}^f$. It has an advantage over the EV calculation because it correctly measures the benefit from travel time saving. However, it does not count the benefit from altering the bundle of final goods consumption as well as the impacts of toll-revenue cycling. Therefore, this measurement serves a comparative purpose for the EV results.

3.2.2 Behavioral adjustments under the cordon toll

How does the cordon toll benefit the workers? Because the cordon toll mainly aims to control the traffic congestion level in the cordoned area, the benefit strongly depends on the extent to which the congestion level in that area can be lessened. Anas and Hiramatsu (2013) explained all of the possible margins of adjustments that the workers can implement to avoid paying the toll, which in turn reduce the congestion level and improve the welfare. However, because our model works under a short-run equilibrium, not all of those aspects are relevant for explaining the source of the workers' welfare gain. Workers whose commuting patterns entail traversing the cordoned area cannot switch their trips to work with others that allow them to pay less or fully exempt them from the toll. Similarly, workers cannot adjust their land size consumption despite the changeability of their disposable income. All margins of adjustments are concentrated on the final goods consumption and the transport behavior.

The first source of welfare improvement possibly comes from the final goods consumption. For a worker residing in the cordoned area, the delivered price for the goods produced outside of the cordon area will be relatively higher than before, which will induce them to consume more of the goods that are produced inside the cordoned zone. The magnitude could be higher for the lower skilled group, as it is more sensitive to the changes of monetary cost than to the changes of travel time cost. In contrast, a worker who resides outside of the cordon could substitute the consumption of goods produced in the cordoned zone with that of the goods produced outside of the ring. The fixed home-to-work arrangement and land allocation, together with the exogenous daily working time, mean that the economy produces a fixed amount of final goods in each zone regardless of the toll level and the regime. Therefore, the total number of shopping trips toward the cordoned area may not vary significantly; it may even remain constant.

The second source, which is perhaps the main source of welfare improvement, is the transport behavior. For all interzonal commuters from/to the cordoned area, switching to an uncharged mode will be more favorable. In the case of tolling all private modes, for example, switching to the public bus will be more attractive; the magnitude could also be higher for the workers with low values of time and high MUI. In addition, the presence of the crowding cost in the public bus due to the additional bus users and the fixed bus capacity deters the workers that have a high value of time from using the bus, as the greater the crowds and the longer the travel time in the bus, the higher the crowding cost becomes. Thus, although the private CBD generates the benefit of a lessened congestion level, it forms at the same time the crowding cost by increasing the average ridership of the public bus. As a comparison, the car cordon toll favors the use of the motorcycle over that of the public bus because the motorcycle runs faster than the bus. It leads to a lower number of additional bus users than that in the private CBD cordon, and at the same time yields a lower additional crowding cost.

Workers whose commuting or shopping trips are not from/to the cordoned area but traverse the cordoned area can opt to circumnavigate the cordoned area. Under the CBD cordon cases, the alternative route that circumvents the CBD is uncharged but takes a longer time to traverse, and thus, workers with a low value of time benefit from this more. If the toll is relatively low, the alternative route is less attractive for the workers with a high value of time because the cordon toll also reduces the travel time inside the CBD.

3.3 Simulation Results

3.3.1 Welfare effects

3.3.1.1 Aggregate effects

Table 3.2 reports the simulation results for all respective scenarios. The private CBD cordon toll that levies all private mode users traversing the CBD zone can save 8.7 minutes of daily travel time, which are equal to 5.8 percent of the daily travel time under no-toll equilibrium. It arises from 5.1 percent of the congestion reduction that is concentrated in the CBD zone. The toll drives 2.2 percent of the trips, particularly those that traverse the CBD, to switch to the public bus, which increases the average ridership to as much as 2.1 passengers. In addition, 10.9 percent of the trips traversing the CBD that have an alternative route prefer to circumnavigate the CBD despite the longer distance required. The results in the CBD shopping trips as well as other zones' shopping trips indicate that there is no change in the pattern of such trips. Workers adjust the quantities of the final goods bundle in a respective zone in response to the changes in the consumer delivered price in such a way that the shopping trips needed are constant. These adjustments bring the benefit values to as much as 225.7 thousand rupiah (22.6 USD) per annum on average or the equivalent of 0.48 percent of the average annual income. Gross benefit per annum per capita in the form of MTTS is 281.9 thousand rupiah. The benefit is more for the higher skilled group because of their higher value of time. As a comparison, Anas and Hiramatsu (2013) reported a benefit per annum per capita of 362 USD from a 5 USD CBD cordon toll in the Chicago MSA, which is 0.83 percent of the baseline average annual income.

Interesting results arise from the car-based cordon tolling. Surprisingly, it performs almost as equally well as, or even better than, the private-based tolling. Under the CBD cordon, the car-based toll generates a 13-percent higher travel time saving than the tolling of both private modes. It produces a 0.2-percent higher congestion reduction and yields 259 thousand rupiah of the annual welfare per capita, which is 15 percent higher than that under the private CBD cordon toll. Similar results apply for the SBD+CBD cordon. An opposite result happens for the SBD cordon case, which reports a slightly weaker result with the car-based toll. Nevertheless, it does not rule out the fact that the performance of the car cordon toll remains high. As pointed out by Anas and Hiramatsu (2013), because the simulation results simultaneously depend on many factors (the distribution of each income group, the ability to avoid the cordon toll, the size of the cordoned area, etc.), such a difference in magnitude may occur. Some mechanisms can be traced, for example, under a smaller cordon in the CBD cordon; car-based tolling reduces more congestion in the SBD than that under the private-based toll because of the effects of route avoidance. The private CBD cordon generates stronger CBD-route avoidance by circumnavigating the CBD zone than that under the car-based toll. As a result, the former provides additional traffic flow in the SBD that negates the congestion reduction due to the smaller number of private mode trips, particularly from the low-skilled group with a low value of time. Meanwhile, the wider cordon encircles the SBD zone through which most of the trips traverse. The private toll thus further reduces congestion because it charges more trips than those charged by the car-based toll. However, the indisputable factor of the high performance of car-based cordon tolling is the characteristic that is inherent in the motorcycle and the public bus. Recall that, since the free flow travel speed of the motorcycle is faster than that of the public bus, any improvement in the congestion will widen the speed gap between both modes. In addition, the public bus has the additional access times and the crowding disutility, while the monetary travel cost between both of the modes does not differ significantly. Therefore, if riding the car becomes more expensive, ceteris paribus, people will not switch to the public bus, but to the motorcycle instead. The car-based cordon tolling will also result in a further decline of car use and yield a relatively high congestion reduction compared to the private-based cordon tolling.

The shift in the modal split during the last decade can partly reflect the mechanism of car cordon tolling. During the last decade, the modal split has dramatically changed from public transport-based trips to private mode-based trips (see Figure 1.2), which are dominated by motorcycle trips. As reported by Dinas Perhubungan Pemda DKI Jakarta (2007), motorcycle ownership climbed dramatically by 7.9 percent per annum on average during 1999-2004, which demonstrates the rapid change in the JMA's modal split during the past decade. While car and motorcycle ownerships have been further facilitated through credit expansion, the quality of the public bus has been unimproved, or rather, it has even deteriorated (JAPTraPIS, 2012), which has led to a greater use of private modes. Because the credit system is more expensive for

Table 3.2: Simulation Results for Transport Behavior and Annual Benefits

	Cordon tolls					
	CBD		SBD		SBD+CBD	
	private	car	private	car	private	car
Average daily travel time saving (minutes)[1]	8.7	9.8	12.6	12.3	13.5	13.5
	5.8	**6.5**	**8.3**	**8.2**	**8.9**	**9.0**
JMA congestion level (percent change)	-5.1	-5.3	-7.0	-6.5	-7.7	-7.2
CBD	-20.8	-18.0	-5.9	-5.5	-9.3	-8.2
SBD	-4.4	-5.0	-7.1	-6.5	-7.6	-7.1
Suburban	-1.7	-1.4	-6.8	-6.7	-7.0	-6.7
Modal split (percent change)						
Car	-1.2	-1.9	-1.2	-2.0	-1.3	-2.3
Motorcycle	-1.0	1.3	-1.3	1.4	-1.7	1.6
Public bus	2.2	0.6	2.5	0.6	3.0	0.7
CBD route avoidance (percent change)[2]	-10.9	0.5	-1.4	-1.0	-4.7	-0.8
Average bus ridership (workers)	27.3	25.8	27.6	25.8	28.1	25.9
Shopping trips to CBD (percent change)	0.0	0.0	0.0	0.0	0.0	0.0
Annual EV per capita (′000 Rp)[3]	225.7	259.2	329.6	325.0	351.7	355.9
	0.48	**0.55**	**0.70**	**0.69**	**0.75**	**0.76**
Annual monetary value of travel time saving (′000 Rp)	281.9	316.9	409.8	396.4	437.2	433.2

[1]Numbers in bold indicate the percentages of time saving w.r.t. the DATT under no-toll equilibrium.
[2]Numbers for the CBD route avoidance are obtained from changes in the number of trips that traverse any route involving the CBD route, excluding those from or to the CBD.
[3]Numbers in bold indicate the percentages of the benefits w.r.t. the average annual nominal income.

the car than for the motorcycle, there is more pressure to substitute the car with the motorcycle.

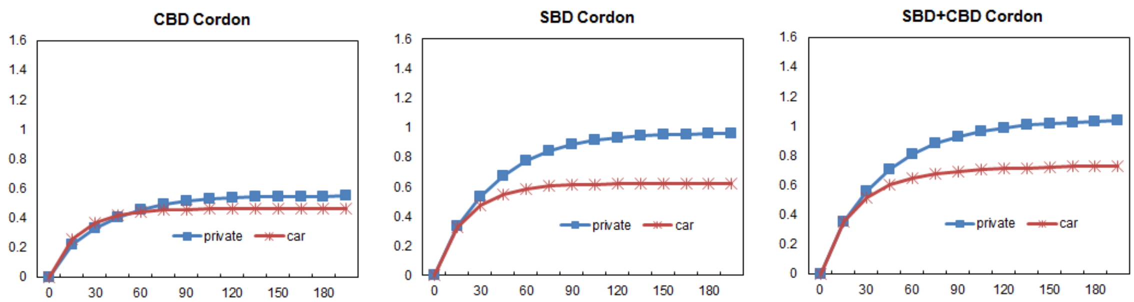
Despite its high performance under the base toll level parameter, the car-based cordon tolling is less performed if the toll level is relatively high. Figure 3.2 juxtaposes the welfare gain for all scenarios with respect to the toll level. Toll for the motorcycle of the private cordon cases is always one-third of the car toll in order to keep the ratio similar to the scenario in the Table 3.1. There are several points that can be drawn from these results. First, all schemes show a sharp increase with the toll, yet at a decreasing speed, and reach almost a zero additional benefit after the toll level reach 150 thousand rupiah (15 USD). At this level , the gain from each scenario is about 546 and 446 (54.6 and 44.6 USD) thousand rupiah for the private and car CBD cordon respectively, and even higher than the SBD or SBD+CBD cordon charges.

Second, the welfare gap between private and car cordon is wider with the toll. The private CBD cordon starts to give higher benefit than the car based cordon after the toll reaches 60 thousand rupiah. Tolling both car and motorcycle and users under fix bus supply and endogenous PCU enable the transport network to reduce much more congestion due to increasing bus ridership and lower pcu for the car and public bus.

Despite its high performance under the base-toll level parameter, the car-based cordon tolling has a lower performance if the toll level is relatively high. Figure 3.2 juxtaposes the welfare gain for all scenarios with respect to the toll level. The motorcycle toll in the private cordon cases is always one-third of the car toll so that the ratio is kept as similar to the scenario in Table 3.1. There are several points that can be drawn from these results. First, all schemes show a sharp increase with the toll, yet at a decreasing speed; then they all yield almost zero additional benefit after the toll level reaches 150 thousand rupiah (15 USD). At this level, the gain from each scenario is about 546 and 446 (54.6 and 44.6 USD) thousand rupiah for the private- and the car-based CBD cordon tolls, respectively, which are even higher than the SBD or the SBD+CBD cordon charges. Second, the welfare gap between the private and the car cordons is wider with the toll. The private-based CBD cordon starts to produce higher benefits than the car-based cordon after the toll reaches 60 thousand rupiah. Tolling both car and motorcycle users under a fixed bus supply and endogeneity enables the transport network to reduce much more congestion, due to the increasing bus ridership and the lower PCU of the car and the public bus.

Unsurprisingly, for the same toll level, a wider cordon under the private SBD and the step-tolling SBD+CBD cordon increases the improvement of more travel time saving. In comparison, the CBD cordon covers an area that is less than one-tenth of that in the SBD and the SBD+CBD cordon. Although the wider rings capture more interzonal trips to be charged, they partially or fully leave more interzonal trips in

Figure 3.2: Sensitivity Analysis of the Annual Welfare Gain with respect to the Toll Level



Note: The X-axis indicates the toll level for private cars, measured in thousand rupiah. The toll level for motorcycles under the private CBD cordon scenario is always maintained as one-third of the toll for cars. The Y-axis measures the average benefit in million rupiah.

the cordoned zones uncharged. In the case of the SBD+CBD cordon, the SBD-CBD interzonal trips are charged much less than those under the CBD cordon, despite the latter's levy of additional charges for entering the CBD. Travel time saving is improved by 30-50 percent of the CBD cordon due to the 1.5-2.1 percent of additional congestion level reduction as a result of the switch of more private mode users to the use of the public bus. This reduction spreads more evenly in all zones rather than remaining concentrated in the CBD, like the reduction from the CBD cordon. Thus, the benefits in the form of the EV and the MTTS are 60-70 and 45-55 percent higher than those of the CBD cordon case.

3.3.1.2 Distribution effects

Aside from examining the extent of the gain from cordon tolls, it is also interesting to examine how welfare gain is distributed among the groups. Table 3.3 presents the information on the welfare distribution among the workers and the regions. As pointed out by Tscharaktschiew and Hirte (2012), benefit distribution may incite particular support for or objections against a specific transportation policy. The results exhibit quite differentiated patterns; nonetheless, they are at least unambiguous. If the avoidance of a road toll is facilitated for a respective party in ways that are greater than those for the other parties, that respective party will obtain a higher welfare gain than the average population.

In terms of the distribution effects with respect to the residential zone, two factors determine the magnitude of the distribution effects: the location of the cordon ring and the charged modes. Under the private cordon toll, the smaller ring, as in the CBD cordon, provides a loss for the residents living inside the cordon than for the rest of the residents. As the smaller cordon does not give the CBD residents enough room for adjustments compared to the other residents, the CBD residents relatively receive more of the toll burden than the benefit of travel time saving that is concentrated in the CBD. The magnitude is higher for the interzonal commuters because almost all of their trips, except for the intrazonal shopping trips, are subject to the toll. Analogously, the wider ring under the SBD and the SBD+CBD cordons provides fewer benefits to the suburban residents, particularly the intrazonal commuters and those who conduct the interzonal SBD and CBD shopping trips. Meanwhile, this is not the case for the car-based cordon. The smaller (or wider) cordons do not significantly harm the CBD (or the suburban) residents (respectively). The car-based CBD cordon allows the CBD residents to enjoy more than the average amount of benefits. The lack of charges for the motorcycle provides more than enough room for the CBD residents to avoid the toll for those groups.

In terms of the distribution effects across the working zone, the trend remains for the smaller ring. The private CBD cordon also charges the CBD workers, particularly the interzonal commuters. This is natural because they are one of the main targets of

Table 3.3: Distribution effects of welfare gain (in thousand rupiah)

	Cordon toll scenarios					
	CBD		SBD		SBD+CBD	
	private	car	private	car	private	car
Average gain	225.7	259.2	329.6	325.0	351.7	355.9
Residential zone						
CBD	-2.9	281.2	436.3	206.5	244.3	200.3
SBD	232.2	341.7	598.5	352.6	631.2	397.6
Suburban	240.8	192.7	109.9	313.9	142.6	337.0
Working zone						
CBD	-131.7	353.8	291.1	320.1	278.5	375.5
SBD	363.4	327.9	333.5	386.6	359.0	423.2
Suburban	213.4	30.7	352.3	193.4	395.3	191.7
Worker						
Low-skilled	97.0	84.8	130.5	101.1	142.5	111.3
Middle-skilled	208.3	242.2	308.7	308.8	328.7	337.3
High-skilled	680.4	840.2	1000.8	1041.6	1062.3	1143.1

the CBD congestion eradication policy. Uncharged motorcycles provide more room for adjustments, and allow those groups to receive a much better gain than they would receive under the private cordon case. In contrast, suburban workers receive a better gain under the car-based cordon for wider cordon cases. However, this result arises possibly because of the effects of the transfer. Those workers are mostly living in the suburban zones, and conduct commuting trips that are fully exempted from the toll. The lump-sum transfer that partly originates from the toll revenue enables those workers to receive a positive net transfer; the number is also higher for the private cordon toll, which results in the accruement of higher benefits under the private cordon toll.

Among the three groups of workers, the low-skilled (or the middle- and the high-skilled) workers are always better off under the private (or the car) cordon toll. One possible reason lies in the opposing effect between the benefit of travel time saving and the income effect of the travel cost revenue transfer. Naturally, both factors positively affect the welfare gain. While the former's effect is relatively clear, the income effect of the transfer depends on its source. Car-based toll will always generate less money than the private toll; it will even cause negative changes to the income on average. The low-skilled group is the most burdened because of the least amount of switching from car use. In addition to the low value of time, this group enjoys a lower benefit under the car cordon than it would under the private cordon. Similar reasoning also works for the middle-skilled group. Meanwhile, the high-skilled group enjoys a higher benefit from the car-based cordon tolling. Aside from the transfer, this result is due to the lower crowding cost produced by the car-based cordon tolling than that is caused by the private-based cordon tolling.

3.3.2 Car use contribution in CBD

I am further interested in analyzing the modal choice behavior of the residents living in the cordoned area. Because the cordoned zones experience significantly lower congestion, car use in the intrazonal cordoned zones is left unchanged or may be even higher, as car users therein do not have to pay the toll to enjoy less congested roads. Table 3.4 presents the contributions of the car use and the modal split in the CBD. The first row of Table 3.4 presents the share of car use for each scenario, while the following rows reveal the percentages of contributions of the car use to the CBD based on the origins. For instance, 19.8 percent of the car trips to the CBD under the status quo are mostly from the SBD (11.6 percent). Significant car trips are driven out under the CBD cordon tolls, as expected: 8.6 and 11.2 percent under the private-based and the car-based CBD cordon tolls, respectively. Most of them originate from the SBD, relative to the others. My focus is on the $0.04 - 0.05$-percent increase in the intrazonal CBD car trips under the CBD cordon, which supports our hypothesis. Moreover, the last part of Table 3.4 shows that there is an increase in private car use in the modal split of the interzonal CBD trips, which is mostly caused by the motorcycle users. This

Table 3.4: Contributions of the Car Use and the Modal Split in the CBD

	no-toll	Cordon tolls (percent change)					
		CBD		SBD		SBD+CBD	
		private	car	private	car	private	car
Contribution of car use							
CBD	19.8	-5.5	-7.7	-1.5	-2.4	-1.6	-3.0
CBD	1.9	0.08	0.07	0.02	0.02	0.03	0.03
SBD	11.6	-3.6	-5.0	0.4	0.4	0.1	-0.3
Suburban	6.3	-1.9	-2.7	-2.0	-2.8	-1.8	-2.8
Modal split for intrazonal CBD trips							
Car	26.5	1.2	0.9	0.3	0.2	0.5	0.4
Motorcycle	47.2	-0.7	-0.6	-0.1	-0.2	-0.2	-0.2
Bus	26.4	-0.5	-0.4	-0.2	-0.1	-0.2	-0.1

is mostly due to the fact that all components of the generalized travel cost are negative functions of the congestion level in the respective zones. For the intrazonal CBD trips, the generalized cost consists of the travel time cost and the gasoline/bus fare. Since there is no alternative route, $\Upsilon^f_{11c} = -C^f_{11c1} = -\left[\rho^f_{1j}\left(\tilde{F}_1\right) g_{11c}\left(\tilde{F}_1\right) + \varrho_{11c}\left(\tilde{F}_1\right)\right]$ and $\frac{\partial \Upsilon^f_{11c}}{\partial \tilde{F}_1} = -\left[\frac{\partial \varrho_{11c}}{\partial \tilde{F}_1} + g_{11c}\frac{\partial \rho^f_{1j}}{\partial \tilde{F}_1} + \rho^f_{1j}\frac{\partial g_{11c}}{\partial \tilde{F}_1}\right] < 0$. Thus,

$$\frac{\partial \Phi_1}{\partial \tilde{F}_1} = -\lambda_3 \kappa \Phi_1^2 \left[\left(C_2' - C_1'\right) \exp\left\{\lambda_3\left(C_2 - C_1\right)\right\} + \left(C_3' - C_1'\right) \exp\left\{\lambda_3\left(C_3 - C_1\right)\right\}\right] > 0$$

, where $C_2' - C_1'$ and $C_3' - C_1'$ are less than zero. This is true because an improvement of the congestion level gives more benefit to car users in the forms of more efficient gas consumption and faster travel speed.

3.4 Sensitivity Analysis

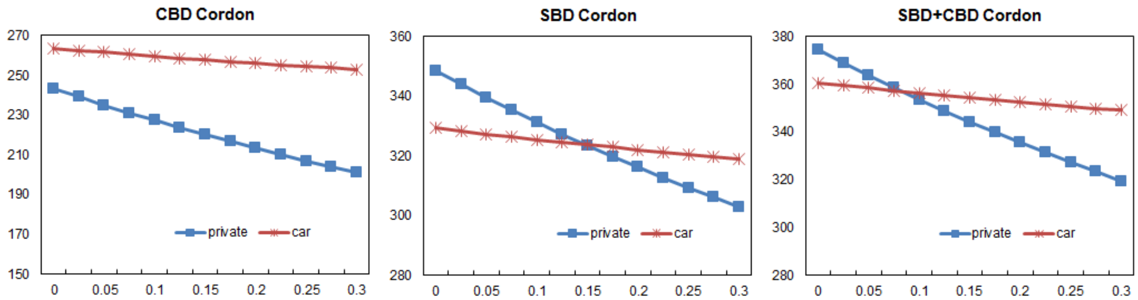
The following section presents the sensitivity analysis of three aspects: the crowding cost of the public bus, the discount for the CBD residents, and the iso-benefit curve. Except for the sensitivity with respect to the crowding cost of the public bus, the analysis will focus on the CBD cordon since it is the most plausible scenario. Other scenarios are undertaken to be used as counterfactual cases in comparative exercises.

In reality, the SBD and the SBD+CBD cases are less discussed due to the unrealistic and extremely high administration costs. For cordon level sensitivity, welfare improvement is calculated for each level of the toll level range. The cordon toll discount is meant for certain CBD residents as a response to their worst-off welfare. The iso-benefit analysis with respect to the car and the motorcycle tolls is undertaken to examine the level of substitutability between both of the toll levels.

3.4.1 The crowding cost of the public bus and the welfare gain

I evaluate the effects of the crowding cost of the public bus on welfare gain to see how changes in the parameter of disutility, ϕ, can improve or undermine the welfare. I expect a negative relationship between ϕ and the welfare gain because the disutility enters the utility function to reduce the hours of leisure. Figure 3.3 presents the sensitivity analysis of all three ring scenarios with respect to ϕ . In our previous simulations, $\phi = 0.11$, based on the work of Haywood and Koning (2013). The annual benefit decreases along with the higher disutility parameter, while the magnitude is higher for the private cordon toll. Increasing ϕ from 0 to 0.3 reduces 13-17 and 3-4 percent of the welfare of no crowding cost effect, and the numbers are higher for the wealthier group who has a higher value of time. The private cordon toll provides more discounts, since this type of toll promotes more public bus use than the car cordon toll, and hence, it creates a higher bus ridership and crowding cost. If the public bus is not convenient enough, the private cordon toll can lose the welfare advantage, as shown under the SBD cordon. The private SBD cordon provides less benefit than the car-based SBD cordon, once $\phi > 0.17$. Similarly, the private SBD+CBD cordon can provide more benefit than the car-based SBD+CBD cordon, if there is an improvement in the public bus such that $\phi < 0.08$.

Figure 3.3: Sensitivity Analysis of the Private and the Car Cordon Tolls with respect to the Crowding Parameter ϕ



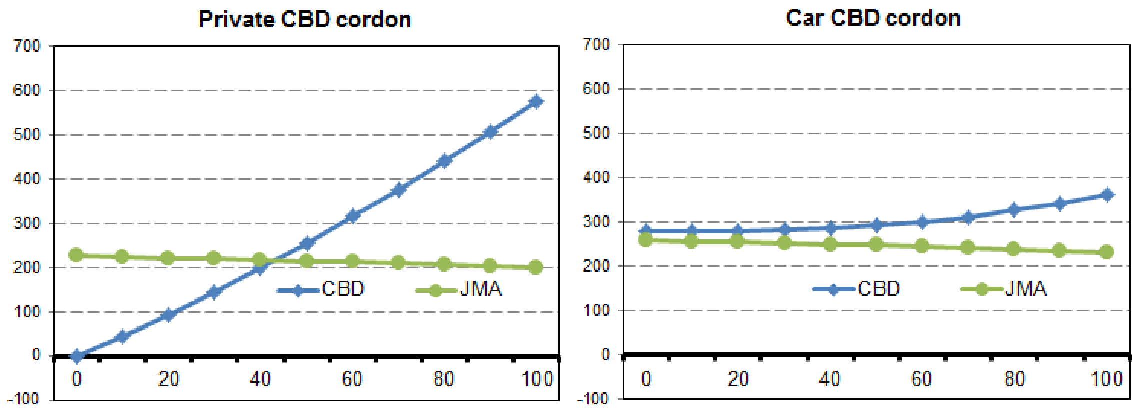
Note: X-axis indicates the values of ϕ. The toll level for the motorcycle under the private CBD cordon scenario is always maintained as one-third of the toll for the car. The Y-axis measures the average welfare gain in million rupiah.

3.4.2 Toll discount and welfare gain

Under the worst-off result, a strong resistance may emerge from the CBD residents. A survey conducted by the JETRO (2008) revealed that 50 percent of the total respondents who live inside the cordon ring oppose the cordon toll implementation plan that would subject their trips to the toll. One possible way to prevent such a resistance is by offering a substantial amount of toll discount for the CBD residents. This scheme is similar to the type of road toll implemented in London called the Area Pricing, in which any trips within a designated area, mostly the CBD, pay a certain amount of toll regardless of their origins. However, the discounted CBD cordon toll is different in that the intrazonal CBD trips are fully exempted. Simulation results are presented in Figure 3.4.

I plot the annual benefit per capita received on average by the JMA residents as well as the CBD residents as a function of the percentages of the discount for the CBD residents in Figure 3.4. The sensitivity analysis exhibits a trade-off between

Figure 3.4: Impacts of the Toll Discount for the CBD residents on the Annual Benefit (in thousand rupiah)



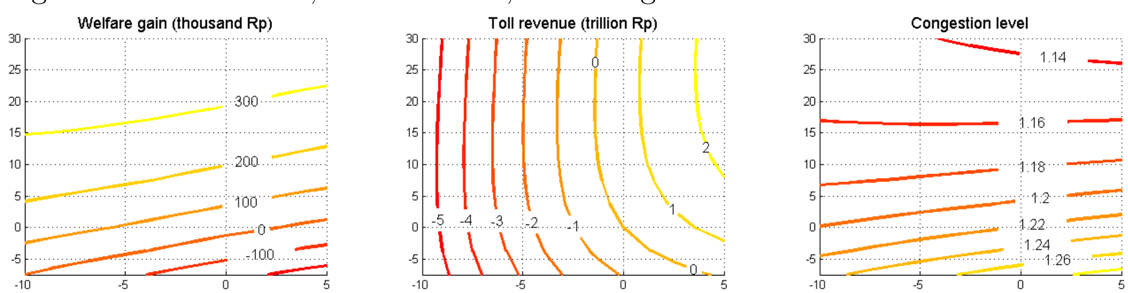
Note: The X-axis represents the percentages of the discount. The Y-axis represents the annual gain (thousand rupiah) for the JMA residents on average and the CBD residents.

the average annual benefit per capita and the CBD residents' gain. A zero discount means the CBD residents fully pay the toll for interzonal trips, which yields a -3 and 300 thousand rupiah benefit for the CBD residents under the private and the car CBD cordon tolls, respectively. While the CBD residents are worst off under the private-based CBD cordon, the car-based CBD cordon rather allows the residents to enjoy a quite sizable benefit that is even higher than that of the JMA residents on average. The numbers increase at the cost of the average benefit as more discounts are introduced. Under the extreme case, a 100-percent discount, which exempts the CBD residents from paying the toll regardless of their transport modes or the type of their trips, offers the CBD residents 200 and 231 thousand rupiah under both scenarios, respectively, by sacrificing approximately 11 percent of the benefits under the no-discount cases.

Another interesting result comes from the trajectory of the welfare gain distribution for both of the CBD tolls with respect to the discount. The CBD welfare distribution accelerates faster under the private CBD cordon than under the car CBD cordon as the discount increases. In the private CBD cordon, any level of discount applies for both auto and motorcycle users, while the car CBD cordon offers the discount for auto users only, as motorcycle users are already fully exempted from the toll. The discount in the private CBD cordon works for a wider range of road user targets than the discount in the car CBD cordon, which results in a more progressive improvement of the shares of the CBD residents' gain.

3.4.3 Iso-benefit under the CBD cordon

Figure 3.5: Iso-Benefit, Toll Revenue, and Congestion Level under the CBD Cordon



Note: For all subfigures, the X- and the Y-axes represent the charges (thousand rupiah) for the motorcycle and the passenger car, respectively.

I simulate the CBD cordon toll scenario under various charges on the private modes to obtain the level of benefit in any combination of charges. The idea is to draw iso-benefit curves that will demonstrate any combination of private car and motorcycle charges that yield the same level of benefit. The simulation results are shown in Figure 3.5. To validate these figures, recall that the private (or the car) CBD cordon generates 225.7 (or 259.2) thousand rupiah of welfare gain. Therefore, an iso-benefit curve connects the private CBD cordon and the car CBD cordon with lower charges. A lower charge for the passenger car will provide the same level as the base-level case unless accompanied by a subsidy on a motorcycle, which will maintain the generalized travel cost gap between both of the modes. Under the base case of the private CBD cordon, the benefit is also equal to the full exemption of the private car and the subsidy of 10 thousand rupiah for the motorcycle. However, such a practice may not be acceptable considering the fast growing trend of motorcycle ownership.

In addition to the issue of motorcycle growth, the subsidization of private modes inevitably burdens the local government's budget. The middle panel of Figure 3.5 presents the annual toll revenue surplus or deficit for each combination of the private car and the motorcycle charges. Any combination of the subsidies located in the bottom left will lead to the toll revenue deficit, while the private and the car CBD cordon tolls of our base scenarios are expected to generate 2.3 and 0.6 billion rupiah annually. The curve itself moves from the bottom left to the top right as a result of the higher cordon charges for both modes, which contrasts with the iso-benefit curve that moves from the bottom right to the top left. Based on these curves, it appears that aiming for a higher benefit can possibly burden the government's budget. Taking into account such a burden, a pricing scheme that solely optimizes welfare gain may not be the best solution for the economy.

At a low level of the charges, the iso-benefit curve exhibits a positive elastic relationship with the motorcycle charges. A positive and elastic slope demonstrates that tolling the motorcycle is unfavorable and has less of an impact than tolling the private car. Because the private car has the highest PCU, reducing one car in the CBD road network lessens the congestion more than the reduction of one motorcycle. The distance between the curves becomes wider as the benefit increases due to the decreasing effect of an additional toll. As presented in Appendix, this is also true for the middle-skilled and the high-skilled groups.

AA more complicated result arises from the low-skilled group since it exhibits two different phases. The first phase lies in the low-level region of the private car toll combined with any level of the motorcycle charges. This phase is similar to that of the other groups and the general results that favor the use of the motorcycle. As the charge for the private car (or the motorcycle) is set between the ranges of 15-30 (or 0-5) thousand rupiah, the curve shows a negative slope for the 100-thousand rupiah welfare gain. In this range, for a given level of the car toll, the ADTS (or the income effect) is lower (or higher) as the toll for the motorcycle gets higher (or lower). It also works for the other groups. However, since the value of time (VOT) for this group is low, the combination of both effects generates a downward-sloping iso-benefit curve. Meanwhile, the other groups have a higher VOT, and therefore, the shape of the iso-benefit curves closely resembles that of the DATT curves.

3.5 Remarks

This chapter evaluates the performance of the CBD cordon toll scenario as proposed by the JETRO. The toll level is 15 and 5 thousand rupiah per crossing for the passenger car and the motorcycle, respectively. Under an environment with constant land size allocation and a fixed home-to-work arrangement, the CBD cordon provides a result that is not always promising in every aspect. The CBD cordon provides a reasonably fair benefit that is relative to its coverage zone. The result is also not disappointing if compared to that of the wider cordon toll; the benefit of the CBD cordon is about half of that of the SBD cordon on average, while the CBD cordon covers significantly less than half of what the SBD zone covers.

The presence of an alternative mode such as the motorcycle, which is faster and slightly more expensive than the public bus, enables the workers to obtain higher travel time saving and benefits under the car cordon. The relatively higher welfare gain of the car cordon with fewer complications during application may tempt the local authority to apply the car cordon. However, the result in the modal split also suggests that, instead of controlling the use of private modes, the car cordon promotes a higher use of motorcycles and a lower increase of public bus use when compared with the private cordon. It implies that the tolling of motorcycles should be accompanied by higher tolls for the car.

The CBD cordon unfortunately has a major disadvantage in the area of welfare distribution. My simulation shows that the private CBD cordon scheme worsens the welfare of the CBD workers and residents. While the welfare loss is, in some extent, permissible for the CBD workers, it may be less tolerable for the CBD residents. Hence, designing a CBD cordon with discounts for the CBD residents may increase their acceptance of the CBD cordon. A 40-percent discount would give the CBD residents the same level of welfare gain as the JMA residents on average.

Appendix: Detailed results for each group of workers

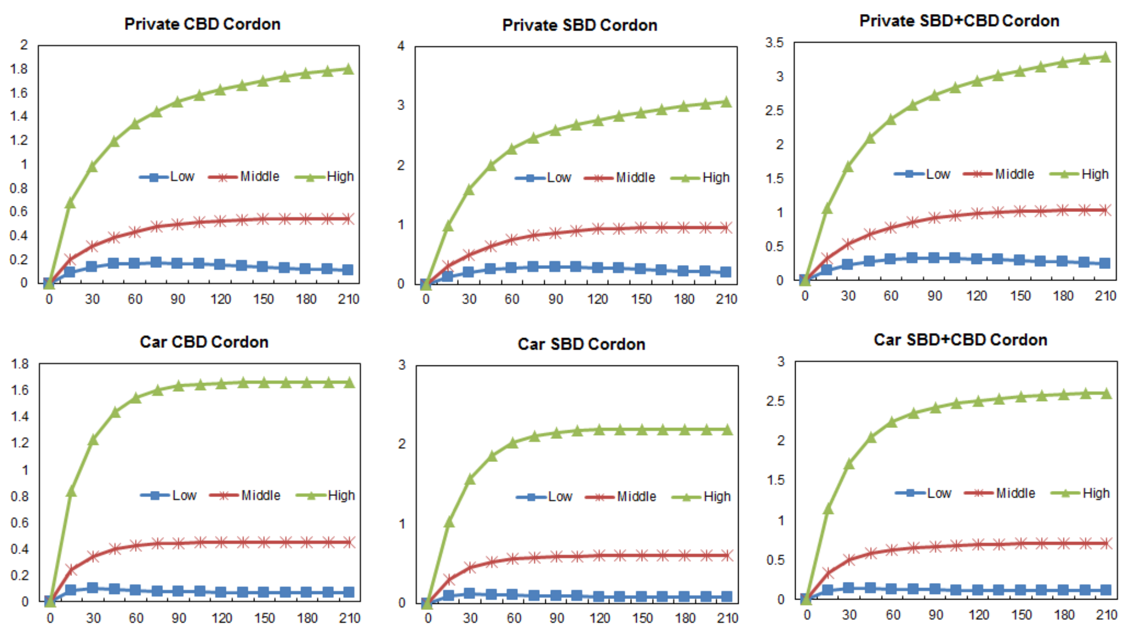
Changes in the Annual Gross Income and Travel Time

	Cordon tolls					
	CBD		SBD		SBD+CBD	
	private	car	private	car	private	car
Annual gross income (percentages of change)						
Average	0.09	-0.01	0.08	-0.01	0.09	-0.02
low-skilled	0.15	-0.04	0.12	-0.07	0.15	-0.07
middle-skilled	0.10	-0.01	0.09	-0.01	0.10	-0.01
high-skilled	0.03	0.02	0.01	0.03	0.01	0.02
Daily travel time (percentages of change)						
low-skilled	5.8	6.7	8.4	8.4	9.0	9.3
middle-skilled	5.7	6.5	8.3	8.1	8.9	8.9
high-skilled	6.0	6.3	8.4	7.8	9.1	8.5

Modal split

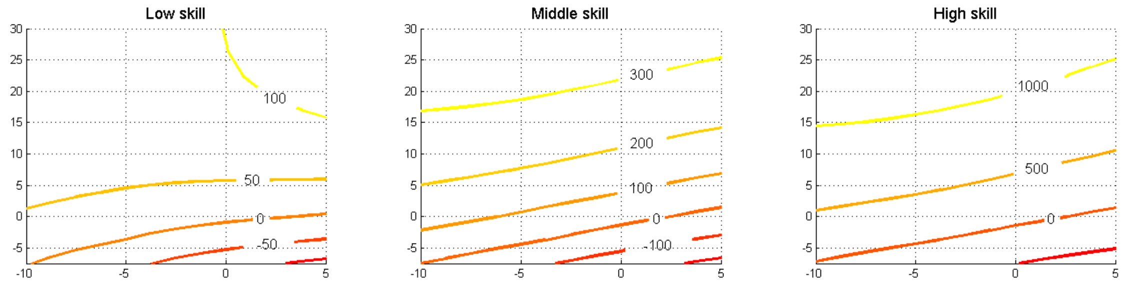
	no-toll	Cordon tolls (percentages of change)					
		CBD		SBD		SBD+CBD	
		private	car	private	car	private	car
Low-skilled							
Car	8.2	-0.5	-0.8	-0.4	-0.7	-0.5	-0.9
Motorcycle	56.6	-1.8	0.6	-2.2	0.6	-2.7	0.7
Public bus	35.2	2.3	0.2	2.6	0.1	3.2	0.2
Middle-skilled							
Car	22.7	-1.4	-2.1	-1.3	-2.2	-1.4	-2.5
Motorcycle	51.7	-0.9	1.4	-1.3	1.4	-1.7	1.6
Public bus	25.6	2.3	0.8	2.6	0.8	3.1	0.9
High-skilled							
Car	36.4	-2.5	-4.0	-2.7	-4.5	-2.9	-5.1
Motorcycle	52.2	0.8	3.0	0.9	3.5	0.8	3.9
Public bus	11.4	1.7	1.0	1.8	1.0	2.1	1.2

Sensitivity analysis of welfare gain for all cordon scenarios across worker



Note: The X-axis and the Y-axis represent the toll levels and the annual net benefits, respectively, the latter of which are measured in million rupiah.

Breakdown of the Iso-benefit Curve



For all subfigures, the X- and the Y-axes represent the charges (thousand rupiah) for the private car and the motorcycle, respectively

Chapter 4

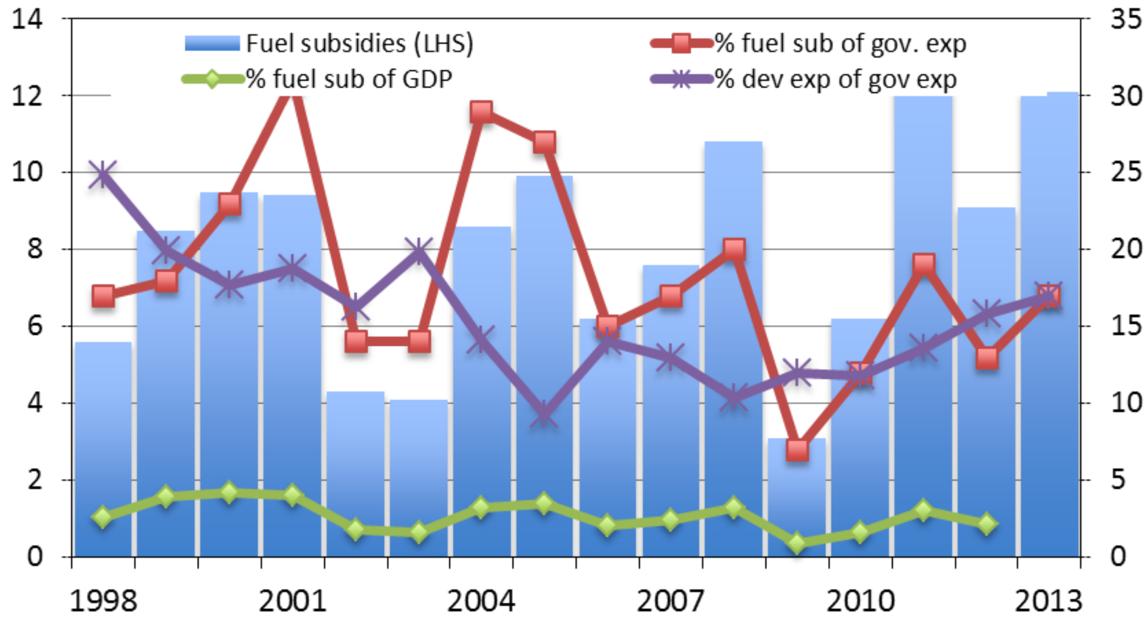
Gasoline Tax vs Cordon Toll

4.1 Introduction

Indonesia has established itself as one of the emerging countries that significantly intervenes in its domestic fuel prices through the fuel subsidy policy. GIZ (2013) categorized Indonesia as a high fuel-subsidized country, which is indicated by the low level of its fuel prices compared to those of the world market. Although several deliberalization policies have been implemented to lower the burden by increasing the fuel prices, particularly during the last decade, the subsidy remains high due to the declining trend in oil lifting and the increasing trend in fuel consumption. Dartanto (2013) documented the Indonesian fuel subsidy during the period of 1998 to 2013 and showed an increasing trend from 5.6 to 12.1 billion USD under the constant price of 2005. As shown in Figure 4.1, in terms of the total government expenditure, the subsidy costs 18.3 percent on average or 2.7 percent of the Indonesian GDP on average. As a comparison, Baig et al. (2007) reported that, in 2005, fuel subsidies, as percentages of the GDP, cost 5.8 percent in Jordan, 9.2 percent in Yemen, 13.9 percent in Azerbaijan, and 4.1 percent in Egypt. Such heavy subsidies hence limit the fiscal room for development and investment expenditures. Development expenditures account for 15.5 percent of the total government expenditure, which is lower than the fuel subsidy. In addition, the fuel subsidy is not regarded as a pro-poor policy, as non-poor households enjoy most of the fuel subsidy. Dartanto argued that, in 2008, more than 41 percent of the gasoline and diesel subsidies went to the highest income group. Hence, there is pressure on the central government to reallocate the fuel subsidy in such a way that a more appropriate allocation is created.

Responding to the need to reallocate the fuel subsidy for other beneficial expenditures, several studies have attempted to quantify the impact of the fuel subsidy reduction and its reallocation in the Indonesian economy. Hartono and Resosudarmo (2008)simulated the impacts of controlling energy consumption, including reducing the fuel subsidy, on the Indonesian economy by using the Indonesian Energy Social Accounting Matrix. They found that a general policy mix between an energy reduction subsidy and an improvement of energy efficiency provides the best outcome. Agustina et al. (2008)simulated the impacts of the oil price rise on Indonesia's public finance in 2008 and estimated the subsidized fuel product elasticity with respect to the price. Their results vary from $(-0.13)-(-0.78)$depending on the products (gasoline, diesel, or kerosene). Dartanto (2013) micro-simulated the impacts of the fuel subsidy reduction on the national fiscal balance and poverty. His main assumption is to reallocate some or all fuel subsidies to government spending, the transfers to households, and other subsidies. Based on his use of the computable general equilibrium model, one of his results suggests that reallocating 25 percent of the fuel

Figure 4.1: Trends in the Fuel Subsidies of Indonesia



Note: Fuel subsidies are measured in billion USD under the constant price of 2005. Except for the fuel subsidies, all measures are shown in the Y-axis on the right-hand side.

Sources: Dartanto (2013), World Bank database

subsidies to government spending reduces the poverty incidence by 0.27 percent. All of these reallocation-impact studies on the Indonesian fuel subsidy policy mostly work with macro policies (except Dartanto's study, which links to the impacts on poverty reduction) and do not address the impacts on the particular issue of the Indonesian transportation sector. Meanwhile, quite a large body of literature has examined the impacts of increasing the gasoline price on transportation behavior.

The initial studies have significantly focused on the price elasticity of demand; the first of these was conducted in 1974, as surveyed by Graham and Glaister (2002). For example, Wheaton, as reported by Anas and Hiramatsu (2012) estimated the effects of the gas price on the gasoline consumption, the miles driven, and the miles per gallon. Meanwhile, by using the second Regional Economy, Land Use, and Transportation

(RELU-TRAN2) SGE model, Anas and Hiramatsu (2012) simulated the response of the economy of the Chicago MSA to a gas price increase to calculate several numbers of the elasticity of private car use w.r.t. the gas price under several equilibrium states. In parallel with those on the price elasticity of demand, there has also been growing literature on the cross-price elasticity between gasoline prices and transit ridership. Nowak and Savage (2013) provided a survey in the case of the US. In more recent years, the empirical studies have broadened to other aspects of transport behaviors, including the effect on traffic levels (Goodwin (1992)), speeding behavior (Wolff (2014)), and traffic safety (Chi et al. (2013)).

Aside from those on the impacts on travel behavior, there has also been growing literature on the welfare effects of gasoline tax. Parry and Small (2005) eestimated the optimal gas tax for the cases of the US and the United Kingdom (UK), respectively. They found that the optimal gas tax is 1.01 USD/gallon for the US under the base price of 2000, or more than twice of the US gasoline tax at that time. On the contrary, the optimal tax for the UK is 1.34 USD/gallon or less than half of the UK gasoline tax. These taxes were estimated to generate welfare improvement for as much as 7.4 and 22.7 percent of the average pre-tax expenditure for the US and the UK, respectively. Applying the same methodology of Parry and Small, **?**estimated the optimal gas tax for Mexico. They found that the optimal tax is 1.92 USD/gallon at 2011 prices and that the relative tax incidence as a percentage of the expenditure is progressive. The welfare improvement is approximately 15.1 percent of the pre-tax expenditure. Tscharaktschiew (2014) proposed a 0.96 euro/l gasoline tax for Germany, or a level that is 48 percent higher than the current level (0.64 euro/l).

Under a different approach, Tscharaktschiew and Hirte (2010a) applied a SGE analysis to compare the effectiveness of the carbon tax (due to gasoline consumption) and the road toll on congestion and CO_2 emission. Since both aspects generate negative externalities toward the city, applying either the carbon tax or the road toll will simultaneously lower the congestion and the emissions levels. A pure Pigouvian type of CO_2 charge will lower 1-11 percent of CO_2 emission. Combining that charge with a congestion toll will further decrease the emissions to 19-21 percent. However, a more ambitious CO_2 reduction campaign may result in welfare losses.

This chapter thus aims to answer the following questions: first, under the era of the deregulation of gasoline prices in Indonesia, how can escalating fuel prices help to reduce the road congestion in the JMA? Second, compared to the ERP plan in Jakarta, how well would the fuel subsidy reduction policy perform? In light of these questions, this paper will contribute to the literature gap twofold. First, in terms of the Indonesian studies, this paper is the first to examine the effects of the gasoline price on the transportation sector of particular Indonesian urbanized areas, i.e. the JMA. It therefore contributes to the debate on the benefits of reallocating the Indonesia fuel subsidy, in which the benefits from easing the congestion level in major urbanized areas in Indonesia are unaccounted for in most cases. Second, in the urban transport economics literature, this paper will enrich the SGE studies by analyzing such an impact under the case of a developing country's urban areas, which behave significantly different from the other cities in the developed countries. Current research has been geared more towards the cities in the developed countries, such as Germany (Tscharaktschiew and Hirte (2010a,b, 2012)) or the United States (Anas and Liu (2007); Anas and Hiramatsu (2012, 2013)). Meanwhile, transportation behavior in the cities of the developing countries, like the JMA, often involves heterogeneous traffic flow, which means that assuming exogenous PCU values may not be relevant for such a case. In addition, the public bus service is limited in that it has a constant capacity supply. Therefore, additional bus passengers will increase the ridership and add to the crowding cost of the public bus. Lastly, in the JMA, the motorcycle is an alternative private mode, aside from the passenger car. As we will see later, the presence of the motorcycle reduces the attractiveness of public bus use under the higher gas price increase, at least for the higher income group. Unless further incentives for public bus use are introduced in the form of gas subsidies, all types of workers will prefer to use the private modes to the public bus.

The remainder of this chapter is organized as follows. Section 4.2 and 4.3 present the scenarios and the simulation results respectively. The sensitivity analysis is provided in the Section 4.4. Section 4.5 concludes.

4.2 The scenarios

To evaluate the economic benefits of gasoline tax, I consider three types of policy scenarios. The first policy is concentrated on the gasoline price increase as a direct implication of reducing the fuel subsidy. There are two scenarios, i.e. the 10- and the 100-percent increases. Given our references on the status-quo equilibrium , new gasoline prices are 7.2 and 13.0 thousand rupiah/l, which are almost equal to 0.72 and 1.3 USD/l, respectively. Both percentages of change scenarios are possible in the real world. As an illustration of this observation, in 2005, the central government decided to reduce a remarkable gasoline subsidy due to a sharp rise in oil prices.

The subsidy reduction led to more than a 100-percent increase in gasoline prices on average. Because public buses consume similar fuels as other private modes, and because most of them are operated privately, the higher gasoline price will directly raise the operating costs of the buses. In this simulation, the bus fare is assumed to increase proportionally with the gasoline price. I refer to these scenarios as the general gas tax policy because the effects of reducing the subsidy on the gas price is similar to those of taxing gas.

The second category is quite similar to the previous scenario, except that the central government keeps the public fare as constant. I refer to it as the policy mix scenario. Similarly, two cases are considered: the 10- and the 100-percent gasoline price increases. Under this policy category, the central government gives substantial amounts of subsidies to the public bus operators to cover the higher gasoline expenditure.

The third policy focuses on the cordon toll plan in Jakarta's CBD. This policy serves as a benchmark for the gas tax simulations. The CBD cordon toll levies all passenger cars and motorcycles entering the area inside the CBD. The tolls are 15 and 5 thousand rupiah per crossing for cars and motorcycles, respectively. Intrazonal trips within the CBD area are exempted from any toll. The public bus transport is exempted from the toll as well.

How will the gasoline tax differ from the CBD cordon toll? The gasoline tax is naturally a distance-based road toll, and thus charges more as the trips get further. It charges all or most of the gas-consumed trips irrespective of their origins or destinations, and covers all zones in the economy. Meanwhile, the CBD cordon toll is local because it only charges the targeted trips that traverse the CBD zone. The effects are concentrated in the CBD zone compared to the broader impacts of the gas tax policy.

4.3 Simulation results

4.3.1 Aggregate effects

Table 4.1 summarizes the simulation results for all respective scenarios. Higher gas prices without a constant public transport fare, as in the case of the general gas tax, compel all types of transport modes to bear higher gasoline consumption. Accordingly, since the passenger car has the highest gasoline consumption per km among the others, a higher gas price increase leads to less car use. For a certain decrease in car use, more users prefer to use motorcycles than those who prefer to use the public bus. Out of the 0.7-percent decrease in car use due to the 10-percent increase of gas prices from the general gas tax, 0.4 and 0.3 percent choose to use the motorcycle and the public bus, respectively. As a result, there is a 2.6-percent reduction in the congestion level, which yields 5 minutes of ADTS or the equivalent of 168 thousand rupiah annually. Welfare improvement in the form of EV is 131 thousand rupiah or the equivalent of 0.28 percent of the annual income on average. At a more radical level, 5.3 percent of a decrease in car use can be obtained from a 100-percent increase of gas prices, and most of the users switch to the use of the motorcycle. This reduces 5.3 percent of the JMA congestion level and yields 24.9 minutes of ADTS, which are equal to 808.2 thousand rupiah on average per annum. The EV is 634 thousand rupiah or amounts to 1.36 percent of the annual income.

Table 4.1: The Effects of the CBD Cordon Toll and the Gasoline Tax

	Scenarios (percent change)				
	CBD cordon	General gasoline tax		Policy mix	
		10%	100%	10%	100%
Average daily travel time saving (minutes)[1]	8.7	5.0	24.9	7.0	37.0
	5.8	**3.3**	**16.5**	**4.6**	**24.6**
Modal split (percent change)					
car	-1.2	-0.7	-5.3	-0.8	-5.1
Motorcycle	-1.0	0.4	3.7	-0.6	-8.5
Bus	2.2	0.3	1.7	1.4	13.6
JMA congestion level (percent change)	-5.1	-2.6	-13.5	-3.9	-24.0
CBD	-20.8	-2.7	-14.0	-3.9	-22.9
SBD	-4.4	-2.8	-14.1	-4.1	-24.3
Suburban	-1.7	-1.7	-10.6	-3.0	-22.9
Gasoline consumption (percent change)	-6.5	-2.6	-15.1	-4.9	-35.2
CBD route avoidance (percent change)[2]	-10.9	-0.3	-1.4	-0.3	-1.8
Average bus ridership (workers)	27.3	25.5	26.8	26.6	38.0
Annual EV per capita ('000 Rp)[3]	225.7	131.8	643.4	185.9	937.9
	0.48	**0.28**	**1.36**	**0.39**	**1.99**
Annual monetary value of travel time saving ('000 Rp)	293.6	168.6	808.2	242.0	1207.3

[1]Numbers in bold indicate the percentages of time saving w.r.t. the DATT under no-toll equilibrium.
[2]Numbers in the CBD route avoidance are obtained from changes in the number of trips that traverse any route involving the CBD route, excluding those from or to the CBD.
[3]Numbers in bold indicate the percentages of the benefits w.r.t. the average annual nominal income.

Although the general gas tax promotes congestion reduction in the JMA, it raises the concern of the difficulty of motorcycle growth control in the JMA. As reported by Dinas Perhubungan Pemda DKI Jakarta (2007), motorcycle ownership has climbed dramatically, which has created a rapid change in the JMA's modal split during the past decade. From the SITRAMP and the JUTPI study, excluding non-motorized transport (NMT), the shares of motorcycle use have more than doubled during the 2002-2010 period from 21.8 to 53 percent. The gasoline price increase hence supports the use of motorcycles more than the use of public transport. Thus, it may generate another problem in the near future for the control of motorcycle ownership unless more incentives are introduced for public transport use.

Once the government can control the public bus fare, more private mode users can be driven to use the public bus transport. In such a case, the public bus gains relatively more attractiveness than it does under the general gas tax policy. Even though it remains as the slowest mode, the public bus is the cheapest among the available modes. A 10-percent increase in the gasoline price under the policy mix leads to an additional 1.4 percent of bus passengers and lowers the JMA congestion to as much as 3.9 percent, which gives 7 minutes of ADTS. The number of all private mode users decreases, and most of the decrease comes from the car users (0.8 percent). Benefits in the form of the MTTS and the EV are 242 and 186 thousand rupiah, respectively. A 100-percent increase in the gasoline price reduces the congestion to as much as 24 percent, which generates 37 minutes of ADTS. It gives 1.2 million rupiah of the MTTS and 938 thousand rupiah of the EV. These numbers are approximately 50 percent higher than the results under the general gas tax scenario. It arises from the substantial switch to the use of the public bus, which leads to a congestion reduction that is almost doubled the reduction obtained under the general gas tax scenario.

Comparing both gas price scenarios with the private CBD cordon toll shows that the outcome of the CBD toll is quite limited. The value of rejected car use is relatively low and falls into 20-25 percent of the gas price increase. Since the charge is designated for trips from and to the CBD, the private CBD cordon toll significantly reduces the CBD congestion level, which contrasts with its smaller change to the congestion levels of the other zones. Meanwhile, the gas tax policy in nature is a distance-based road toll that charges all or private mode trips. The toll is higher as the distance extends; it therefore influences all zones and affects in a more global way than the CBD cordon toll. As a result, a relatively low level of gas price increase can compensate for the results of the private CBD cordon policy.

4.3.2 Distributional effects

Aside from examining the aggregate results, I am interested in examining the distributional effects of the gas tax scenarios.Table 4.2 reports the distribution effects with respect to the types of workers and the commuting patterns. Unsurprisingly, workers with higher skills and a higher value of time always acquire the highest gain. The gain is even higher under the policy mix scenarios, which offer higher travel time saving. The gains are approximately three times greater than the low-skilled workers' gains, although the low-skilled group obtains better travel time saving.

An interesting result arises from the distribution effects on the commuting patterns. I divide the commuting patterns into two categories: interzonal and intrazonal commuting. Intrazonal commuters benefit more than the interzonal commuters under the general gas tax scenario. However, the opposite occurs under the policy mix scenario: the intrazonal commuters benefit rather less. The gap widens with a higher percent increase in the gas tax. These results indicate that the gasoline tax provides workers with less room for adjustments to reduce their monetary costs than the policy mix scenario, and that the magnitude is significant for the long-distanced commuters. With further limited room for adjustments, the interzonal commuters' benefit of time saving is relatively weaker than the additional travel cost. In contrast, the policy mix provides workers with sufficient room for adjustments to avoid the tax by switching to the public bus. The magnitude is higher for the interzonal workers.

Table 4.2: Distribution Effects of the Gas Tax Scenarios across Workers and Commuting Patterns (in thousand rupiah)

	General gasoline tax		Policy mix	
	10%	100%	10%	100%
Effects across workers				
Low-skilled	52.3	261.4	79.8	475.5
Middle-skilled	123.7	608.5	169.3	850.1
High-skilled	398.9	1904.2	572.4	2704.0
Effects across commuting patterns				
Intrazonal	150.9	1214.6	134.6	738.5
Interzonal	125.6	457.4	202.6	1002.9

4.3.3 Effects of the crowding cost of the bus

Higher benefits from the policy mix scenarios indicate that, despite the crowding cost of the public bus, which reduces the attractiveness of the public bus, the benefit of higher congestion reduction matters more. Would the same apply if the crowding cost is sufficiently high? Table 4.3 juxtaposes three different levels of the crowding cost parameter, ϕ, and how they affect the welfare gain from gasoline tax policies. The values ofϕ represent the base case, the medium crowding cost parameter, and the high crowding cost parameter, respectively. Medium and high cost parameters are set to five and ten times greater than the base case parameter. Naturally, a higher ϕ directly decreases the gain through two channels. First, higher ϕ reduces the attractiveness of the public bus and leads to lower congestion reduction. Second, it reduces the workers' leisure. The magnitude is higher for the workers that have a high value of time.

Table 4.3: The Effects of the Crowding Cost on the Welfare Gain of Gasoline Tax

	General gasoline tax		Policy mix	
	10%	100%	10%	100%
Base case ($\phi = 0.11$)	131.8	643.4	185.9	937.9
Medium crowding cost ($\phi = 0.55$)	125.7	618.7	154.5	723.1
High crowding cost ($\phi = 1.1$)	121.1	598.8	131.1	562.9

Higher ϕ marginally decreases the gain under the general gas tax scenario. Medium and high ϕ cost 5 and 8 percent of the base case results under the 10-percent increase of the gasoline tax, respectively. Similarly, under a 100-percent increase, both levels only reduce by 4 and 7 percent, respectively. This is natural, as we have seen in Table 4.1,the general case leads to a small increase in bus passengers even after the gas price is doubled. Higher ϕ significantly affects the results of the policy mix scenario. A high level of ϕ cuts 30 and 40 percent from the base case under the 10- and the 100-percent increases, respectively. The policy mix scenario now provides lower benefits than the general gas tax scenario under the 100-percent increase. The higher the percentage of gas tax, the higher the reduction is because of the substantial increase in the average ridership. Table 4.1 demonstrates that the average ridership under the 100-percent gas increase of the policy is 38 passengers, which is significantly higher than the 25.2 passengers under the no-toll scenario. It creates a high crowding cost particularly for the high-skilled group and the long-distance commuters.

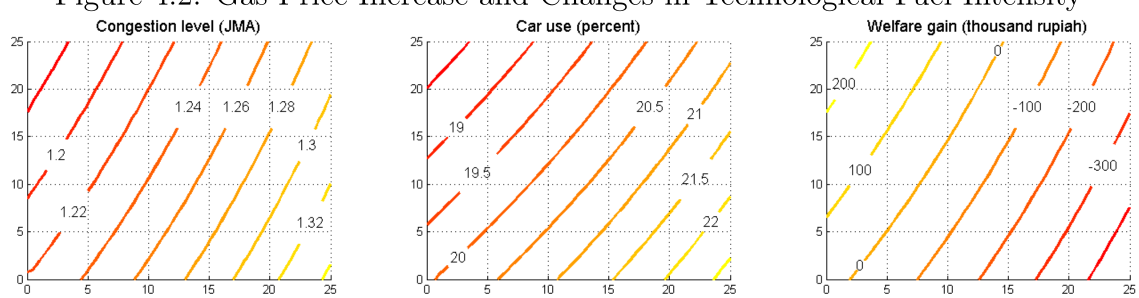
4.4 Sensitivity Analysis: Technology Efficiency and Iso-Benefit

In this section, I test the sensitivity analysis for the case if there are advancements in private transport mode technology. Two cases are considered; change in technological fuel intensity and free-flow travel speed. In this section, I conduct a sensitivity analysis of the cases with advancements in private transport mode technology. Two cases are considered: changes in the technological fuel intensity (TFI) and the free-flow travel speed.

4.4.1 Efficiency in technological fuel intensity (TFI)

One of the recent technology advancements in the area of private modes emphasizes the greater efficiency of gasoline consumption. Hence, it is interesting to see how an improvement of the TFI of private modes, along with a gas price increase, affects the welfare gain. Following Anas and Hiramatsu (2013), I simulate the decrease in the TFI of both motorcycles and cars together with the general gas tax scenario. The results are presented in 4.2.

Figure 4.2: Gas Price Increase and Changes in Technological Fuel Intensity



Note: The X-axis indicates the percentages of change in the improvement of the technological fuel intensity (TFI) for both cars and motorcycles, while the Y-axis indicates the percentages of change in the gas price.

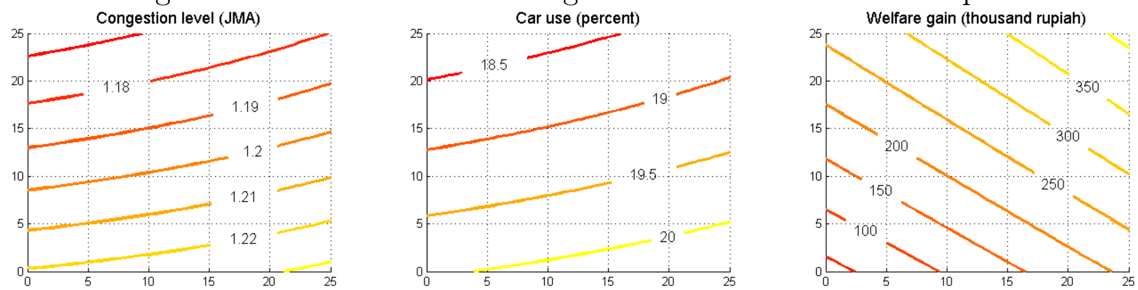
More efficient gas consumption will have opposite effects from an increase in gas prices because lower TFI adversely affects the monetary travel cost. It increases the attractiveness of the use of private modes, which results in a higher congestion level. Hence, this simulation enables us to see how technological improvement may hinder the benefits from the gas price increase. On the left panel of Figure 4.2, the results of the congestion level in the JMA demonstrate the opposition between the improvement of TFI technology and the gas price increase because the iso-congestion curve moves from the top left corner to the bottom right. It implies that the economy can be worst off for introducing a more efficient engine. As a result, the welfare gain moves from the bottom right to the top left. Any combination of the gas price and the TFI improvement may lead to zero gain or even worst-off conditions.

4.4.2 Improvement in free-flow travel speed

Another possible technological advancement is an improvement of the free-flow travel speed. A better free-flow travel speed directly reduces the travel time needed for private mode users and affects the gasoline consumption per km due to the speed-gas consumption function. However, in this possible scenario, the magnitude will be different from the scenario above , since both factors work in different terms with the generalized travel cost. Figure 4.3 presents the result.

The results of the congestion level exhibit a similar pattern to those of the TFI-gas tax simulation, yet the slope is rather flatter. Improvement in the free-flow travel speed has a direct impact of widening the gap of the generalized costs among modes. In this case, car users will benefit more because a one-percent increase of car speed reduces more travel time than the same percent of increase in motorcycle speed. The gap widens along with further travel distance and higher percentages of improvement. However, since the effects of such an improvement are greater than the effects of an additional congestion level due to the additional private mode use, it allows the private mode users to move relatively faster than the status-quo equilibrium, and improves

Figure 4.3: Gas Price and Changes in the Free-Flow Travel Speed



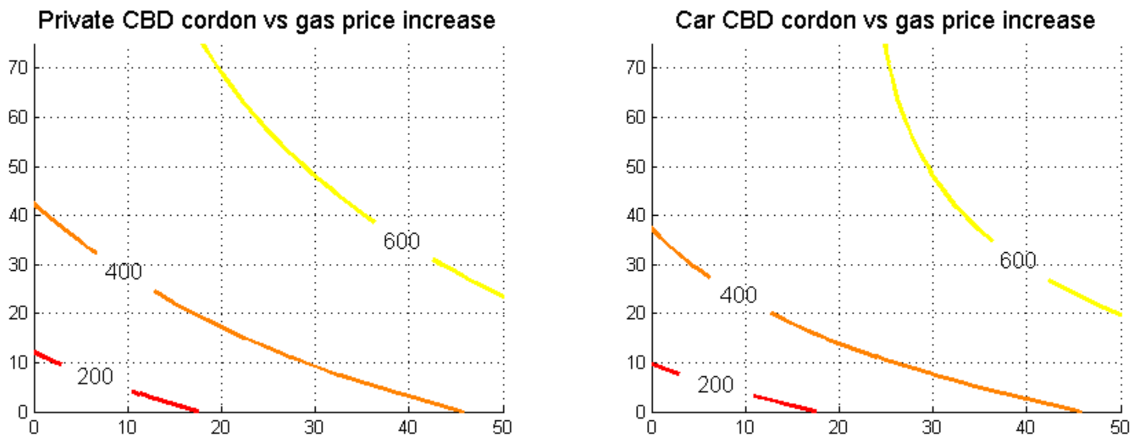
Note: The X-axis indicates the percentages of change in the improvement of the technological free-flow travel speed for both cars and motorcycles. The Y-axis indicates the percentages of change in the gas price

the welfare. A combination of the faster speed and the gas price increase will thus improve the welfare gain.

4.4.3 Iso-benefit between the CBD cordon and the gasoline price

Both the CBD cordon toll scenarios and the general gas tax scenario are simulated together to obtain the level of benefits from any combination of these aspects. The private and the car CBD cordon tolls are considered. The idea is to draw iso-benefit curves that will demonstrate any combination of the cordon toll level and the percentages of increase in gas prices that will deliver the same level of benefits. The increase in gasoline price can be positive for congestion level reduction, as it provides an additional disincentive for private mode use. Hence, its curvature is expected to be downward-sloping and the curves are expected to move from the origin to the top right corner as the benefit goes higher. This simulation enables us to analyze the interchangeability between both policies in meeting a certain level of benefit. Figure 4.4 presents the simulation results.

Figure 4.4: CBD Cordon vs Gas Price Increase



In both subfigures, the X- and the Y-axes represent the percentages of change in the gas price and the CBD cordon toll level (thousand rupiah). The curves represent iso-benefit measured in thousand rupiah.

Welfare gains from the private and the car CBD cordon are equal to the gain of 22 and 25 percent of the gas price increase, respectively. This is consistent with our results in the previous chapter because the car CBD cordon generates a higher gain than the private CBD cordon. The curvature that reflects the trade-off between both factors' iso-benefits is more inelastic towards the CBD cordon because the source of the gain under the CBD cordon is more localized than under the gas price increase. The welfare gain of the CBD cordon is generated through the lower congestion that is concentrated in the CBD while the gas price case is from the lower congestion in all zones in the JMA. Hence, under a high level of the CBD cordon toll, the additional welfare gain is incremental along with small improvements in the congestion level. In contrast, there remains a wide room for congestion level improvement in the general gas price. With 10 percent of the gas price increase, congestion level in the JMA is improved by 1.6 percent, and a similar number is obtained under the car CBD cordon scenario with most of the improvement concentrated in the CBD.

4.5 Remarks

This chapter aims to examine the additional benefits of the fuel subsidy reduction in Indonesia. While existing literature on Indonesian fuel subsidy policies have greatly focused on their impact on macroeconomic indicators, our study is the first to attempt to quantify the potential impact of reducing Jakarta's congestion level by using the SGE model. Aside from the benefit of the potential 0.27-percent reduction in the poverty incidence, as found by Dartanto (2013), the gas price increase potentially benefits the people because it stimulates road users to substitute the passenger car with the motorcycle and the public bus. The congestion level and the travel time in turn will be lower, which will yield additional welfare gain. In addition, this chapter compares the performance of the CBD cordon tolling analyzed in Chapter 3 to that of the gasoline tax.

The main results of this study concerning the gas price change policies can be summarized as follows. All gasoline price scenarios directly cause lower congestion levels through the lower prevalence of private transport modes; the magnitude is also higher along with higher percentages of gas price change. Moreover, when the government can maintain the bus fare to be at least equal to the status-quo level under the policy mix scenario, the magnitude will be significantly higher, which implies that more private modes will be driven out. Between the two private modes, car users are more affected because of the high GPM ; however, aside from public bus users, motorcycle users also increase under the general gas tax scenarios. On the other hand, all private mode users decrease under the policy mix. Since the policy mix drives out more private mode users, it provides more travel time saving and higher annual welfare than the general gas tax increase scenarios.

The private CBD cordon tolling is added in order to compare the performances of the gas price scenarios. In short, the performance of the toll scenario is relatively limited due to a narrow implementation zone. The private CBD cordon works more locally, and hence the congestion improvement is concentrated in the CBD zone. Uncharged public transport and route choices extend the ability of the workers to avoid the toll, which results in the low performance of the private CBD cordon. In contrast, gas price increases affect all trips that use at least two private modes, and therefore limit the cost avoidance behavior. As a result, the welfare gain of the private CBD cordon toll is in the range of 20-25 percent of the gas tax results.

Appendix A: Detailed simulation result for each skill group

Table 4.4: Detailed Simulation Results for Each Skill Group

	Status-quo	Scenarios (percentages of change)				
		CBD cordon	Gas price increase		Policy mix	
			10%	100%	10%	100%
Low-skilled						
Car	8.2	-0.5	-0.3	-2.3	-0.4	-2.4
Motorcycle	56.6	-1.8	0.2	1.7	-1.2	-12.2
Bus	35.2	2.3	0.1	0.5	1.5	14.6
Middle-skilled						
car	22.7	-1.4	-0.8	-6.0	-0.9	-5.9
Motorcycle	51.7	-0.9	0.4	3.9	-0.6	-8.1
Bus	25.6	2.3	0.3	2.1	1.5	14.0
High-skilled						
car	36.4	-2.5	-1.4	-10.2	-1.5	-8.7
Motorcycle	52.2	0.8	1.0	7.7	0.6	-0.7
Bus	11.4	1.7	0.4	2.4	0.9	9.4
Average daily travel time saving (ADTS)						
Low-skill		9.0	10.5	13.1	13.9	23.4
Middle-skill		8.5	9.6	12.0	13.2	19.6
High-skill		8.8	9.4	11.5	13.5	23.4

Chapter 5

Cordon Toll and Location Effects

5.1 Introduction

The previous chapters discuss the benefits of the CBD cordon toll on the economy as well as the causal effects beneath the welfare improvement. The benefits of the CBD cordon tolls are relatively small at less than one percent of the annual income, which is equal to 20-25 percent of the benefits of the gas price increase depending on. In this chapter, I focus on the second aspect of the impacts of cordon tolling: changes in the workers' residential and job choices.

Land use analysis is undoubtedly one of the topics that lie in the heart of urban economics; it focuses on land allocation among the producers, the consumers, and/or transportation behavior. Land use analysis perhaps started around the 1970s in the pioneering work of Solow and Vickrey (1971) who analyzed the land use under a long and narrow city. They assumed a production city with an exogenous total road area but allowed the shape of the road to be endogenous. Further, they showed that the market city tends to over-allocate the land to transportation, particularly near its center. In another setup, Kanemoto (1980) provided a theoretical framework for the optimal and market land use allocations between road and housing consumption under a circular monocentric city assumption and showed that the total land allocated for housing is greater under the market city. Both studies shed a common logic that land allocation for transportation (i.e. roads) is higher near the center, and decreases as the distance from the CBD extends. Ogawa and Fujita (1980) then pioneered the theoretical analysis of land use under a multicentric city. Wheaton (2004) combined two additional features, i.e. the firm's spatial agglomeration by Anas and Kim (1996) and the transportation congestion by Solow (1973) into Ogawa-Fujita's polycentric model to synthesize a mixed land use between residential and employment uses.

While early studies concentrated on building theoretical frameworks, recent works on the land market and/or location effects have been more dominated by simulation analyses. With more features added to the model, deriving a closed form of the analytical results is not possible in most cases. A simulation analysis of changes in the land market and/or the location effects of an urban policy can also be generally divided into at least two categories. The first category focuses the simulation on the impacts of a certain urban policy on the land or the housing market. For example, there have been some studies on the interlink between the land and/or the housing market and the urban land restriction, or the zoning restriction, in particular. A recent study conducted by Magliocca et al. (2011) used an agent-based model, namely the coupled housing and land markets (CHALMS), to build a closed equilibrium in housing and land markets. It incorporates three types of agents: the consumer, the farmer, and the developer, whose behaviors follow the microeconomic foundations.

The model captures the dynamics of land conversion to residential uses over time. The farmer interacts with the developer in the land market whilst the consumers interact with the developer in the housing market. Population growth as the exogenous parameter drives the equilibrium dynamic. The model itself was then applied by Magliocca et al. (2012) to test the impact of zoning in the fringe areas.

The second category focuses on examining the linkage between urban policies and both the land/housing markets and the employment market simultaneously. The idea is that a simultaneous relationship exists between the worker's job location choice and/or the labor market and commuting. Clark et al. (2003) and Ommeren and Fosgerau (2009) provided examples of the empirical work, while for the theoretical approach, we may refer to the work of Ommeren et al. (1999). Later works have specifically show that the congestion and the residential moving behaviors relate to one another through the job search model with a moving cost feature. Meanwhile, the simulation-based approach for examining both effects was widely examined in Anas' studies and by his co-authors in various literatures. The idea is that a respective worker has a set of home-work arrangement choices and he/she chooses one possible arrangement that maximizes his/her utility under the logit approach. Hence, any small perturbation in the worker's utility due to urban policy alters the matrices of the probabilities of choosing a home-work arrangement, which in turn alters the urban land use, the residential density, and the employment density in each urban zone.

Eliasson and Mattsson (2001) analyzed the effects of road pricing on transport and location patterns. The city is star-shaped with one city center; eight rays, each of which contains four zones, extend from the center. Under a Pigouvian congestion pricing, which taxes all trips by their externality, they found that the tax allows the city to be less dispersed. On the other hand, the result of applying a toll ring is ambiguous and strongly depends on where the ring is located. The city is less dispersed if the land supply inside the ring is sufficiently large that it can satisfy a certain level of commuting, shopping, and service activities, and vice versa. Anas and Rhee (2006, 2007) discussed the effects of urban growth boundaries on city formation and showed that while such policies render the city more compact, a strict boundary is harmful and creates a negative welfare change. Fujishima (2011) simulated cordon tolling in a multicentric city to obtain a more concentrated result of the residential and the employment density as the final result of workers' toll-avoidance behavior.

Anas and Hiramatsu (2013) focused on the effects of cordon-pricing policies on economic welfare as well as on workers' commuting patterns. This study numerically determines the optimal cordon toll by using a detailed general equilibrium model, named the RELU-TRAN2, which is calibrated for the Chicago MSA, and consists of 15 zones including the CBD, the city, the inner suburbs, the outer suburban counties, and a peripheral exurban area. They found that under the CBD cordon toll, the number of CBD residents decreases as the toll increases, yet as the toll level climbs high enough, it starts to increase as more new residents are gained from the other zones. Meanwhile, the broader cordon that circumscribes the inner suburbs generates concentration effects. Their basis argument examined whether the benefit from the variety of goods offered inside the cordon is high enough to overcome the cost of living inside the ring under post-toll equilibrium. If the former factor dominates the latter, there will be a resident inflow into the cordoned area, and vice versa.

In this chapter, I simulate the effects of road tolling policy on the JMA residents' commuting decisions. My findings on the private CBD cordon toll, i.e. the dispersion of residents from a narrow cordon ring, confirm the results of Eliasson and Mattsson (2001) as well as Anas and Hiramatsu (2013) The CBD cordon, which encircles the CBD area, is too costly for the CBD residents to remain inside the CBD. Nonetheless, if the toll level is high enough, the dispersion results will weaken, as workers will respond by choosing more intrazonal commuting and sacrificing their interzonal shopping trips. In contrast, my results on employment changes under the car CBD cordon contradict their results because the toll rather invites more people to work in the CBD. The car CBD cordon toll provides workers with enough room for adjustments that they can work in the CBD without paying the toll excessively.

The remainder of this chapter is organized as following. Section 5.2 explains the scenarios used in the simulation. The results are presented in the Section 5.3. I provide some sensitivity analysis in the Section 5.4. An extended discussion is provided in the Section 5.5 under the medium run environment in which worker cannot alter residential choice and land size consumption. Section 5.6 concludes.

5.2 Scenarios

Since I am interested in investigating the effects of cordon tolls on urban land use, I focus on simulating the cordon schemes that establish the CBD and the SBD as the cordoned areas, respectively. Both schemes therefore represent both narrower and wider toll ring scenarios to confront the arguments of Eliasson and Mattson (2001) and Anas and Hiramatsu (2013). For both schemes, I introduce two scenarios. The first scenario is to levy all private modes (i.e. the private car and the motorcycle), as in the JETRO study. The private car and the motorcycle must pay 15 and 5 thousand

Table 5.1: Workers' Distribution in the Home-Work Arrangement (percentage)

		Working			
		CBD	SBD	Suburban	Total
Living	CBD	1.4	3.3	0.0	4.7
	SBD	11.7	30.1	0.0	41.8
	Suburbs	7.1	21.5	24.9	53.5
	Total	20.3	54.8	24.9	100.0

rupiah per crossing, respectively. An alternative scenario is to focus solely on the car as the toll target.

Another considered type of road pricing is area pricing, which is quite similar to the cordon toll. This type of toll has been applied in London since 2005. The main difference is that the area toll charges all trips inside the designated area regardless of their origins (Santos and Verhoef, 2011). In the previous chapter, I apply a similar CBD road toll called the discounted CBD cordon toll, which discounts all interzonal trips that originate from the CBD. The discounted CBD cordon toll does not charge intrazonal CBD trips while the discounted CBD area toll charges them under the discounted rate.

For the benchmark results, the workers' detailed distribution based on the home-work arrangement under no-toll equilibrium is presented in 5.1.This table is a detailed version of the results of the benchmark city, as shown in 2.3 of the Chapter 2. The SBD-SBD commuting choice is the most preferred commuting pattern with 30.1 percent, followed by the suburb-suburb choice (24.9 percent). Similar magnitude is also found in the suburban zones. In total, 56.4 percent of the total workers prefer intrazonal commuting. There are no CBD and SBD residents working in the suburban zones due to the model restriction. Hence, together with the shopping pattern and the production technology, the no-toll results yield a lower portion of suburban workers than those of the SBD and the CBD workers, relative to the respective areas of the zones.

5.3 Simulation Result: Land Use Allocation and Urban Land Rent

It should be noted that the cordon toll policies will directly affect all workers, not only those who live and/or work in the cordoned area, but also those whose commuting choices traverse the cordoned area. For the latter group, although the toll may not directly affect their commuting cost, it may affect their shopping trips. Delivered consumer goods prices in the cordoned area are relatively higher than the status-quo prices, which may force the latter group to consume less or substitute the cordoned area goods with the other consumer goods that are produced outside of the cordoned area.

Table 5.2: Simulation Results of Land Use and Workers' Residential and Employment Decisions

		Scenarios (percent change)							
	no-toll	Cordon				Area			
		CBD		SBD		CBD		SBD	
		private	car	private	car	private	car	private	car
Percent land for consumption									
CBD	36.8	-0.3	-0.3	0.8	-0.4	0.1	-0.4	-0.3	-0.9
SBD	54.2	-0.2	0.0	0.8	-0.1	-0.2	0.0	0.2	-0.2
Suburbs	30.0	0.2	0.1	-1.2	0.2	0.2	0.1	-0.2	0.4
Residential density (thousand/km^2)									
CBD	8.7	-0.9	-0.2	0.8	-0.6	-0.5	-0.3	-0.5	-1.1
SBD	6.4	0.0	0.1	1.3	-0.1	-0.1	0.1	0.4	-0.1
Suburbs	2.0	0.1	-0.1	-1.1	0.1	0.1	0.0	-0.3	0.1
Employment density (thousand/km^2)									
CBD	37.3	-1.6	0.3	-0.3	0.0	-2.0	0.2	-0.3	0.1
SBD	8.4	0.6	0.2	-0.2	0.2	0.7	0.2	-0.1	0.4
Suburbs	1.0	0.0	-0.7	0.8	-0.5	0.0	-0.6	0.4	-0.9

The cordon toll policies mostly affect the first group via both commuting and non-commuting trips. As the commuting cost gets higher, workers may alter their home-work arrangements to avoid paying the toll. There are two responses of changing the arrangements, and these have opposite effects on the residential density of the cordoned area. If the toll is high enough, a representative worker who works in the cordoned area may move to the nearby working area to avoid the toll during the commute. This mechanism follows Fujishima's findings that the number of consumers who live in the cordoned area is increasing due to the cordon toll. However, consumers who live in the cordon area suffer from higher shopping costs for consuming goods that are produced outside of the cordon area. Such a tendency will drive people to move out of the cordoned area. Thus, the residential cordoned area will be denser if the cost saving from commuting trips by moving into the cordon area is higher than the cost saving from non-commuting trips by moving out of the area. In conclusion, as asserted by Eliasson and Mattsson (2001) as well as Anas and Hiramatsu (2013), the effect of the cordon toll can be ambiguous, and strongly depends on where the cordon is placed.

The table 5.2 shows how the residential density changes under the respective toll policies. In general, two types of toll policies are considered: the cordon and the area tolls. Both scenarios are also divided into two schemes, depending on where the ring is placed. The first scheme assumes that the ring surrounds the CBD, while the second scheme assumes that the ring surrounds the SBD. All of these schemes are then compared under the cases of the government imposing the toll for all private modes (cars and motorcycles) and for the car only.

In terms of the private-based toll, the simulation results show that the private CBD cordon toll causes more dispersion effects on the CBD zone. It leads to a 0.1- and a 1.6-percent decrease of the CBD residents and the workers, respectively. These results are similar to the findings of Eliasson and Mattsson (2001) or Anas and Hiramatsu (2013) that a narrow cordon ring rather forces people to leave the cordoned area. This type of toll allows the CBD residents to bear higher annual travel costs than the other residents, as they have more trips that are subject to the toll than those who live outside the CBD. Since any commuting pattern that traverses the CBD is more costly, the most attractive toll-avoidance response is to live and work outside of the CBD. Some commuting patterns will completely exempt the workers from the toll regardless of their transport modes, while some others will still have to pay the toll, since the route of the home-work arrangement must traverse the CBD as the cordoned area. The magnitude is higher for the lower skilled group because it is more sensitive toward any changes in the monetary cost. In contrast, the high-skilled group values the travel time improvement inside the CBD area more than the lower skilled group, which makes the high-skilled group reluctant to leave the CBD zone.

The SBD cordon toll rather induces people to live in the cordoned area, and thus increases the land allocation for the workers' consumption in both the CBD and the SBD, while leaving the suburban areas less dense. 1.1 percent of the suburban residents now prefer to move into the cordoned area. Despite levying more suburb-suburb trips, the SBD cordon exempts more trips, i.e. the CBD-SBD (and vice versa) trips, from the toll. Such an exemption attracts more workers to live and work in the regions inside the cordon. Residing and working inside the cordon now means no toll for commuting; further, only six of the ten shopping trips are subject to the toll. As a comparison, living in any suburban area leads to at most three free-toll shopping trips. Workers with a low value of time, but a high MUI, are more eager to move into the cordoned area than those with a high value of time but a low MUI. The former (or the latter) group will always be more (or less) sensitive toward changes in the monetary travel cost than changes in the travel time cost. Under the SBD cordon, travel time improvement is quite substantial, which explains why the latter group has less motivation to move into the SBD or the CBD. Decreasing land consumption demand in the suburban areas forces the land rent to decrease and causes the producers to substitute land with labor. As a result, more jobs are created in the suburban zones.

A substantial toll discount under the area toll for workers living inside the ring may hinder them from moving out. Those workers will still have to pay for all of their trips, including the intrazonal trips, although under a discounted price. Under the 50-percent discount, the effects are fewer than those of the cordon cases. For instance, the dispersion forces in the CBD area generate a 0.5-percent decrease of the CBD residents, compared to a 0.8-percent decrease under the CBD cordon. Analogously, concentration effects in the SBD area are also fewer; there is a 0.3-percent decrease of the suburban residents. Under the CBD area toll, the 50-percent discount lets the CBD workers pay half of the charges for all private mode trips, including the interzonal and the intrazonal trips. For the CBD residents, because the number of interzonal trips dominates the total trips, the benefit from the discount is bigger than the cost of the intrazonal trips for the CBD residents. Thus, the dispersion effects from charging the intrazonal trips are much less than the additional concentration effects that are produced by the discount.

The car area toll that levies the car users only provides the residents/workers with more margins of adjustments so that they can access the cordoned area; therefore, changes in the residential and the employment density are relatively fewer than those under the private tolling. For example, the car CBD cordon toll induces 0.2 percent of the CBD residents to move out compared to the 0.9-percent decrease under the private CBD cordon. In a more extreme case, the car SBD tolling generates rather the opposite effects on the residential and the employment choices in the cordoned area. The car SBD cordon increases 0.1 percent of the suburban residents, and at the same time decreases 0.5 percent of the suburban employment. A similar trend also applies to the car SBD cordon. These results contradict the findings of Eliasson and Mattsson (2001); Anas and Hiramatsu (2013) since both studies obtained a concentration effect under the case of a wider cordon ring. In our results, the toll exemption of motorcycles provides a sufficient margin of adjustment that invites the workers to the city, and even attracts Jakarta's residents to live in the suburban areas. Because travel time improvement is mostly in the suburbs for the SBD toll cases, workers, particularly those with a high value of time, are attracted to the full enjoyment of this benefit by adopting new commuting patterns that involve the suburban zones. The car CBD toll also induces more interzonal shopping trips, which lead to an increased demand for SBD-produced goods. As a result, more jobs are created in the SBD at the cost of fewer jobs in the suburbs.

5.4 Sensitivity Analysis

5.4.1 Location effects of the CBD cordon toll

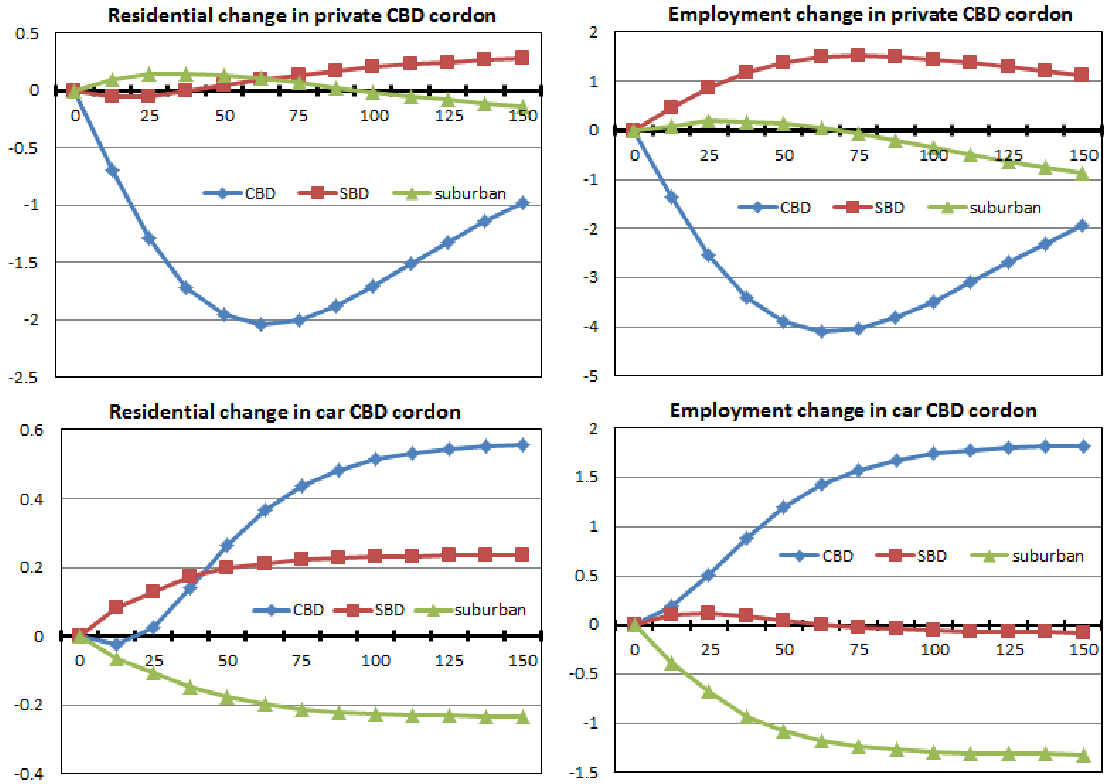
Figure 5.1 reports the sensitivity analysis results of the residential and the employment changes under the private mode and the car CBD cordon with respect to the toll level. The first row is for the private CBD cordon, while the second is for the car CBD cordon. Results of the private CBD cordon share a similar tendency with those of the studies on a narrow cordon ring. A higher private cordon toll yields more costs during interzonal shopping trips in terms of the CBD cordon, and significantly raises the commuting costs for the CBD commuters. CBD employment mostly shifts into the SBD zones, and together with the higher land demand for production caused by the increasing demand for the SBD's final goods, it forces some SBD residents to relocate to the suburban areas. Under 75 thousand rupiah (7.5 USD) as the toll level, the dispersion effect reaches its peak: approximately 2 and 4 percent of the CBD residents and the CBD employment decrease, respectively, while beyond these figures, the dispersion rate diminishes. As Anas and Hiramatsu (2013) showed, under the CBD cordon, the CBD producers substitute land with labor. Because the substitution effect is higher than the output effect (i.e. the effect due to changes in the demand for the CBD's final goods), the CBD wage tends to increase. The process continues to maintain the wages high enough that it leads to further residential demand for the CBD.

The car CBD cordon yields a similar residential dispersion curvature, except that the effect is smaller and disappears faster. While a low-level toll charge reduces the number of the CBD residents, the car CBD cordon toll rather draws more residents to the CBD once the toll is beyond 25 thousand rupiah. The toll always creates concentration effects on the employment that has the suburban workers as its particular source . These results contradict those of Anas and Hiramatsu (2013) who obtained strong concentration effects on the residential and the employment choices, at least until the toll is sufficiently high. Our results occur as the car CBD cordon toll provides enough of a more convenient alternative transport mode that is fully exempt from the toll, i.e. the motorcycle, while, at the same time, the toll itself manages to capture more of a sizable travel time saving than the private CBD cordon toll. Compared to switching to the public bus, switching to the motorcycle is more convenient due to its faster speed and lack of crowding disutility. Because time saving is concentrated in the CBD and the net benefit increases along with the higher toll, the concentration effects remain persistent.

5.4.2 Location effects and area discount

Area pricing has shown that, under a sufficient discount for the residents of the cordoned area, it produces an anti-sprawl result, as new residents from outside the ring move into the ring to enjoy the benefit. Thus, it is interesting to analyze the behavior of resident flows with respect to the discount level. We perform a sensitivity analysis of the area pricing discount with respect to the changes in the number of residents in each region. The discount is simulated under two different cases: the tolling of all private modes and the tolling of cars only (Figure 5.2). As we noted earlier, the area discount provides more incentives for workers to live inside the ring, and the tendency is higher as the discount increases. Thus, an area toll under a zero discount renders the CBD unattractive, and workers tend to move out to the

Figure 5.1: Residential and Employment Changes under the CBD Cordon Toll Levels

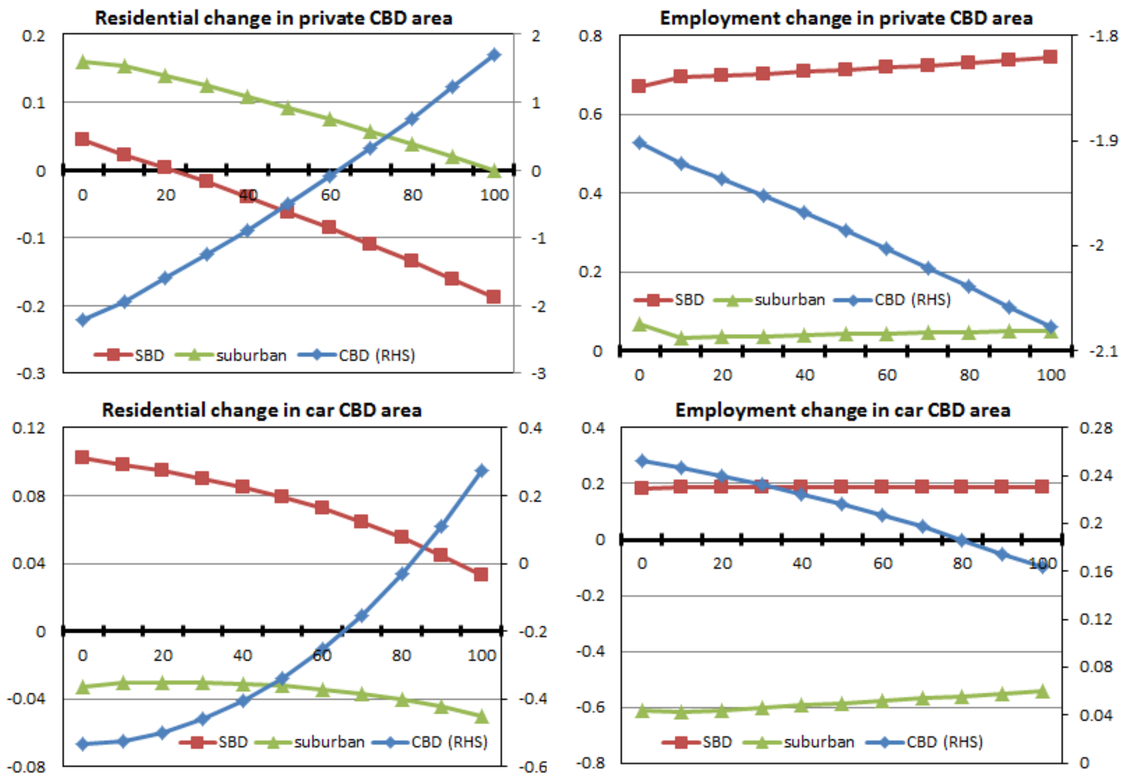


Note: The X- and the Y-axes in all of the graphs represent the toll levels in thousands rupiah and the percentages of the change in the number of residents/workers, respectively.

SBDs and the suburban areas. As more discounts are introduced, the CBD starts to significantly attract more workers.

Higher residential demand for the CBD that is driven by higher discounts in turn affects the production sector: it compels the production sector to move out of the CBD. Because living in the CBD is more attractive due to the substantial toll discount, the CBD-SBD home-work arrangement becomes the most attractive under the CBD area scenarios. Residents enjoy a discounted toll while working in the SBD. The magnitude and the number of discounts are higher. I also obtain the cut-off discount levels for the CBD area cases that set the number of residents and those employed in the area ring as constant, as shown in 5.2.As both scenarios are highly unattractive for commuting CBD workers, more discounts discourage workers to work in the CBD. In contrast, approximately 55-60 percent of the toll discount extends the benefits obtained by the CBD residents so that they remain in the cordoned area. Beyond these numbers, a positive inflow occurs.

Figure 5.2: Percentages of Residential and Employment Changes under the CBD Area Toll Discount



Note: The X- and the Y-axes in all of the graphs represent the percentages of the toll discount and the percentages of the change in the number of residents/workers, respectively. The percentages of the change for the CBD zone are shown in the Y-axis on the right-hand side

The effects of the discount on employment, on the other hand, are relatively smaller than those on residential density. This is understandable because the discount is offered to the CBD residents, but not to the CBD workers. At a zero-discount toll, any changes in the employment are more or less similar to those under the CBD cordon toll; working in the CBD becomes less attractive and employment tends to be more concentrated in the SBD zones. Additional discounts are proven to cause a further decrease in CBD employment, although to a lesser degree . One possible reason is that the discount itself produces less congestion reduction in the CBD, which gives CBD employment more disadvantages.

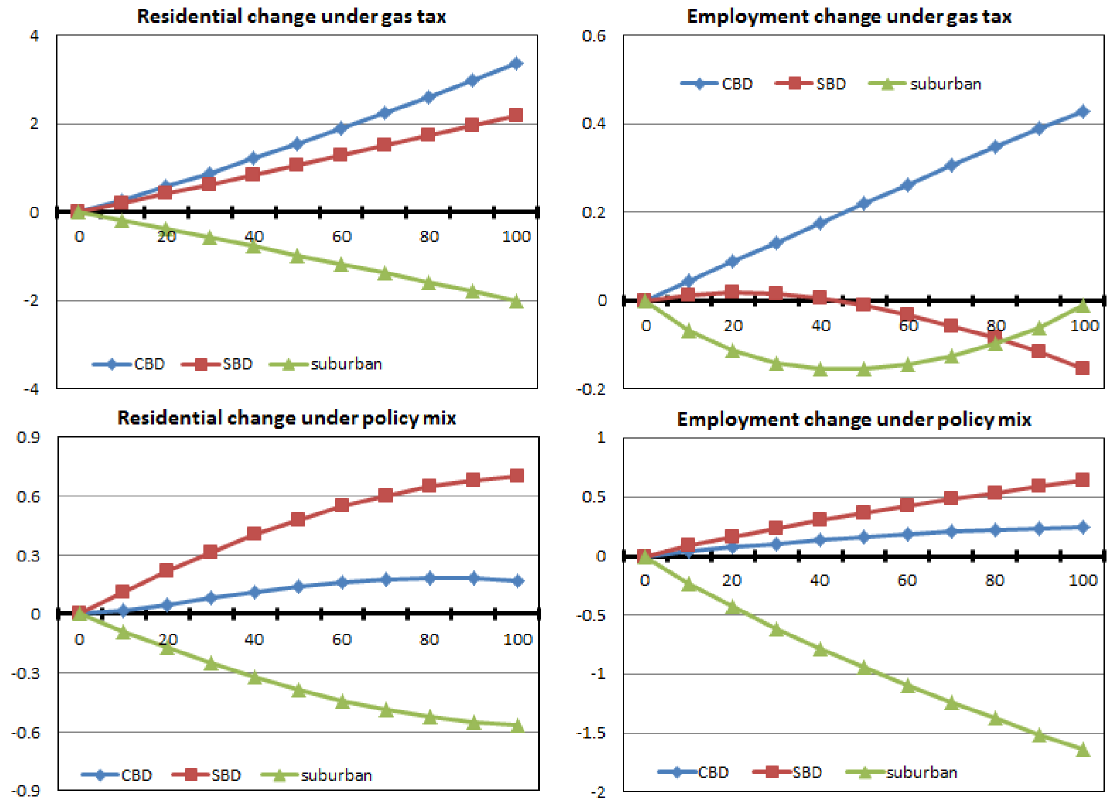
5.4.3 Location effects of gasoline price increase

This section examines increasing gasoline price policies. Two alternatives are introduced, i.e. the general gas price change and the policy mix scenarios. The former assumes that an increase in gas prices directly affects the monetary travel cost of all transport modes, including the bus fare, while the latter assumes a constant bus fare. I refer to these as the general gas tax and the policy mix, respectively. Figure 5.3 presents the results.

The first and the second columns represent the results of the general gas tax and the policy mix scenarios, respectively. Both the general gas tax and the policy mix scenarios consistently produce concentration effects in the city (the CBD and the SBD zones) for both the residential and the employment sectors, while the magnitude increases as gas prices change with increased percentages, except in the case of employment changes under the general gas price increase. Residential changes are stronger than those of employment, since moving the living place affects not only the commuting cost but the shopping cost as well. Generally, suburban residents and workers decrease along with increasing percentages of change in the gas price, and moving residents and workers are distributed in the CBD and the SBD zones. A higher gas price costs almost all trips in general, and hence shortens the commuting distance. Living or working in more connected zones becomes more preferable. As a result, there is more of an inflow to the SBDs than to the CBD, as the former have better connectivity than the latter. In addition, the general gas tax provides a relatively higher magnitude than the policy mix scenario, which is particularly evident in the residential decision, since the gas tax costs more for the residents. Under the policy mix scenario, public bus fare remains unchanged, which leads to less of a driving force towards greater concentration.

There is an exception for employment changes under the general gas tax. Beyond 40 percent of the gasoline price increase, some SBD employment will relocate, and more jobs will be created in the CBD and the suburban zones. Evident in Figure 5.3, the general gas tax scenario provides a stronger effect on residential changes than the policy mix scenario. As a result, a strong residential increase in the SBD zone drives out the production sector. More production will take place in the suburbs, which will create further employment.

Figure 5.3: Percentages of Residential and Employment Changes under the Gas Price Increase



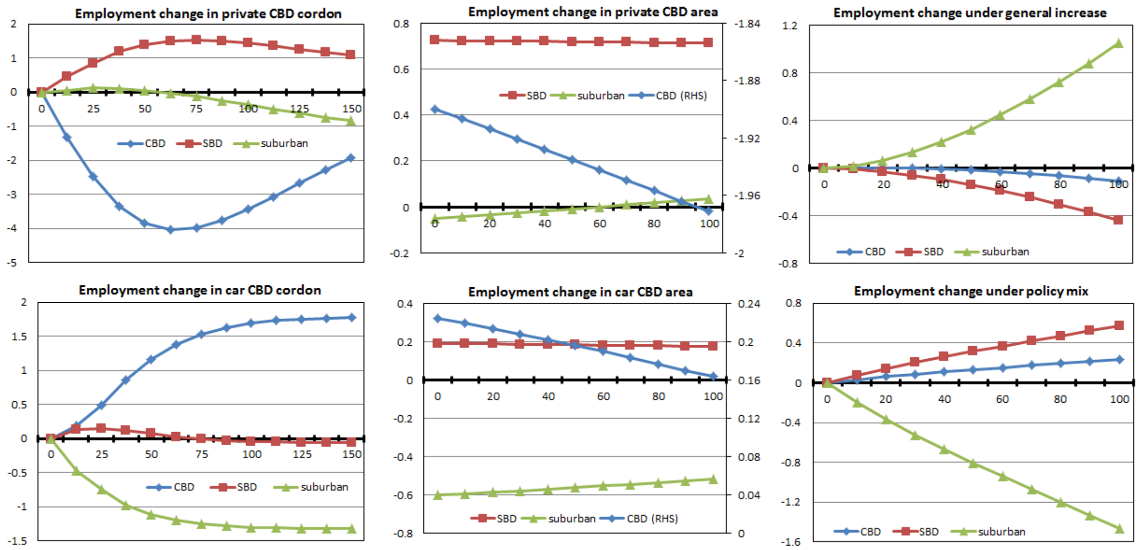
Note: The X- and the Y-axes in all of the graphs represent the percentages of the toll discount and the change in the number of residents (in thousand), respectively. The first and second rows represent the figures of the residents and the employment inflows, respectively.

5.5 Location Effects under an Inelastic Residential Choice Demand

So far, the simulations assume that workers' location demand and labor supply are elastic, while in reality adjusting to the changes in urban land use may take some years. Amundsen (1985) argued that a high moving cost hampers the residents from easily moving out of the current residential zone. Labor supply is relatively more elastic, as argued by Manning (2003) in another study; Manning asserted that almost 20 percent of the workers have job tenure in less than one year. Combining those two features, I create a medium-run environment that assumes an inelastic location demand and an inelastic urban land use allocation. The following subsection solely discusses the changes in job concentration with respect to the presence of the CBD cordon toll, the area toll discount, and the gasoline price increase. Another study that has a different framework involving a simple transportation sector and labor market was conducted by McArthur et al. (2010). McArthur et al. (2012) tested the model by simulating some road pricing scenarios and their impacts on employment. They modeled the unemployment feature, which is similar to the SGE model used byAnas and Hiramatsu (2013) or Tscharaktschiew and Hirte (2010b) to examine the positive impacts on unemployment, as a particular road toll may increase the demand for final goods and the demand for labor. Since I do not model the unemployment sector, the impacts of changes in the generalized travel cost on employment will only cause the workers to alter their working places.

Simulation results under the fixed residential choice assumption are presented in Figure 5.4. In general, assuming an inelastic fixed residential choice does not significantly alter the curvature of employment changes. Slight differences in the magnitude represent the workers' behaviors in anticipating changes in the generalized cost by fully exploiting his/her elastic labor supply. Because the option to change the residential zone is no longer available, the CBD residents cannot opt for any commuting pattern that does not involve the CBD area. Thus, the second-best alternative response is to choose the intrazonal CBD commuting. Thus, the dispersion effects in the private CBD cordon are now slightly lower than the effects under the case of a

Figure 5.4: Employment Changes under the Inelastic Location Demand



Note: The X-axis for the CBD cordon toll simulation indicates the toll level for cars in thousand rupiah, while for others it represents the percentages of the discount (the CBD area) and percentages of the change (gas price increase). Employment changes in the CBD zone are shown in the Y-axis on the right-hand side.

flexible location demand. Similarly, the discount on the area toll negatively affects, albeit in an incremental pace, the CBD employment. The employment changes under the policy mix also reflect a similar logic: a 100-percent increase of the gas price leads to a 1.5-percent decrease of the suburban residents, which is slightly lower than the 1.6-percent decrease under the flexible regime.

I find a significant difference of employment changes under the general gas tax policy. The CBD employment decreases while the opposite occurs under an elastic residential location demand. Recall that the general response to the gas tax is to shorten the travel distance. Our target in residential density implies that 47 and 53 percent of the total residents live in Jakarta and the suburban areas, respectively. A relatively even residential distribution between the two residential zones indicates not only an increase in suburban employment but also that some suburban workers alternate their working places from the CBD and the SBD zones to the suburbs.

5.6 Conclusions

In this chapter, I investigate the effects of several road tolls on the residential and the employment patterns of the JMA. All road toll scenarios are simulated under an elastic and an inelastic location demand. I summarize the results as follows.

First, the cordon toll encourages the residents inside the ring to move out, if the cordoned area is relatively small. The opposite occurs as the ring gets wider. This result confirms the basic findings of Eliasson and Mattsson (2001) or Anas and Hiramatsu (2013). However, the opposite results are found when the toll is levied for cars only. The car-based tolls rather disperse and concentrate the residents inside the cordon ring for the smaller and the larger rings, respectively.

Second, if the local authority would rather keep the number of residents in the cordoned area as constant, the area toll scheme can be the alternative. It provides fewer dispersion effects as more discounts are introduced, and thus the simulation provides cutting points that leave the number of residents inside the ring unchanged. Evidently, the magnitude eventually lessens if the toll target is solely focused on the car.

Third, a more compact urban form can be obtained by applying a gas tax policy. The response to higher gas prices is the shortening of the home-work travel distance and the shopping trips, which results in a greater demand from the people for residential zones in the CBD and the SBD. Hence, the gas tax policy would be effective in shaping a more compact city form.

Last, assuming a perfectly inelastic residential location choice allows the workers to exploit fully the opportunity to change their job location choices by anticipating an increase of the generalized travel cost. Hence, in general, the curvature of employment changes does not differ significantly from the results under the flexible residential location choice. An exceptional result concerns the general gas tax policy, which obtains an increased level of suburban employment. However, this does not alter the conclusion that the gas tax policy leads to a reduction of the commuting distance, since half of the JMA residents currently reside in the suburban areas.

Appendix A: Breakdown Results for Each Group of Workers

Table 5.3: Percentage of Change in Residential Density (thousand/km^2) for Each Type of Workers

	no-toll	Scenarios (percent change)							
		Cordon				Area			
		CBD		SBD		CBD		SBD	
		private	car	private	car	private	car	private	car
Low-skilled									
CBD	2.7	-1.2	0.0	1.3	-0.3	-0.7	-0.1	-0.1	-0.6
SBD	2.0	-0.1	0.1	1.5	-0.1	-0.1	0.0	0.4	-0.1
Suburbs	0.6	0.2	0.0	-1.3	0.1	0.2	0.0	-0.3	0.1
	5.0	-0.8	-0.2	0.8	-0.6	-0.5	-0.5	-0.6	-1.2
SBD	3.7	0.0	0.1	1.3	0.0	0.0	0.1	0.5	-0.1
Suburbs	1.2	0.1	-0.1	-1.1	0.1	0.1	0.0	-0.3	0.2
High-skilled									
CBD	1.0	-0.1	-0.2	-0.1	-0.7	0.2	-0.2	-1.1	-1.4
SBD	0.7	0.1	0.2	0.7	0.1	0.0	0.1	0.3	0.0
Suburbs	0.2	0.0	-0.1	-0.5	0.0	0.0	0.0	-0.1	0.1

Table 5.4: Percentages of the Change in Employment Density (thousand/km^2) for Each Type of Workers

	no-toll	Scenarios (percent change)							
		Cordon				Area			
		CBD		SBD		CBD		SBD	
		private	car	private	car	private	car	private	car
Low-skilled									
CBD	11.6	-2.2	0.3	-0.4	0.0	-2.6	0.3	-0.5	0.1
SBD	2.7	0.7	0.1	-0.3	0.2	0.8	0.1	-0.3	0.3
Suburbs	0.3	0.4	-0.6	1.2	-0.4	0.4	-0.5	1.1	-0.8
Middle-skilled									
CBD	21.6	-1.4	0.3	-0.3	0.0	-1.8	0.2	-0.3	0.1
SBD	4.8	0.6	0.2	-0.2	0.2	0.7	0.2	0.0	0.4
Suburbs	0.6	-0.1	-0.7	0.7	-0.5	0.0	-0.6	0.3	-0.9
High-skilled									
CBD	4.1	-0.7	0.3	-0.2	0.0	-1.1	0.2	-0.1	0.1
SBD	0.9	0.5	0.2	0.0	0.3	0.6	0.2	0.2	0.5
Suburbs	0.1	-0.4	-0.7	0.3	-0.5	-0.4	-0.6	-0.4	-1.1

Chapter 6

Conclusions

6.1 Summary of findings

The subject of the ERP plan has been discussed since the early 2000s as one of the transportation policies for controlling the CBD's congestion levels. In recent years, the ERP plan has developed in a concrete way, as the central government passed Government Regulation (PP) No. 32/2011 for Traffic Management and Engineering, which provides a legal framework within which Jakarta's local government may execute the ERP plan. This dissertation develops a SGE simulation to analyze the economic impacts of the ERP plan that are in the forms of welfare gains and the location choices for living and working. The model is built to satisfy the micro foundation of the economic agents, including the consumer's utility maximization, the producer's cost minimization, and the government's transfer behavior. What makes the model different from other spatial equilibrium models is that the JMA has three main transport modes, i.e. the private car, the motorcycle, and the public bus, which significantly differ in size, speed, and comfort. The presence of the motorcycle enables us to introduce simpler tolling system alternatives that focus on cars only; these alternatives have a high performance relative to that of the tolling system that targets both the private car and the motorcycle users. As the heterogeneous characteristics lead to heterogeneous traffic flows, assigning the endogenous PCU assumption is more appropriate. In addition, the limited public bus service burdens the users in the form of the crowding cost of the public bus.

I discuss the effects of the CBD cordon toll plan as proposed by the JETRO in Chapter 3. While charging all private modes for entering the CBD earns the annual gain of 225 thousand rupiah, which amounts to 0.5 percent of the gross annual income, the car-based CBD cordon toll, which levies car users only, surprisingly gives a slightly higher benefit. Although the car-based toll charges a smaller amount of trips than the private-based toll, more motorcycle users enable the car-based toll to acquire more travel time saving than additional public bus users would under the private-based toll. The magnitude is higher if the perceived crowding cost of the public bus is higher. However, at a sufficiently high toll level, the private-based toll will always drive out more private mode users and yield a higher gain than the car-based toll.

In the Chapter 4, I compare the private CBD cordon toll results with those of the gasoline tax policy in the form of an increase in the gas price. Because the nature of the gas tax policy is a distance-based tax that reaches all transport modes, a small increase in the gasoline price to as much as 24 percent is sufficient to match the welfare gain of the CBD cordon toll. Moreover, an even smaller percentage of increase can be sufficient if the gas tax does not directly affect the bus fare.

I examine the long-term impacts of the cordon tolls, the area tolls, and the gasoline tax policies in the form of changes in workers' living and working zone decisions in

Chapter 5. The private CBD cordon and the CBD area tolls costs both the CBD residents and the CBD workers, and tend to drive them out of the CBD. Although the discount of the private CBD area toll reduces residential relocation, it increases job relocation. The car-based tolls lessen the impacts or even generate the opposite effects. The gas tax policy rather forces the workers to shorten their commuting distances, and forms a more compact city. All of these effects are generally stronger under an inelastic residential location demand.

6.2 Policy implications

Table 6.1 reproduces several possible anti-congestion policies that have a similar toll level as the private CBD cordon toll level. The gas price increase is set to as much as 25 percent. The annual welfare gain from the private CBD cordon is estimated as approximately 225 thousand rupiah on average or 0.48 percent of the annual income. The private CBD toll generates higher toll revenues, greater gas consumption reduction of private modes, better private mode control, and higher congestion reduction than the car CBD toll or the gas tax, due to the higher public transport use. Furthermore, it controls more of the CBD's traffic congestion. The private CBD area allows the CBD residents to enjoy a higher benefit than they would receive under the private CBD cordon. The car tolling policy has strong advantages over private tolling in the areas of simplicity, welfare gain, travel time saving, and the benefit distribution to the CBD residents. Meanwhile, the gas price is the least costly policy, since it does not require any additional infrastructure to support the policy. However, raising the gas price will be more complicated, since the policy must be approved by the House of Representatives. Recall that all road toll scenarios in Table 6.1 require an infrastructure system, such as gantries and a sensor and information system; furthermore, the private CBD toll will cost more because it covers more trips than the car CBD toll.

Table 6.1: Simulation Results of the Cordon Toll, Area Toll, and Gasoline Tax

	private CBD cordon	car CBD cordon	private CBD area	car CBD area	25% gas tax
Toll level					
car	15.0	15.0	15.0	15.0	-
motorcycle	5.0	-	5.0	-	-
Discount (percent)	-	-	50.0	50.0	-
Gas price increase (percent)	-	-	-	-	25.0
Annual welfare gain (thousands rupiah)	225.7	259.2	216.8	238.7	257.4
Annual toll revenue (trill. Rp)	2.3	0.6	2.1	0.7	0.0
Percent gas consumption reduction (private mode)	6.5	5.5	5.7	5.0	5.6
Share of public bus use	29.1	27.5	28.8	27.4	27.5
Percent congestion reduction					
CBD	20.8	18.0	17.5	16.3	5.3
JMA	5.1	5.3	4.7	4.8	5.1
Average daily travel time saving (minutes)	8.4	9.5	7.9	8.7	9.4
Benefit distribution					
CBD resident	-2.9	281.2	43.4	204.8	410.2
CBD worker	-131.7	353.8	-232.8	306.3	320.3
Long-term impact on Jakarta					
Residential	(-)	(-)	(-)	(-)	(+)
Employment	(-)	(+)	(-)	(+)	(-)

Note: Sign (+) and (-) in long-term impact session indicate concentration and dispersion effect in Jakarta (CBD+SBD zones) respectively.

Taken into account all of these aspects, the choosing of the appropriate policy hence strongly depends on the underpinning objectives of the local government. If the local government emphasizes the improvement of the CBD congestion and the toll revenue, the private CBD cordon and area are perhaps the better options. An earmarking policy of the toll revenue for the public bus is necessary to increase the acceptance level. It is even more important to the government that the car-based toll attracts greater bus ridership than greater motorcycle use. The gas tax will always be the best option with respect to the benefit distribution, since the tax burden is distributed more equally. The burden is based on the distance traveled, not the origin or the destination. However, as long as the gas tax cannot be administered locally, controlling the gas tax will be much more difficult and less effective for the local government. Massive gas smuggling tends to occur if the gas price in the JMA is higher than in the adjacent regions.

Lastly, the gas tax also has the advantage of promoting a more compact urban form. Gaigne et al. (2012) asserted that there is a wide consensus among international institutions and governments to prefer a more compact city than a dispersed city. Under a compact urban form, there is less travel distance, which reduces more gasoline consumption in the long run.

6.3 Limitations and future research

Although this model introduces many calibration targets, it also has several major drawbacks that limit a deeper analysis. First, congestion externality is the sole source of externality in the model. I do not consider economic density as a type of positive externality in public bus usage. Furthermore, I neglect the possibility of urban agglomeration, particularly in the CBD and the SBD. Introducing urban agglomeration in the model would hypothetically lead to a lower welfare gain, since there would be two types of externalities working in opposite directions. Second, I assume that the city is closed in the sense that any improvement within the city systems has no effect on migration. Yet, in reality, a wider gap in utility between the municipal and the rural areas would directly increase rural migration to an urbanized area. To capture this effect, a bigger model that allows the consideration of the choice to live in urban or rural areas must be introduced. Last, it would be interesting to introduce a peak-load cordon pricing that has a higher price in the morning and the afternoon peaks than in the other periods. It would need a careful and complicated assignment in the zonal trips for each period.

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Appendix A

Algorithm for Calibration

Calibration procedure mainly follows Anas and Rhee (2006). Transportation loop is built in the spirit of Anas and Liu (2007). In essence, there are three nested-loops to be satisfied. First loop is set to meet market equilibrium. Second loop is for the workers' behavior. Last loop is for the transportation sector. All loops keep iterated until satisfy maximum relative error condition. For a given iteration step t and $x_i^1 \in \mathbf{X^1} = \left\{\mathbf{p}, \mathbf{w^f}, \mathbf{R}\right\}$, first loop requires $\max_{\forall_i} |\frac{x_{i,t}^1 - x_{i,t-1}^1}{x_{i,t-1}^1}| < \Xi_1$, where Ξ_1 is tolerance level for loop 1 or the loop keeps continue until $t > t_{max}$. Similarly, the second and third loop are set such that the absolute deviation is less than Ξ_2 and Ξ_3 respectively. For the second loop, the targeted parameters are vectors of expected travel time and travel cost of each $i - j$ trip, or $x_i^2 \in \mathbf{X^2} = \left\{\bar{\mathbf{g}}^{\mathbf{f}}, \bar{\mathbf{G}}^{\mathbf{f}}\right\}$. The last loop targets the zonal flow or $x_i^3 \in \mathbf{X^3} = \{\mathbf{F^z}\}$. The tolerance level and the maximum iteration step are set 10^{-4} percent and 100 respectively. The calibration procedure in detail can be described as follows.

Step 1 (Initialization). This first step is to define the initial values of prices vector $\left\{p, w^f, R, \bar{G}, \bar{g}\right\}$ and parameters. For the values of producer prices p, it is derived once input prices $\left\{w^f, R\right\}$ are determined (initialized).

Step 2 (Worker's utility maximization and commuting arrangement). Given the initial values in Step 1, I calculate the workers' income, the Marshallian demand of final goods, lot sizes, time leisure, and utilities. Vectors of utilities are used as the input for nested-logit decision on the home-to-work commuting arrangement. The home-to-work commuting arrangement and the Marshallian demand of final goods determine the daily commuting and shopping trips respectively.

Step 3 (Transportation equilibrium). Step 1 also gives the initial values of generalized cost and these values determine the mode-route arrangement for each worker. From the mode-route arrangement, the vector of traffic flows and zonal traffic flows are determined. Zonal traffic flows are then determined the congestion level, travel time, PCU, and gasoline cost. The public bus charge is exogenous. Given travel time and other costs, new vectors of generalized cost are updated and re-enter the process until $x_i^3 < 10^4$ or the iteration step reaches 100.

Step 4 (Updating worker's loop). Equilibrium in the transportation loop gives information on the expected annual travel times cost and monetary time costs. These vectors will re-enter the worker loop and the process will keep continue until the tolerance level is satisfied or the maximum iteration step is reached.

Step 5 (Equilibrium in urban economy). Equilibrium for output, labor and land markets is determined. Combining the conditional demand from producers with workers' labor supply satisfies equilibrium in labor markets. Combining the producers' conditional land demand and workers' land demand with total land available satisfies equilibrium in land markets. Equilibrium in output markets is determined by workers' demand and producers' targeted output. New vector of prices and land, labor, and output allocations are determined. The process will stop if the tolerance level is satisfied or the maximum iteration is reached. Figure A.1-A.3 illustrate the algorithm process.

Figure A.1: The Market Equilibrium Algorithm

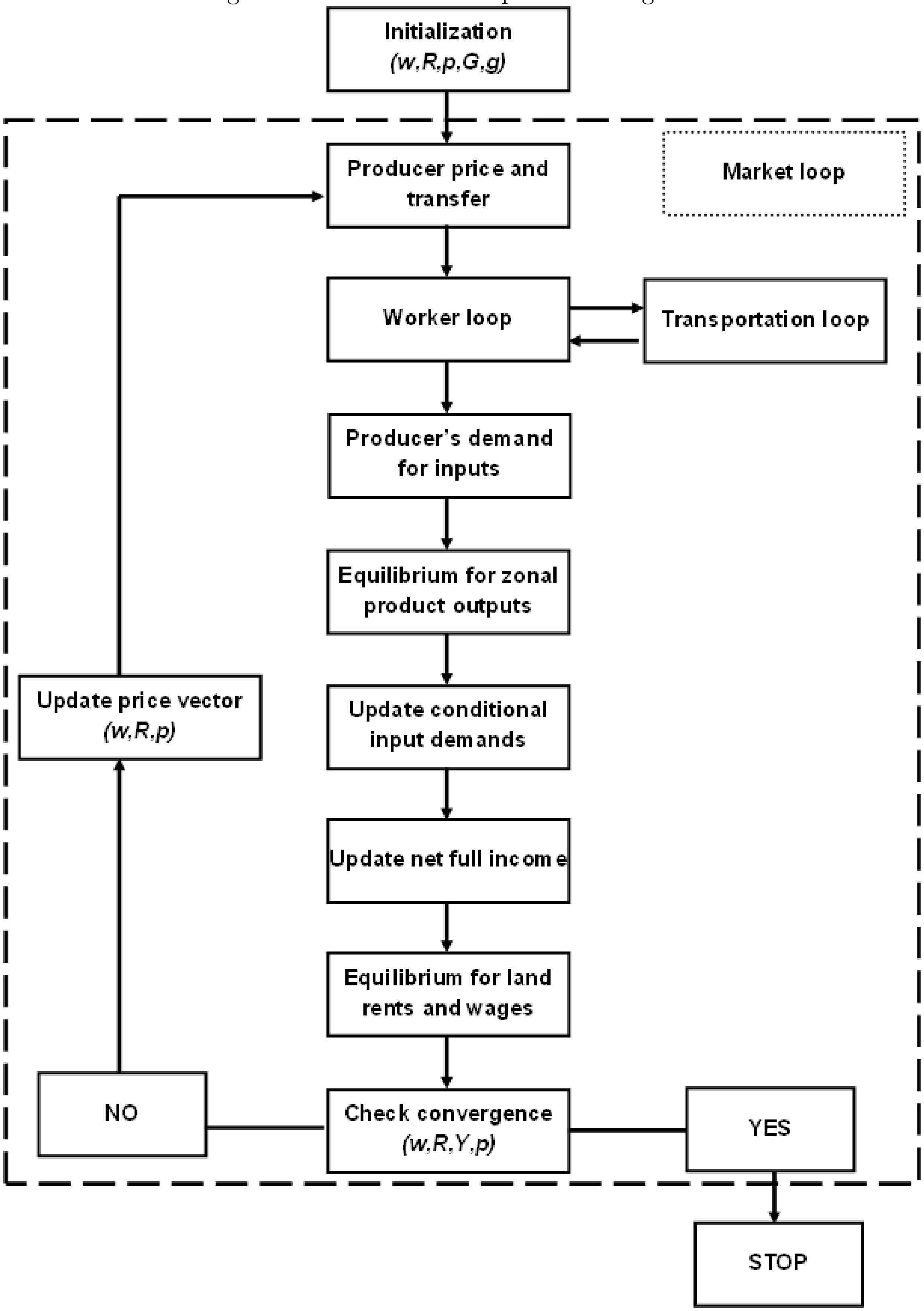


Figure A.2: The Worker Loop Algorithm

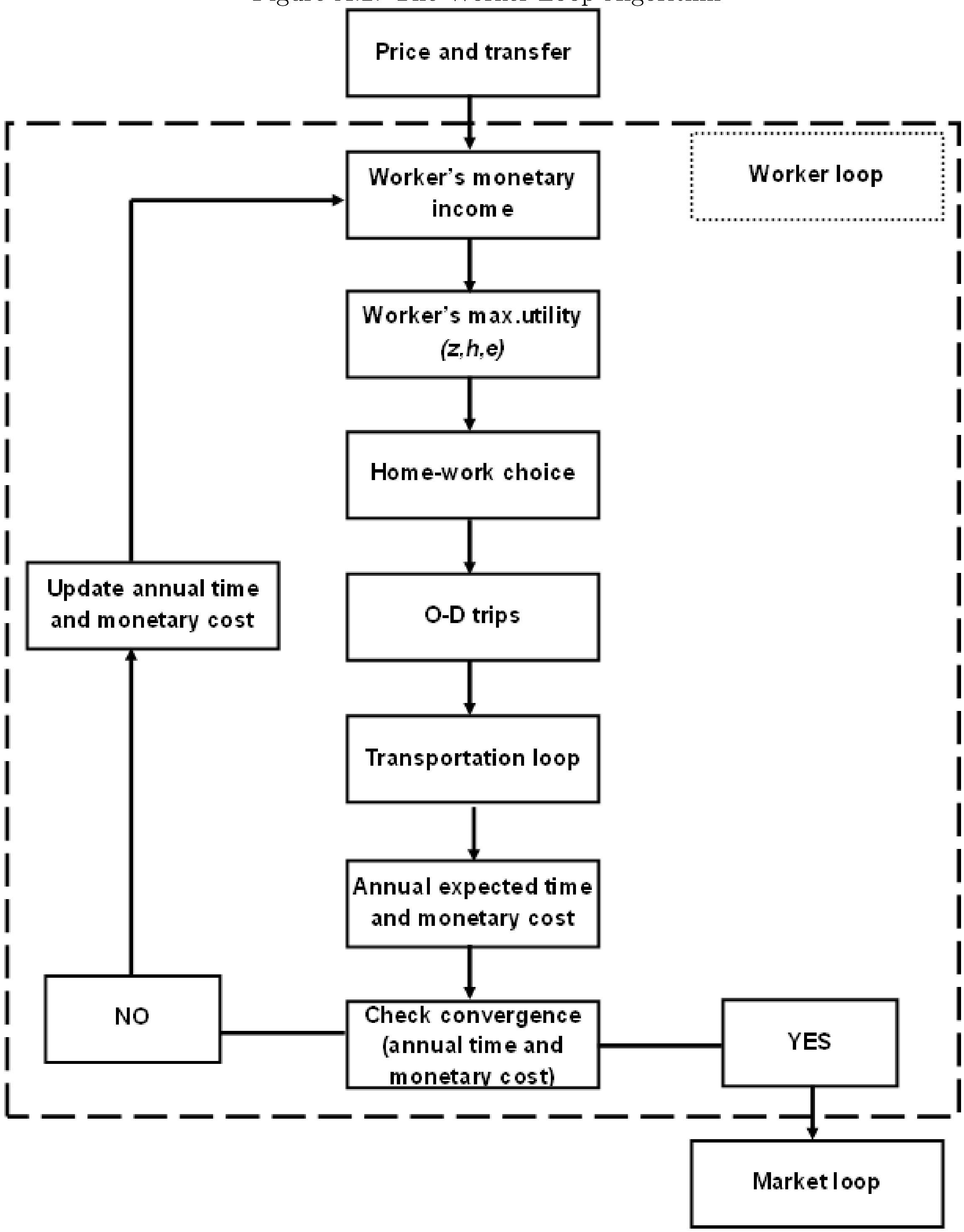
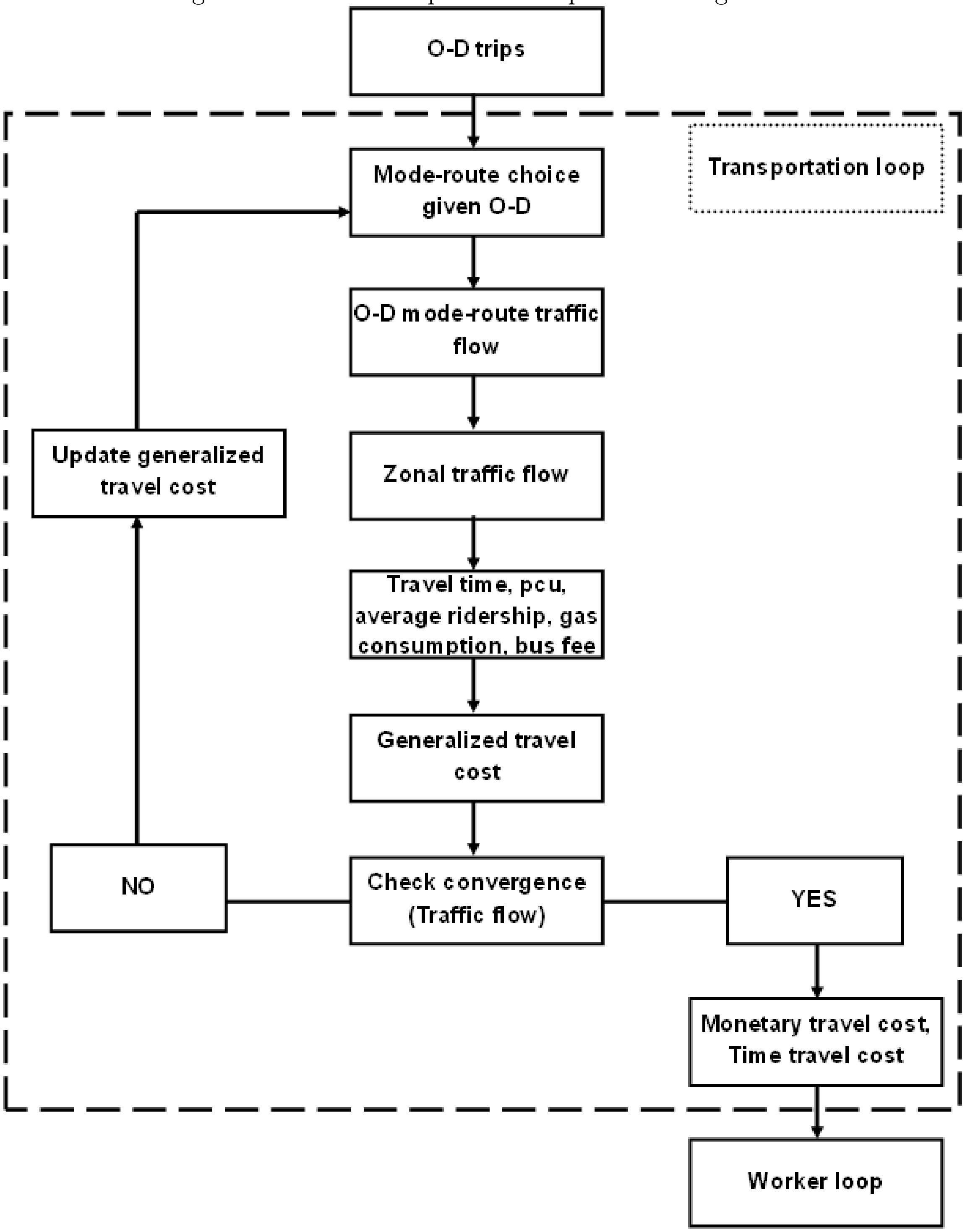


Figure A.3: The Transportation Equilibrium Algorithm



Appendix B

Glossary of Notations and Parameters

B.1 Glossary of notations

Notation	Explanation
	Worker
N^f	number of f-type workers
U	direct utility function
V	indirect utility function
E	expenditure function
z	consumption of final goods
h	land lot consumption
e	leisure
ε	random term in utility function due to home choice
ν	random term in utility function due to work choice
δ_1	proportion of total final goods expenditure from total income
δ_2	proportion of total land lot expenditure from total income
δ_3	elasticity of substitution of final goods
δ_4^f	parameters in utility function of leisure
S	total hours endowment in a year
$\tilde{p}$	consumer delivered price of final goods
$\bar{g}$	expected annual generalized time cost for return trip
$\bar{G}$	expected annual generalized monetary cost for return trip
$\varkappa$	shopping parameter
D	total working days in a year
s	exogeneous daily working hours
λ_1	dispersion parameter of home nest in home-work decision

λ_2	dispersion parameter of work nest in home-work arrangement decision
Λ	probability home/work zone choice to be chosen
	Transport
λ_3	dispersion parameter of transport nest in transport-route decision
λ_4	dispersion parameter of route nest in transport-route decision
Φ	probability a worker choose a mode-route
C	round trip generalized travel cost
Θ	mode choice endowment
O	route choice
ϵ	random term in generalized transport cost due to mode choice
ϖ	random term in generalized transport cost due to route choice
g'	per kilometer travel time
α	parameter in travel time function
ς	per car equivalence unit (pcu)
F	traffic flow
$\tilde{F}$	generalized traffic flow
ρ	values of time for any home-work pair
τ	toll level
ϱ	gasoline consumption (or bus fare)
ϱ'	per kilometer gasoline consumption (or bus fare)
σ	parameters in gasoline consumption − travel speed function
ϕ	parameter of crowding cost
ι	average ridership
	Producer
Y	aggregate regional production function
B	Solow residuals
M	employment input
L	land input
μ^f	proportion of f-th employment cost from producer's total revenue
η	proportion of land cost
w	worker's wage
R	land rent
p	producer's price
	Government
Δ	lumpsum transfer
CV	compensating variation
	Urban structure
A_k	total land available in region k
K_k	total road allocation in region k

d_k	diameter length of region k

B.2 Values of parameters

Urban structure					
$A_1 = 50$	$A_{2-4} = 200$	$A_{5-10} = 200$	$d_1 = 50$	$d_{2-4} = 200$	$d_{5-10} = 200$
$K_1 = 50$	$K_2 = 50$	$K_3 = 50$	$K_4 = 50$	$K_{5-10} = 50$	
Producer					
$B_k = 1$					
$\eta_1 = 0.12$	$\eta_{2-4} = 0.19$	$\eta_{5-10} = 0.67$	$\mu_1^1 = 0.30$	$\mu_{2-4}^1 = 0.28$	$\mu_{5-10}^1 = 0.12$
$\mu_1^2 = 0.48$	$\mu_{2-4}^2 = 0.44$	$\mu_{5-10}^2 = 0.18$	$\mu_1^3 = 0.10$	$\mu_{2-4}^3 = 0.09$	$\mu_{5-10}^3 = 0.03$
Worker					
$N = 9.200.000$	$N^1 = 0.11N$	$N^2 = 0.58N$	$N^3 = 0.31N$		
$\delta_1 = 0.8$	$\delta_2 = 0.2$	$\delta_3 = 0.6$	$\delta_4^1 = 0.15$	$\delta_4^2 = 0.30$	$\delta_4^3 = 0.50$
$S = 6000$	$\bar{e} = 1000$	$s = 8$	$D = 250$	$\lambda_1 = 2.7$	$\lambda_2 = 3.5$
Transport					
$\lambda_3 = 7.5$	$\lambda_2 = 12$	$\varsigma_1 = 1.0$	$\varsigma_2 = 0.25$	$\varsigma_3 = 1.7443$	$\hat{g} = 0.15$
$\iota_1 = 1.84$	$\iota_2 = 1.342$	$\iota_3 = 25.24$	$\kappa = 0.07$	$\varkappa = \frac{1}{25}$	
$\bar{\sigma}_1 = 0.2648$	$\bar{\sigma}_2 = 0.062$	$\bar{\sigma}_3 = 0.85$	$\hbar_{ij1o}^1 = -0.17$	$\hbar_{ij1o}^2 = -0.03$	
$\bar{\varsigma}_1 = 1.091$	$\varsigma_1^1 = -0.0092$	$\varsigma_1^2 = -0.0102$	$\varsigma_1^3 = 0.0161$	$\varsigma_1^4 = 5.10^{-5}$	
$\bar{\varsigma}_2 = 0.3073$	$\varsigma_2^1 = -0.1459$	$\varsigma_2^2 = 0.0962$	$\varsigma_2^3 = -0.0152$	$\varsigma_2^4 = 4.10^{-4}$	
$\bar{\varsigma}_3 = 1.7443$	$\varsigma_3^1 = 0.2634$	$\varsigma_3^2 = -0.1233$	$\varsigma_3^3 = 0.0161$	$\varsigma_3^4 = -4.10^{-4}$	
$\sigma_1^1 = -0.0082$	$\sigma_1^2 = -0.001$	$\sigma_2^1 = 8.10^{-5}$	$\sigma_2^2 = 10^{-5}$		
$\alpha_{11} = 65$	$\alpha_{12} = 55$	$\alpha_{13} = 55$	$\alpha_{14} = 55$	$\alpha_{15} = 50$	$\alpha_{16} = 50$
$\alpha_{17} = 50$	$\alpha_{18} = 50$	$\alpha_{19} = 50$	$\alpha_{110} = 50$		
$\alpha_{21} = 55$	$\alpha_{22} = 50$	$\alpha_{23} = 50$	$\alpha_{24} = 50$	$\alpha_{25} = 45$	$\alpha_{26} = 45$
$\alpha_{27} = 45$	$\alpha_{28} = 45$	$\alpha_{29} = 45$	$\alpha_{210} = 45$		
$\alpha_{31} = 45$	$\alpha_{32} = 40$	$\alpha_{33} = 40$	$\alpha_{34} = 40$	$\alpha_{35} = 35$	$\alpha_{36} = 35$
$\alpha_{37} = 35$	$\alpha_{38} = 35$	$\alpha_{39} = 35$	$\alpha_{310} = 35$		
$\alpha_2 = 1.05$	$\alpha_4 = 2$	$\alpha_{31} = 0.069$	$\alpha_{32} = 0.0368$	$\alpha_{33} = 0.0368$	$\alpha_{34} = 0.0368$
$\alpha_{35} = 0.0219$	$\alpha_{36} = 0.0219$	$\alpha_{37} = 0.0219$	$\alpha_{38} = 0.0219$	$\alpha_{39} = 0.0219$	$\alpha_{310} = 0.0219$