

UC Berkeley

UC Berkeley Electronic Theses and Dissertations

Title

Analyzing the Structure of Informal Transport: The Evening Commute Problem in Nairobi, Kenya

Permalink

<https://escholarship.org/uc/item/09h9f1jk>

Author

Chavis, Celeste

Publication Date

2012

Peer reviewed|Thesis/dissertation

**Analyzing the Structure of Informal Transport: The Evening Commute
Problem in Nairobi, Kenya**

by

Celeste Chavis

A dissertation submitted in partial satisfaction of the
requirements for the degree of

Doctor of Philosophy
in

Engineering – Civil and Environmental Engineering

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA, BERKELEY

Committee in charge:

Prof. Carlos Daganzo, Chair

Prof. Mark Hansen

Prof. Daniel Chatman

Fall 2012

Analyzing the Structure of Informal Transport: The Evening Commute Problem in
Nairobi, Kenya

Copyright © 2012

by

Celeste Chavis

Abstract

Analyzing the Structure of Informal Transport: The Evening Commute Problem in
Nairobi, Kenya

by

Celeste Chavis

Doctor of Philosophy in Engineering – Civil and Environmental Engineering

University of California, Berkeley

Prof. Carlos Daganzo, Chair

In many parts of the world, particularly in developing countries, informal privately-operated transportation plays an integral role in people's mobility. This study systematically analyzes the development and structure of informal transit systems as a function of the network, user, and modal characteristics for an evening commute problem along a linear corridor where passengers originate uniformly from a central business district and have destinations uniformly distributed along the corridor. The model jointly takes into account user mode choice and operator fare and frequency decisions. Three types of operators each with different objectives are analyzed: (1) informal transit with competing operators, (2) a welfare-maximizing government, and (3) a private monopoly or company. Policies, such as fare regulation and vehicle licensing schemes, are presented to help rationalize private and informal transit service using a government-operated service as the baseline. The use of continuum approximation tools allow for a 2-D graphical representation of the regulatory environments. Using Nairobi, Kenya as a case study, it was concluded that with proper regulation and oversight informal transit can perform similar to publicly provided transit.

To my parents for their love and support
and to my grandparents for their example and encouragement.

Contents

Contents	ii
List of Figures	iv
List of Tables	v
Acknowledgments	vi
1 Introduction	1
1.1 Background and Motivation	1
1.1.1 Overview of Informal Transit	1
1.1.2 Pros & Cons of Informal Transit	2
1.1.3 Organizational Structure & Operation	3
1.1.4 Regulating Informal Transit	4
1.2 Existing Literature	6
1.2.1 Socially Optimal Transit Design	6
1.2.2 Modeling Competition	7
1.2.3 Gaps in the Literature	7
1.3 Scope of Study	8
1.3.1 Dissertation Outline	8
2 Model Formulation	9
2.1 Study Site: Nairobi, Kenya	9
2.2 Basic Model	12
2.2.1 User Model	12
2.2.2 Operator Model	15
3 Comparing Operating Regimes	19
3.1 Government Baseline Regimes	19
3.1.1 Welfare of Transit Users and Passengers	20
3.1.2 Total Welfare Across All Modes	22
3.1.3 Sensitivity to Operating Cost	23
3.2 Company Regime	23
3.3 Informal Transit Regime	25

4	Regulating Informal Transit	30
4.1	Self-Regulation: Associations and Cartels	30
4.2	Government Imposed Regulation	31
4.2.1	Goals	31
4.2.2	Measures of Improvement	33
4.2.3	Types of Regulation	33
4.2.4	Enacted Regulation in Nairobi	34
4.2.5	Results	34
4.3	Other Policy Interventions	40
4.3.1	Increasing Wages	43
4.3.2	Increased Density	43
5	Conclusions	45
5.1	Summary & Insights	45
5.2	Future Work	46
	Bibliography	47
A	Variable List	49
B	Sensitivity of Surplus to Fare	51
C	Input Parameters	54
C.1	User Characteristics	54
C.2	Route Characteristics	55
C.3	Operator Costs	56
D	Results	60

List of Figures

1.1	Urban population by Major Geographical Area	2
2.1	Map of Nairobi, Kenya	10
2.2	Map of <i>Matatu</i> Routes	11
2.3	Diagram of Model	12
2.4	Corridor	13
2.5	User Mode Choice	14
3.1	Decision Space (14 seats): Government Regimes	21
3.2	Decision Space (14 seats): Company Regime	24
3.3	Decision Space: Informal Regime	26
3.4	Minimum Profit Margin vs. Number of Buses and Hourly System Profit	28
4.1	Visualization of Regulatory Goals	32
4.2	Fare and Headway Regulation Decision Space for Informal Transit without Seatbelt Requirements (14 seats)	35
4.3	Fare and Headway Regulation Decision Space for Informal Transit with Seatbelt Requirements (14 seats)	36
4.4	Optimal Solutions under Fare and Headway Regulation for Informal Transit (14 seats)	37
4.5	Optimal Solutions under Fare and Headway Regulation for Informal Transit with Seatbelt Enforcement (14 seats)	38
4.6	Fare and Headway Regulation Decision Space without Seatbelt Re- quirements (25 seats)	39
4.7	Fare and Headway Regulation Decision Space with Seatbelt Require- ments (25 seats)	39
4.8	Optimal Solutions under Fare and Headway Regulation for Informal Transit with Seatbelt Enforcement (25 seats)	41
4.9	Optimal Solutions under Fare and Headway Regulation for Informal Transit with Seatbelt Enforcement(25 seats)	42
B.1	User Mode Choice	52
D.1	Decision Space and Equilibrium Solutions (25-seats): Government Regime	62

List of Tables

1.1	Classes of informal transport	3
1.2	Types of regulation	5
2.1	Operating regimes	16
3.1	Bus operating input parameters	19
3.2	Shortsighted government results (14 seats)	22
3.3	Government results (14 seats)	23
3.4	Company results (14 seats)	24
3.5	Informal transit results	27
3.6	Informal transit results under extortion (25 seats)	29
4.1	Self-regulation results	31
4.2	Informal transit regulation results (14 seats)	36
4.3	Regulated results (25 seats)	40
4.4	Results with a Shorter Route with Increased Demand	44
C.1	User and route characteristics	54
C.2	List of all bus operating costs	59
D.1	Shortsighted government baseline results (detailed)	60
D.2	Government baseline results (detailed)	61
D.3	Company/cartel results (detailed)	61
D.4	Informal transit results with full competition (detailed)	63
D.5	Equilibrium solutions with concentrated demand	63

Acknowledgments

This thesis would not have been possible without the efforts, guidance, and support of many. First and foremost, I would like to express my sincere gratitude to my adviser, Prof. Carlos Daganzo, for being an exemplary example of a researcher and for always being available to his students. In addition, I'd like to thank my committee members Prof. Mark Hansen and Prof. Daniel Chatman for their guidance and insight. I would also like to acknowledge my financial supporters the Institute of Transportation Studies, The Ford Foundation, and the National Science Foundation.

Many have supported me throughout this time near and far. I am grateful for the my surrogate California family whom are too many to name. These people include members of the Black Graduate Engineering and Science Students (BGESS) organization, Black Graduate Students Association (BGSA), Berkeley Scholars to Cal, and my colleagues in the Institute of Transportation Studies (ITS). Special thanks are due to my officemates Vikash Gayah, Eleni Christofa, and Karthikgeyan Sivakumaran. We began as officemates but left as collaborators, supporters and most importantly, lifelong friends. Other people in ITS that I must express gratitude towards are Tierra Bills, Eric Gonzales, Ilgin Guler, Prof. Joan Walker and Prof. Alex Skarbadonis. And to my neighbor, Josephine Masabala, thank you for opening your home and heart to me during my time at Cal. And though we've been separated by distance thanks are due to Celina Dozier and Bryan Ellis for always lending an ear and helping me navigate the PhD process.

I must take the time to show my appreciation to those who first introduced me to the possibility of pursuing my PhD - Dr. Oliver McGee and Dean Minnie McGee. Dr. McGee your love of research and dedication to your students is unmatched. And to Dean McGee, thank you pushing your students to excel in ways we never thought possible all while never forgetting that 'To whom much is given, much is expected'. Lastly, but most importantly, to my parents Craig and Bonita Chavis and to my brother Craig Jr., without your love and encouragement I would not be where I am today.

Chapter 1

Introduction

1.1 Background and Motivation

In many parts of the world, particularly in developing countries, informal privately-operated transportation plays an integral role in people's mobility. Informal transport operates illicitly and recklessly, unchecked by government regulation. Characterized by small vehicle, bare-bone service, these vehicles are common across the globe. Informal transport is prevalent in Africa, Latin America, and the Caribbean. These systems may be the primary mode of transport (e.g. the *matatus* in Nairobi), provide feeder services (e.g. Hong Kong light buses), or serve niche markets (e.g. Little Cuba cabs of Miami).

These systems, which have many colloquial names such as *dala-dala* (Tanzania), *jeepney* (Philippines), *robot* (Jamaica), and *tro-tro* (Ghana), provide mobility to the transit captive. Despite the prevalence of such systems many governments have had difficulty in rationalizing the systems from a policy point of view. Some local authorities, particularly in the poorest parts of the world, have allowed the informal transport sector evolve with little regulation and oversight and are content to let it exist on the margins of society. Much of this is due to the poorly understood benefit-cost nature of informal transport (Cervero & Golub, 2007).

Though these systems are a primary source of mobility for millions of people across the globe, they have many drawbacks particularly pertaining to safety and congestion. Governments are now at a crossroads with informal transit. And as evidenced in Figure 1.1 this problem is of growing importance as populations continue to migrate to urban areas, particularly in Asia and Africa, thus increasing demand for informal transport.

1.1.1 Overview of Informal Transit

There are various types of informal transit ranging from minibuses to pickups to motorcycles. Many informal transport modes are not subject to a fixed route. The amount of flexibility varies; while some vehicles have fixed routes along popular cor-

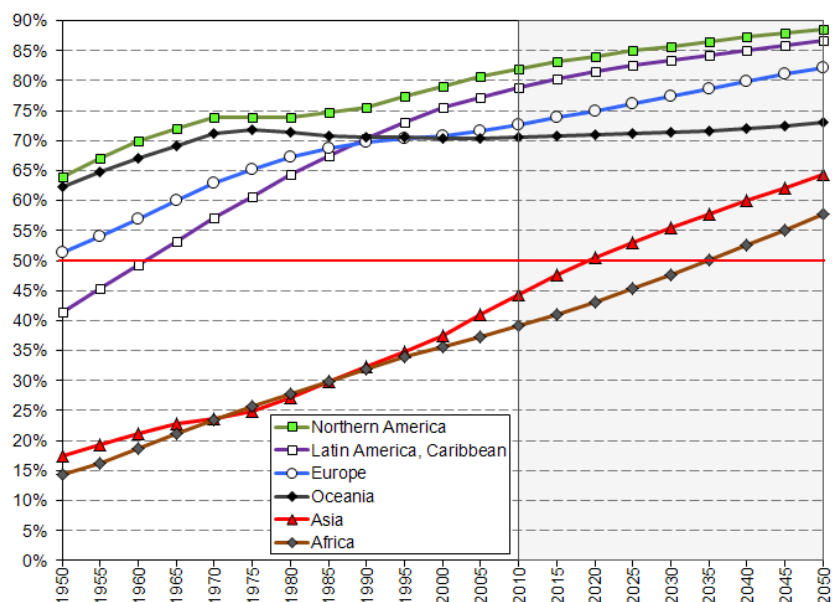


Figure 1.1. Urban population by Major Geographical Area (in per cent of total population) (Source: United United Nations (2011))

ridors, others, generally smaller vehicles, have variable, demand responsive routes. In addition to the routes, the size of the vehicle varies, with vehicles ranging from motorcycles to minibuses. Smaller vehicles tend to be used as feeder systems for fixed-route public transit. The range in vehicle size reflects the service niche and coverage area as seen in Table 1.1. This study focuses on fixed-route minibuses as they are the closest comparison to traditional publicly provided fixed-route systems. Minibuses also follow fixed routes though some deviation may be allowed during off-peak hours. They tend to have a capacity up to 25 passengers but may hold up to 50 passengers with standees. Fares are generally fixed for route-based services (minibus and microbus) but are variable for smaller, flexible-route services.

1.1.2 Pros & Cons of Informal Transit

The prevalence of informal transit can impose significant costs to passengers, as the lack of oversight can lead to erratic scheduling and service, and poor safety. Moreover, the abundance of vehicles causes congestion and pollution. Due to cutthroat competition that results in low profit margins, aggressive driving and inadequate investment in safety and insurance is common. This also leads to disorderly operations such as cutting routes short in order to serve the profitable direction and waiting at the terminal until vehicles are full before departing. The lack of accountability and captivity to these systems makes it difficult for passengers to express complaints, and drivers are subjected to working long hours at low wages (Cervero, 2000). In Latin

Table 1.1. Classes of informal transport (Source: Cervero & Golub (2007))

<i>Class</i>	<i>Routes</i>	<i>Schedules</i>	<i>Capacity</i>	<i>Niche</i>	<i>Coverage</i>
Minibus/ Jitney	Fixed	Semi-fixed	12-25	Line-Haul & Distribution	Subregion
Microbus/ Pickup	Fixed	Semi-fixed	4-11	Distribution	Subregion
3-wheeler/ Motorcycle	Variable	Variable	1-4	Feeder	Neighborhood
Pedicab/ Horse-cart	Variable	Variable	1-6	Feeder	Neighborhood

America the stiff competition for passengers is known as ‘*la Guerra del Centavo*’ or ‘the war for the cent’.

Despite all these disadvantages, informal transit has many benefits. Informal transportation provides service coverage when government agencies lack the capital and/or organization. They are important as their maneuverable, small and low cost vehicles provide much needed mobility, particularly to the poor. In addition, informal transit can fill important gaps in the market. Private operators are more responsive to changes in the market and, by organizing into cooperatives and route associations, can provide service with relatively low costs per-seat. In addition, smaller vehicle sizes allow for reduced headways and therefore, reduced overall travel times (Cervero & Golub, 2007).

1.1.3 Organizational Structure & Operation

Due to the fragmented nature of informal transport systems their operations are complex as many stakeholders are involved. Unlike formal public transport which is vertically integrated, consisting of management on top and vehicle operators at the bottom, informal transport is horizontally structured with decisions distributed among various stakeholders. The following are the key stakeholders in the informal transport industry:

- Owners
- Operators (drivers and conductors)
- Passengers
- Cooperatives & Route Associations
- Government
- Enforcement officers.

Additionally, other stakeholders such as vehicle importers, petroleum workers, stage workers, etc. are also impacted by the industry. Each stakeholder is jockeying for a piece of this lucrative industry.

Minibus ownership is dispersed as 80% of owners only have one vehicle (Kumar & Barrett, 2008) and it is common for owners to rent out their vehicles to drivers, with the exception being in Latin America where many vehicle owners are also the primary

operator. When owners employ drivers, owners must align drivers' incentives with their objective of maximizing profit. This results in drivers paid a variable salary that either depends on the total revenue for the day or fixed on the realization of the daily target which is typically around 20-25% of the expected gross daily revenue (Cervero, 2000). Drivers not only need to make the day's target, but are also expected to cover day-to-day expenses such as fuel, minor maintenance, and bribes to enforcement officers. This results in marginal profits at best. It also causes drivers to compete with other drivers for passenger since the effort the driver makes to seek potential passengers on the road directly affects the profits made. This results in the collectively damaging behavior that minibuses are known for.

One way the informal transit industry tries to alleviate these negative impacts is by self-regulating, e.g. by organizing themselves into route associations or cooperatives. These are a key component to the success and viability of informal transport. They operate terminals on the behalf of vehicle owners, helping to ensure somewhat equitable splits in profit and enforcing civility amongst members. Owners typically pay a membership fee and sometimes drivers pay a fee each time the terminal is accessed. Routes tend to run between terminals operated by a cooperative and vehicles are loaded in strict rotation. This helps prevent passengers from rejecting vehicles in poor condition (Kumar & Barrett, 2008). Moreover, the fact that drivers often pay a fee for each trip encourages them to leave only with full vehicle loads, which increases passenger wait times.

Unfortunately, route associations have the tendency to morph into competition stifling cartels. These cartels may prevent competition by limiting entry and/or by fixing fares. From Mexico City's route associations that have frozen vehicle permits to the violent turf wars of South Africa's minibus industry, examples are present across the globe. The collectively damaging behavior of informal transit systems and the ease with which route associations can evolve into cartels have led many governments to regulate informal transit. Passengers, who are predominantly captive users, are largely without a voice in the informal transport industry. Because of this, governments must serve as their voice via regulation. However, passengers are not the only stakeholders that may benefit from regulation.

1.1.4 Regulating Informal Transit

“Corruption and the police and these gangs is the biggest problem and the biggest obstacle that there is in our business and dealing with these people on a daily basis, it's hard because if [you] fail the full protection fee, that is you putting your life on the line. If you fail to bribe the police you're going to end up in jail. Okay, now if you drive carelessly you're going to end up in the hospital or in the mortuary. So our job, there are a lot challenges in our job but it is the only job that is available.”
(Healy, 2012)

- James Kariuki, driver

As expressed in that quote from James Kariuki, a minibus driver in Kenya, these systems are plagued with corruption and predatory practices from a variety of sources

Table 1.2. Types of regulation

QUALITY	QUANTITY	PRICING
Vehicle standards	Market entry	Setting or restricting fares
Insurance coverage	Allocating routes	Providing subsidies
Operator qualifications	Franchising & tendering	
Limiting driver hours		

such as police and gangs. Though drivers are often to blame for the poor safety record of informal transit, they are working within their environment. Governments thus must decide how best to handle the presence of such systems and are faced with four options: acceptance, recognition, regulation, and prohibition (Cervero, 2000). Acceptance and prohibition represent the two extremes: acceptance assumes that the government accepts the necessity of informal transit and imposes no regulation while prohibition bans informal transit all together. Recognition provides rules and standards mainly pertaining to safety, vehicle specification, and labor practices but lets the market set supply; whereas regulation also controls market entry and exit.

According to Iles (2005), types of regulation typically fall into three broad categories: quality, quantity, and pricing. Quality regulation, the most widely accepted, pertains to regulation that improves safety and the environment such as vehicle inspections or crew licensing. Quantity standards tend to deal more with correcting market forces by setting the extent of services provided, for example, the number of vehicles, the service frequency, and route licenses. Lastly, governments may also control fares and provide subsidies if needed. Table 1.2 groups various types of regulatory measures according to these categories.

Competition must be maintained in order to create incentives for efficient operation. Competition can take two main forms. “Competition in the market” encourages competition between operators and/or modes. In completely liberalized markets both entry and fare may be uncontrolled, though qualitative standards may still be set. However, in other instances fares and routes may be determined by the regulatory agency. Under “competition for the market”, a particular area is contracted out to a monopoly operator for a specified amount of time. The authority has the power to determine routes and fares if desired.

For regulation to work governments must have the institutional capacity to enforce and monitor the regulations. There are many examples of how a lack of oversight allows corrupt officials to pocket money that could instead be used by the government or owners and operators to improve services. In addition, past experience has shown that there may be adverse effects from regulation. For example, fare regulation may lead to route proliferation in order to encourage multiple transfers (Kumar & Barrett, 2008).

1.2 Existing Literature

One can see from the previous overview that informal transit is complex in nature and vital to the mobility of many across the globe despite their inherent problems. Many studies (Gwilliam, 2003; Iles, 2005; Cervero, 2000; Kumar & Barrett, 2008) provide comprehensive reviews of informal transit systems, and some (Aligula *et al.*, 2005; Chitere & Kibua, 2004; Kimani *et al.*, 2004) are specific to our study site of Nairobi, Kenya. This literature provides rich case studies and accompanying recommendations - most of which pertain to the regulation of such systems. On a more generic vein, Cervero (2000); Cervero & Golub (2007) discuss how various forms of regulation can improve informal transit. Earlier Gwilliam & Scurfield (1996) not only looks at the effects of regulation to the informal sector, but also explores the benefits of deregulating urban public transport by considering the extent to which regulatory reform may improve performance and the nature of the regulatory reform necessary to achieve the greatest benefit.

Competitive mass transportation has received little attention in the operations research and modeling literature - particularly when referring to the informal sector. The following discusses the analytical body of literature and can be divided into two broad categories: (1) system optimal design for a given mode; and (2) competition amongst and within particular modes. The latter category is of particular interest when it comes to understanding the informal transit sector. Walking is a mode of interest as non-motorized transport, particularly walking, captures a large share of trips in many developing countries.

1.2.1 Socially Optimal Transit Design

Many idealized models exist that jointly model the generalized operator and user (monetary and time) costs of fixed-route public transport. These studies are of interest because their use of continuum-approximation frameworks allow for generalizable insights. Given the assumption of exogenous demand, Holroyd (1967), Mohring (1972), and Jansson (1980) constructed models that determined the optimal frequency of fixed-route transit systems by minimizing the total generalized system cost. Mohring (1972) analyzed a single corridor and found that when all resources were accounted for, the optimal frequency was proportional to the square root of demand. Jansson (1980) expanded the previous study to determine the optimal fleet size and concluded that observed conventional bus frequencies are generally too low and bus sizes too large. By looking at the welfare-maximizing subsidy level for urban transport, Mohring (1972) and Jansson (1980) determined that due to user economies of scale of public transport, subsidies are necessary to produce socially optimal frequencies.

More recently, Jara-Díaz & Gschwender (2003) extended the model in Jansson (1980) by allowing operating costs to depend on vehicle size and the value of time to depend on a load factor. Van Reeve (2008) found that if demand is dependent on pricing and frequency decisions, then the profit-maximizing frequencies align with

welfare-maximizing frequencies. Though some of the studies account for competition indirectly via elasticity in passenger demand, none directly account for the attributes and costs of competing modes.

1.2.2 Modeling Competition

Viton (1982) presented an equilibrium model for a duopoly of two transit operators, one private and the other public, competing on a simplified corridor. Later, Harker (1988) expanded this model and looked at a network of competing modes. Each mode served a separate, non-overlapping corridor without transfers between modes. Fernandez & Marcotte (1992) presented a fully deregulated network model that took into account competition within and between modes (car and transit). The operators allocated their vehicles to lines in order to maximize profit given that passengers were in user equilibrium and minimized their individual costs. Subsequently, Zubieta (1998) relaxed the perfect competition assumption of the previous study to examine the case where few companies control the transit market.

More recently, by relaxing the exogenous fare assumption and allowing for elastic demand, Zhou *et al.* (2005) extended the Zubieta (1998) model. Zhou *et al.* (2005) assumed operators were allowed to vary only their fare structure as opposed to frequency as seen in earlier works. Along similar lines, Yang *et al.* (2001) developed a model that took into account the effect of value-of-time on the price and frequency of competing bus modes (minibus vs. conventional bus) along a corridor where the buses also compete with private vehicles. In a similar analysis, Gronau (2000), from the perspective of a central transport authority, studied the optimal mix of conventional buses and minibuses when passenger's value-of-time varies.

1.2.3 Gaps in the Literature

The development of transportation networks is complicated and reflects the decisions of multiple entities. Most single-mode, system optimal literature isolates the transit mode and optimizes the system without regard to competing modes. In addition, the assumption of fixed demand in many of the studies is unrealistic. Recent literature pertaining to competition of transit modes attempts to rectify this gap. None of the studies, however, jointly optimize for fare and frequency with varying trip lengths for competing private operators, a welfare-maximizing public operator, as well as a monopoly private operator. In addition, the trade-off between walking and taking transit has not been directly modeled. In many regions where private transport flourishes, people have low wages and have no access to personal vehicles and the modal trade off is primarily between walking and mass transportation. No model in the existing literature considers elastic demand with endogenous fares and frequencies in both regulated and deregulated environments.

1.3 Scope of Study

Unlike previous studies, this thesis develops a continuum-approximation framework that optimizes for fare and frequency for different types of operators in different regulatory environments while taking into account the mode choice decisions of users of the system. For maximum transparency, we consider a simplified problem exhibiting the necessary features. This scenario is the evening commute for a single corridor where commuters travel from a downtown terminal to continuously distributed destinations along its length.

Three idealized operator regimes with different objectives are analyzed: a) informal transit with competition between operators, b) government provided public transport, c) private transport provided by a monopoly, i.e. company. In addition, the study determines which regulatory measures best mitigate the disadvantages of privately provided transport while maintaining its benefits. Policies, such as fare regulation and vehicle licensing schemes, are proposed to help rationalize private and informal transit service. Government-operated service is used as the baseline for comparisons. The use of continuum approximation tools allows for an intuitive 2-D graphical representation of the regulatory environments' performance.

1.3.1 Dissertation Outline

This dissertation analyzes informal transit in an idealized corridor representative of Nairobi, Kenya. The model, however, can be generalized to other locales. Chapter 2 presents the continuum-approximation model which jointly takes into account the mode choice decision of users and the fare and frequency decision of operators under the three operating regimes: informal transit with independent operators, government, and company. The results of the model when applied to Nairobi are presented in Chapter 3. This chapter shows how informal transit operates in the absence of regulation and compares the results to the government and company regimes.

Chapter 4 explores the benefits of various regulatory measures. The following are the regulations analyzed in the study:

- Fare regulation,
- Headway regulation,
- Banning small vehicles,
- Banning overfilling vehicles,
- Changing land use patterns, and
- Increasing wages.

Lastly, Chapter 5 summarizes key findings of the study and outlines future work.

Chapter 2

Model Formulation

The development of transportation networks is complicated and reflects the decisions of multiple entities. Unlike previous works, this study develops a continuum-approximation framework in which fare and frequency are determined endogenously for different types of operators within various regulatory environments, while taking into account the mode choice decisions of users of the system. For maximum transparency, we consider a simplified problem exhibiting the necessary features. This scenario is the evening commute for a single corridor where commuters travel from a downtown terminal to continuously distributed destinations along its length, as in Figure 2.4.

The model simultaneously represents the decision processes of both the users and operators in an equilibrium framework. Users choose the trip option that minimizes their generalized costs, or conversely maximizes their utility, given the fare and vehicle frequency of service provided by operators. Operators aim to set the fare and frequencies that maximize their objective. A generic system with independent operators is compared to systems run by either a private company or a welfare-maximizing government. Section 2.1 describes the study site for which most comparisons are made. Section 2.2 develops the user cost model in Section 2.2.1 and the operator model in Section 2.2.2. A list of all variables can be found in Appendix A.

2.1 Study Site: Nairobi, Kenya

This study uses the city of Nairobi as a case study. Informal transit in Nairobi is representative of many developing countries. Nairobi has a sparse, radial network that is plagued by congestion. Nairobi, located in eastern Africa, is the economic hub of Kenya. Growth has been rapid as many are migrating from rural areas to the city. Figure 2.1 shows the primary road network in Nairobi. The majority of jobs are located in the central business district (CBD) and with the majority of the population residing outside of the CBD. Of the nearly 4.8 million trips made each day in Nairobi in 2004, only 16% were made in private vehicles; 36% used public transport and 48% were made on foot. Most residents do not have access to private vehicles. The vast

majority (about 80%) of public transport trips in Nairobi are carried by minibuses known as *matatus*. The remaining public transport trips are served by traditional fixed route buses, a commuter rail line, and other shuttle services such as those run by schools. The term *matatu* is a colloquial term that refers to the initial fare charged of 30 cents.

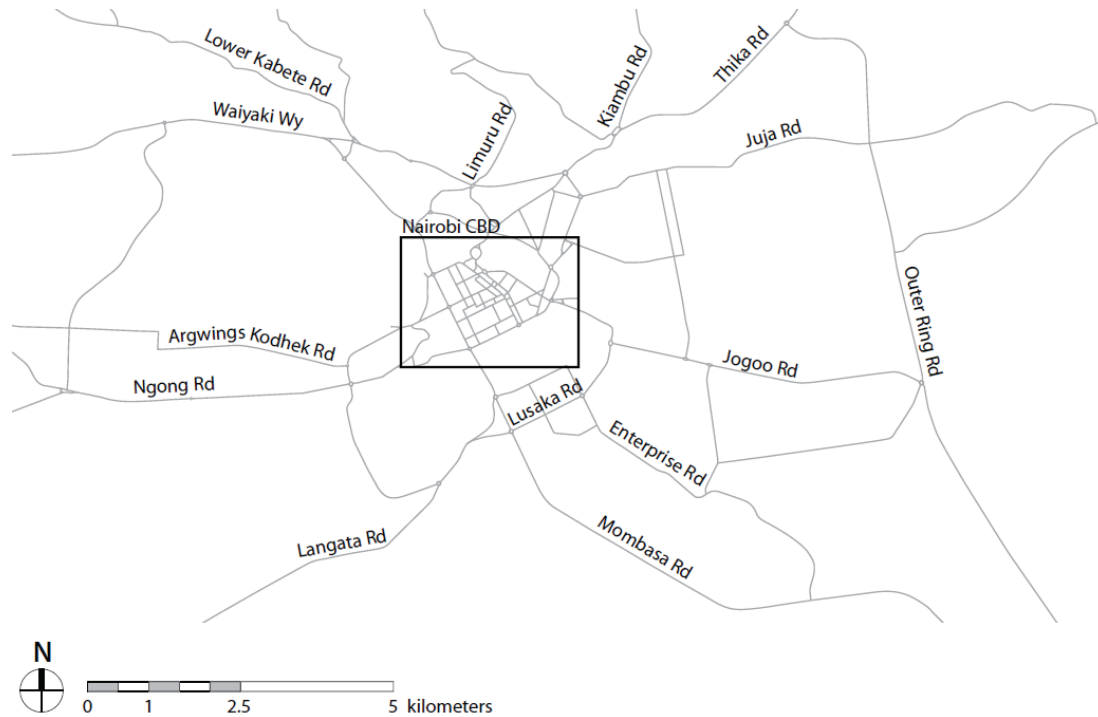


Figure 2.1. Map of Nairobi, Kenya

Prior to 1973, mass transport in Kenya was dominated by a few multinational companies such as the Overseas Trading Company (OTC) and the Kenyan Bus Service (KBS). KBS, though still in existence, experienced a decline in mode share due to the emergence of *matatus* beginning in the 1960s. Post 1973, after a presidential decree legalizing *matatus* as a public service vehicles, the industry grew rapidly. As one can see by Figure 2.2, nearly all routes terminate in the CBD. Though *matatu* terminals exist, buses arbitrarily pick up passengers anywhere along route due to insufficient capacity at the terminal or their desire to bypass queues.

The rapid growth of the industry spurred regulation both internally and externally. Beginning in the 1980s owners began to organize themselves into associations and in the mid-1990s these organizations evolved into Savings and Credit Cooperatives (SACCROS) that are responsible for organizing route-based operations and addressing members concerns. In addition to route-based cooperatives, many owners also belong to one of two main national organizations: the Matatu Welfare Association (MWA) or the Matatu Owners Association (MOA).

Over time government officials began to see the need for regulations as *matatus*

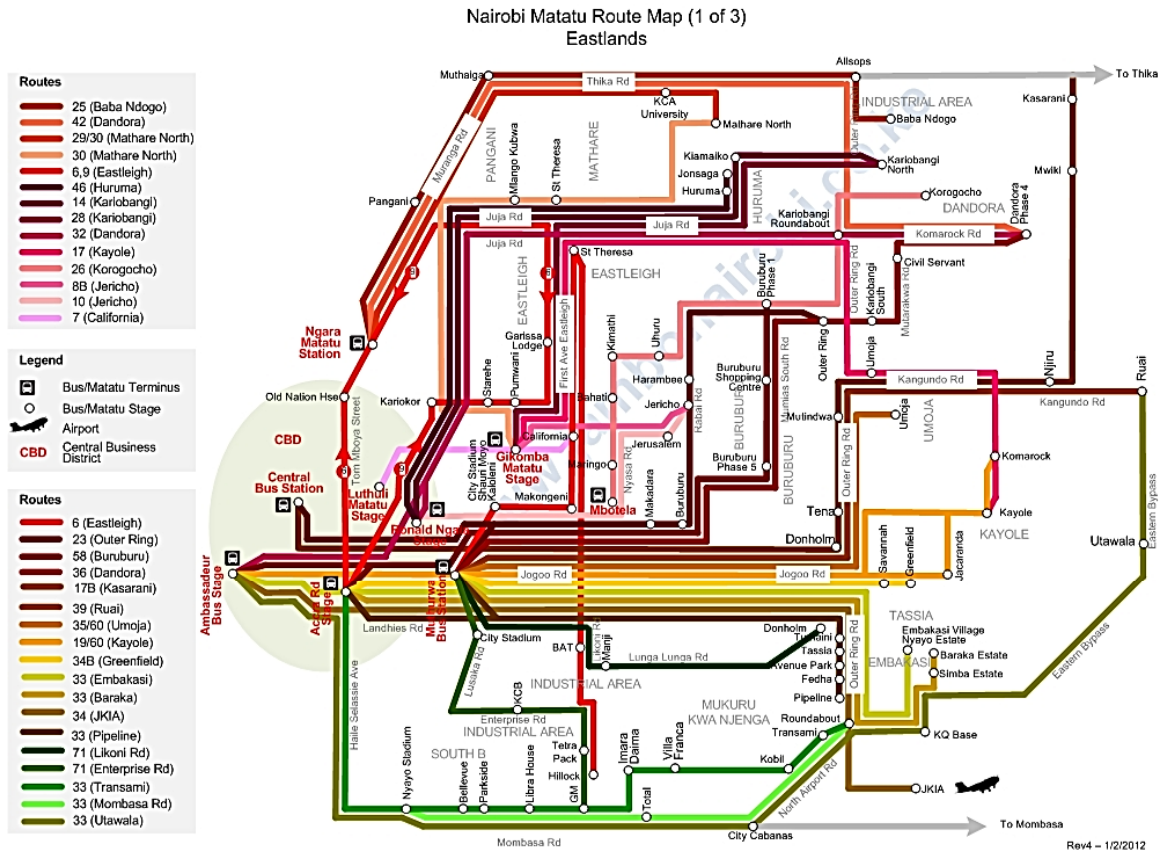


Figure 2.2. Map of *Matatu* Routes Serving Eastern Nairobi (Source: www.jambonairobi.co.ke)

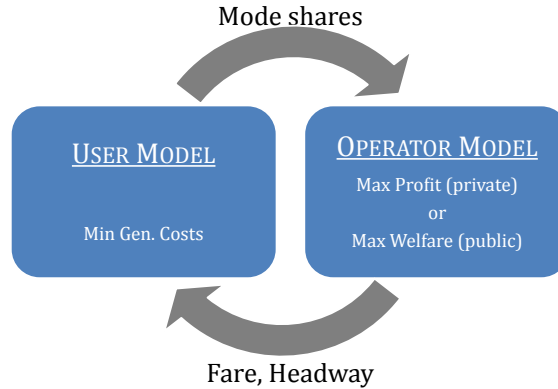


Figure 2.3. Diagram of Model

bore much of the blame for accidents and traffic related fatalities. The Traffic Amendment Act of 1982 recognized *matatus* as public service vehicles (PSVs) and required *matatus* to carry insurance. In 2004 the Michuki Rules which focused on the safety and quality of service were introduced. Speed governors were introduced, vehicle capacity was reduced by requiring seat belts for all customers on board thereby reducing Nissan vehicles to 14 passengers down from 18. Lastly, in 2010, aiming to curb congestion, the government announced a plan to phase out 14-seat *matatus* over 10 years in favor of buses with a capacity greater than 25. One of the major drawbacks of the recent rules and regulations, is that it has allowed for increased corruption by police. Often, instead of imposing fines, police take bribes instead. Many of these recent reforms can be tested using the model developed below.

2.2 Basic Model

The model assumes two sets of decision-makers: the users of the system and the operators of the system. Figure 2.3 represents this simultaneous decision making. We assume that users choose the mode that minimizes their costs based on the fare and frequency decisions of the operators. Section 2.2.1 describes the user model and Section 2.2.2 the operator model. Here we look at in town trips and assume a fixed fare and uniform demand.

2.2.1 User Model

Considered is a linear corridor of length (L) as in Figure 2.4. It is assumed that all potential trips originate from a terminal in the central business district (CBD) to which users arrive at an average rate λL (pax/hr) and that the desired destinations are distributed uniformly along the corridor. The parameter λ (pax/hr-km) gives the number of users wishing to travel to a unit distance along the corridor per unit time. It is assumed that passengers and buses are served in the order they arrive at the

terminal, and that there are a sufficient number of buses on the system such that all demand can be served. Buses charge a fixed fare, F , regardless of trip length. This is typical of many informal transit systems.

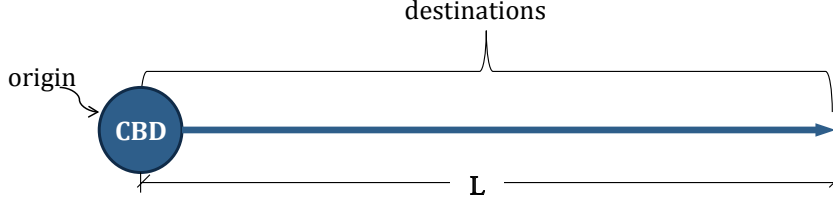


Figure 2.4. Corridor

It is also assumed that potential users do not have access to private automobiles and therefore have three possible options: walk to the destination (w), take a bus to the destination (b), or forgo the trip due to prohibitively high costs (\emptyset). These users are assumed to be identical in all respects except for their destination, to have perfect information, and to choose the option that minimizes their total generalized cost (\$). The generalized cost takes into account all out-of-pocket costs, as well as the times associated with walking, riding, and waiting. These times are converted into monetary costs by multiplying them by appropriate values of time, which have dimensions of (money/time). It is assumed that all users have the same out-of-vehicle value of time (β_o) and in-vehicle value of time (β_i), and receive the same benefit from making the trip ($\$_o$).

The equations for the generalized cost of walking ($\$_w$), bus transit ($\$_b$), and not making the trip ($\$_\emptyset$) are given in the equations below:

$$\$ _w(l) = \beta_o \frac{l}{v_w} \quad (2.1)$$

$$\$ _b(l) = F + \beta_o D + \beta_i \frac{l}{v_b} + \beta_i \tau s(l) \quad (2.2)$$

$$\$ _\emptyset = \$ _o \quad (2.3)$$

where τ = lost time per stop, l = the distance from CBD of the trip destination, $s(l)$ = the number of stops made prior to location l , v_w = walking speed, v_b = bus speed including stops due to traffic, and D = the expected delay at the CBD due to waiting for the bus to arrive.

The generalized costs of walking and bus transit depend on the location, l , of the destination; see Figure 2.5. As shown in (2.1), walkers only incur a travel time cost due to the location of their destination. Recall that each user derives the same benefit ($\$ _o$) for making the trip regardless of destination. When one chooses to not travel, the benefit of making the trip is not realized, i.e. the net utility is zero. Therefore, the generalized cost of not traveling is $\$ _\emptyset = \$ _o$. Thus, the net utility from making the trip is the difference between $\$ _o$ and the generalized cost as shown in Figure 2.5.

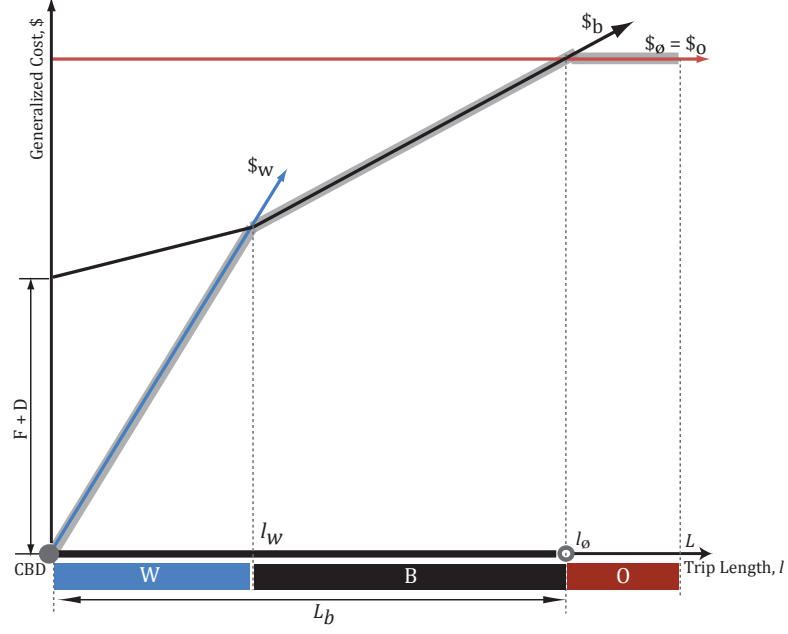


Figure 2.5. User Mode Choice

The generalized cost of a bus trip is dependent on the arrival rate of the passengers and the fare and frequency decisions of the operator. Frequency will be modeled by the headway, H [hr], between departures from the terminal. Equation 2.2 is based on the following expected costs incurred by bus passengers:

- Fixed fare = F
- Expected passenger waiting cost = $\beta_o D = \beta_o \frac{H}{2}$
- ‘Line haul’ travel time cost = $\beta_i \frac{l}{v_b}$
- Expected loss time due to stopping = $\beta_i \tau s(l)$

Due to inherent uncertainties in passenger waiting times and the number of passengers on a bus, we assume bus transit passengers make their decision based on expected values. The expected wait time, D , is a function of the distribution of desired passenger arrivals to the CBD. When demand is uniform, as assumed here, the expected waiting time, D , is $\frac{H}{2}$. We assume that there are no fixed stops on the route, but instead the driver makes a stop for each passenger. Therefore, bus passengers experience a loss time for each individual who alights prior to them. The number of stops made by the time the bus is a distance l from the CBD are:

$$s(l) = \begin{cases} \lambda H (l - L_w) & \text{for } L_w \leq l \leq L_b \\ 0 & \text{o.w.} \end{cases} \quad (2.4)$$

where L_w = the maximum distance from CBD where people choose to walk.

Users are utility maximizing and will choose the mode with the least generalized cost. Therefore, the cost of making a trip to a destination l from the CBD, $\$(l)$, is

the lower envelope of the cost curves in Figure 2.5 as shown in the equation below

$$\$(l) = \min \{ \$_w, \$_b, \$\emptyset \}. \quad (2.5)$$

At a location $l = l_w$, the cost of walking is equal to the cost of taking the bus. Therefore, l_w can be found by setting Equation 2.1 equal to Equation 2.2 and solving for l_w . Likewise, the location where transit costs equal the cost of not making the trip, l_\emptyset , can be found by setting Equation 2.2 equal to Equation 2.3 and solving for l . Thus, the maximum distance where people will choose to walk and take the bus, respectively, is

$$L_w = \min \{ L, l_w \} \quad (2.6)$$

$$L_b = \min \{ L, l_\emptyset \}. \quad (2.7)$$

Bus operators will either operate until they reach of the end of the corridor or no longer have passengers on board.

The average number of users walking, N_w , taking a bus, N_b , and not making the trip, N_\emptyset , per bus trip are:

$$N_w = \lambda H L_w \quad (2.8)$$

$$N_b = \lambda H \cdot (L_b - L_w) \quad (2.9)$$

$$N_\emptyset = \lambda H \cdot (L - L_b). \quad (2.10)$$

The total hourly surplus, S , is the sum of the hourly user surplus to walkers and the hourly surplus to bus passengers; i.e.:

$$S = S_w + S_b + S_\emptyset \quad (2.11)$$

where,

$$S_w = \int_{l=0}^{L_w} \lambda \cdot (\$_o - \$_w(l)) dl \quad (2.12)$$

$$S_b = \int_{l=L_w}^{L_b} \lambda \cdot (\$_o - \$_b(l)) dl \quad (2.13)$$

$$S_\emptyset = \$_o - \$\emptyset = 0. \quad (2.14)$$

We advance that the number of bus passengers, N_b , and user surplus, S_u , will be variables in the operator model as well.

2.2.2 Operator Model

This section considers the operation of informal transit and two types of monopolistic systems: one run publicly by the government and another one run privately by a

Table 2.1. Operating regimes

	OPERATIONS	OBJECTIVE	FREE ENTRY?
a) <i>Competition</i>	Dispersed	Max revenue per trip, R	Y
b) <i>Government</i>	Centralized	Max hourly system welfare, W	N/A
c) <i>Company</i>	Centralized	Max hourly system profit, Π	N/A

company or group. As will be shown below the three regimes, a) informal, b) government, and c) company, capture different behavior and varying levels of coordination amongst drivers on the system.

The operators in each regime also have different objectives. They are: to maximize revenue per trip in case (a); social welfare in case (b); and total system profit in case (c). In case (b), we assume that the government, who is the sole operator, wants to maximize the total welfare for both itself and the users. In case (c), the goal is to maximize the total profit made on the corridor after accounting for all costs. The informal (a) and company (c) regimes look at the two extremes of privately provided transit. The informal regime assumes all operators are competing against one another whereas the company regime aims to analyze the most unified system that can be provided through privately-operated transit. For comparison, the government regime represents the socially optimal system.

In cases (b), and (c) there is no incentive to have unused buses. Thus, the number of buses on the route, B , is the minimum number to guarantee the service frequency, which we call B_{min} , so $B = B_{min}$. However, in the informal regime (a), if market entry is not regulated, additional operators will enter the market until profits, after accounting for driver wages, operating costs and some return on capital, are reduced to zero. Therefore, in this case $B = B_{max}$ where B_{max} is the number of buses that makes profits vanish to the minimum acceptable level. In the informal regime, the excess buses will be queued. Given these queuing delays, the drivers' objective is to maximize the revenue generated each trip. Table 2.1 summarizes these assumptions. The formula for each operating objective is derived below.

Based on the mode shares derived from the user model in Section 2.2.1, transit operation measures can be derived. The model assumes that buses are served in the order in which they arrive at the origin; therefore, the cycle time (or the time between successive departures from the terminal) of every bus is HB . This time consists of the amount of time it takes to deliver all passengers and return to the terminal, T , and the delay to buses when queued at the terminal, Q . Therefore, $HB = T + Q$.

For a given number of buses, B , the average bus queuing delay is

$$Q = HB - T, \quad (2.15)$$

where the vehicle's expected round trip time, T , is given by

$$T = \frac{2L_b}{v_b} + 2\tau N_b. \quad (2.16)$$

This assumes that all buses travel a distance L_b and back.

The minimum number of buses, B_{min} , is obtained by setting $Q = 0$. Thus, $B_{min} = \frac{T}{H}$. Recall from (2.7) and (2.9) that L_b and N_b are functions of F and H . Thus Q , T , and B_{min} are functions of F and H .

A key defining characteristic of informal transit is the lack of operation planning. Informal transit costs are divided into those incurred by the investor or owner (α_h^i, α_d^i) and those incurred by the operator (α_d^o, α_h^o). Costs are divided into distance-based costs (α_d) such as fuel and maintenance given in monetary units (Ksh) per veh-km, and hourly costs (α_h) such as employee wage and vehicle depreciation, both given per veh-hr. In Nairobi, most owners rent out their vehicles to drivers for fixed fee, the purpose of which is to capture the majority of the revenue made on the corridor ensuring high profits. The operators (i.e. driver and conductor) are responsible for fuel and minor maintenance while the vehicle owner pays association fees, insurance, licenses and taxes in addition to the purchase price of the vehicle. Both owners and operators are often subjected to extortion from police and gangs. The components of each cost are described in Appendix C. When transit is run by a monopoly, either public (case b) or private (case c), all costs are included in the fare and headway decision.

The total operating cost¹ of a round trip, which is the sum of costs to the investor (C^i) and to the operator (C^o), is a linear combination of the distance traveled ($2L_b$) and the cycle time (HB). Thus, for any $B \geq B_{min}$:

$$\begin{aligned} C &= C^i + C^o \\ &= (\alpha_d^i + \alpha_d^o) \cdot 2L_b + (\alpha_h^i + \alpha_h^o) \cdot HB. \end{aligned} \quad (2.17)$$

where $C^i = \alpha_d^i \cdot 2L_b + \alpha_h^i \cdot HB$ and $C^o = \alpha_d^o \cdot 2L_b + \alpha_h^o \cdot HB$. Likewise, the total revenue per trip of the system is

$$\begin{aligned} R &= R^i + R^o \\ &= FN_b \end{aligned} \quad (2.18)$$

where R^i = revenue per trip retained by investor and R^o = revenue per trip retained by operator.

Privately provided transit, cases (a) and (c), must be profitable for the investor. Risky businesses, such as the competitive *matatu* industry, may require higher profit margins than one where a company has a monopoly on the corridor. The profit margin for investors is defined as

$$p = \frac{\text{gains}}{\text{investment}} = \frac{R^i - C^i}{C^i}. \quad (2.19)$$

Thus the private owner will only invest when $p \geq p_{min}$ or equivalently, $R^i \geq C^i \cdot (1 + p_{min})$. It is assumed that operators, after accounting for all costs including

¹Vehicle depreciation costs are included.

driver's and conductor's wages, must breakeven, i.e. $R^o \geq C^o$. We can now add these two inequalities to show that the system will attract new entrants if $R^i + R^o \geq C^o + C^i \cdot (1 + p_{min})$, which is equivalent to $\frac{R-C}{C^i} \geq p_{min}$. It turns out that this constraint also holds when transit is provided by a company. This is true because in this case $C^o = 0$ and $R^o = 0$, resulting in the constraint $p \geq p_{min}$. Thus the constraint $\frac{R-C}{C^i} \geq p_{min}$ applies to both of the private operator regimes.

The average user costs derived in the user sub-model and the transit operating costs and cycle time above, yield formulas in terms of F and H for the hourly producer profit (Π) where the total hourly profit, Π ,

$$\Pi = \frac{R - C}{H} \quad (2.20)$$

and for the total hourly welfare for users and operators combined,

$$W = S + \Pi. \quad (2.21)$$

Thus the maximization problems that are solved for the informal (*a*), government (*b*), and company (*c*) regimes are:

$$Z_a = \max_{F,H} R \quad \text{s.t. } B = B_{max} \text{ and } \frac{R - C}{C^i} \geq p_{min} \quad (2.22)$$

$$Z_b = \max_{F,H,B} W \quad \text{s.t. } B = B_{min} \quad (2.23)$$

$$Z_c = \max_{F,H,B} \Pi \quad \text{s.t. } B = B_{min} \text{ and } \frac{R - C}{C^i} \geq p_{min}. \quad (2.24)$$

Chapter 3

Comparing Operating Regimes

This chapter uses the model of Chapter 2 to compare informal transit in the absence of regulation to a publicly provided transit system. We look at the two most common vehicle sizes in Nairobi: 14-seats and 25-seats. With overloading, we assume that a 14-seat bus has a capacity of 18 individuals whereas a 25-seat bus has a capacity of 32 individuals. Each *matatu* has a driver and conductor on board. The conductor takes up one of the available seats thus making the nominal capacity 17 passengers and 31 passengers for 14-seat and 25-seat vehicles, respectively. Input parameters are derived in Appendix C. Table 3.1 presents the operating costs for each regime. Informal transit is unique because some portion of the costs, such as fuel costs, are borne by the operators rather than the owners of the vehicles. In addition, the operator must supplement their wages with some of the revenues hence incurring an additional cost. In the government and company cases, the vehicle owner, i.e. the agency or company, bears all the costs. The basic scenario, assuming a single route with fixed fares and uniform demand, is examined below.

3.1 Government Baseline Regimes

Generally studies aim to maximize the social welfare across the transit agency and transit passengers, i.e. $W_b = S_b + \Pi$. In Section 3.1.1, we assume as is conventional that the government takes this typical approach and maximizes the welfare for

Table 3.1. Bus operating input parameters

	Informal		All Others	
	14-seat	25-seat	14-seat	25-seat
α_h^o [Ksh/hr]	200	200	0	0
α_d^o [Ksh/km]	20	26	0	0
α_h^i [Ksh/hr]	53	81	253	281
α_d^i [Ksh/km]	0	0	20	26

transit passengers and agency. In Section 3.1.2 we assume (more reasonably) that governments aim to maximize the total welfare across all users and operators of the corridor *regardless of mode*, i.e. $W = S_w + S_b + S_\emptyset + \Pi$ as in (2.21). It will be shown that due to the modal trade-offs inherent in this model, the two assumptions lead to substantially different results. Thus, it is important to include all users on the system regardless of mode. The government benchmark for comparing the other options will use this assumption.

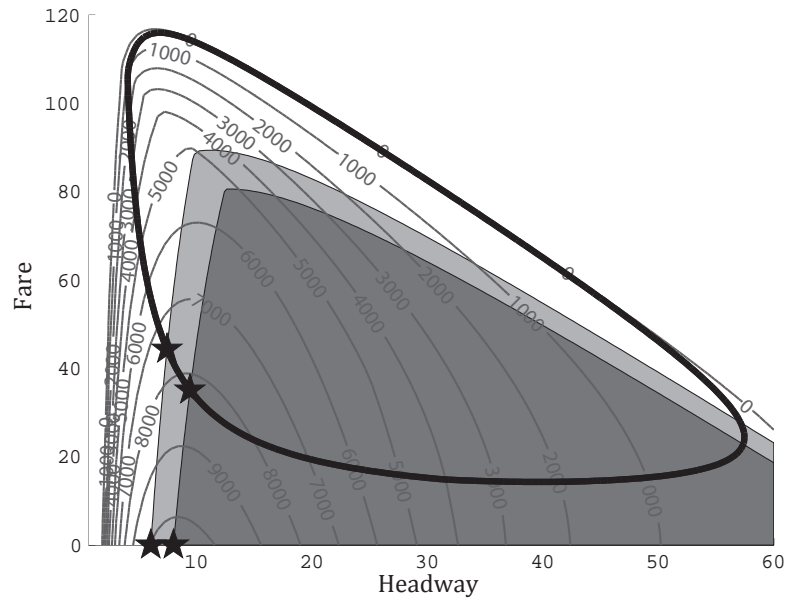
3.1.1 Welfare of Transit Users and Passengers

Here we examine the case of a (shortsighted) government that focuses on transit and ignores the other modes. The contours in Figure 3.1 represent the total hourly welfare to transit passengers and operators, i.e. the sum of the operator profit and transit passengers surplus across all vehicles ($\Pi + S_b$) given a particular fare and headway decision. We assume that the 14-seat minibus has a physical capacity of 18 passengers with overloading and a 25-seat minibus has a physical capacity of 32 passengers. Thus the area in light gray represents the fare-headway combinations that result in overloading and the dark gray area that which are infeasible. Note that this shading is independent of the operating regime and will be consistent throughout the analysis. Lastly, the bold contour denotes the fare-headway combinations that result in the minimum acceptable profit. For the government scenario, we set the minimum expected profit margin, p_{min} , equal to zero since governments view mass transit as a public good.

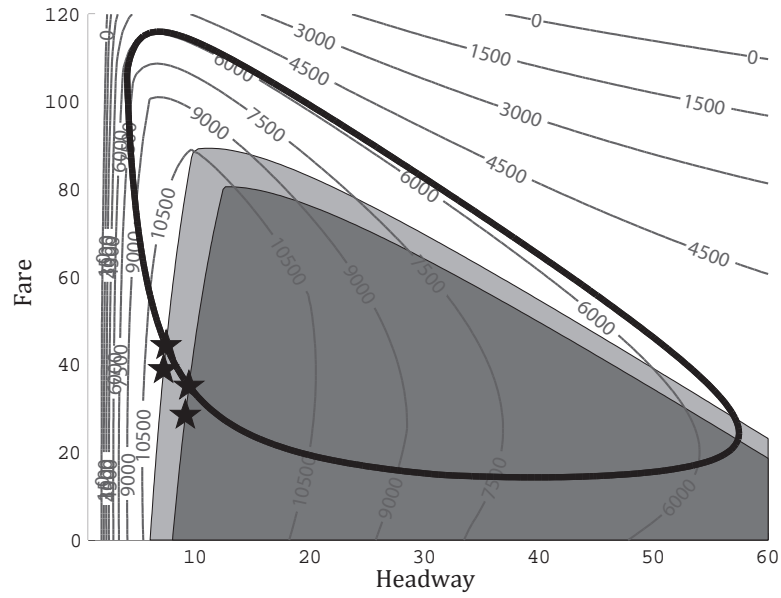
Table 3.2 summarizes key results for the transit-only welfare-maximizing scenario of a shortsighted government. The superscripts of the objective denote the constraints included for the solutions on each row. The following constraints (and labels) are considered: none (superscript “ o ”), meets minimum desired profit margin (superscript “ p ”), and/or no overloading (superscript “ N_b ”). Each row on the table corresponds to one of the starred points on Figure 3.1. It was found that it is optimal to use the smaller 14-seat vehicles.

Consider the first row of the table. Because our shortsighted government only considers the welfare to those who take transit and the operator, it is optimal to not charge users a fare. This maximizes the number of users who take transit rather than walk. Vehicles depart every 8 minutes. However if the agency aims to break even ($p_{min} = 0$), second row of the table, the optimal fare is 35 Ksh with the headway only increasing by a minute. The social welfare (to transit users and operators only) is 10,400 Ksh/hr at optimality and 8,220 Ksh/hr for the break even case. Note that the total welfare across all modes changes very little while the welfare to transit users and operators in these two scenarios differs by nearly 2,200 Ksh/hr . This is due to the lower hourly welfare to transit users which results from the increased fare in the break-even scenario. This increased fare causes a 15% decrease in transit’s mode share.

When overfilling is not allowed (row 3) headway is reduced, thus making users better off but at the expense of significantly higher operating deficits (deficits in-



(a) Transit Welfare Only



(b) Total Welfare

Figure 3.1. Decision Space and Equilibrium Solutions (14-seats): Government Regimes

Table 3.2. Shortsighted government results (14 seats)

Obj.	H	F	B	S	Π	W	N_b	$\%_w$	$\%_b$	W_b
W_b^o	8	0	9	15953	-4496	11457	17	5	95	10400
W_b^p	9	35	7	11684	0	11684	17	20	80	8220
$W_b^{N_b}$	6	0	11	16618	-5756	10862	13	4	96	10055
$W_b^{N_b,p}$	7	44	9	11289	0	11289	13	22	78	7524

creased by 28%). However, if the agency must break even without overfilling (row 4), the burden falls on the users as user surplus decreases by 3%.

As mentioned earlier, for the given inputs, it was also found that 14-seat minibuses are always ideal. This is a result of the given inputs having little economies of scale with respect to vehicle size. For detailed results of the 25-seat scenario refer to Table D.2.

3.1.2 Total Welfare Across All Modes

Here we optimize transit to maximize everyone’s welfare regardless of mode. Following (2.23), the contours in Figure 3.1(b) represent the total hourly welfare amongst the transit operators, transit passengers, and walkers. As in Section 3.1.1, it is ideal to use small, 14 seat vehicles.

Consider now the unconstrained scenario (row 1). When one considers all modes, at optimality the system incurs a deficit of 746 Ksh/hr . At optimality the fare is 28 Ksh and vehicles depart every 9 mins with transit capturing 83% of all trips. When the fare is increased by 7 Ksh the system breaks even as shown in row 2, and loses a mere 3% of trips.

Banning overloaded vehicles (row 3) yields similar results. However, vehicles depart more frequently (every 7 mins), which is offset by a fare increase of around 10 Ksh. Users are in fact worse off from a user surplus point of view when overloading is prevented. Row 4 shows the results if the government aims to break even while still preventing overfilling. In this case there is not much difference at optimality between the shortsighted government that optimizes for transit only and one that optimizes across modes. Our results show that in the case of 14 seat vehicles, if the goal of the government is to break even the results are equivalent whether the government is maximizing total welfare or simply transit welfare. This, however, is not generally true. It was not true for large vehicles as it was optimal to depart with less than full loads; see Figure D.1. In order to examine the system in its entirety, we assume the government seeks to maximize total welfare henceforth.

Appendix B further explores the difference between a our government model and the shortsighted government by examining how total surplus and transit surplus depend on fare.

Table 3.3. Government results (14 seats)

Obj.	H	F	B	S	Π	W	N_b	$\%_w$	$\%_b$	W_b
W^o	9	28	8	12443	-746	11697	17	17	83	8628
W^p	9	35	7	11684	0	11684	17	20	80	8220
W^{N_b}	7	39	9	11893	-595	11298	13	20	80	7830
$W^{N_b,p}$	7	44	9	11289	0	11289	13	22	78	7524

3.1.3 Sensitivity to Operating Cost

One of the primary arguments in favor of the privatization of transport either formal or informal, is the reduction of costs in the private sector. In many developing countries the costs per passenger kilometer has been shown to differ by 100% or more between their public and private fleets. In Europe it was found that introducing competition may lead to a reduction in operating costs per vehicle mile of upwards of 30% (Gwilliam & Scurfield, 1996). Typically, public fleets utilize large buses and private fleets minibuses in developing countries. For comparison sake, we studied the effect of a 30% increase in hourly operating costs in the government scenario. As the distance-based cost is dominated by fuel costs we keep this value the same.

A 30% increase in hourly operating costs resulted in a 18% increase in fare at optimality. Headways generally remained equivalent as did the mode share since fares remained relatively low. At optimality the fare was 33 Ksh, and if the agency was more restrictive and did not allow overloading nor provided subsidies the fare was 51 Ksh for 14-seat buses. Users and the operator shared the burden of the increase as both profit and user surplus decreased. For detailed results refer to Table D.1.

3.2 Company Regime

This analysis was repeated for the private monopoly or company regime. In contrast to a government system which takes users into account by including their surplus, we found that the private company monopoly was detrimental to users as the lack of competition resulted in predatory fares. As shown in Table 3.4, the optimal company fares are nearly 3 times that which are socially optimal. The substantially higher fares and slightly higher headways resulted in people walking further distances and lower transit mode shares. It was optimal to walk for all trips under 3 km. From an operator point of view smaller vehicles were still preferred, although users would be slightly better off with larger vehicles due the reduction in fare.

When small vehicles are used it is optimal to fill vehicles. The contours in Figure 3.2 represent the hourly system profit for a given fare-headway combination. As shown in the figure, the optimal point lies along the upper most portion of the vehicle capacity contour line.

The gray line that intersects the vehicle capacity contours represents the fare-

Table 3.4. Company results (14 seats)

Obj.	H	F	B	S	Π	W	N_b	$\%_w$	$\%_b$
Π^o	12	81	6	7088	3734	10821	17	39	61
Π^{N_b}	10	89	7	6947	3576	10522	13	41	59

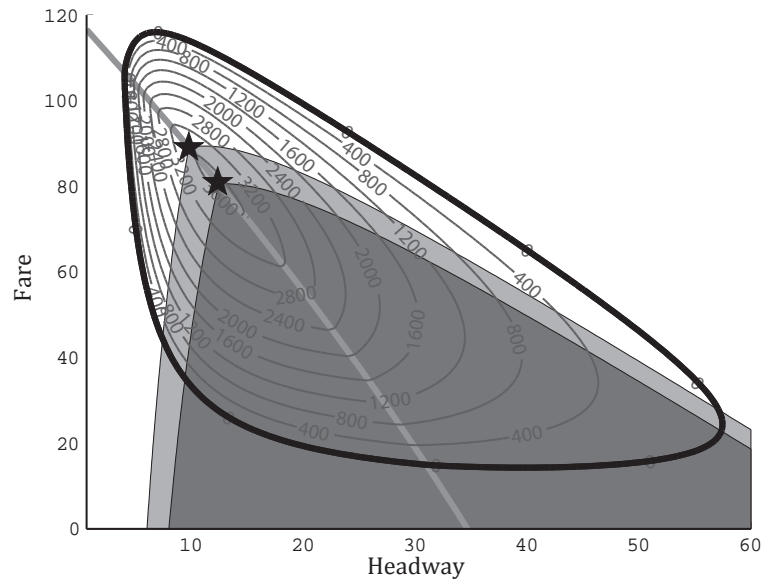


Figure 3.2. Decision Space and Equilibrium Solutions (14 seats): Company Regime

headway combinations where the costs of taking the trip equals the trip benefit for the person who's destination is at the end of the corridor, i.e. $l_\emptyset = L$ where

$$l_\emptyset = \frac{\$o - F - H\beta_i(1 - \tau\lambda L_w)}{\beta_i(1/v_b + \tau\lambda H)} \quad (3.1)$$

since demand is uniform and $\beta_o = 2\beta_i$. In other words, on the gray line, service is provided to the end of the corridor with the highest possible fare that ensures everyone in L makes the trip. Note that the stars are along this line. Thus, the company service in Nairobi would have the highest possible fares that would entice every distant user along this corridor to travel.

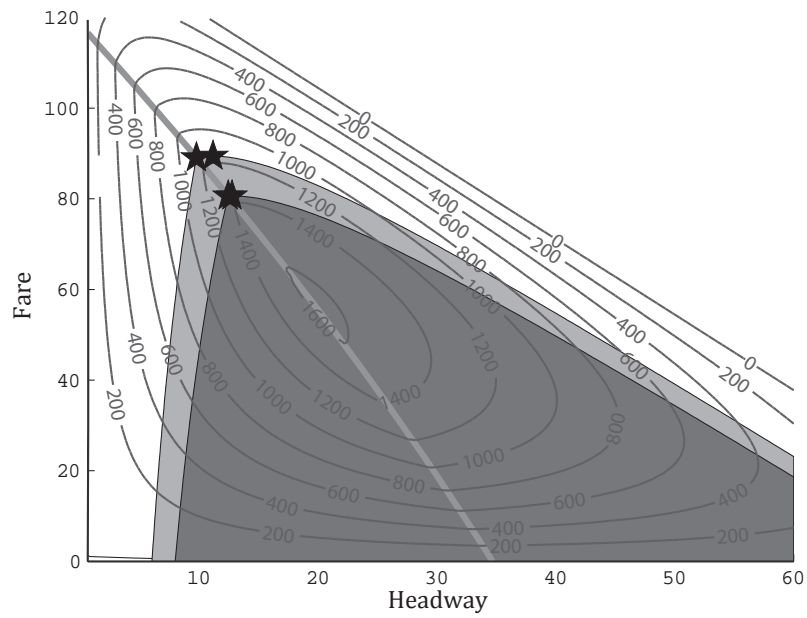
As an aside, note that the shape of the vehicle capacity contours, which remains constant regardless of regime, can be explained intuitively. The area under the $l_\emptyset = L$ curve represents the fare-headway combinations where everyone is able to take the trip or in other words, $L_b = L$ since $l_\emptyset > L$. Since along the contour vehicles depart once full, if the fare was lower vehicles would have to depart more frequently due to the higher demand. Thus the vehicle capacity contour line has an increasing slope. In the area above the $l_\emptyset = L$ curve, the fare-headway combinations result in people with the longest trips not making the journey. The higher the headway the lower the fare must be to try to recapture some of the demand from those desiring longer trips. This results in a descending passenger curve when $L_b = l_\emptyset$. Therefore the optimal solution of this scenario has vehicles departing the terminal with full vehicles and charging a fare just low enough to users traversing the entire corridor to find the trip beneficial.

3.3 Informal Transit Regime

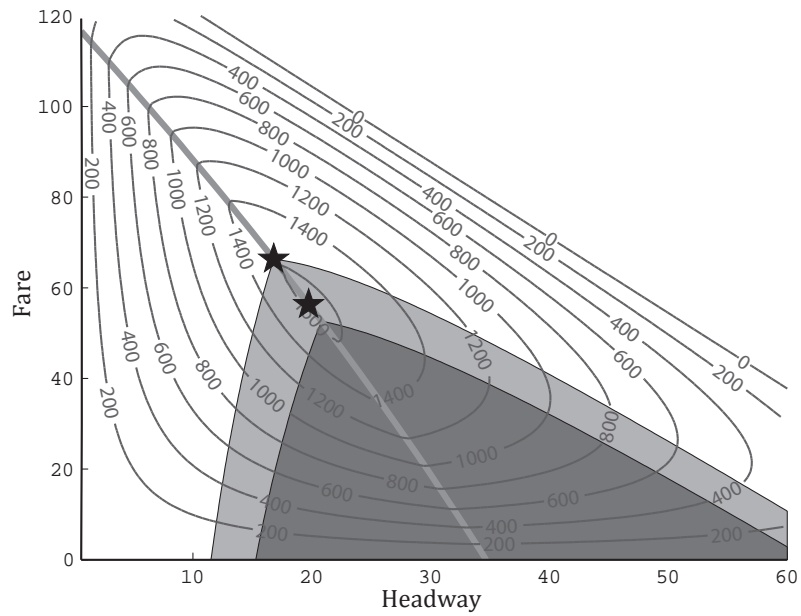
Informal Transit with Competition

As mentioned earlier, when informal transit exists in a liberalized market with competing operators, operators will continue to enter the market until the system reaches some equilibrium profit, p_{min} . Figure 3.3 shows the decision space and equilibrium solutions for these competing operators with the model of Chapter 2. Recall that the operators' objective is maximizing the revenue per trip. Buses are assumed to queue at the terminal and are served in the order in which they arrive. Because operators make their decision in isolation once they reach the head of the queue, the optimal revenue per trip is independent of the number of buses on the corridor.

Table 3.5 presents the results of the analysis. Note from the table that it is optimal to use the larger (25-seat) vehicles because they allow operators to generate more revenue due to their larger capacity. In reality, the initial cost of these vehicles is a relatively large impediment for their use. Despite the longer passenger wait times, passengers are better off due to the lower fare charged. The fare premium of smaller buses is representative of operations in Nairobi. The Githurai Route 45 has 14-seat and 25-seat buses plying the route. The 14-seat buses charge a fare of 80 Ksh whereas



(a) 14-seats



(b) 25-seats

Figure 3.3. Decision Space and Equilibrium Solutions: Informal Regime

Table 3.5. Informal transit results

Obj.	H	F	L_b	B_{min}	$B_{p=0}$	S	Π_{max}	W_{max}	N_b	$\%_w$	$\%_b$	R
14-seats												
R^o	13	81	7.4	5	20	7036	3672	10708	17	39	59	1371
$R^{N_b,L}$	10	89	7.5	7	21	6947	3576	10522	13	41	59	1158
25-seats												
R^o	20	56	7.5	4	13	7535	2585	10120	29	35	65	1638
R^{N_b}	17	66	7.5	5	15	7349	2974	10323	24	37	63	1592

the larger bus around 50 Ksh. This premium is justified due to the maneuverability of smaller buses and the ability to fill quicker.

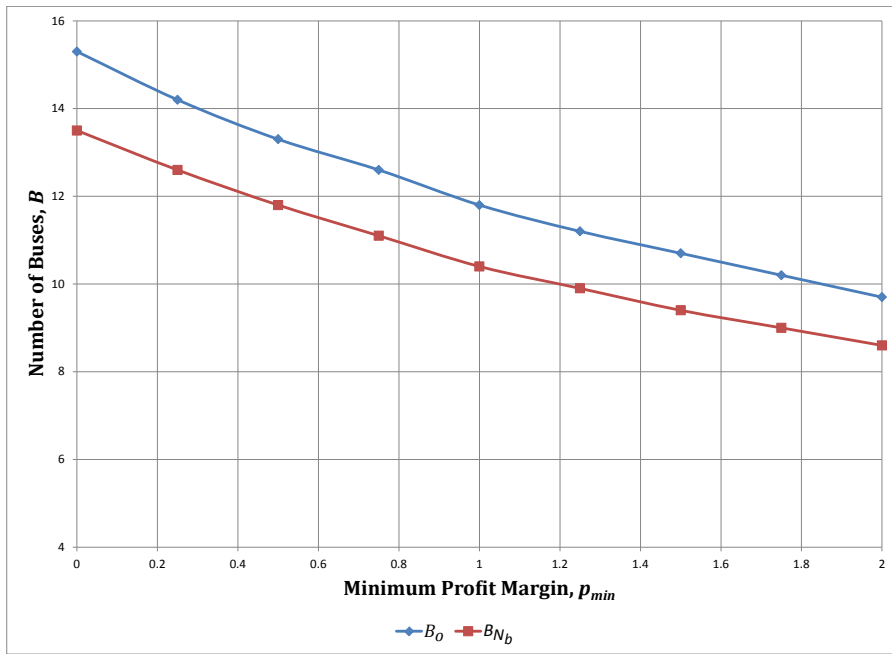
At optimality, roughly 65% of people will take transit if 25-seat vehicles are used. This is 5% more than the mode share with 14-seat vehicles. Both shares are considerably less than that which is socially optimal. In addition, one can see from the equilibrium service length, L_b , that with the smaller vehicles there is a tendency to want to cut the route short making the trip not viable for those wanting to travel to the furthest destinations.

Since entry to the route is unrestricted, people will continue to invest in the industry as long as the profit margin is greater than the minimum acceptable level, i.e. $p_{min} \leq p$. The system performance obvious depends on p_{min} . In view of this, Figure 3.4(a) shows the maximum number of buses the system can sustain given p_{min} . When $p_{min} = 0$ the revenues equal the costs and roughly 3 times as many buses ply the corridor than what is needed. The *matatu* industry, however, is risky as vehicles are frequently in accidents and are even susceptible to theft; therefore, for people to invest in an industry with such high startup costs and risk more significant returns are required. Moreover, the model does not include any congestion penalties. Hence this model is an upper bound on the number of buses that route can sustain. Figure 3.4(a) shows how the number of buses on the system varies with p_{min} and Figure 3.4(b) the resulting profit.

If entry is restricted, as is often the case with gang-controlled lucrative corridors, then the number of buses on the corridor would be $B = B_{min}$ as this would allow for maximum profits. For 25-seat vehicles, this results in a maximum hourly profit on the system of 2585 Ksh/hr.

Extortion and Bribery

One of the main complaints cited by operators of informal transit is the prevalence of extortion and the necessity to bribe the police. As derived in the appendix, both owners and operators are subjected to extortion. Extortion from gangs and bribery to the police take away a portion of profits from informal transit that could instead be reinvested in infrastructure from the government, used by owners to make vehicles safer, or provide a more comfortable standard of living for operators. It is assumed



(a) Number of Buses, B



(b) Hourly System Profit, Π

Figure 3.4. Minimum Profit Margin vs. Number of Buses and Hourly System Profit

Table 3.6. Informal transit results under extortion (25 seats)

	Π_{max}		B_{max}	
	w/o extortion	w/ extortion	w/o extortion	w/ extortion
R^o	2584	2301	13	11
R^{N_b}	2974	2665	15	12

that drivers are subjected to roughly 55 Ksh/hr in extortion and bribes and owners extortion and bribes translates to approximately 11 Ksh/hr .

Table 3.6 presents the maximum system profits that can be made on the corridor with and without extortion when 25-seat vehicles are used. This is the system profits when there is no bus delay, i.e. when entry is restricted on the corridor. Extortion reduced the potential maximum profit by 10%. If free entry is allowed, extortion reduced the number of buses that will be on the corridor by 15-20%. The cost of extortion has no social benefit and could instead be reinvested in the industry via safety and infrastructure improvements.

Chapter 4

Regulating Informal Transit

As shown in Chapter 3, informal transport is unable to provide service comparable government welfare-maximizing operation without regulation. Moreover, free entry allows for excess vehicles to operate on the corridor resulting in diminished profits. This chapter address potential ways of regulating informal transit. Section 4.1 assumes that associations and cartels self-regulate the system in order to retain higher profits. In Section 4.2 a government agency is regulating informal transit in order to improve system welfare.

The continuum-approximation model derived in Chapter 2 allows us to graphically represent the fare - frequency decision space of the operator(s). Moreover, it provides a tool for decision-makers to aid in evaluating policies related to minibus operation. This chapter uses this tool to evaluate various regulatory options. Lastly Section 4.3 examines the effects of other factors such as increased wages and changes in land use patterns on informal transit operation.

4.1 Self-Regulation: Associations and Cartels

Due to the degradation of profits when there is free entry, route associations often morph into price-fixing and competition stifling cartels. The goal of a cartel, in fact, is identical to that of a company - maximize profits on the corridor as in (2.20). The primary difference, however, between the company model and the cartel model is that the cartel has the same costs as in the informal transit model with competition where operators and owners share operating costs. Since we assumed the same total costs in the government and company models as the informal model the cartel results would be identical to the company results.

Table 4.1 presents the optimal profits from informal transit with entry restricted and with the influence of a cartel. It is assumed that entry is regulated by the association so $B = B_{min}$ in both cases. Though profits as whole were higher in the 14-seat case, the benefit of cartelization, was greater with 25 seats as measured in the percentage change of profit. With a 14 seat bus, there was only a mere 2% gains but when larger 25-seat vehicles are used the gains around 22%. These benefits

Table 4.1. Self-regulation results

Restrictions	H	F	B	S	Π	W	N_b	$\%_w$	$\%_b$
Informal ¹	13	81	5	7036	3672	10708	17	39	59
Cartel ²	12	81	6	7088	3734	10821	17	39	61
Informal ¹	20	56	4	7535	2585	10120	29	35	65
Cartel ²	13	78	5	7148	3159	10307	18	39	61

¹Controls entry²Controls fare and entry

arise because of the higher fares that the cartel can charge. Thus, there is not much incentive to form cartels when 14-seat vehicles are used. With 25 seats, the public is worse off, user surplus diminished and there is a 4% loss in the mode share of transit.

4.2 Government Imposed Regulation

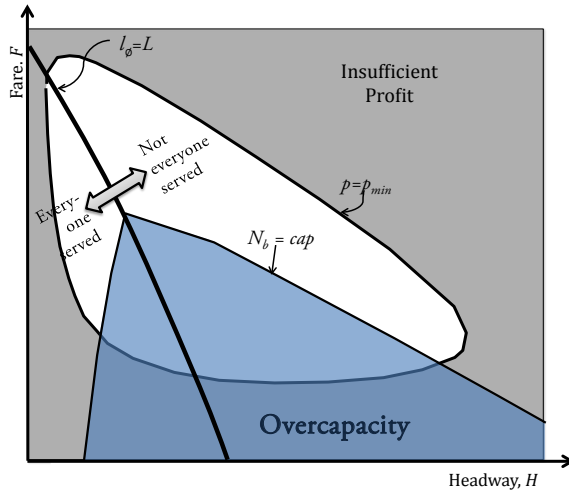
4.2.1 Goals

Chapter 3 compared unregulated informal transit operation with competition, private company, as well as government provided transport. Welfare was lower and users had significantly less surplus with private transport than in the government scenario. The results showed that informal transport, in particular, has a proclivity for overfilling vehicles and shortening routes. In addition, there was an overabundance of buses in the competitive informal transit scenario. Here we assume that the regulatory agency aims to address these pitfalls by requiring regulation to meet the following goals:

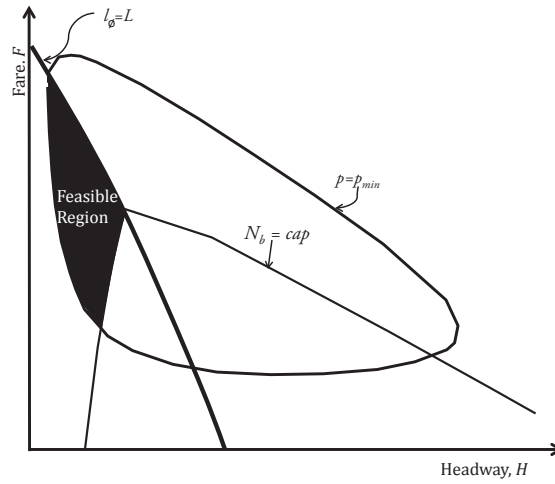
1. Improve the system
2. Serve everyone on the corridor
3. Prevent overfilling vehicles
4. Maintain a profitable system
5. Reduce bus queuing delay, if present.

Since our model utilizes a continuum-approximation framework, we are able to visualize these goals on a plot; see Figure 4.1. The axes of this plot represent the decision space for the operator(s) in terms of fare and headway. Goals 2-4 are visualized on this figure. The figure assumes that Goal 5 is met, i.e., that buses are run such that there is no queue present (i.e., $B = B_{min}$). System improvement is measured by an increase in welfare along the corridor.

Goal 2 is violated for all fare-headway combinations that lie above the $l_{\varnothing} = L$ curve the formula for which is given in (3.1). Similarly, Goal 3 is violated when the operator's decision lies in the triangular shaded area in Figure 4.1(a). In this regime, operators allow more passengers to board than the number the vehicle is designed for. Goal 4, requiring the system to have at least some minimum profit margin,



(a) Outcome Domains



(b) Feasible Region

Figure 4.1. Visualization of Regulatory Goals

is violated in the gray area outside the $p = p_{min}$ contour. This goal is important because owners will not invest if they cannot make a profit. Subsidies could help but we assume that the government is either unwilling or unable to provide subsidies. Therefore, any fare-headway combinations that lie outside of the $p = p_{min}$ curve are unacceptable. This yields the feasibility region for Goals 2-5 shown in Figure 4.1(b). Any other fare-headway combinations will violate at least one of the goals. Goal 1 is achieved by operating at a point in the feasible region that improves the deregulated performance.

4.2.2 Measures of Improvement

We assume that the goal of regulation is to increase the total welfare on the system, forcing a privately run system to resemble our ideal government system. The following solutions will be used for comparison:

- **First best** - Government system that maximizes welfare and meets all of the above goals except Goal 4.
- **Second best** - Government system that maximizes welfare without violating any of the above goals.
- **Third best** - Regulation that maximizes welfare given a system ran by a private operator (either informal or cartel).

The first best and second solutions follow easily from Chapter 3. The third best solution is discussed below.

4.2.3 Types of Regulation

In order to improve service from a socially optimal perspective without owning and operating the system, the government is assumed to have an agency that can issue regulations, and that those regulations are enforced. The following regulatory policies are considered:

1. **Fare regulation** - agency sets fare
2. **Headway regulation** - agency sets headway
3. **Seat-belt requirements** - prevents operators from overloading vehicles
4. **Vehicle licensing** - limit the number of vehicles on the corridor
5. **Control vehicle size** - agency stipulates bus size
6. **Route regulation** - agency ensures vehicles serve the whole corridor.

These policies may be implemented singularly or in combination. We assume, however, that the government must allow the operator to either price service or determine vehicle headways. Thus, fare regulation and headway regulation may not be done in conjunction. The vehicle licensing policy is pertinent for informal transit, where operators compete against one another and there is free entry.

4.2.4 Enacted Regulation in Nairobi

Two of the above-mentioned policies have been considered in Nairobi: 1) seat belt requirements and 2) requiring the use of large vehicles. The seatbelt policy was enacted in 2004 and the process of phasing out 14-seat minibuses in favor of 25-seat and larger buses began in 2010. In Nairobi 14 seat vehicles are more prevalent due to lower start up costs.

The results of Chapter 3 showed that imposing seat belt regulation when 14-seat vehicles are used by competing operators causes both users and operators to be worse off. As shown in Table 3.5, the operator may be more likely to cut the route short. With 25-seat vehicles, however, seatbelt regulation was beneficial from a social welfare perspective. The slight reduction in surplus was offset by an increase in operator profits and an increase in welfare. With a private monopoly (i.e. company or cartel), seatbelt regulation is not needed for 25-seat vehicles as the optimal solution does not result in overfilled vehicles; see Table 3.4. There is a tendency to overfill when 14-seat vehicles are used, however. In this case, when capacity is constrained users and operators are worse off and there is a slight decline in mode share. One drawback of our model, is that quality-focused regulations such as those affecting safety and comfort are not directly accounted for. Thus the benefits of preventing overfilling are not fully reflected in the model.

The transition to larger 25-seat buses has not been met with open arms by transportation suppliers. Owners are opposed to the regulation due to the high startup costs. Drivers and conductors are concerned about the loss of jobs. Furthermore, our model suggests that the use of 25-seat vehicles does not improve welfare on the system. This is due to a loss of profits to operators. By shifting to large vehicles, the number of buses was reduced by 20-30%. This serves as an upper bound in the amount of jobs that may be lost. The model does not reflect the congestion mitigation effects that the transition may have, masking a major benefit of the transition on the public at large. From a user perspective, the transition to 25-seat vehicles is beneficial as user surplus increased due to decreased fares. The model predicts that transitioning to larger vehicles is more beneficial with competing operators as in the case in Nairobi. Based on the model, user surplus is expected to rise 7%.

4.2.5 Results

Below we show the results of regulation for informal transit with competition and with cartelization for $p_{min} = .25$. Recall that a cartel behaves identically to a company when unit costs across the system are equivalent. Under competition there is an excess number of vehicles on the corridor. As discussed in Chapter 3 these additional vehicles do not provide any benefit on the system. Thus we assume that with competition, the number of vehicles will be regulated to minimum number of buses necessary, B_{min} , or in other words that which imposes no queue at terminal for buses. Thus from here onward, with competing informal transit we assume that the government limits vehicle licensing.

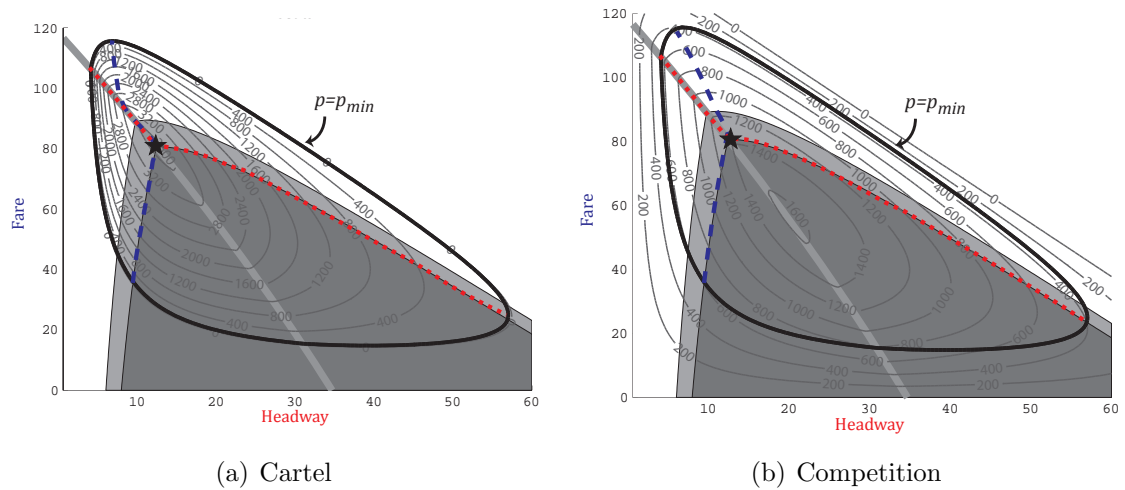


Figure 4.2. Fare and Headway Regulation Decision Space for Informal Transit without Seatbelt Requirements (14 seats)

14-seat Vehicles

Figures 4.2 and 4.3 show how the system will operate given fare regulation (dashed line) or headway regulation (dotted line). Figure 4.2 assumes only fare and headway regulation for a cartel in (a) or a competing informal transit in (b) in the absence of seatbelt regulation, and in Figure 4.3 in the presence of seatbelt (or vehicle capacity) regulation. The dashed lines represent the headway decision of the operator given the fare set by the regulatory agency whereas the dotted line represents the converse - the fare that the operator would set given the headway chosen by the agency. The star on each figure is the equilibrium solution without fare or headway regulation.

Figure 4.4 shows the same regulation lines as Figure 4.2. Like before, the star represents the equilibrium solution without regulation. The black and gray dots represent the 1st and 2nd best solutions, respectively. The figure also includes the welfare contours, which allows us to compare the solution and evaluate the effectiveness of the regulation. Note that we plot the welfare contours on the figures that are greater than or equal to the welfare of the equilibrium solution without regulation thereby satisfying Goal # 1. It turns out that for 14-seat vehicles there is no fare or headway regulation that improves the hourly welfare on the corridor while meeting all the goals set above. The only way the government could meet all the goals would be to set both the fare and headway resulting in the 2nd best solution.

Figure 4.5 presents the same information of Figure 4.3 when the government imposes seatbelt requirements. The dark bar along the y-axis shows the feasible range of fares that satisfy all the goals, whereas the dark bar along the x-axis shows the range of headways in minutes that satisfy the goals. Note that the bar on the x-axis is absent in part (a) and quite short in part (b). With the cartel, only fare regulation is beneficial whereas informal transit (with competing operators) can benefit from either fare regulation or headway regulation (though fare regulation is significantly

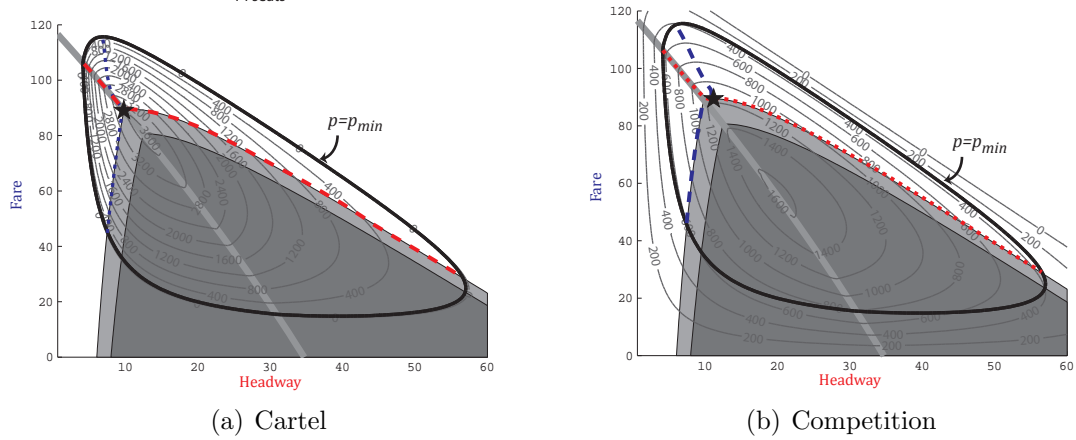


Figure 4.3. Fare and Headway Regulation Decision Space for Informal Transit with Seatbelt Requirements (14 seats)

Table 4.2. Informal transit regulation results (14 seats)

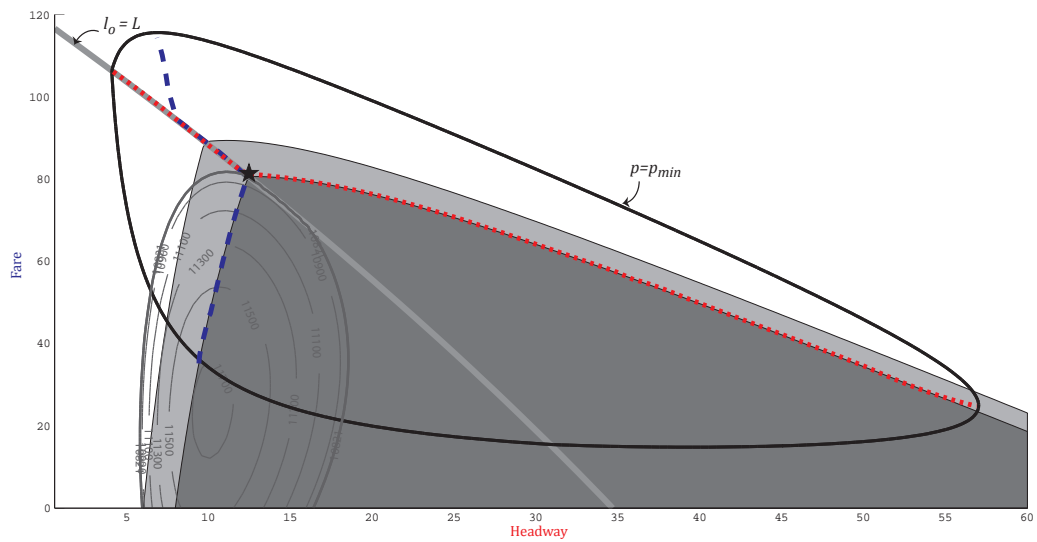
Regulation	H	F	L_b	B	S	Π	W	N_b	$\%_w$	$\%_b$
Optimal Solution										
1 st best	7	39	7.5	9	11893	-595	11298	13	20	80
2 nd best	7	45	7.5	9	11168	117	11285	13	22	78
3 rd best*	7	45	7.5	9	11168	117	11285	13	22	78
Equilibrium Without Regulation										
Cartel	12	81	7.5	6	7088	3734	10821	17	39	61
Competition	13	81	7.4	5	7036	3672	10708	17	39	59

* fare and overfilling controlled

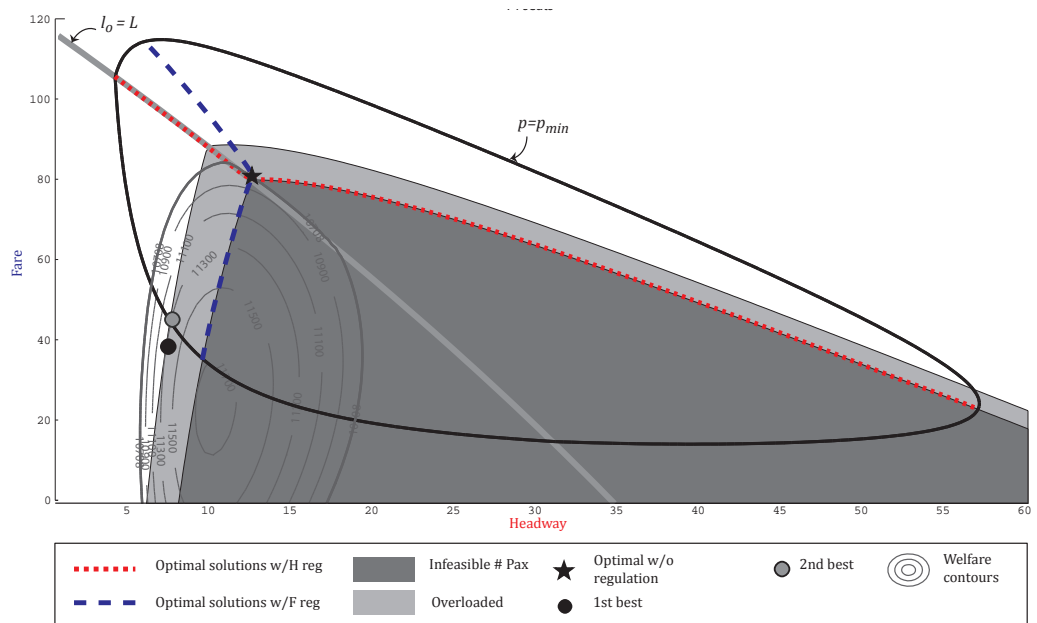
better than headway regulation). As shown in Table 4.2, the optimal fare regulation is identical to the 2nd best solution and is identical across scenarios since the optimal solution is the intersection of the capacity and $p = p_{min}$ curves. By lowering fares considerably, the mode share of transit increased by 20% as user surplus was exchanged for producer profits. Users had a 60% increase in surplus. Thus, for 14-seaters fare regulation was found to be more effective than headway (dispatching) regulation.

25-seat Vehicles

The same analysis is performed for 25-seaters. As before, Figures 4.6 and 4.7 show the regulation lines of (a) a cartel and (b) competing informal transit in the absence of seatbelt regulation and with seatbelt regulation, respectively. Also as before, Figure 4.8 shows the same regulation lines and the same optimal point, in addition to the welfare contours, as Figure 4.6. Unlike in the 14-seat case the optimal solutions do not always result in full vehicle loads. The figures show that without controlling

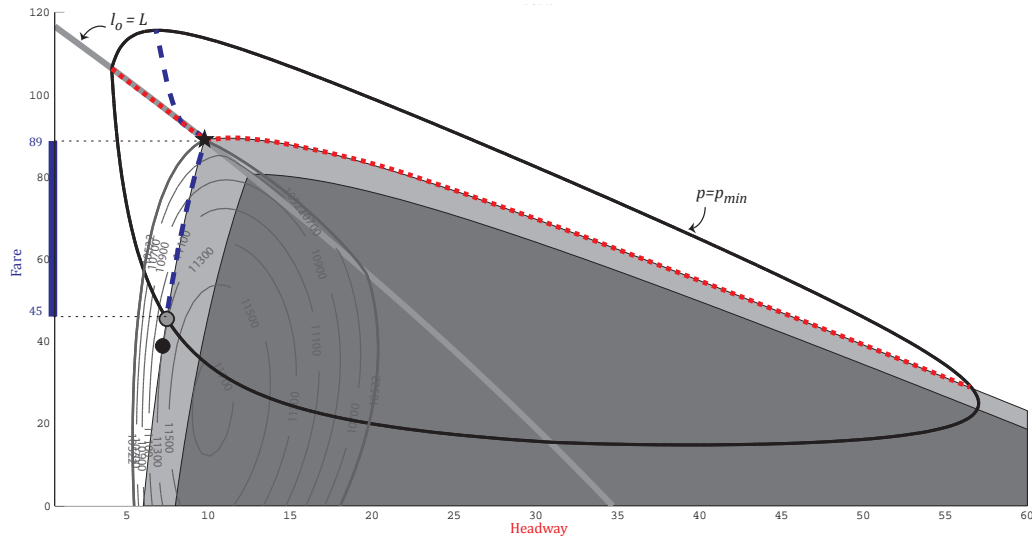


(a) Cartel

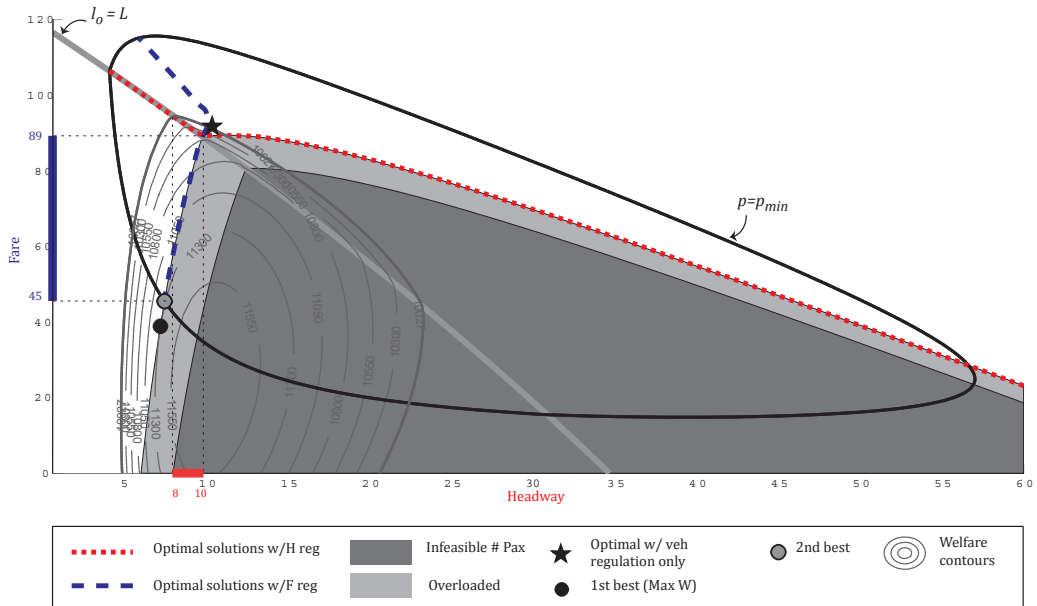


(b) Competition

Figure 4.4. Optimal Solutions under Fare and Headway Regulation for Informal Transit (14 seats)



(a) Cartel



(b) Competition

Figure 4.5. Optimal Solutions under Fare and Headway Regulation for Informal Transit with Seatbelt Enforcement (14 seats)

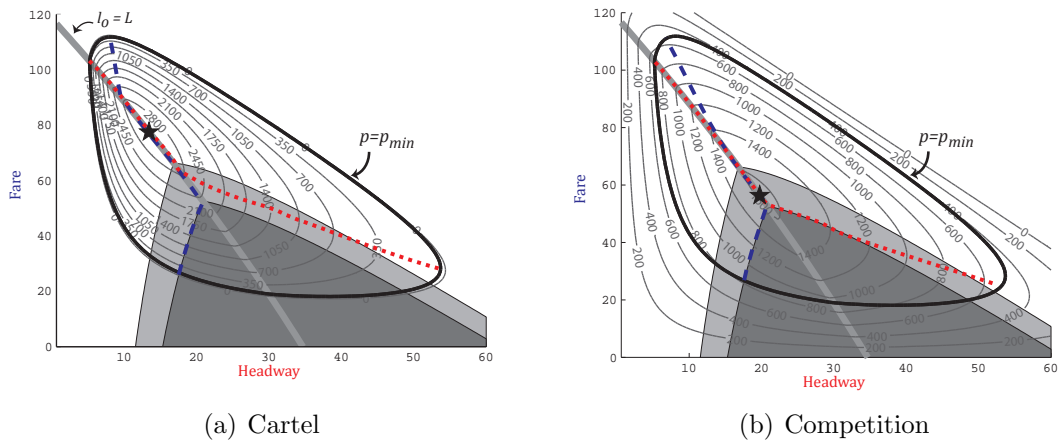


Figure 4.6. Fare and Headway Regulation Decision Space without Seatbelt Requirements (25 seats)

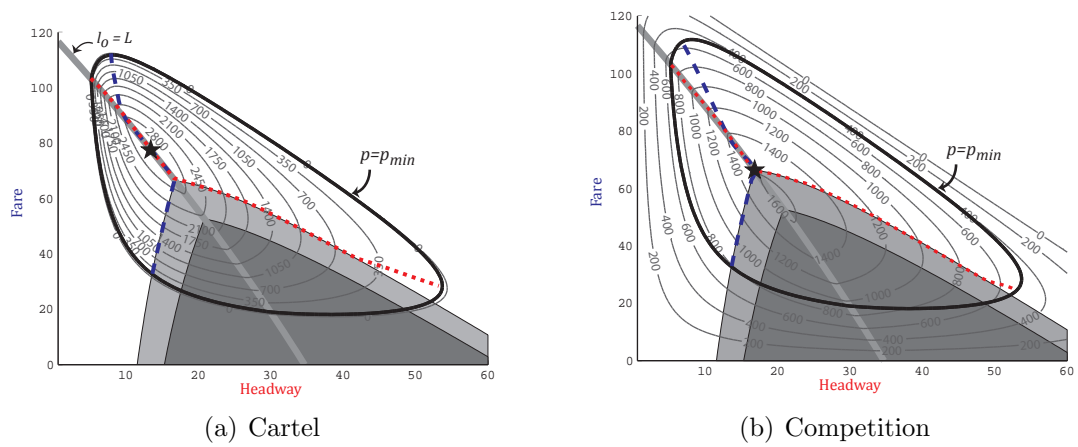


Figure 4.7. Fare and Headway Regulation Decision Space with Seatbelt Requirements (25 seats)

Table 4.3. Regulated results (25 seats)

Regulation	H	F	L_b	B	S	Π	W	N_b	$\%_w$	$\%_b$
Optimal Solutions										
1 st best	11	27	7.5	7	11986	-938	11048	21	18	82
2 nd best	12	37	7.5	6	10891	128	11018	21	22	78
3 rd best*	14	33	7.5	6	10842	118	10959	24	21	79
Suboptimal Policies										
F or H reg.	15	72	7.5	5	7231	3120	10351	21	38	62
Seatbelt reg.	17	66	7.5	5	7349	2974	10323	24	37	63
Without Regulation										
Cartel	13	78	7.5	5	7148	3159	10307	18	39	61
Competition	20	56	7.5	4	7535	2585	10120	29	35	65
Increased Wages										
3 rd best*	14	41	7.5	6	9937	112	10049	24	25	75

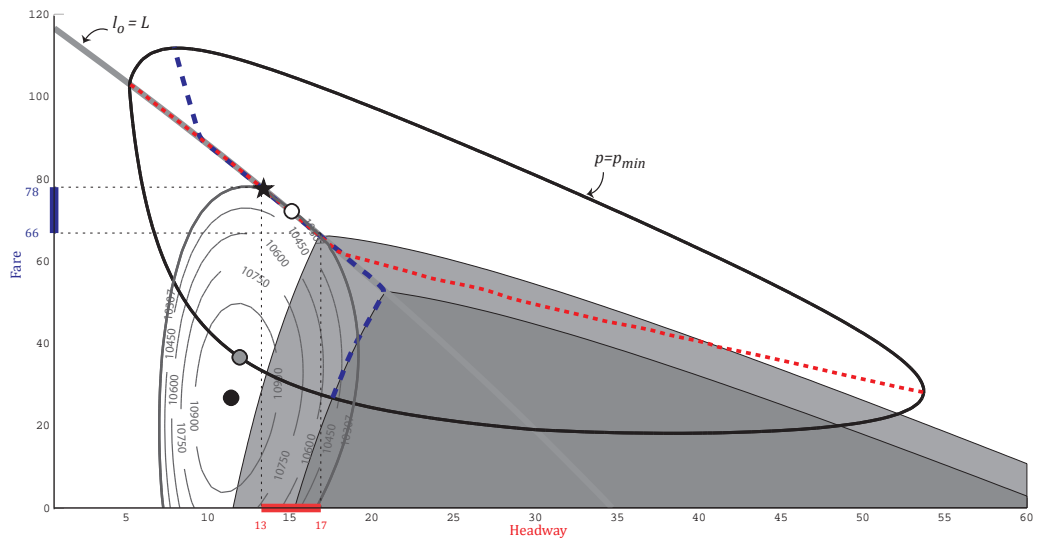
*Fare regulation and seatbelt restriction

overfilling, agencies may set fares in the range of 66 to 78 Ksh to meet the goals set above (shown along the y-axis) and headways of 13 to 17 mins when operated by a cartel and 12-17 min with competition. As shown in Table 4.3 under suboptimal policies, regulation provides very little benefit in either case.

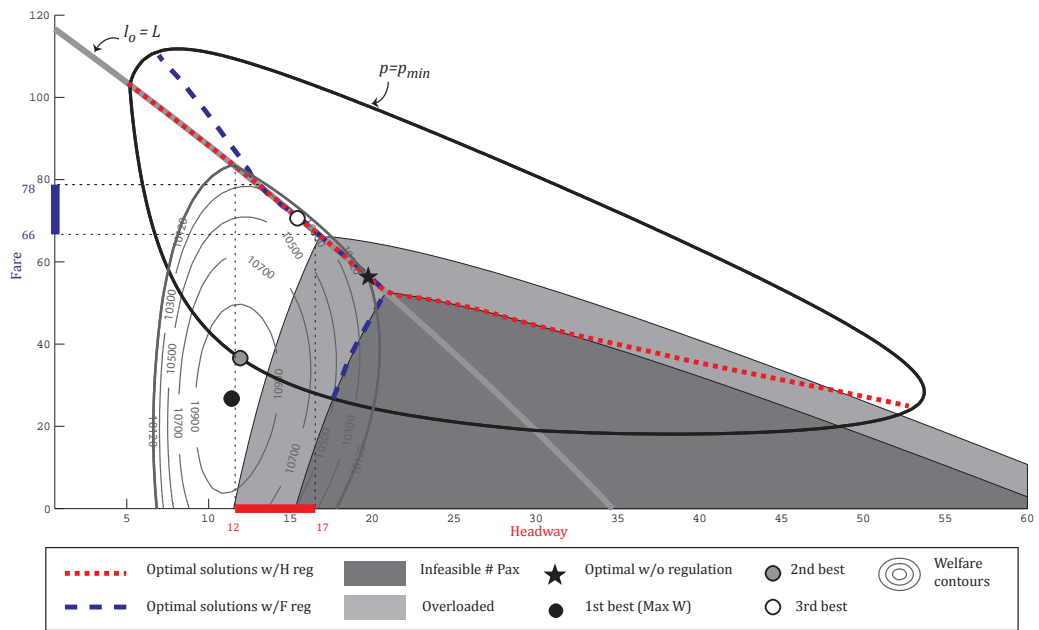
Similarly to the 14-seat case, when 25-seat vehicles are used, it is necessary to restrict vehicle capacity in order to provide the greatest increase in welfare. Figure 4.7 shows the fare and headway regulation lines when vehicle capacity is restricted. As shown in Figure 4.9, the minimum feasible fare dropped to 33 Ksh. It is optimal to set the fare equal to the minimum. This allows significant increases in welfare and user surplus due to a decrease in operator profits. Compared with the unregulated scenario, and as shown by Table 4.3, user surplus increased by 52% when service was provided by a cartel and by 44% when there was competition. Similarly, welfare increased by 6% and 8% respectively. As in the 14 seat case, this regulation forces cartels and competition regimes to operate identically. Under such regulation, transit is able to capture 79% of the mode share, only 3% less than in the welfare-maximizing government model.

4.3 Other Policy Interventions

Next we turn our attention to other measures that could effect the operation of informal transit such as increased wages and changing land use patterns.

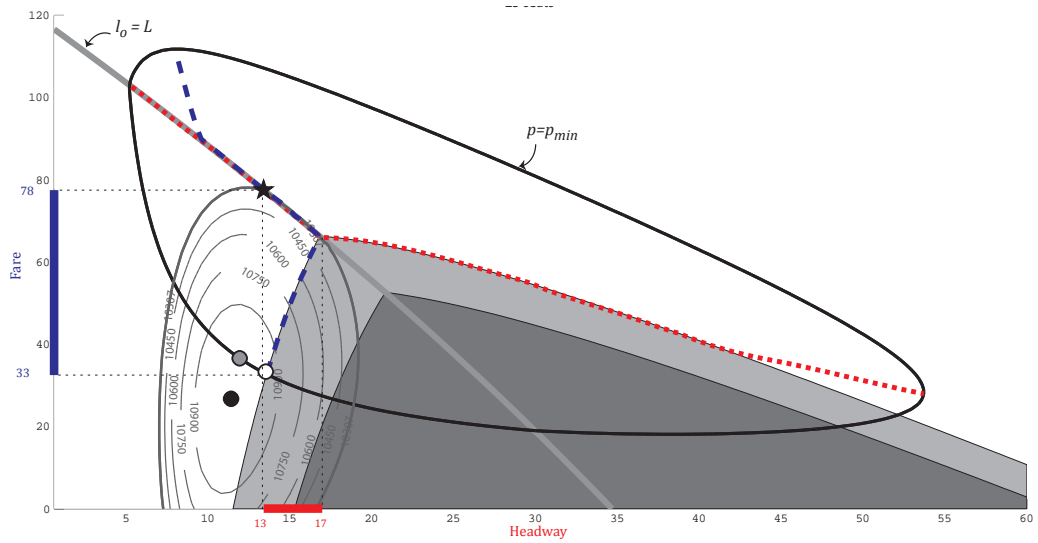


(a) Cartel

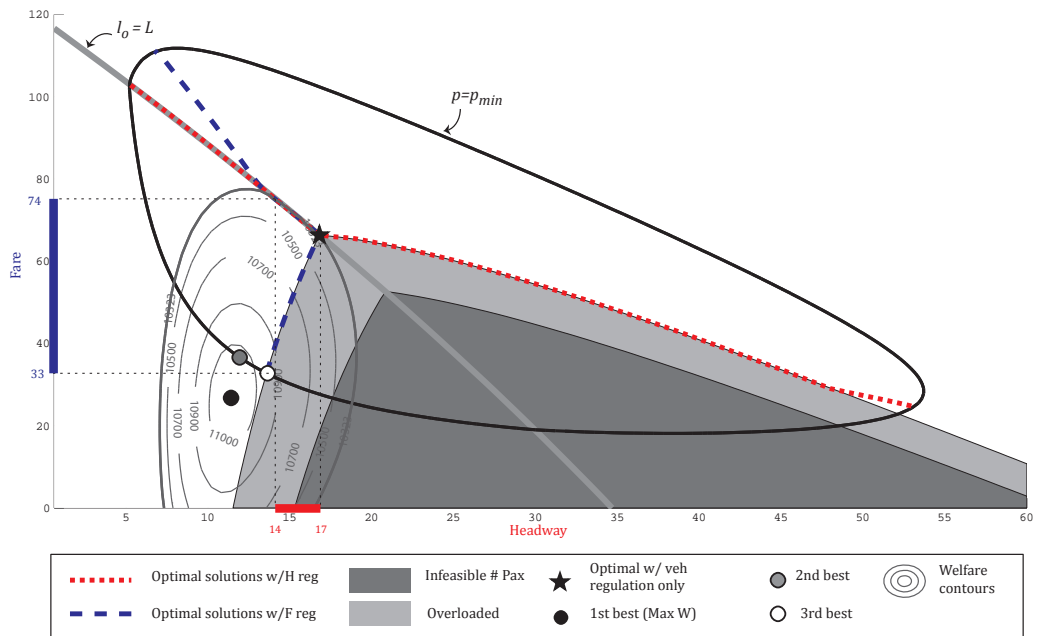


(b) Competition

Figure 4.8. Optimal Solutions under Fare and Headway Regulation for Informal Transit with Seatbelt Enforcement (25 seats)



(a) Cartel



(b) Competition

Figure 4.9. Optimal Solutions under Fare and Headway Regulation for Informal Transit with Seatbelt Enforcement(25 seats)

4.3.1 Increasing Wages

The abundance of cheap labor aids to congestion and the cut throat competition of informal transit. Bus drivers and conductors in Nairobi are paid lower than average wages. If drivers were paid at the average wage, the total wages for drivers and conductors would be increased to 350 Ksh/hr up from 200 Ksh/hr as described in Appendix C.

Increasing the hourly operating costs decreases the number of buses that will operate along the corridor when entry is not controlled. When $p = 0$, as in Chapter 3, the number of buses, B_{max} , decreased by 30% to 9 buses. If the system was regulated, the government would have to offset the increase in costs and would set the fare to 41 Ksh when enforcing seatbelt requirements; see Table 4.3. Compared with the corresponding (3^{rd} best) scenario with lower wages, the increase in wage reduced both the welfare and user surplus by 8%, and caused a 4% decrease in transit mode share.

4.3.2 Increased Density

The rate at which trips depart the CBD, λL is 135 pax/hr in the analysis above. Keeping this rate the same, we assume that land use regulations have been enacted that concentrate trips closer to the CBD thus reducing the route length, L , to 5 km and the demand density of destinations, λ increases to 27 trip/km-hr. Table 4.4 presents the results for this scenario, assuming no regulation. As expected, increasing the demand density of trip destinations is beneficial for users regardless of operating regime. For the government regime, increased density reduced subsidies and lowered the optimal fare. Mode shares remained relatively constant before and after land use changes.

The increased density greatly reduced the profits for privately provided transport. It was found that it was still optimal for users to make trips under 3 km via walking which is now a greater proportion of trips. Thus, headways were greater and vehicles had to wait longer before departing. The transit mode share dropped by over 20% with the increased density. 14-seat vehicles are preferred in all operating regimes.

Table 4.4. Results with a Shorter Route with Increased Demand

	Obj	H	F	L_b	B_{min}	S	Π_{max}	W	N_b	$\%_w$	$\%_b$	L_w
Previous Results												
14 seats	W^o	9	28	7.5	8	12443	-746	11697	17	17	83	1.3
	Π^o	12	81	7.5	6	7088	3734	10821	17	39	61	2.9
	R^o	13	81	7.4	5	7036	3672	10708	17	39	59	2.9
25 seats	W^o	11	27	7.5	7	11986	-938	11048	21	18	82	1.4
	Π^o	13	78	7.5	5	7148	3159	10307	18	39	61	2.9
	R^o	20	56	7.5	4	7535	2585	10120	29	35	65	2.6
Increased Trip Destination Density												
14 seats	W^o	9	21	5	6	14666	-713	13954	15	20	80	1.0
	Π^o	15	76	5	3	9704	2598	12302	14	59	41	3.0
	R^o	23	77	5	2	8994	2327	11321	17	67	33	3.4
25 seats	W^o	10	23	5	6	14204	-806	13398	17	22	78	1.1
	Π^o	17	75	5	3	9582	2279	11861	15	60	40	3.0
	R^o	30	56	5	2	9132	1784	10917	26	62	38	3.1

Chapter 5

Conclusions

5.1 Summary & Insights

This study presented an approach to jointly model the decision processes of users and operators on a corridor using a continuum-approximation framework. The model assumes that users choose either to walk, take transit, or not make the trip. Though applied to car-less users along a corridor with the characteristics of Nairobi, Kenya, the results can be generalized to other cities and other modes.

Chapter 3 compared three idealized operating regimes: (a) competing informal transit, (b) government, and (c) private monopoly. We noted that something is amiss when one optimizes for the social welfare of transit without the inclusion of other available modes. Therefore, our analysis optimizes the social welfare of everyone, including people who walk or do not travel. The properly captures the effect of induced demand.

At optimality, the welfare-maximizing system required subsidies and as found in previous work, smaller vehicles. The resulting fare was significantly less than when transit was provided privately, either by a monopoly or with competition. This trend held even when the unit operating costs were 30% greater for the government than for private transit. The high fares of privately provided transport resulted in individuals walking for trips under 3 km.

The private monopoly set fares higher than competitive informal transit, and had a preference for smaller vehicles. In the informal transit case with free competition, the selfish tendencies of the operators reduced profits and 25-seat vehicles were preferred. Larger vehicles allowed operators to earn more revenue prior to departing the CBD. However, this results in longer queuing times and lower profits at equilibrium.

The welfare-maximizing government regime provides better transport from a user perspective. It may be argued that developing countries require better transit; however, they may also be less capable of providing the subsidies required to operate optimal systems. Fortunately, Chapter 4 showed that with inexpensive regulation, informal transit operators can provide service comparable to a welfare-maximizing public entity. Fare regulation coupled with vehicle capacity enforcement provided the

best service. In addition, vehicle licensing is necessary if individual operators compete to provide the service. It was found that fare regulation coupled with preventing overfilling was ideal and resulted in nearly 78% of trips being served by transit. Headway regulation, on the other hand, was much less beneficial. For fare regulation to be successful, the government must make sure that consumers are aware of fares set.

Though Nairobi has already imposed seatbelt regulations that outlaw vehicle overfilling, it is still common practice, particularly outside of terminals. Enforcement of policies have proven difficult in Nairobi, and bribery of police is commonplace. Extortion by gangs is also a problem. Extortion and bribery make people less likely to invest in the industry. It was found that extortion and bribery reduce welfare significantly. Extortion and bribery costs could in turn be redirected to increased wages for operators or go towards vehicle and infrastructure improvements.

The two forms of regulation currently enacted in Nairobi have opposing effects from an operational perspective. Requiring seat belts reduces the capacity of vehicles, and in turn, encourages more buses on the route. Restricting owners to purchasing 25-seat vehicles, on the other hand, reduces the number of vehicles on the corridor. It was shown that a reduction in the number of vehicles may also be attained by increasing unit operating costs such as raising drivers' wage. In fact, there may be less opposition from drivers and conductors to the use of 25-seat vehicles if wages were increased because drivers could then work fewer hours for the same day's pay.

5.2 Future Work

This study was limited in scope as the model analyzed a simplified corridor in isolation. It assumed that all customers have the same value of time and derived the same benefit from making the trip. It also ignored the automobile as a competing mode. Furthermore, it was assumed that different number of transit vehicles on the system required by the different scenarios does not influence the network's ability to handle trips, so congestion was unaccounted for. In reality, a large number of 14-seater buses can create congestion and its externalities. The model also lacks the ability to quantify quality regulation measures such as those effecting safety and comfort. However, by focusing on the important metrics of costs and time, the model is a good first approximation. It should be refined in the future.

Future work may also account for heterogeneity amongst user and operators. In addition, varying demand patterns such as peak vs off-peak and non-uniform demand should be considered. The corridor analysis may also be extended to more complex origin-destination patterns. Despite its simplicity, and also because of it, the model lends itself to cross-city comparisons of informal transit.

Bibliography

- Aligula, EM, Abiero-Gariy, Z., Mutua, J., Owegi, F., Osengo, C., & Olela, R. 2005. Urban public transport patterns in Kenya: A case study of Nairobi City. *Kenya Institute for Public Policy Research and Analysis (Unpublished Special Report)*.
- Cervero, R. 2000. *Informal transport in the developing world*. United Nations Pubns.
- Cervero, R., & Golub, A. 2007. Informal transport: A global perspective. *Transport Policy*, **14**(6), 445–457.
- Chitere, P.O., & Kibua, T.N. 2004. Efforts to improve road Safety in Kenya.
- Ference, Meghan. 2011. Utanijenga – you will build me: Moral ambiguity and the stigma of risky business in Nairobi's transportation industry. 4th European Conference on African Studies.
- Fernandez, E., & Marcotte, P. 1992. Operators-users equilibrium model in a partially regulated transit system. *Transportation Science*, **26**(2), 93.
- Gronau, R. 2000. Optimum diversity in the public transport market. *Journal of transport economics and policy*, 21–41.
- Gwilliam, K. 2003. Urban transport in developing countries. *Transport Reviews*, **23**(2), 197–216.
- Gwilliam, K., & Scurfield, R. 1996. Competition in public road passenger transport. *World Bank Report TWU-24*. Washington, DC.
- Harker, P.T. 1988. Private market participation in urban mass transportation: application of computable equilibrium models of network competition. *Transportation science*, **22**(2), 96.
- Healy, Mike. 2012. *The reluctant outlaw*. Aljazeera World.
- Holroyd, M. 1967. The optimum bus service: a theoretical model for a large uniform urban area. *Vehicular traffic science: proceedings*, 308.
- Howe, J., & Bryceson, D. 2001. Poverty and urban transport in East Africa. *Pages 267–272 of: Proceedings - Institution of Civil Engineers Municipal Engineer*, vol. 145. Citeseer.

- Iles, R. 2005. *Public transport in developing countries*. Elsevier Science.
- Jansson, J.O. 1980. A simple bus line model for optimisation of service frequency and bus size. *Journal of Transport Economics and Policy*, 53–80.
- Jara-Díaz, S., & Gschwender, A. 2003. Towards a general microeconomic model for the operation of public transport. *Transport Reviews*, **23**(4), 453–469.
- Kariuki, James. 2012. *Wambururu's blog - Matatu's: Kenyan mode of public transport vehicles*.
- Kimani, N.P., Kibua, T.N., & Masinde, M. 2004. *The role of the matatu in Kenya: economic costs, benefits, and policy concerns*. Institute of Policy Analysis and Research.
- Kumar, A., & Barrett, F. 2008. Stuck in traffic: Urban transport in Africa. *AICD, Background Paper, World Bank, Washington, DC*.
- Mohring, H. 1972. Optimization and scale economies in urban bus transportation. *The American Economic Review*, **62**(4), 591–604.
- Small, K.A., & Verhoef, E.T. 2007. *The economics of urban transportation*. Psychology Press.
- UBS. 2010. *Prices and Earnings: A global purchasing power comparison*. Tech. rept. Wealth Management Research.
- United Nations. 2011. *World urbanization prospects: The 2011 revision*. United Nations.
- Van Reeve, P. 2008. Subsidisation of urban public transport and the Mohring effect. *Journal of Transport Economics and Policy*, **42**(2), 349–359.
- Viton, P.A. 1982. Privately-provided urban transport services: Entry deterrence and welfare. *Journal of Transport Economics and Policy*, 85–94.
- Yang, H., Kong, Y., *et al.* 2001. Value-of-time distributions and competitive bus services. *Transportation Research Part E: Logistics and Transportation Review*, **37**(6), 411–424.
- Zhou, J., Lam, W.H.K., & Heydecker, B.G. 2005. The generalized Nash equilibrium model for oligopolistic transit market with elastic demand. *Transportation Research Part B: Methodological*, **39**(6), 519–544.
- Zubieta, L. 1998. A network equilibrium model for oligopolistic competition in city bus services. *Transportation Research Part B: Methodological*, **32**(6), 413–422.

Appendix A

Variable List

α_d	=	Bus operating cost per distance traveled	[Ksh/km]
α_d^i	=	Hourly operating costs incurred by investor	[Ksh/km]
α_d^o	=	Hourly operating costs incurred by operator	[Ksh/km]
α_d^i	=	Distance-based operating costs incurred by investor	[Ksh/km]
α_d^o	=	Distance-based operating costs incurred by operator	[Ksh/km]
α_h	=	Hourly bus operating cost	[Ksh/hr]
β_i	=	In-vehicle value of time	[Ksh/hr]
β_o	=	Out-of-vehicle value of time	[Ksh/hr]
Π	=	Hourly bus system profit	[Ksh/hr]
$\$$	=	Generalized cost of potential trip	[Ksh]
$\$_{\emptyset}$	=	Generalized cost of choosing not to travel	[Ksh]
$\$_b$	=	Generalized cost of making trip by bus	[Ksh]
$\$_o$	=	Benefit of taking trip	[Ksh]
$\$_w$	=	Generalized cost of making trip via walking	[Ksh]
τ	=	Loss time due to passenger alighting	[hr/pax]
λ	=	Demand density of destinations along the corridor	[pax/hr-km]
B	=	Number of buses on corridor	[buses]
B_{min}	=	Minimum number of buses to guarantee service frequency	[buses]
B_{max}	=	The number of buses that makes profits vanish the minimum acceptable level	[buses]
C	=	Total operating cost per trip	[Ksh]
C^o	=	Operator/driver operating cost per trip	[Ksh]
C^i	=	Investor/owner operating cost per trip	[Ksh]
D	=	Average bus passenger delay/waiting time	[hr]
F	=	Bus fare	[Ksh]

H	=	Headway between buses	[hr]
l	=	Distance of trip destination from the CBD	[km]
l_w	=	Distance where cost of walking is equal to the cost of taking the bus	[km]
l_\emptyset	=	Distance where the cost of taking the bus is equal to the cost of not making the trip	[km]
L	=	Length of corridor	[km]
L_b	=	Bus service length from CBD	[km]
L_w	=	Maximum distance from CBD that people will walk	[km]
N_\emptyset	=	Number of people not making trip per bus trip	[users]
N_b	=	Number of passengers per bus trip	[pax]
N_w	=	Number of walkers per bus trip	[users]
Q	=	Average bus queuing delay	[hr]
R	=	Revenue per trip	[Ksh]
R^i	=	Revenue per trip that go towards investor	[Ksh]
R^o	=	Revenue per trip that go towards operator	[Ksh]
S	=	Hourly surplus across all users	[Ksh/hr]
$s(l)$	=	Number of stops made when destination is a distance l from the CBD	[stops]
S_b	=	Hourly surplus for bus passengers	[Ksh/hr]
S_w	=	Hourly surplus for walkers	[Ksh/hr]
S_\emptyset	=	Hourly surplus for those not making trip	[Ksh/hr]
T	=	Round trip time spent delivering customers	[hr]
v_b	=	Average bus speed including traffic stops	[kph]
v_w	=	Walking speed	[kph]
W	=	Total hourly welfare (or surplus) across all users and operators regardless of mode	[Ksh/hr]
W_b	=	Hourly welfare for bus users and operators	[Ksh/hr]
Z_i	=	Objective function for informal case	[Ksh]
Z_c	=	Objective function for company case	[Ksh/hr]
Z_g	=	Objective function for government case	[Ksh/hr]

Appendix B

Sensitivity of Surplus to Fare

Here we examine how total surplus depends on fare. For maximum transparency we consider the common case where the whole corridor is served so $L_b = L$ and the loss time per stop is negligible ($\tau = 0$). The linkage between surplus and fare occurs because $\$b(l)$, as given in (2.2), depends on F , which fixes the height of the middle line in Figure B.1. To explain this dependence we shall write $\$b(l, F)$ instead of $\$b(l)$. The figure also shows that the intersection abscissa L_w also depends (linearly) on F . We express this dependency by writing $L_w(F)$ and defining¹

$$\frac{\partial L_w}{\partial F} = K. \quad (\text{B.1})$$

With this notation (2.12)-(2.14) becomes:

$$S_w = \int_{l=0}^{L_w(F)} \lambda \cdot (\$o - \$w(l)) dl \quad (\text{B.2})$$

$$S_b = \int_{l=L_w(F)}^L \lambda \cdot (\$o - \$b(l, F)) dl \quad (\text{B.3})$$

$$S_\emptyset = \$o - \$\emptyset = 0. \quad (\text{B.4})$$

Now take the derivative of $S = S_w + S_b + S_\emptyset$ with respect to F . Note that the derivative of the third term S_\emptyset is zero. For the first term, using the rules of differentiation for integrals, we get:

$$\begin{aligned} \frac{\partial S_w}{\partial F} &= \frac{\partial S_w}{\partial L_w} \cdot \frac{\partial L_w}{\partial F} \\ &= \lambda \cdot (\$o - \$w(L_w)) \cdot K \end{aligned} \quad (\text{B.5})$$

¹The value of the constant K is $\frac{v_b v_w}{\beta_i (2v_b - v_w)}$, as can be seen by solving for the intersection point of lines $\$w$ and $\$b$.

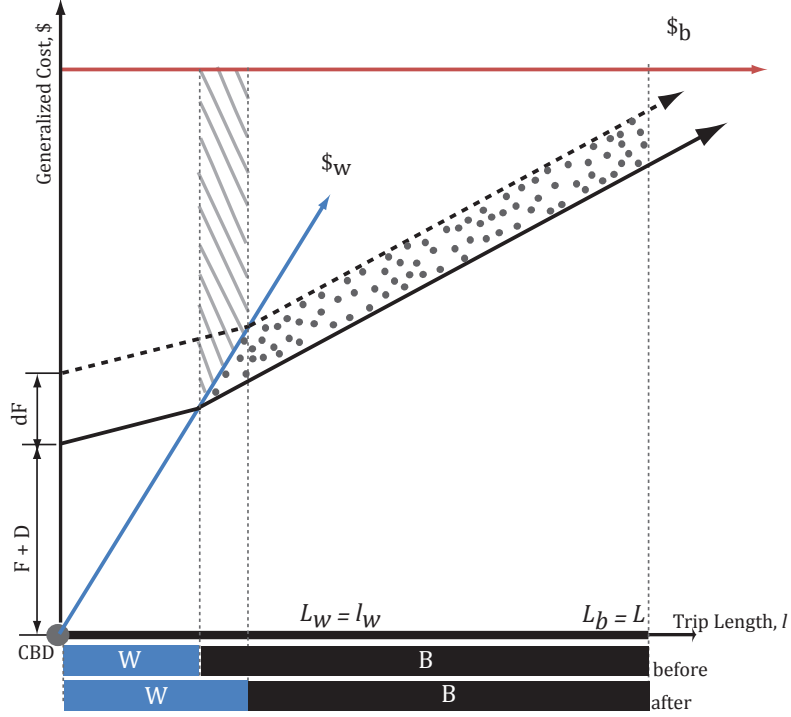


Figure B.1. User Mode Choice

This expresses the rate of increase in surplus to walkers diverted from transit due to an increase in fare. The amount corresponding to a change in fare dF is highlighted by the hashed area in Figure B.1.

Similarly, for the second term we have:

$$\begin{aligned} \frac{\partial S_b}{\partial F} &= \frac{\partial S_b}{\partial \$_b} \cdot \frac{\partial \$_b}{\partial F} + \frac{\partial S_b}{\partial L_w} \cdot \frac{\partial L_w}{\partial F} \\ &= -\lambda(L - L_w) - \lambda \cdot (\$_o - \$_b(L_w)) \cdot K \end{aligned} \quad (\text{B.6})$$

since $\partial \$_b / \partial F = 1$. The first term in (B.6) represents the rate of reduction in surplus for transit users because they are diverted to walking, also represented by the hashed area in Figure B.1. This term cancels the increase in surplus for walkers in (B.5) since $\$_w(L_w) = \$_b(L_w)$. Thus the hatched area does not contribute to the change in surplus.

The second term in (B.6) is the reduction in surplus for the users that stay with transit and suffer the higher fare. This is highlighted by the dotted area in Figure B.1. Thus the net reduction rate arises because of these users only. This is shown both by the figure and by the final expression for the derivative obtained by adding (B.5) and (B.6).

$$\frac{\partial S}{\partial F} = \frac{\partial S_w}{\partial F} + \frac{\partial S_b}{\partial F} + \frac{\partial S_\emptyset}{\partial F} = -\lambda(L - L_w) \quad (\text{B.7})$$

Recall that shortsighted government objective is to maximize $S_b + \Pi$ whereas in our model the objective is to maximize $S_w + S_b + S_\varnothing + \Pi$. As shown by comparing (B.6) to (B.7), the shortsighted government overestimates the loss in user surplus that arise from an increase in fare by $\lambda \cdot (\$_o - \$_b(L_w)) \cdot K$. This is because with this method one counts the disbenefit due to the reduced number of transit users without compensating for the benefit of the increased number of walkers.

Appendix C

Input Parameters

The input parameters for this work are based on values from Nairobi, Kenya. The following presents the derivation and assumptions of each parameter.

Table C.1. User and route characteristics

β_i	=	100 Ksh/hr	λ	=	18 pax/km-hr
β_o	=	200 Ksh/hr	L	=	7.5 km
$\$_o$	=	160 Ksh	v_b	=	18 km/hr
τ	=	0.01 hr	v_w	=	5 km/hr

Ksh=Kenyan Shillings, 100 Ksh \approx 1.2 USD (2012)

C.1 User Characteristics

Values of Time

The monetary value one associates with an hour of time is their value of time. The value of time inside a vehicle can be approximated as half of the wage rate, while the time out of vehicle is roughly double (i.e. equal to the wage rate) (Small & Verhoef, 2007).

A UBS (2010) study which compares the wage rates of various cities relative to New York City found that the average hourly wage rate in Nairobi is 8.2% of the average hourly wage rate in New York City given an exchange rate of 100 Ksh = \$1.232. Assuming an hourly wage of 30 \$/hr in New York City, the average hourly wage rate in Nairobi is approximated as:

$$\text{Hourly wage} = .082 \cdot 30 \text{ \$/hr} \cdot \frac{100}{1.232} \text{ Ksh/\$} = 200 \text{ Ksh/hr.} \quad (\text{C.1})$$

Therefore, the in-vehicle and out-of-vehicle values of time are $\beta_i = 100 \text{ Ksh/hr}$ and $\beta_o = 200 \text{ Ksh/hr}$, respectively.

Benefit of Trip

Aligula *et al.* (2005) found that the average household expenditure in Nairobi is 27,620 Ksh of which 16.5% is dedicated to transportation. Thus assuming that individuals make 2.5 trips a day and there are 3.5 individuals per household we can approximate the proportion of trip costs that is attributed directly to fares. The study also found that people wait an average of 12 minutes for a *matatu* to arrive and spend 78 minutes traveling. By multiplying the wait time by the out-of-vehicle value of time, we convert this time into monetary units as denoted by the second term in (C.2). Lastly, we can determine the third term, the amount of value associated with the time it takes to travel to destination, by subtracting an average access time of 15 mins from the traveling time since access is not considered in this analysis and multiplying by the in-vehicle value of time. We assume that value of making the trip is a lower bound on the benefit of a trip, thus the benefit of a trip ($\$_o$) is approximated as

$$\begin{aligned} \$_o &= 0.165 \cdot \left(\frac{27620 \text{ Ksh/mth-hh}}{3.5 \text{ person/hh} \cdot 30 \text{ days/mth} \cdot 2.5 \text{ trips/day-person}} \right) \\ &\quad + 200 \text{ Ksh/hr} \cdot \left(\frac{12}{60} \text{ hr} \right) + 100 \text{ Ksh/hr} \cdot \left(\frac{78 - 15}{60} \text{ hr} \right) \\ &= 17 + 40 + 105 \approx 160 \text{ Ksh.} \end{aligned} \tag{C.2}$$

Table C.1 provides a summary of all the input parameters.

C.2 Route Characteristics

Recall that the model assumes that individuals will either walk or take the bus to their destination. We assume a walking speed, v_w , of 5 km/hr. According to Howe & Bryceson (2001) the average speed of *matatus* including stops was 18 km/hr for *matatus* though it was noted that the speed in the city can be as low 8 km/hr during peak periods. On the other hand, KBS buses had an average trip speed 11.5 km/hr due to their lack of maneuverability. In addition, a loss time for stop of 0.01 hr due to passenger alighting and vehicle acceleration and deceleration is assumed.

Aligula *et al.* (2005) determined the average ridership including cars to be 2136 trips/hr in Nairobi. These trips represent 52% of all trips made in the city, the rest being via non-motorized modes. We assumed that there were roughly 15 non-overlapping corridors in the city of Nairobi and at a length around 15 km. Therefore the corridor demand is estimated as

$$\lambda = \frac{2136}{.52} \text{ trips/hr} \cdot \frac{1}{15 \text{ routes}} \cdot \frac{1}{15 \text{ km/route}} = 18 \text{ trips/km-hr.} \tag{C.3}$$

C.3 Operator Costs

In our analysis we divide costs that are imposed to the vehicle operator and the vehicle owner as often these are separate entities. Table C.2 presents all costs considered in this analysis.

Distance-based Operating Cost

We assume that distance-based costs are composed of fuel and maintenance costs.

Fuel Costs

Currently, fuel in Nairobi, Kenya is around 118 Ksh/liter. Due to the fact the majority of vehicles are purchased secondhand and that Nairobi is congested, we assume a fuel efficiency of 6.5 km/liter for 14 seat and 5 km/liter for 25 seat minibuses. Therefore, we estimate the cost per unit distance due to fuel for 14- and 25-seat minibuses, respectively, as

$$\text{Cost due to Fuel (14-seats)} = \frac{118 \text{ Ksh/liter}}{6.5 \text{ km/liter}} = 18 \text{ Ksh/km} \quad (\text{C.4})$$

$$\text{Cost due to Fuel (25-seats)} = \frac{118 \text{ Ksh/liter}}{5 \text{ km/liter}} = 24 \text{ Ksh/km}. \quad (\text{C.5})$$

Maintenance Costs

Kimani *et al.* (2004) estimated the daily maintenance costs for 14-seat and 25-seat minibuses to be roughly equal at 384 Ksh/day. The study also found that a 14-seat minibus spends 2050 Ksh/day on fuel and a 25-seat minibus 2500 Ksh/day. Knowing that at the time of the study fuel was roughly 70 Ksh/liter we can calculate the expected kilometers per day driven by vehicle type as

$$\text{km per day (14-seats)} = 2050 \text{ Ksh/day} \cdot \frac{6.5 \text{ km/liter}}{70 \text{ Ksh/liter}} = 190 \text{ km/day} \quad (\text{C.6})$$

$$\text{km per day (25-seats)} = 2500 \text{ Ksh/day} \cdot \frac{5 \text{ km/liter}}{70 \text{ Ksh/liter}} = 179 \text{ km/day}. \quad (\text{C.7})$$

Therefore, the maintenance cost for each vehicle type is

$$\text{Cost due to Maintenance (14-seats)} = \frac{384 \text{ Ksh/day}}{190 \text{ km/day}} \approx 2 \text{ Ksh/km} \quad (\text{C.8})$$

$$\text{Cost due to Maintenance (25-seats)} = \frac{384 \text{ Ksh/day}}{179 \text{ km/day}} \approx 2 \text{ Ksh/km}. \quad (\text{C.9})$$

Hourly Operating Cost

Wages

According to Kimani *et al.* (2004), each vehicle on average hires two sets of drivers and conductors. Vehicles tend to be in operation for 18 hr/day thus requiring each set of drivers to work 9 hours. Drivers and conductors are paid a daily wage of roughly 476 Ksh and 355 Ksh, respectively, regardless of vehicle type. The actual amount *matatu* drivers and conductors take home is often greater than this amount as they split all profits that remain after meeting owner's daily target. Though widely varied by day, drivers on average collect 1000 Ksh/day after accounting for expenses (Kariuki, 2012). This means that drivers on average are able to supplement their salary $1000 - 476 = 524 \text{ Ksh}/\text{day}$ from revenues. Thus, assuming an even split of the revenues between drivers and conductors, the real hourly take home pay of operators (driver and conductor combined) is

$$\text{Income} = \frac{476 + 355 + (2 \cdot 524) \text{ Ksh}/\text{day}}{9 \text{ hrs}/\text{day}} \approx 200 \text{ Ksh}/\text{hr}. \quad (\text{C.10})$$

Recall that we assumed above that the average wage rate in Nairobi was $200 \text{ Ksh}/\text{hr}$. If drivers and conductors were paid a more competitive rate, say one that puts them at the average income level in Nairobi, then they should have an income of

$$\text{Income}' = 200 + 200 \cdot \frac{355 \text{ Ksh}/\text{day}}{476 \text{ Ksh}/\text{day}} \approx 350 \text{ Ksh}/\text{hr}. \quad (\text{C.11})$$

assuming conductors still make the same fraction of that of drivers.

Extortion and Bribery

Drivers of *matatus* are constantly harassed by police enforcement and gangs for a portion of their profits. In Nairobi, the Mungiki gang control profitable routes to Dandora, Eastleigh, and Kayole. In personal interviews conducted by Ferece (2011) drivers note that on average 500 Ksh/day goes to extortion and bribery. Therefore, the hourly cost component due to bribes and extortion is

$$\text{Extortion to Operators} = \frac{500 \text{ Ksh}/\text{day}}{9 \text{ hrs}/\text{day}} = 55 \text{ Ksh}/\text{hr}. \quad (\text{C.12})$$

Owner Operating Costs

Vehicle Depreciation

The 14-seater minibus is most common in Nairobi due to it being significantly more affordable than larger vehicles. Most 14-seater vehicles are imported used and cost owners 1.5 million Ksh where as a new 25-seater minibus costs around 4 million Ksh. We assume that the 14-seater minibuses will operate for 10 years since bought used,

and the 25-seater for 15 years and that the vehicle is operational 75% of the year due to weekends and time off for repair and when operational, it is operational for 18 hrs/day. Therefore, the hourly costs due to vehicle depreciation is

$$\text{Veh Depreciation (14-seats)} = \frac{1.5 \times 10^6 \text{ Ksh/veh}}{10 \text{ yrs/veh} \cdot (0.75 \cdot 365) \text{ days/yr} \cdot 18 \text{ hrs/day}} = 30 \text{ Ksh/hr} \quad (\text{C.13})$$

$$\text{Veh Depreciation (25-seats)} = \frac{4 \times 10^6 \text{ Ksh/veh}}{15 \text{ yrs/veh} \cdot (0.75 \cdot 365) \text{ days/yr} \cdot 18 \text{ hrs/day}} = 54 \text{ Ksh/hr.} \quad (\text{C.14})$$

Government Imposed Fees

According to Kimani *et al.* (2004), owners must pay a taxes on their vehicles of around 70 hrs/day and 91 hrs/day for 14-seat and 25-seat vehicle respectively, and a daily parking fee of 70 Ksh. Once again assuming 18 hours of service per day, the hourly costs are

$$\text{Taxes \& licensing fees (14-seats)} = \frac{70 \text{ Ksh/day}}{18 \text{ hrs/day}} = 4 \text{ Ksh/hr}, \quad (\text{C.15})$$

$$\text{Taxes \& licensing fees (25-seats)} = \frac{91 \text{ Ksh/day}}{18 \text{ hrs/day}} = 5 \text{ Ksh/hr}, \quad (\text{C.16})$$

and

$$\text{Parking/Terminal fee} = \frac{70 \text{ Ksh/day}}{18 \text{ hrs/day}} = 4 \text{ Ksh/hr.} \quad (\text{C.17})$$

Insurance

Since *matatus* are public service vehicles they are required to have insurance. Kimani *et al.* (2004) notes that owners of 14-seat *matatus* pay 240 Ksh/day towards insurance and owners of 25-seat vehicles 290 Ksh/day. Thus, the hourly insurance costs are

$$\text{Insurance (14-seats)} = \frac{240 \text{ Ksh/day}}{18 \text{ hrs/day}} = 13 \text{ Ksh/hr} \quad (\text{C.18})$$

$$\text{Insurance (25-seats)} = \frac{290 \text{ Ksh/day}}{18 \text{ hrs/day}} = 16 \text{ Ksh/hr.} \quad (\text{C.19})$$

Association Fees

Most vehicle owners are members of route associations. Route associations charge fees upwards of 10,000 Ksh per year. This money goes to the operating, savings and credit cooperative for maintenance of the route. This translates into an hourly cost of

$$\text{Association Fee} = \frac{10000 \text{ Ksh/yr}}{(0.75 \cdot 365) \text{ days/yr} \cdot 18 \text{ hrs/day}} = 2 \text{ Ksh/hr.} \quad (\text{C.20})$$

Table C.2. List of all bus operating costs

		14 seats	25 seats
<i>Hourly costs to operator,</i> α_h^o [Ksh/hr]	Wage	200	200
	Extortion	55	55
<i>Distance cost to operator,</i> α_d^o [Ksh/km]	Fuel	18	24
	Maintenance	2	2
<i>Hourly cost to investor,</i> α_h^i [Ksh/hr]	Vehicle depreciation	30	54
	Licensing/Taxes	4	5
	Parking Fee in CBD	4	4
	Insurance	13	16
	Association fees	2	2
	Extortion	11	11

Extortion

Owners often complain that gangs require upwards of 200 Ksh/day as a fee to operate on the route (Kimani *et al.*, 2004). Therefore, when gangs are present we assume an hourly cost to owners of

$$\text{Extortion to Owners} = \frac{200 \text{ Ksh/day}}{18 \text{ hrs/day}} = 11 \text{ Ksh/hr.} \quad (\text{C.21})$$

Operating costs are divided into hourly, distance-based costs, and fixed costs per trip. Table C.2 summarizes the bus operating costs and each is derived below.

Appendix D

Results

Table D.1. Shortsighted government baseline results (detailed)

Obj.	H	F	L_b	B	S	Π	W	N_b	$\%_w$	$\%_b$	p (%)	W_b
14-seats												
W_b^o	8	0	7.5	9	15953	-4496	11457	17	5	95	-100	10400
W_b^p	9	35	7.5	7	11684	0	11684	17	20	80	0	8220
$W_b^{N_b}$	6	0	7.5	11	16618	-5756	10862	13	4	96	-100	10055
$W_b^{N_b,p}$	7	44	7.5	9	11289	0	11289	13	22	78	0	7524
25-seats												
W_b^o	9	0	7.5	8	15562	-4812	10751	19	6	94	-100	9547
W_b^p	13	34	7.5	6	11013	0	11013	22	21	79	0	7355

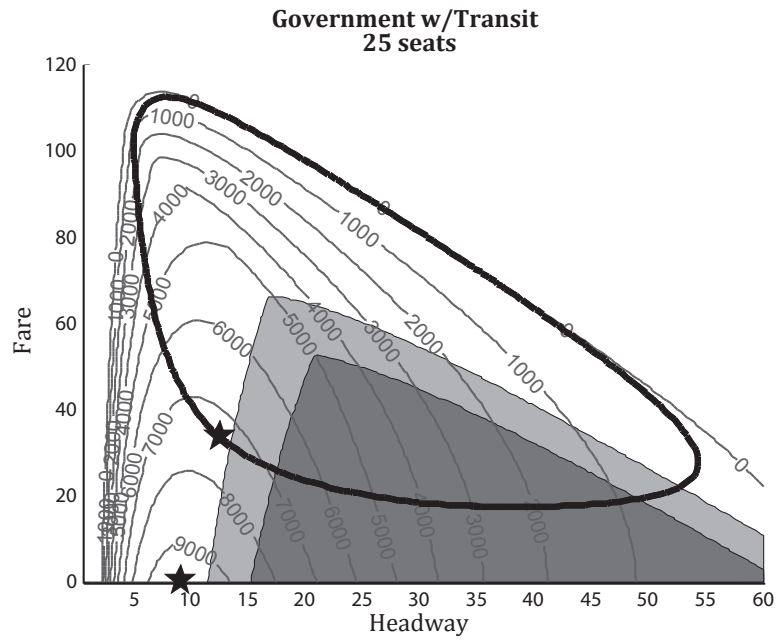
Table D.2. Government baseline results (detailed)

Obj.	H	F	L_b	B	S	Π	W	N_b	$\%_w$	$\%_b$	p (%)	W_b
Initial Inputs (14-seats)												
W^o	9	28	7.5	8	12443	-746	11697	17	17	83	-19	8628
W^p	9	35	7.5	7	11684	0	11684	17	20	80	0	8220
W^{N_b}	7	39	7.5	9	11893	-595	11298	13	20	80	-12	7830
$W^{N_b,p}$	7	44	7.5	9	11289	0	11289	13	22	78	0	7524
Initial Inputs (25-seats)												
W^o	11	27	7.5	7	11986	-938	11048	21	18	82	-24	7858
W^p	12	35	7.5	6	11025	0	11025	21	21	79	0	7338
30% Increase in Hourly Operating Costs (14-seats)												
W^o	9	33	7.5	8	11886	-769	11117	17	19	81	-17	7756
W^p	10	40	7.5	7	11101	0	11101	17	22	78	0	7348
W^{N_b}	7	45	7.5	9	11233	-617	10616	13	22	78	-12	6825
$W^{N_b,p}$	8	51	7.5	9	10606	0	10606	13	25	75	0	6520
30% Increase in Hourly Operating Costs (25-seats)												
W^o	12	29	7.5	6	11512	-1007	10505	22	19	81	-24	7096
W^p	13	39	7.5	6	10477	0	10477	22	23	77	0	6547

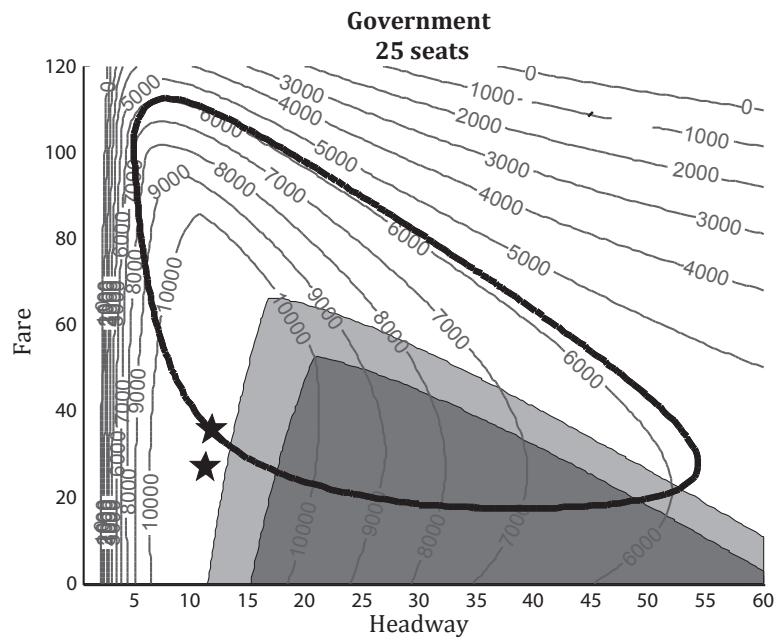
Table D.3. Company/cartel results (detailed)

Obj.	H	F	L_b	B	S	Π	W	N_b	$\%_w$	$\%_b$	p^*
14-seats											
Π^o	12	81	7.5	6	7088	3734	10821	17	39	61	129
Π^{N_b}	10	89	7.5	7	6947	3576	10522	13	41	59	101
25-seats											
Π^o	13	78	7.5	5	7148	3159	10307	18	39	61	97

* p given for company case



(a) Transit Welfare Only



(b) Total Welfare

Figure D.1. Decision Space and Equilibrium Solutions (25-seats): Government Regime

Table D.4. Informal transit results with full competition (detailed)

Obj.	H	F	L_b	B_{min}	$B_{p=0}$	S	Π_{max}	W_{max}	N_b	$\%_w$	$\%_b$	R
Initial Inputs (14-seats)												
R^o	13	81	7.4	5	20	7036	3672	10708	17	39	59	1371
R^L	12	81	7.5	6	20	7093	3733	10827	17	39	61	1370
R^{N_b}	11	89	7	6	19	6700	3326	10027	13	42	52	1162
$R^{N_b,L}$	10	89	7.5	7	21	6947	3576	10522	13	41	59	1158
Initial Inputs (25-seats)												
R^o	20	56	7.5	4	13	7535	2585	10120	29	35	65	1638
R^{N_b}	17	66	7.5	5	15	7349	2974	10323	24	37	63	1592
With Extortion (25-seats)												
R^o	20	56	7.5	4	11	7535	2301	9836	29	35	65	1638
R^{N_b}	17	66	7.5	5	12	7349	2665	9836	24	37	63	1592
Higher Wages (25-seats)												
R^o	20	56	7.5	4	9	7535	1940	9475	29	35	65	1638

Table D.5. Equilibrium solutions with concentrated demand

Obj	H	F	L_b	B	S	Π	W	N_b	$\%_w$	$\%_b$
14-seats										
W^o	9	21	5	6	14666	-713	13954	15	20	80
W^p	9	27	5	6	13932	0	13932	15	25	75
W^{N_b}	7	25	5	7	14501	-615	13887	13	22	78
$W^{N_b,p}$	8	31	5	6	13870	0	13870	13	26	74
Π^o	15	76	5	3	9704	2598	12302	14	59	41
Π^{N_b}	15	76	5	3	9704	2598	12302	14	59	41
R^o	23	77	5	2	8994	2327	11321	17	67	33
R^{N_b}	19	88	5	3	8931	2355	11285	13	69	31
25-seats										
W^o	10	23	5	6	14204	-806	13398	17	22	78
W^p	10	30	5	5	13368	0	13368	17	28	72
Π^o	17	75	5	3	9582	2279	11861	15	60	40
R^o	30	56	5	2	9132	1784	10917	26	62	38
R^{N_b}	29	60	5	2	9103	1878	10981	24	63	37