Wesleyan University The Honors College

Collusion among the Cellular Carriers in Thailand: An Empirical Investigation

by

Napat Phichaphop
Class of 2008

A thesis submitted to the
faculty of Wesleyan University
in partial fulfillment of the requirements for the
Degree of Bachelor of Arts
with Departmental Honors in the Mathematics-Economics Program

Middletown, Connecticut April, 2008

ACKNOWLEDGMENTS

I would like to first thank Professor Christiaan Hogendorn, my amazing thesis advisor, for his invaluable support and constant encouragement. The insightful discussions we have had throughout the year greatly helped me develop my thesis idea into a concrete argument. Without his guidance, this thesis could not have been finished. I also would like to thank Professor Manolis Kaparakis for his dedicated help with econometric analyses and how to implement them in Stata and SAS. Countless nights have been spent running these programs, but even more nights would have been necessary without his assistance. I am greatly indebted to Professor Sorrayuth Meenaphant as well for his comments that really got everything started, especially his suggested approach to formulating a testable hypothesis. I also appreciate the advice from Dr. Somkiat Tangkitvanich that provides necessary background about Thailand's cellular phone industry for me to start my research, putting things into perspective. I am grateful to all the faculty members in the Economics Department, Wesleyan University for their helpful comments made during the thesis progress presentation in the Fall.

In addition, I would like to thank all my friends and fellow thesis writers for their continuous mental support, wonderful accompaniment, and best wishes for me to successfully finish this thesis. There were times that I got stuck and wanted to give up, yet my friends are the ones who listened to my frustrating complaints and motivated me to keep going. Occasional procrastination, which was necessary to keep my mind fresh and clear, was also willingly encouraged by these people.

I truly appreciate the cooperation from the Investor Relations Department at AIS and DTAC for their assistance in providing me with necessary company data. I also thank the Stock Exchange of Thailand for sharing with me the quarterly financial reports filed by these two companies, as well as the journalists at various local newspapers for their opinions that partially justifies my thesis argument. I am particularly grateful to Mr. Piti Hongsaranakorn for directing me to the right data source, as I had not been able to find necessary data until late February.

Last but not least, I would like to thank my family for having always been there for me when I need them. They are also one of my main inspirations that encourage me to pursue my interests, and I very much appreciate everything they have done for me.

Everyone above has been a crucial factor for my work completion. To them I dedicated this thesis.

Abstract

This work investigates the game-theoretic structure between the two major players, namely AIS and DTAC, in Thailand's cellular telephone industry. The duopolistic competition with limited entry has prompted criticism around the two incumbents that they have been tacitly colluding in prices and advertising spending. Applying a theoretical framework proposed by Gasmi, Laffont, and Vuong (1992) with the Three-Stage Least Squares method, this paper finds that the non-collusive model with DTAC as leader and AIS as a follower in both price and advertising yields the best result, contrasting with the popular belief. Full-Information Maximum Likelihood method is also employed but does not produce any indicative results due to limited availability of the data as well as high multicollinearity among variables. Furthermore, incorporating the structural break in 2002 upon the entry of the third firm does not improve goodness of fit of the model to our data.

Table of Contents

I. INTRODUCTION

In today's business world, it is undeniable that the competition has become more intensified than ever. With more efficient markets, better facilitated trades, and more advanced technology, obstacles for the market mechanism to function well have been reduced continuously. However, there still exist a number of industries that are far from being perfectly competitive, particularly ones with few players, large fixed costs, and barriers to entry. Such an environment could potentially induce cooperation between competitors and consequently cause various anti-competitive behaviors to take place.

There are a few types of market conduct that are considered collusive or anti-competitive. The ones we frequently see include: predatory pricing, cartels, price fixing, market share fixing and advertising expense fixing. When any form of collusion occurs, microeconomic theory suggests that there will be an increase in deadweight loss to the welfare of the society, as well as the shifts in consumer and producer surpluses from what would have been at the non-collusive equilibrium. As most of the time the change will be in favor of the producers, it is crucial for the government to enforce appropriate regulations to prevent collusive behavior among producers from happening. This enforcement applies especially in industries where the impact on people's consumption is large, and a slight increase in the product price will significantly affect their ability to consume.

According to some studies that explore the existence of tacit or explicit collusion, including Slade (1990) and Hay and Kelly (1974), industries such as transportation, electricity, and natural resources are among the most frequently studied ones in this area. These industries share a few common characteristics, notably the large fixed costs incurred upon entry, which act as a natural barrier for new entrants once incumbents have established strong presence in the market. Generally, few firms who operate in such environments are heavily regulated by the government or relevant entities, either through granting concessions or implementing strict guidelines to be followed. Being closely monitored, these firms would find it very difficult to engage in an explicit collusion such as a formal cartel. They are also deterred by the government's tight control not to tacitly collude. Nevertheless, given each firm's market power, it is conceivable that the possibility of a tacit collusion would be high provided the incentives they have.

The potential of such an occurrence is even greater in less developed markets. In a country where the mechanism for inspection has not yet been put in place, firms are arguably even more prone to colluding with one another. The opportunity to gain that extra surplus is great, and the inspection method to detect collusion is long-delayed and most likely ineffective. One of the reasons for this is that antitrust lawsuits are much less exploited in most developing countries. As such, firms can employ various channels of communication to achieve certain level of collusion they find manageable.

Consequently, this paper has chosen a mobile phone industry in Thailand as the focused subject of study for a few reasons. First of all, the mobile phone industry has the characteristics that nurture an oligopolistic competition environment. As Valletti (2004) also suggests, its significant fixed costs and small number of concessions limited by the government are the two main factors that make the industry a natural oligopoly. It is not free for entry, and one would need a very large amount of investment to construct the networks and the infrastructure in order to operate, not to mention the bandwidth availability and the government's permission. This entry condition is especially true for international markets, as Harwood, Lake, and Sohn (1997) assert that "96% of all telecommunications revenue generated outside the U.S. goes to entities that either are monopolies or are dominant carriers favored by the governments," which makes countries like Thailand a suitable subject for this study. As the two leading operators in Thailand's mobile phone industry have accounted for over 80 percent[1] of the market share since their inceptions in 1991 until 2006, the market in which they operate can be regarded as a duopoly.

Second, Thailand does not currently have a very effective system established to detect and prevent market misconduct. Many major corporations are widely suspected of having taken advantage of such loosely controlled system and benefited from it in many ways, and the government still does not have adequately strong evidence to deal with such violations. Moreover, rules and regulations are different among countries. Controversial conducts like parallel pricing that tacit collusion causes, as Nikomborirak (2005) suggests, may not be considered a violation of competition laws in many countries, making it more plausible for companies to jointly price their products. The lack of effective competition, as Tangkitvanich and Ratananarumitsorn (2002) argue, causes the total cost of using a mobile phone in Thailand to be higher than that of other countries in the region.

Third, in the past few years we have seen two cases of similar collusive behavior in the telecommunication sectors. Three French mobile phone operators,

[1] Reuters India, January 11, 2008 and Equity Report by Thanachart Securities PCL, Feb 29, 2008.

Orange SA, SFR SA, and Bouygues Telecom, were accused of "colluding by fixing market shares and minimum prices."[2] The news report says that the three firms had their staff meet regularly to "discuss their market strategies and exchange confidential information." Moreover, Spain's three largest mobile operators were also alleged of price fixing.[3] This news has shed some light on the probability of a few major mobile phone operators colluding with one another, even within relatively more developed economies like those of France and Spain. Suspecting a collusive behavior in the telecommunication sector is, therefore, quite justified and worth further investigation.

For these reasons, the cellular carriers in Thailand would be an interesting sample to explore the existence of collusion. The competition ground in this particular industry has demonstrated conducive environment to collusive behavior, as will be shown in detail later in the next chapter.

In addition, a striking observation about the mobile phone sector in Thailand is that, upon the entry of the third firm, we could notice a rapid price cut across the companies. The prices of both mobile phones and connection charges reduced dramatically due to the third firm's strategy to quickly steal market shares from the incumbents. Some may see this phenomenon as a normal consequence of having more competitors in the industry. Others may wonder, however, how the profit margin could become significantly narrower compared to what it was previously. Looking at the airtime charge for pre-paid service, for example, we will see that the

[2] Datamonitor, December 2, 2005.
[3] International Business Times, February 27, 2008.

number came down from 5 baht per minute in 2002 to 0.25 baht per minute in 2005.[4] The firms' ability to sacrifice such a large margin to compete poses a question whether or not the prices were jointly maintained at a near-monopoly level before. Alternatively, some may perceive this as a predatory pricing strategy to drive the third firm out of the business, which implies that the incumbents would also need to absorb some losses temporarily until the competition stabilizes.

Several economic researchers express their perspectives in response to this issue. Nikomborirak (2007) asserts that "the rapid surge in the cellular subscriber base after the year 2000 was due to outbreak of a price war upon the entry of a third major player ***after a long period of tacit price collusion*** under a duopolistic market structure." As far as predatory pricing goes, Meenaphant (2007) says[5] that "the price competition initiated by the latest entrant, fiercely competing for new subscribers, prompted the two existing leaders in the market to react. However, they are main rivals in the market, and as such, it's not conceivable to say that they would collude to deter the new entry." The current interpretations of this situation remain quite controversial, which is the motivation of this paper to explore and disentangle it further.

Note that if we pay close attention to the French and Spanish mobile operators, however, we will see that those allegations are only supported by documents and verbal evidence, not by a formal empirical analysis. Had the investigation not been supplied with sufficient qualitative proofs, the whole

[4] Obtained from DTAC and AIS annual reports. Baht is a currency used in Thailand. Exchange rate as of April 13, 2008: 31.35 baht per U.S. dollar. The rate went up as high as 56 baht per U.S. dollar during the 1997 Asian Financial Crisis, before which it was pegged at around 25 baht per U.S. dollar.
[5] Quoted from a discussion with Dr. Sorrayuth Meenaphant, a professor of industrial organization in Thailand.

collusive conducts among these companies could have gone unnoticed. Thus, it is quite necessary to develop some analytical tools that are capable of empirically verifying whether or not collusion takes place.

Yet, such attempt would seem a bit beyond the scope of this paper. One of the key remaining challenges to undertake such a study is that it requires appropriate economic theories and rigorous empirical tests to produce reliable and legitimate results. Assumptions about firms' strategic behaviors then have to be made to incorporate certain restrictions from economic theory. As such, it is very difficult to find a universal technique that can accommodate all sorts of companies or industries and verify the existence of collusion.

Some recent literature in industrial organization has been dedicated for the development of theoretical framework and empirical techniques in testing for collusion. At this moment, we have found an econometric model proposed by Gasmi, Laffont, and Vuong (henceforth "GLV") in 1992 to be a good background for our study. The model they develop mainly considers prices and advertising to be the strategic variables of each firm. Then, they apply game-theoretical concepts such as Bertrand-Nash equilibrium to formulate a few different equations, each of which is based on assumption each possible game structure predicts. The details and specifications of this model will be discussed later in the text.

The GLV approach raises an interesting insight for collusion on non-price aspects (i.e. advertising expenses) among firms. Gasmi and Vuong (1991) assert that firms may choose to compete on the non-price areas, where they can implement aggressive strategies without being easily detected compared to employing a price reduction. This concept is in fact appropriate for the Thai cellular phone industry as the main operators invest quite heavily in advertising spending.

One of the explanations for this large advertising expense is that the cellular telephone sector is a service industry which provides consumer products considered necessary in everyday life. As such, the steady demand of the products constantly induces operators to allocate a significant portion of their budgets to advertising their products and differentiating themselves from other brands. Especially for the Thai cellular carriers, advertisement on television and other channels have been one of the key marketing instruments they intensively compete on. Also, all the major companies consistently re-brand themselves and offer promotions to attract new customers in order to build brand loyalty for their long-run benefits. This characteristic of the industry makes it imperative to pay close attention to both prices and advertising, which is what the GLV model has targeted towards.

It is worth noting that the GLV model mainly focuses on a duopoly case where the two firms are largely dominant in the industry. As that has also been the case in Thailand’s mobile phone sector up until recently, we will treat the industry as a qualified sample to use this method of analysis. Theoretically, we could expand our model to accommodate a three-firm case and eventually generalize the method to an n-firm environment, with certain restrictions required by the relevant economic theories to be imposed. Such an approach, however, would likely be too demanding for the limited data we have, and thus we will treat it as a future extension. While we do not formally pursue this extension at this moment, another aspect that will also be covered here is the effect of the possible structural change during the firms' operational period, which in this case refers to the 1997 Asian Financial Crisis and the entry of a third competitor in 2002. As also suggested by the GLV model, incorporating the structural change into the equation system will likely produce more reliable estimates.

Assuming that firms would prefer cooperating with one another for higher profits whenever possible, it is necessary to develop tools and mechanism to effectively detect collusive behavior among companies. There has been extensive debate among policy makers in many countries regarding the government intervention in telecommunication sectors whether or not it is appropriate. For instance, Parker and Röller (1997) attempt to test for the benefit of having the government limited the number of operators in the cellular phone industry to two firms on the competition. Miravete and Röller (2004) also explore more specifically about whether accelerating the license granting process for the second operator would increase the welfare of the society. Rapid progresses in both technology and businesses have prompted the need of having suitable measures for policy analyses and competition monitoring. The approach which this paper aims at developing, along with others techniques that are already put in place, will effectively help tackle problems that may arise in various competitive environments and ensure that we allocate our resources appropriately.

The content of this paper is structured into six sections. Section two provides some literature review pertaining to recent developments in industrial organization and particularly in determining an existence of collusion. Several models and empirical techniques are also introduced briefly with comparisons in terms of advantages and disadvantages of each method. Section three summarizes the background of Thailand’s cellular phone sector and its relevance to the empirical analysis of collusive behavior. Section four discusses specifically about the model proposed by Gasmi, Laffont, and Vuong (1992) and its applicability to our study. Certain modifications to the model are also introduced in order to better accommodate the competition conditions in Thailand’s cellular phone sector and potential structural changes over time. Game-theoretic assumptions are also explained and applied to generate a set of equations in each case. Section five gives detailed information about the econometric techniques used in our analysis. Section six describes our data set and their sources, as well as the summary statistics. Section seven contains the results of the regression analyses and other empirical estimation, including the Maximum Likelihood Ratio and other important statistics for each of our assumptions. Section eight includes the discussion of the results, further study, and the conclusion of this paper.

II. LITERATURE REVIEW

There have been several developments in constructing a model to effectively explore various types of collusive behavior among competitors. For example, Fabra and Toro (2005) apply a time varying transition-probability Markov-switching model[6] to the Spanish electricity market in order to identify whether or not tacit collusion exists. This technique allows them to detect a significant difference in the price levels over the observed period and attribute the price variations to certain independent variables. After formulating a profit-maximization equation based on Nash static structure, they have found that the data on prices are not consistent with the optimal value the model predicted. As the actual behavior of these firms could not be explained by the demand and cost conditions alone, a conjecture was subsequently made that the Spanish electricity producers may have tacitly colluded and caused the market outcome to deviate from its non-collusive equilibrium.

This method, however, has a few limitations which may not be suitable for our analysis. First, it requires an intensive dependence on time-series data to apply this technique. As Fabra and Toro (2005) states, the time varying transition probabilities (TVTP) framework allows the probability of structural (e.g. collusive-competitive regime) switching to change over time, as well as treating the expected duration of a switching as a continuous spectrum. As such, the lack of restrictions and predetermined conditions expose the model to many estimation errors, which in turn implies that variations in the data set are then especially necessary for the model to be efficient and applicable. For this reason, as Lee and Chen (2006) also attest, the TVTP framework is likely to be appropriate with a long series of data such as exchange rates or asset prices.

[6] A time-series model that treats the disturbance term as a Markov process, used when assuming a probability of the current period does not depend upon the previous period. This process is frequently applied when there is a presence of serial correlation in the disturbance term, and is claimed to be superior to the random walk process. (See Intriligator, Bodkin, and Hsiao (1996), or Lee and Chen (2006) for detail).

Accordingly, while the data in Fabra and Toro (2005) from the Spanish electricity industry are collected at a daily frequency for a year (i.e. 365 data points), in our case we only have about 52 data points available. This shortage of data may lead to unreliable estimates as discussed above. In addition, the difference in the industry condition and products may also be problematic. The electricity industry offers identical products from all the companies, whereas in the Telecom sector we generally deal with differentiated products, making the demand on our data set even greater than those in electricity or exchange rates studies. Although there are a few advantages this method provides, its limitations prevent us from directly applying the method to our study at this moment.

Apart from the data-intensive empirical methods we have discussed, recent literature also sheds some light on qualitative approaches to test for collusion. Feuerstein (2005) conducts a survey of literature and summarizes the theory of implicit collusion, based on the framework of infinitely repeated games. He asserts that it had been understood among economists how firms repeated interactions did not simply fall into basic game-theoretical patterns such as Cournot or Bertrand. The possibility of colluding and deterring others from cheating by a price war threat have made the issue more complex. The mechanism of collusion has turned into a focus of interest in the 1990s, mainly triggered by the detection of several high-profile international cartels.

A rigorous empirical treatment began to materialize in one of the key recent studies in industrial organization. The model and empirical techniques, which will be the main foundation of this paper, comes from the econometric techniques proposed by Gasmi, Laffont, and Vuong (1992) in their paper on the soft-drink industry. In that article, they attempt to test for a collusive behavior between Coca-Cola and PepsiCo through the lens of game theory and optimization. As the soft-drink industry, particularly cola in this case, has long been regarded as a duopoly in a differentiated market, the characteristics of the current competitors resemble those of the Thai cellular phone sector.

The technique used in their paper involves a Full-Information Maximum Likelihood (FIML) estimation for each of the assumption-incorporated models. In short, they started by formulating a few equations to accommodate different game-theoretical assumptions of how firms interact. Then, they impose constraints determined by relevant economic theories to alleviate the demanding use of data. After the first-order conditions of the demand and cost functions are derived, they combine and rewrite all the equations into one system of non-nested equations to be estimated simultaneously. This is where the FIML method becomes very effective, as it allows these equations to be non-linear without violating any of its statistical properties and utilizes all the information available. Consequently, a Maximum Likelihood ratio is calculated for each of the assumption and then compared with one another to find what model best fits the actual data. The technical details will be discussed in the model section.

In fact, the FIML technique has been introduced in IO literature before Gasmi, Laffont, and Vuong apply it in their research. Bresnahan (1987) conducts a study on the American automobile industry from 1994-96 with the hypothesis that a dramatic 45% production increase and the price decrease in 1995 was a result of a temporary change in behavior of mainly the three major companies (i.e. Ford, GM, and Chrysler) from collusive to competitive regime. The estimation results from each competing model, produced by the FIML method, are associated with the maximum likelihood ratio, which is usually reported in the logarithmic form. Subsequently, these ratios are compared among models by employing the Cox test for non-nested models. However, the model selection method used by Gasmi, Laffont, and Vuong (1992) is different from the original Cox test in a few aspects, and is argued to be more suitable to the analysis like the one in this paper where model specifications are simplified for empirical tractability and may not be a very precise reflection of the reality.[7]

After the Gasmi, Laffont, and Vuong (1992) paper was published, several follow-up works and further development of the estimation techniques came out. One interesting journal, written by Golan, Karp, and Perloff (2000), introduces the Generalized Maximum Entropy technique, an alternative approach to account for the possibility of firms employing mixed strategies. Note that in all the models mentioned previously, it is initially assumed that a firm's strategy would fall into one category or another for a definite period of time. Lifting that restriction would allow a more complete analysis that accounts for many more possible cases to best explain the actual data.[8] However, since we do not have adequately long time-series, excluding

[7] From Gasmi, Laffont, and Vuong (1992): "Goodness of fit is measured according to the Kullback-Leibler (1951) Information Criterion, which is here equivalent to the mean square error criterion. Some properties of these tests are that they are symmetric and directional, and that neither model needs to be correctly specified as opposed to the more familiar Cox type tests. Hence, these tests are especially appropriate in our case for our competing models might be at best approximations to what really happened."

[8] The oligopoly model in Golan, Karp, and Perloff (2000) paper considers a mixed strategy as a distribution of probability for each possible strategy and calculate the expected profit by summing up the probability-weighted profit in each case.

all the restrictions determined by economic theory would potentially put us at a disadvantage rather than increase the reliability of our results.

The framework proposed by Gasmi, Laffont, and Vuong (1992) is also applied in analyses for other industries. Kadiyali (1996) has implemented it to study the U.S. photographic film industry. She specifically discusses in her paper how an entry of a new competitor will be treated (deter or accommodate) based on the current market information and structure. The framework established in her analysis will be useful to our study when we focus on the entry of the third firm.

A very interesting and relevant study by Parker and Röller (1997) on collusive conduct in the U.S. mobile phone industry proposes some concepts and techniques to explain non-competitive prices phenomenon. Similar to the Thai cellular carries in this paper, the U.S. Federal Communications Commission (FCC) granted licenses to only two cellular carriers "within a strictly defined geographic region" in 1983 in order to foster competition and drive down prices. However, the prices reduction did not appear to be significant upon the entry of the second firm. The primary interest of Parker and Röller (1997), therefore, is whether or not the regulatory system that creates a duopoly in the U.S. mobile phone sector causes collusion in pricing to take place. Similar to Gasmi, Laffont, and Vuong (1992), the demand function and the cost function are also derived to find first-order conditions of each firm's profit maximization. On the other hand, the approach to estimating the marginal cost in Parker and Röller (1997) incorporates the variables that are specifically chosen for the cellular telephone industry, which makes it more directly relevant to the study in this paper. The detailed equations will be stated later in the model section.

By employing a 3SLS method on the profit-maximizing equation and with the inclusion of a collusive parameter to represent each game-theoretical structure, Parker and Röller (1997) finds that the empirical results reject all the non-collusive hypotheses with statistical significance.[9] It is imperative to acknowledge, however, that prices of providing cellular phone services are the only strategic variables in Parker and Röller (1997), leaving out the advertising expenses as an irrelevant factor. As this paper finds it convincing and more logical to include advertising as another variable, an extension to their model will be made to accommodate this additional data.

Furthermore, the model used in Parker and Röller (1997) involves the information on "multi-market contact" and "cross-ownership." The main difference between the cellular industry in the U.S. and in Thailand is that multi-market contact and cross-ownership do not apply to the latter where the whole country is treated as a single market, and that both major cellular carriers do not jointly own any license.

In addition to the works done in the duopolistic telecommunication industry, the Spanish fertilizer industry is also modeled and analyzed empirically with the similar structure. Pazo and Jaumandreu (1999) have developed a three-firm oligopoly model with price ceilings. Cournot and Stackelberg interactions are also assumed as the main hypotheses. By applying General Method of Moments, they have found that the Stackelberg equilibrium is the most likely outcome for their particular sample. Due to the scope of this paper, the analytical framework from the fertilizer study will not be applied to this paper, but we will consider it as a possible extension.

---

[9] The hypotheses of perfect competition, cartel (joint monopoly), and Cournot competition are rejected at t-statistics of 20.30, 3.39, and 8.45, respectively.

All of the works mentioned here, notably Gasmi, Laffont, and Vuong (1992) and Kadiyali (1996), provide a rich theoretical background and various empirical frameworks to be applied in our analysis. We shall return to them consistently throughout this paper for reference.

III. INDUSTRY BACKGROUND

Before we move on to the model and empirical section, it would be helpful to understand how the mobile phone sector has evolved to become what it is today. There are quite a few aspects of development in this sector that can be related to our analysis, and perhaps explain some of the relevant qualitative factors for which the model may fail to account.

History and Developments

Hossain (2001) provides a thorough and concise summary of the key developments in the Thai telecommunication sector. In 1869, the Thai government decided to initiate the telecommunication system foundation by allowing a British company to establish a telegraph system for various provinces in Thailand. As the British company was not able to complete the project, the government stepped in and assigned the Ministry of Defense to continue the telegraph network construction. A 78-kilomeeter telegraph line were put in place as a connection between Bangkok and a few surrounding provinces by 1878. Later in 1897, the Post and Telegraph

Department (PTO) was established as a result of organizational restructuring to be in charge of telegraph, telephone, and postal system.

The coverage of the telegraph network became more adequate in major cities and towns in 1945, and subsequently in 1946 the government started to provide basic telephone services. However, the expansion of these communication services was still not fast enough. It was estimated that only 25% of the population had access to telephone services in 1980, and only about one out of every two provinces in Thailand had telegraph services in 1988.

The following table, excerpted from Lindley and Hossain (1996), summarizes important developments of Thailand's telecommunication sector in a chronological order:

1875	First telegraph service
1881	First telephone service
1897	Post and Telegraph Department (PTD) established
1954	Telephone Organization of Thailand (TOT) established
1971	First radio paging service
1972	First car phone installed
1976	Communications Authority of Thailand (ACT) established
1991	True Corp. (then "TelecomAsia" or "TA") was given a 25-year concession to install 2 million telephone fixed lines for Bangkok Metropolitan Area
1991	TT&T (Thai Telephone & Telecom) was given concession to install one million telephone fixed lines for the rural areas
1995	Privatization plans of TOT and ACT announced

The Ministry of Transport and Communications supervises PTD, TOT, and ACT, who jointly constitute an infrastructure for the telecommunication system in Thailand. The operations run by the government's entity, however, were not as efficient and consistently improving as other private-run businesses, prompting the need for private sector's involvement to optimize the business model and bring in new technologies. Consequently, the government's decision in 1991 to open up the sector which had long been monopolized to the private sector resulted in two new entrants to run the fixed-line telephone systems. By the end of 1995, the two companies (namely TA and TT&T) had obtained concessions to run the total of 4.1 million fixed-lines. PTD's role has since converted into mainly policy rules and regulations for radio communications, with TOT for regulation of domestic fixed-line and wireless telephone services concessions, while the CAT has become both an all-system regulator and a key domestic provider. (See TOT Act of 1954 and CAT Act of 1976 for more details).

In order to keep up with the world's rapid progress in telecommunication technology and to inherently maximize its support to other parts of the economy, the government decided to reemphasize its intention to direct the telecommunication sector towards liberalization. It announced that it would aim to privatize all the State Owned Enterprises by 1997 and subsequently create a National Telecommunications Commission (NTC) to oversee the industry. The NTC then made a commitment with the World Trade Organization (WTO) to liberalize the industry by 2006. However, the continuing effort to push forward this transition has been slow and ineffective due to various structural incompatibilities. At present, the sector still requires some supervision from the government as the market is not ready to be fully liberalized yet. Many aspects of the policy to privatize tie closely to the benefit of both the government and the public, resulting in long delays and difficulties in completing the conversion. Especially after the election in 2001 that the chairman of the industry-leading mobile phone operator became the Prime Minister of Thailand, things started to get even more complicated, and some of the decisions made by the new government seemed to not be in the best interests of the public, further obstructing the progress of sectoral liberalization.

Initiation of the mobile phone services

In the 1970s, wireless communication technologies were adopted and first introduced to Thai consumers. Starting with the paging services, the technology later evolved into an acquisition of the first mobile phone service in the Nordic Mobile Telephone (NMT) 470 MHz frequency in 1986, followed by the NMT 900 MHz services in 1990. This new mobile phone technology quickly picked up the pace and became popular among users. A year after its introduction, the cellular mobile telephone services were still seeing higher demand than expected, partly attributed by the increasing need in a prompt, efficient method of communication to foster the strong economic growth at that time.

After several unsuccessful efforts to accommodate the excess demand for the services, TOT and ACT decided that it was time to bring in private sectors to help expand the network and improve the technology to better provide users with sufficient capacity and quality. Such move would also help relieve the public sector's shortage of capital to invest in network construction more adequately. Successively, in October 1990, TOT granted a concession to Advanced Info Service, a private company, to operate as a cellular carrier in one of the NMT spectra (i.e. frequency). In September 1991, CAT then followed the move by granting a concession to a company called Total Access Communication to also provide mobile phone services on another allocated spectrum. The two companies remain the industry leaders who together have been accounted for 75-95% of the market share in the cellular phone industry[10]. Later in 2001-2002, three more companies were granted concessions to operate in additional frequencies: TA Orange in GSM with CAT, Hutch in CDMA as a joint venture with CAT, and Thai Mobile in PCS 1900 MHz as a joint venture between TOT and CAT.

Company Information

Advanced Info Service PLC (AIS)

AIS was founded by the former Prime Minister Thaksin Shinawatra in 1986. The company operates cellular phone services under a 25-year build-transfer-operate (BTO) concession which was granted on October 1, 1990. The ownership of the constructed network was transferred to TOT, and AIS pays certain regulatory fees as a revenue-sharing scheme to operate on the network. This type of concession applies to all the telecom grantees in Thailand as the law requires a sole ownership to belong to the government (state monopoly). The Company first operated in the NMT 900 analog system and later shifted its focus to a more effective digital system called GSM 900 MHz. The company started by offering only the post-paid services, charging for a certain monthly fee with additional per-minute charge when the usage is over the preset limit. After 2002, the company began to offer pre-paid services as well, eliminating the monthly base fee and incur higher per-minute charge. The current market share of AIS is estimated at 51%, maintaining its leadership in the industry.

[10] Securities analyst’ estimates between 1992-2007.

The structure of its concession fee to the government was initially set to be 15% for the first 5 years and a 5% increment in every five years until the concession ends. There have been some amendments later to accommodate the Company's request and enhance its competitiveness. In 1996, the Company received an approval to extend its concession from 20 to 25 years through October 2015. In 2001, the Company also successfully negotiated its pre-paid revenue sharing scheme down to 20% until the end of its concession. There is no access charge to TOT for AIS pre-paid subscribers as TOT is a grantor of its concession, while other firms under CAT concessions would have to pay. For post-paid, however, everyone has to pay 178 baht a month for the access charge (used to be 200 baht).

Total Access Communications (DTAC)

DTAC was founded in 1989 to provide wireless telecommunication services in an analogue AMPS 800 Mhz and a digital GSM 1800 Mhz frequency bands in Thailand under a 27-year concession granted by CAT with the same structure as AIS's concession, except that there is no amendment for the fee reduction in pre-paid service, and DTAC has to pay TOT an access charge of 18% of revenue for pre-paid to access TOT's networks. As the pre-paid cellular phone services account for almost 90% of the overall market, this additional charge does undermine the competitiveness other companies have against AIS. Recent movements of telecom market liberalization, triggered by the introduction of Interconnection Charges (IC) which would overlap with the access charge, prompted DTAC and operators other than AIS to stop paying this access charge. DTAC argues that to maintain fairness among competitors, every company has to be subject to the same regulatory fee structure. As of February 2008 the dispute is not over yet, although there is a high possibility of DTAC winning the case, which will eliminate the access charges for all the companies.

DTAC, however, also has an advantage over AIS in some aspects. The most notable one is perhaps the initial spectrum allocation for DTAC which was significantly greater than that given to its rivals. DTAC was originally assigned the entire 150 MHz bandwidth in the 1800 MHz frequency, some portions of which it later sold to other companies to make extra profit. As the NTC and other regulatory body do not have the authority to reallocate frequencies, this advantage will remain intact throughout the concession period. As of February 2008, DTAC has about 31% market share, placing second in the industry.

True Corporations (TrueMove)

Recently entered the mobile phone market in 2002 as TA Orange, True Corporation has rapidly been building up its subscriber base in the past few years. True Corp. (formerly known as "TelecomAsia") was awarded a concession to operate on the digital GSM 1800 MHz, on which it operate under the brand "TA Orange." The detail of its concession is for the most part the same as DTAC. The marketing strategy to penetrate the market includes sharp price cut during the promotional period to lure in subscribers, and the provision of all-in-one services that include cable TV and internet connection together with the cellular phone services as a package. True currently has about 15% market share.

Hutchinson (Hutch)

A joint venture between Hutchinson Whampoa of Hong Kong and the CAT, Hutch was granted a concession in 2002 and launched its operation in February 2003, shortly after True Move. While all other service providers operate on the GSM technology, Hutch chose to differentiate its products by operating with the Code Division Multiple Access (CDMA) technology. This new innovation greatly expands the feasibility of transferring data on the network in addition to day-to-day regular phone calls. The pricing, however, was done at a premium well above the market's average, which did make sense given what services it had to offer. Hutch's current market share is estimated at around 2%.

Thai Mobile

The latest entrant to the industry, Thai Mobile is a joint venture between TOT and ACT with the purpose of providing an affordable and flexible alternative to mobile phone users who may not be satisfied with the current incumbents. It operates with the Personal Communication Services (PCS) technology, which is compatible to many other technologies such as GSM, CDMA, and TDMA. Nevertheless, due to the slow coverage expansion of its network, the subscriber growth has not been significant, and market analysts have yet to foresee the trend for this product to be a big hit in the market. Thai Mobile's current market share is under 1%.

Competition

Since their inceptions, AIS and DTAC had been the only operators in the industry up until 5-6 years ago. The market characteristic was then an oligopoly in a government-regulated environment. Below is a chronology of some key developments of the two firms and the industry[11]:

1990	AIS were granted a 20-year BTO concession from TOT to operate
1991	DTAC were granted a 20-year BTO concession from CAT to operate
1994	DTAC agreed to pay TOT access charge to use its networks
1995	DTAC listed on the Singapore Exchange Trading Ltd. (SGX) and also agreed to issue 42.8 million shares to TOT for access charge discounts
1996	DTAC's concession was extended by CAT for 7 years to 2018
2000	Telenor Asia Pte., a Norwegian company, bought 29.94% of DTAC shares
2001	Access charge calculation for prepaid changed from a fixed rate of 200 baht per month per subscriber to 18% of the value of prepaid vouchers. DTAC also launched GPRS service and rebranded itself to DTAC (previously "TAC") with major marketing effort
2002	DTAC unlocked IMEI[12] codes to allow all mobile handsets to use its network
2003	DTAC launched its pre-paid service called "DPrompt" which later became very popular. The new concept for post-paid where less charge is incurred for additional minutes. Excise Tax is also enforced.
2004	DTAC's credit rating upgraded to A- and changed outlook from stable to positive.[13] Strong marketing effort continued especially in the pre-paid sector, targeting at teenagers and low-income users. Commercially launched EDGE technology.
2005	Various marketing strategies were applied. Competition on price started to intensify.

[11] DTAC annual report, 2005

[12] International Mobile Equipment Identity, which locks a handset to be compatible with certain networks.

[13] Rated by Tris Rating, a nationally acclaimed rating agency in Thailand

IV. MODELS

This paper primarily adopts the theoretical framework set up by Gasmi, Laffont, and Vuong (1992). In order to apply different game structures to the model, it is assumed that participating firms behave rationally such that each firm tries to maximize its profit in the absolute term. Given that the competition is modeled as an interactive game, it is necessary to first derive a demand function and a cost function for each competing firm. We shall start with the most simple two-firm case as our reference point.

Demand Function

The proposed demand function is as follows:

$$q_i = \gamma_{i0} + \alpha_{ii} p_i + \alpha_{ij} p_j + \gamma_{ii} A_i^{\frac{1}{2}} + \gamma_{ij} A_j^{\frac{1}{2}} \;,\; [\gamma_{i0} = \beta_{i0} + \beta_{i1} y]$$

Where q_i, y, p_i, A_i represent the product quantity, population income, product price, and advertising expenses for firm $i, i = 1, 2$, while α's and γ's are unknown coefficients to be estimated in the empirical analysis. As initially suggested, $\alpha_{ii} \geq 0, \alpha_{ij} \leq 0, \gamma_{ii} \geq 0$ will be the pre-determined constraints in the empirical analysis.

Note that this paper mainly follows Gasmi, Laffont, and Vuong (1992) rationale to keep the demand function simple (e.g. linear) so that the limitation in terms of data availability does not become an issue.[14] In addition, this specific form of advertising expenses in the equation accommodates the fact that the marginal effect of advertising on the quantity is presumably diminishing. Lagged terms for

[14] Compared to the model in Gasmi, Laffont, and Vuong (1992), the dummy variable for seasonal factor is not included here due to the non-seasonal nature of the telecommunication industry, where as it is an important determinant for demand in the soft-drink industry.

advertising are not introduced here because, as suggested in the soft-drink paper by Clarke (1976), advertising effect for consumer products generally does not last longer than two quarters. In addition, Golan, Karp, and Perloff (2000) argue that firms are assumed to play a repeated (static) game, and although adding lagged variables on prices and advertising costs is theoretically possible, it would become very difficult to do an empirical analysis due to data limitation. They further suggest that treating the advertising cost as a "demand shifter" rather than a strategic variable is also possible but would oversimplify the firm's decision making process from reality.

However, Simon and Sebastian (1987) have a different view on the effect of advertising. Their work on the relationship between advertising and the diffusion of new telephones in West Germany suggests that "advertising attained its maximum effect after several months." They find that 72% of the total advertising effect unravels between 4 to 9 months after the advertisement started. In addition to being a new innovation available to consumers, the German telephone also relies largely on the network size, as is the case in this paper for the cellular phone sector in Thailand. The economics of networks also integrates the concept of switching costs, which cause customers to be "locked in" with the services to which they subscribe after a period of time. Accordingly, lagged advertising expenses could have significant effects on the quantity demanded. The original model above is preserved at this point to simplify the derivation. We shall return to this assumption later in the further discussion section where potentially useful modifications are introduced.

Cost Function

In the Gasmi, Laffont, and Vuong (1992) paper, the production costs in the soft-drink industry can be estimated quite conveniently by considering the capital and labor factors that go into producing a bottle of soft-drink (e.g. sugar, workers, plastic). The cost of services in the telecommunication sector is, however, hard to evaluate precisely. Owing to the nature of the industry, fixed costs are generally very large and marginal costs are close to zero, given that the network capacity constraint is not violated. Thus, this paper postulates two different ways to derive the cost functions.

First and most simplified, assuming that the marginal cost is zero, the average cost function can basically be constant as the fixed cost divided by the quantity. This option would be plausible if we conceive the network construction as always being planned ahead. The Thai government does require under the BTO concession that cellular carriers must complete the construction of the majority (generally 90%) of their network coverage prior to the launch of their services.[15] As such, most of the network construction costs would be incurred since the beginning of their operations and does not affect quarter-to-quarter variations in average costs. Given that we are in a static framework, decisions on prices and advertising expenses would then be made in accordance with average variable costs in each quarter.

However, by disregarding the marginal cost despite its relative size compared to other figures in the production function, we may run into a problem of oversimplification. This reason leads this paper to consider the second approach that compromises with the concern of omitting some important variables. This alternative method of the cost estimation includes several variables from the production process

[15] Hossain (2001)

such as electricity, customer service staff, and other resources required to be allocated when an additional service is provided.

Parker and Röller (1997) formulate an equation to estimate the marginal cost of a cellular telephone industry as follows:

$$MC_{ts} = \beta_0 + \beta_1 Q_{ts} + \beta_2 Energy + \beta_3 Prime + \beta_4 Wages + \beta_5 Rent + \beta_6 Operation$$

Where *Q*, *Energy*, *Prime*, *Wages*, *Rent*, and *Operation* represent quantity, electricity prices, costs of capital, labor costs, rental cost, and overhead & operating cost, respectively, and the subscripts indicate time period and market in which the marginal cost is estimated.[16]

Note that the cost of capital (i.e. *Prime*), which is normally considered as a fixed network construction cost rather than part of a marginal portion, is included in the equation. To justify the aforementioned treatment of the network construction cost, an additional assumption is made that the marginal network costs do not exactly resemble a step-wise function. This means we believe that the network isn't built just for a temporary use in a specific point in time. It would be more reasonable to equally spread the costs throughout a few quarters in which the usage of that particular network takes place. This rationale allows us to then use cost of capital as a proxy of the smoothened network cost function, treating it as a steady flow of costs to the operation.

Alternatively, we could also use the actual data on costs as observed from the firms' financial reports, which would in fact eliminate the need of estimating the costs from other exogenous variables. The only concern with this approach is that the

[16] Since multi-market framework is not the case in this paper, we will only consider the time period as a subscript.

accounting data might not always be a good proxy for true economic costs, upon which our profit-maximization model is based. There is also a discussion regarding whether or not it is appropriate to use accounting data from companies' financial reports in the empirical analysis. Zimmerman (2002) argues that accounting measures do not always represent the real factors that goes into the decision-making process of the management. Many times, accounting practice merely serves the presentation purposes, whereas economic profits or costs are not directly taken into account. The opposing argument would say, however, that the approaches to reconcile accounting methods and economic concepts such as revenue recognition principle and matching principle help bridging the gap between the two. As Beatty (2007) also asserts that accounting practices are crucial to the decision making process of the management, special attention shall be dedicated while treating accounting information. Due to the fact that using accounting costs will reduce the demand on our limited data and simplify the model, this paper will consider using both accounting figures and economic cost estimation to run our analysis and compare the results accordingly.

One could analyze this marginal cost from two different perspectives: per minute and per subscriber. In view of the nature of cellular phone plans, considering the per-subscriber figures would be a more feasible and desirable approach. There have been consistent developments in the mobile phone industry in terms of types of promotions and offers to attract customers. Various plans with different rates are presented to allow flexibility to fit each individual's usage style, and thus making it very difficult to find representative price and cost per minute. As it is more manageable to collect the data from a per subscriber basis, average price and cost per subscriber will be more favorable and practical measures for our empirical analysis.

Recent work in physics and computer science has developed some of the most accurate methods to estimate the marginal cost in providing wireless telephone services. For example, Whitaker, Raisanen, and Hurley (2005) undertake an extensive study on the cost approximation in the cellular phone industry and find that the marginal cost of the additional coverage would go up tremendously when the network coverage has reached 90% of the area. Nevertheless, as the focus of this paper is to explore collusive strategies in terms of price and advertising costs, the technical details of the marginal cost derivation will not be exploited in the strictest form.

Hence, it would perhaps be appropriate to start with a simple, previously verified model. From a theoretical perspective the best candidate at this point would be the second approach above by Parker and Röller (1997). From a data standpoint, on the other hand, we shall first take advantage of the direct cost observations we have from the firms' income statements despite the accounting-economic discrepancy mentioned earlier, as is also employed in Roberts and Samuelson (1988). Assuming that the accounting practice used was adequately acceptable and reconcilable with economics, the first cost estimation method in this paper will be a mere adoption of the actual costs from financial statements. After that, the other approaches will be applied accordingly.

Profit function

With regard to the demand function and the cost function developed above, the profit function can then be derived as follows:

$$\pi_i = (p_i - c_i)\cdot q_i - A_i$$
$$= (p_i - c_i)\cdot(\gamma_{i0} + \alpha_{ii} p_i + \alpha_{ij} p_j + \gamma_{ii} A_i^{\frac{1}{2}} + \gamma_{ij} A_j^{\frac{1}{2}}) - A_i$$

As guided by Gasmi, Laffont, and Vuong (1992), game theory suggests that the interactions between the firms can be modeled in several different cases, as detailed below:

Case 1 Nash static equilibrium

In order to identify the type of competition, this paper first establishes the simultaneous non-cooperative model for a Nash static equilibrium as a reference point. By strategically determine the price of services (p_i) and the advertising expenses (A_i), each firm will aim at maximizing its profit (π_i). Accordingly, the four first-order conditions with respect to p_1, p_2, A_1, A_2 are derived as following:

$$\frac{d\pi_1}{dp_1} = \frac{d}{dp_1}[(p_1 - c_1)\cdot(\gamma_{10} + \alpha_{11} p_1 + \alpha_{12} p_2 + \gamma_{11} A_1^{\frac{1}{2}} + \gamma_{12} A_2^{\frac{1}{2}}) - A_1]$$

$$= \frac{d}{dp_1}[(p_1 - c_1)\cdot(\gamma_{10} + \alpha_{11} p_1 + \alpha_{12} p_2 + \gamma_{11} A_1^{\frac{1}{2}} + \gamma_{12} A_2^{\frac{1}{2}}) - A_1]$$

$$= (p_1 - c_1)\alpha_{11} + (\gamma_{10} + \alpha_{11} p_1 + \alpha_{12} p_2 + \gamma_{11} A_1^{\frac{1}{2}} + \gamma_{12} A_2^{\frac{1}{2}}) = 0 \qquad \text{A1)}$$

$$\frac{d\pi_1}{dA_1} = \frac{d}{dA_1}[(p_1 - c_1)\cdot(\gamma_{10} + \alpha_{11} p_1 + \alpha_{12} p_2 + \gamma_{11} A_1^{\frac{1}{2}} + \gamma_{12} A_2^{\frac{1}{2}}) - A_1]$$

$$= (p_1 - c_1) \cdot \tfrac{1}{2}(\gamma_{11} A_1^{-\frac{1}{2}}) - 1 = 0$$

$$\tfrac{1}{2} p_1 \cdot (\gamma_{11}) - \tfrac{1}{2} c_1 \cdot (\gamma_{11}) - A_1^{\frac{1}{2}} = 0 \qquad \text{(A2)}$$

$$\frac{d\pi_2}{dp_2} = \frac{d}{dp_2}[(p_2 - c_2) \cdot (\gamma_{20} + \alpha_{21} p_1 + \alpha_{22} p_2 + \gamma_{21} A_1^{\frac{1}{2}} + \gamma_{22} A_2^{\frac{1}{2}}) - A_2]$$

$$= (p_2 - c_2)\alpha_{22} + (\gamma_{20} + \alpha_{21} p_1 + \alpha_{22} p_2 + \gamma_{21} A_1^{\frac{1}{2}} + \gamma_{22} A_2^{\frac{1}{2}}) = 0 \qquad \text{(A3)}$$

$$\frac{d\pi_2}{dA_2} = \frac{d}{dA_2}[(p_2 - c_2) \cdot (\gamma_{20} + \alpha_{21} p_1 + \alpha_{22} p_2 + \gamma_{21} A_1^{\frac{1}{2}} + \gamma_{22} A_2^{\frac{1}{2}}) - A_2]$$

$$= (p_2 - c_2) \cdot \tfrac{1}{2}(\gamma_{22} A_2^{-\frac{1}{2}}) - 1 = 0$$

$$\tfrac{1}{2} p_2 \cdot (\gamma_{22}) - \tfrac{1}{2} c_2 \cdot (\gamma_{22}) - A_2^{\frac{1}{2}} = 0 \qquad \text{(A4)}$$

Case 2 Stackelberg[17] competition on price and advertising

Taking into account the time dimension of the interactive game, it is arguable that one firm moves before the other. Plausible scenarios include: one firm having a dominant market power compared to its rival, one firm being particularly aggressive to appear as a market leader, or other relevant marketing strategies. When that is the case, the competition is then modeled by the leader-follower structure. Suppose Firm 1 is a leader and Firm 2 is a follower, we first derive the first-order conditions for the follower, contingent upon the expected value p_1 and A_1 :

[17] The term "Stackelberg" is used loosely in Gasmi, Laffont, and Vuong to represent the game structure where there is a leader and a follower in whether price or advertising, which is different from a Nash static competition in which none of the firms is perceived as a leader. Thus, we will avoid using the term "Stackelberg" interchangeably with the term "leader-follower."

$$\frac{d\pi_2}{dp_2} = (p_2 - c_2)\alpha_{22} + (\gamma_{20} + \alpha_{21}p_1 + \alpha_{22}p_2 + \gamma_{21}A_1^{\frac{1}{2}} + \gamma_{22}A_2^{\frac{1}{2}}) = 0$$

$$2p_2\alpha_{22} = c_2\alpha_{22} - (\gamma_{20} + \alpha_{21}p_1 + \gamma_{21}A_1^{\frac{1}{2}} + \gamma_{22}A_2^{\frac{1}{2}})$$

$$p_2 = c_2 / 2 - (\gamma_{20} + \alpha_{21}p_1 + \gamma_{21}A_1^{\frac{1}{2}} + \gamma_{22}A_2^{\frac{1}{2}}) / 2\alpha_{22} \qquad \text{(B1)}$$

$$\frac{d\pi_2}{dA_2} = (p_2 - c_2)\cdot\tfrac{1}{2}(\gamma_{22}A_2^{-\frac{1}{2}}) - 1 = 0$$

$$p_2 = c_2 + 2\gamma_{22}^{-1}A^{\frac{1}{2}} \qquad \text{(B2)}$$

With some algebraic derivation, as stated in Gasmi and Vuong (1991), we will get two more first-order conditions as follow:

$$\frac{d\pi_1}{dp_1} = (p_1 - c_1)[\alpha_{11} - \alpha_{21}\frac{\alpha_{12} + \frac{1}{2}\gamma_{12}\gamma_{22}}{2\alpha_{22} + \frac{1}{2}\gamma_{22}^2}] + (\gamma_{10} + \alpha_{11}p_1 + \alpha_{12}p_2 + \gamma_{11}A_1^{\frac{1}{2}} + \gamma_{12}A_2^{\frac{1}{2}}) = 0 \qquad \text{(B3)}$$

$$\frac{d\pi_1}{dA_1} = (p_1 - c_1)\cdot\tfrac{1}{2}[\gamma_{11} - \gamma_{21}\frac{\alpha_{12} + \frac{1}{2}\gamma_{12}\gamma_{22}}{2\alpha_{22} + \frac{1}{2}\gamma_{22}^2}]A_1^{-\frac{1}{2}} - 1 = 0 \qquad \text{(B4)}$$

<u>Case 3</u> Leader-follower on price and Nash on advertising

A combination between Case 1 and Case 2. The rationale in this case is that both firms may already know from the relative market powers who will be a leader and a follower for price, whereas they still cannot distinguish in the advertising area where the order of movements is not readily obvious.

As a result, the common equation with Case 2 is $\frac{d\pi_2}{dp_2} = 0$ which is first assumed for the follower (i.e. Firm 2).

We get $p_2 = c_2 / 2 - (\gamma_{20} + \alpha_{21} p_1 + \gamma_{21} A_1^{\frac{1}{2}} + \gamma_{22} A_2^{\frac{1}{2}}) / 2\alpha_{22}$, which immediately follows:

$$\frac{d\pi_1}{dp_1} = (p_1 - c_1)[\alpha_{11} - \alpha_{21} \frac{\alpha_{12}}{2\alpha_{22}}] + (\gamma_{10} + \alpha_{11} p_1 + \alpha_{12} p_2 + \gamma_{11} A_1^{\frac{1}{2}} + \gamma_{12} A_2^{\frac{1}{2}}) = 0$$

<u>Case 4</u> Collusion in both price and advertising

Assuming that the two firms would try to maximize their weighted-average joint profits, we consider the following objective functions:

$$\phi = \lambda \pi_1 + (1-\lambda)\pi_2 \qquad \lambda \in (0,1)$$

while λ represents the market power of firm 1 to bargain with firm 2 (i.e. if they were identical we would have $\lambda = 0.5$ which means equally splitting the total profit). Thus, we get the following first-order conditions:

$$\underset{(p_1, p_2, A_1, A_2)}{Max} \phi = [\lambda \pi_1(p_1, p_2, A_1, A_2) + (1-\lambda)\pi_2(p_1, p_2, A_1, A_2)]$$

$$\frac{\partial \phi}{\partial p_1} = \lambda \frac{d\pi_1}{dp_1} + (1-\lambda)\frac{d\pi_2}{dp_1} = \lambda[q_1 + (p_1 - c_1)\alpha_{11}] + (1-\lambda)(p_2 - c_2)\alpha_{21} = 0$$

$$= \lambda q_1 + \lambda \alpha_{11} p_1 - \lambda \alpha_{11} c_1 + (1-\lambda)\alpha_{21} p_2 - (1-\lambda)\alpha_{21} c_2$$

$$= q_1 + \alpha_{11} p_1 + \frac{(1-\lambda)\alpha_{21}}{\lambda} p_2 - \alpha_{11} c_1 - \frac{(1-\lambda)\alpha_{21}}{\lambda} c_2$$

which can be estimated when the direct observations on cost are available. If the cost is to be estimated by other exogenous variables, the cost function can then be substituted in for c_1 and c_2:

$$= \lambda q_1 + \lambda \alpha_{11} p_1 - \lambda \alpha_{11}(\beta_{10} + \beta_{11} w) + (1-\lambda)\alpha_{21} p_2 - (1-\lambda)\alpha_{21}(\beta_{20} + \beta_{21} w)$$

$$=[-\lambda\alpha_{11}\beta_{10}-(1-\lambda)\alpha_{21}\beta_{20}]-\lambda q_1+(\lambda\alpha_{11})p_1-(\lambda\alpha_{11}\beta_{11})w+[(1-\lambda)\alpha_{21}]p_2-[(1-\lambda)\alpha_{21}\beta_{21}]w$$
$$=\mu_{11}+\mu_{12}q_1+\mu_{13}p_1+\mu_{14}w+\mu_{15}p_2=0 \qquad \text{-------} \quad (C1)$$

Similarly,

$$\frac{\partial\phi}{\partial p_2}=\lambda\frac{d\pi_1}{dp_2}+(1-\lambda)\frac{d\pi_2}{dp_2}=\lambda(p_1-c_1)\alpha_{12}+(1-\lambda)[q_2+(p_2-c_2)\alpha_{22}]=0$$

$$q_2+\frac{\lambda\alpha_{12}}{(1-\lambda)}p_1+\alpha_{22}p_2-\frac{\lambda\alpha_{12}}{(1-\lambda)}c_1-\alpha_{22}c_2=0$$

$$=\mu_{21}+\mu_{22}q_2+\mu_{23}p_1+\mu_{24}w+\mu_{25}p_2=0 \qquad \text{-------} \quad (C2)$$

$$\frac{\partial\phi}{\partial A_1}=\lambda\frac{d\pi_1}{dA_1}+(1-\lambda)\frac{d\pi_2}{dA_1}=\lambda[(p_1-c_1)\tfrac{1}{2}\gamma_{11}A_1^{-\frac{1}{2}}-1]+(1-\lambda)(p_2-c_2)\tfrac{1}{2}\gamma_{21}A_1^{-\frac{1}{2}}=0$$

$$=\lambda[(p_1-c_1)\tfrac{1}{2}\gamma_{11}A_1^{-\frac{1}{2}}-1]+(1-\lambda)(p_2-c_2)\tfrac{1}{2}\gamma_{21}A_1^{-\frac{1}{2}}$$

$$=[(p_1-c_1)\tfrac{1}{2}\gamma_{11}-A_1^{\frac{1}{2}}]+\frac{(1-\lambda)}{\lambda}(p_2-c_2)\tfrac{1}{2}\gamma_{21}$$

$$=\tfrac{1}{2}\gamma_{11}p_1-\tfrac{1}{2}\gamma_{11}c_1-A_1^{\frac{1}{2}}+\tfrac{1}{2}\frac{(1-\lambda)}{\lambda}\gamma_{21}p_2-\tfrac{1}{2}\frac{(1-\lambda)}{\lambda}\gamma_{21}c_2$$

$$=\mu_{31}p_1+\mu_{32}c_1+A_1^{\frac{1}{2}}+\mu_{33}p_2+\mu_{34}c_2=0 \qquad \text{-------} \quad (C3)$$

$$\frac{\partial\phi}{\partial A_2}=\lambda\frac{d\pi_1}{dA_2}+(1-\lambda)\frac{d\pi_2}{dA_2}=\lambda(p_1-c_1)\tfrac{1}{2}\gamma_{12}A_2^{-\frac{1}{2}}+(1-\lambda)[(p_2-c_2)\tfrac{1}{2}\gamma_{22}A_2^{-\frac{1}{2}}-1]=0$$

$$=\tfrac{1}{2}\gamma_{12}p_1-\tfrac{1}{2}\gamma_{12}c_1+\tfrac{1}{2}\frac{(1-\lambda)}{\lambda}\gamma_{22}p_2-\tfrac{1}{2}\gamma_{22}c_2-A_2^{\frac{1}{2}}$$

$$=\mu_{41}p_1+\mu_{42}c_1+A_1^{\frac{1}{2}}+\mu_{43}p_2+\mu_{44}c_2=0 \qquad \text{-------} \quad (C4)$$

Rewrite these four first-order conditions and the two demand functions in terms of the variables for which we have the data, namely q_i, y, p_i, A_i:

$$q_1 - \gamma_{10} - \gamma_{11} y - \alpha_{11} p_1 - \alpha_{12} p_2 - \gamma_{11} A_1^{\frac{1}{2}} - \gamma_{12} A_2^{\frac{1}{2}} = u_1$$

$$q_2 - \gamma_{20} - \gamma_{21} y - \alpha_{21} p_1 - \alpha_{22} p_2 - \gamma_{21} A_1^{\frac{1}{2}} - \gamma_{22} A_2^{\frac{1}{2}} = u_2$$

$$\mu_{11} + \mu_{12} q_1 + \mu_{13} p_1 + \mu_{14} w + \mu_{15} p_2 = u_3$$

$$\mu_{21} + \mu_{22} q_2 + \mu_{23} p_1 + \mu_{24} w + \mu_{25} p_2 = u_4$$

$$\mu_{31} p_1 + \mu_{32} c_1 + A_1^{\frac{1}{2}} + \mu_{33} p_2 + \mu_{34} c_2 = u_5$$

$$\mu_{41} p_1 + \mu_{42} c_1 + A_1^{\frac{1}{2}} + \mu_{43} p_2 + \mu_{44} c_2 = u_6$$

Note that the second-order condition has to hold, which means the Hessian matrix from this system of equations has to be negative-semidefinite, the detail of which can also be found in Gasmi, Laffont, and Vuong (1992). This gives us more restrictions to be imposed in our analysis in addition to those from economic theory.

Case 5 Collusion in advertising, Nash in prices

$$\frac{d\pi_1}{dp_1} = \frac{d}{dp_1}[(p_1 - c_1)\cdot(\gamma_{10} + \gamma_{11} y + \alpha_{11} p_1 + \alpha_{12} p_2 + \gamma_{11} A_1^{\frac{1}{2}} + \gamma_{12} A_2^{\frac{1}{2}})]$$

$$= (p_1 - c_1)\alpha_{11} + (\gamma_{10} + \gamma_{11} y + \alpha_{11} p_1 + \alpha_{12} p_2 + \gamma_{11} A_1^{\frac{1}{2}} + \gamma_{12} A_2^{\frac{1}{2}}) = 0$$

$$\frac{d\pi_2}{dp_2} = \frac{d}{dp_2}[(p_2 - c_2)\cdot(\gamma_{20} + \gamma_{21} y + \alpha_{21} p_1 + \alpha_{22} p_2 + \gamma_{21} A_1^{\frac{1}{2}} + \gamma_{22} A_2^{\frac{1}{2}})]$$

$$= (p_2 - c_2)\alpha_{22} + (\gamma_{20} + \gamma_{21} y + \alpha_{21} p_1 + \alpha_{22} p_2 + \gamma_{21} A_1^{\frac{1}{2}} + \gamma_{22} A_2^{\frac{1}{2}}) = 0$$

Assuming that the second-order conditions hold (sign restrictions imposed), the Implicit Function Theorem yields a unique solution in the following form:

$$p_1(A_1, A_2) = K_0 + K_1 A_1^{\frac{1}{2}} + K_2 A_2^{\frac{1}{2}}$$

$$p_2(A_1, A_2) = H_0 + H_1 A_1^{\frac{1}{2}} + H_2 A_2^{\frac{1}{2}}$$

Which allows us to form 6 equations as did in Case 4

Case 6 Collusion in prices, Nash in advertising

Similarly, we can invoke IFT to get a functional form of A_1, A_2 in terms of p_1, p_2. The mathematical derivation of case 5 and 6 can also be found in Gasmi, Laffont, and Vuong (1992) and will not be repeated here.

V. ECONOMETRIC TECHNIQUES

As Gasmi, Laffont, and Vuong (1992) suggests, this paper initially considers employing the Full-Information Maximum Likelihood (FIML) estimation to determine which model best fits the actual data. In brief, FIML indicates which pair of a mean and a standard deviation maximizes the likelihood function below:

$$L(\alpha, \Sigma) = c_1 + n \log \| B \| - \frac{n}{2} \log | \Sigma | - \frac{1}{2} tr\{\Sigma^{-1}(BY' + \Gamma X')(YB' + X\Gamma')\}$$

Where the general simultaneous equation model is in the form of $BY + \Gamma X = \varepsilon$, with B representing a vector of coefficients as an implicit form of structural parameters in vector α, and ε is a column vector of the error terms, all elements of which are assumed to have the i.i.d. distribution: $N(0, \Sigma)$.

It is important to note here that in order to use the FIML method, the error terms are assumed to be jointly normally distributed, which sometimes raises a question of whether or not it is legitimate to assume the real world data to behave in this specific way. This paper, however, finds the assumption about the distributional shape of the errors not inhibitive and will use it as a main method of estimation.

Table 1 below summarizes the correlations between variables in the data set this paper uses.

	aissub	dtacsub	aisarpu	dtacarpu	aissga	dtacsga	realgdp	dtacacpu	aisacpu
aissub	1.00								
dtacsub	0.99	1.00							
aisarpu	-0.91	-0.87	1.00						
dtacarpu	-0.90	-0.86	0.89	1.00					
aissga	0.72	0.67	-0.70	-0.78	1.00				
dtacsga	0.79	0.79	-0.65	-0.77	0.86	1.00			
realgdp	0.95	0.95	-0.84	-0.80	0.62	0.71	1.00		
dtacacpu	-0.88	-0.84	0.87	0.94	-0.75	-0.76	-0.80	1.00	
aisacpu	-0.80	-0.77	0.95	0.77	-0.59	-0.47	-0.78	0.77	1.00

Table 1: Pair-wise correlation matrix for variables in our data set

Where aisssub, aisarpu, aissga, and aisacpu represent AIS's number of subscribers, average revenue per user (proxy for price), selling, general administrative expenses (proxy for advertising), and cost of operation, respectively.[18] As the figures above demonstrate, there is a high correlation between most pair of variables in this data set. Kadiyali (1996) also encounters the similar problem in her analysis on the U.S. photographic film industry. She suggests that the issue of multicollinearity among endogenous variables will cause, among various problems, the coefficient estimates to bias upwards or the singularity of the variance-covariance matrix. This issue also becomes problematic in this paper, as will be shown later in the result section. Kadiyali (1996) proposes a measure to resolve this problem by using

[18] More discussion regarding our data set can be found in the next section.

additional data from the pre-entry period where the film industry was a monopoly, allowing some variables to be eliminated from the equation, and thus their coefficients. Unfortunately, this technique would not work with the Thai cellular phone industry here as there was no monopolistic period (i.e. the first two firms entered the market around the same time) and thus the model will not benefit from variable reduction.

However, it is also mentioned earlier in this paper that two different approaches in estimating the average cost per subscriber (i.e. *marginal* cost per subscriber in the optimization problem as fixed cost will be dropped as a result of differentiating the profit equation) are applied. According to the high correlation above, using the direct cost observations will put us at an advantage since it will not be necessary to estimate additional coefficients from the cost equation as the other approach requires.

Accordingly, this paper shall proceed with the direct cost approach, using the FIML technique while the estimation gives meaningful results. Where that is not the case, the 3SLS method shall then replace the FIML as Kadiyali (1996) does in her analysis. Note that there are two contrasting arguments here proposed by Gasmi, Laffont, and Vuong (1992) and Kadiyali (1996). The former assert that using multi-stage least square or FIML method without constraints would yield unreliable results, as well as would not estimate the structural parameters which includes the collusive parameter λ and other coefficients from the cost function. On the other hand, the latter states that FIML would not work due to high multicollinearity between variables, making it imperative to use other methods that are less affected by multicollinearity, which in that case is the 3SLS method. The latter further argues that after imposing some restrictions from economic theory on several coefficients, the FIML model estimation failed to converge as the minimized sums of squared errors were extremely high, which this paper also finds to be the case for many models. The next section shall detail the estimation results and further compare the efficiency of these two techniques.

A study by Kadiyali, Sudhir, and Rao (2001) compiles various estimation techniques and establish a structural framework for analyzing competitive interactions among firms. They find that among various literature in the New Empirical Industrial Organization (NEIO) framework, 3SLS is the method of estimation used in most studies, whereas only a few studies employ FIML estimation or General Method of Moments technique, partly because they are the more recently developed methods. Kadiyali *et al.* also suggest that the maximum likelihood estimation, full or limited-information, has been shown in many cases to be a special case of the GMM estimation. Although the trend also shows that there has been a convergence in tackling problems in industrial organization with FIML and GMM, there still exists some shortcomings and incompatibility of these methods to data that exhibit certain types of characteristics, including high multicollinearity. As a result, some studies that choose to use FIML or GMM procedures, such as Hall (1987), still include 3SLS as a comparison.

Additionally, the 3SLS method also does not assume any particular distribution for the error terms, whereas the FIML method requires all the error terms to be assumed jointly normally distributed. Even when multivariate normal distributions of the disturbances are assumed, Kennedy (2003) states that both 3SLS and FIML techniques will be "at least as asymptotically efficient as other estimators that utilize the same amount of information" since their asymptotic variance-covariance matrices are identical. Thus, regardless of the distribution of the disturbance terms, 3SLS will be at least as good an estimator as the FIML. Although a number of studies in industrial organization do not hesitate to make such an assumption for the error terms, it would still be beneficial for us to allow for other possibilities in interpreting the distributional shape of the errors.

In order to determine which model performs the best in terms of fitting the actual data, the model selection method generally associated with the 3SLS process is a direct comparison of the minimum sum of squares, which is calculated with the estimation results. Alternatives include Cox's likelihood ratio test for non-nested models, as also used by Bresnahan (1987) mentioned in the literature review, and Vuong's test.[19] which are associated with the FIML and GMM techniques. Therefore, this paper shall follow the trend and first use 3SLS as a default method to produce coefficient estimates.

To summarize, below are all the game-theoretical models adopted from Gasmi, Laffont, and Vuong (1992) for the competition between AIS and DTAC[20]:

Model 1	Nash competition in both prices and advertising
Model 2	One firm is a leader in price and advertising
Model 3	One firm is a leader in price, and Nash in advertising
Model 4	Collusion in both price and advertising
Model 5	Collusion in advertising and Nash in price

[19] Calculated by the difference between the log-likelihood ratios of two competing models, and subsequently normalize it by Schwarz correction to adjust for the number of parameters estimated. (See Gasmi, Laffont, and Vuong (1992) for details.)

[20] In the models that has a leader-follower structure, there will be two sub-cases, A and B, to represent the situations where DTAC leads and AIS leads, respectively.

Model 6 Collusion in price and Nash in advertising

In response to the argument that the Asian Financial Crisis in 1997 may have affected the demand and cost functions of the cellular carriers, and ultimately their strategic behaviors in the competition, it is reasonable to consider a measure to distinguish between these two periods (i.e. pre-crisis and post-crisis). Gasmi, Laffont, and Vuong (1992) also account for the structural change in the cost functions of Coca-Cola Company and PepsiCo Inc. due to a sugar crisis (i.e. price hike) in 1979. Kadiyali (1996) also includes a dummy variable to accommodate the potential structural change after a second firm entered the U.S. film industry.

However, due to the fact that the proposed breakpoint in 1997 does not lie in the middle of the observation range but rather close to the earlier end (i.e. 1995), there would be too few observations before 1997 (i.e. 8 out of 52 data points) to be compared with after 1997. As such, any results produced by employing a dummy variable for this breakpoint would not yield enough variations to run meaningful statistical tests, whereas in the soft drink industry the breakpoint in 1979 is eligible as it lies fairly in the middle of the studied time period.

Subsequently, we consider another convincing candidate for a breakpoint. Having proposed earlier the possible structural or strategic change due to the entry of new entrants in 2002, we then select this data point to replace 1997. The variations in the data for pre-entry and post-entry in this case will be adequate (28 and 24 data points, respectively). Note that this speculated effect of new entry on the competition is also used as a hypothesis in the U.S. film industry study by Kadiyali (1997), while economic theory supports the rationale.

Hence, we will postulate several models to accommodate the breakpoint hypothesis. One way to assign game-theoretic assumptions for each model to be based on is to allow for all possible combinations of two previously proposed models (i.e. Model 1- Model 6). This method would technically yield the total of 30 different models. However, by merely matching any of these assumptions with one another, some of the new models would be rather unfounded and not supported by either economic theory or intuition.

Accordingly, this paper will not hesitate to employ economic theory to select theoretically reasonable models and eliminate the rest. Microeconomic theory predicts that prices will generally be driven down as the competition intensifies upon the entry of an additional firm to the competition. As the data on declining prices after entry also show[21], it would be a more convincing argument to state that collusion, if at all, shall precede the competitive regime and not vice-versa. This proposition rules out the cases where the two firms first engage in a non-cooperative competition and later collude with each other.

Furthermore, the empirical results of the six models above show that Models 2, 4, and 5 have substantially lower minimized sums of squares than the rest. This implies that these three models, to a certain extent, may be a closer resemblance of the strategic interactions that actually happened between AIS and DTAC, which helps narrow down the possibility of matching combinations for the models with a breakpoint. Hence, the remaining justified models are:

---

[21] Note that prices generally fall after entry, and the main task here is to verify whether or not there is a marginal decrease potentially resulted by the breakdown of collusion between the incumbents (AIS and DTAC).

Model 7 — Collusion in advertising until 2002q1, and collusion in both price and advertising afterwards

Model 8 — Collusion in advertising until 2002q1, and one firm is a leader in price afterwards

Model 9 — Collusion in price and advertising until 2002q1, and Nash competition in price and advertising afterwards

Model 10 — Collusion in price and advertising until 2002q1, and one firm is a leader in price and advertising afterwards

Model 11 — One firm is a leader in price and advertising until 2002q1, and Nash in both variables afterwards

Model 12 — Nash competition in price and advertising until 2002q1, and one firm is a leader in both variables afterwards

Note that some of the game-theoretic assumptions above differ from those of Gasmi, Laffont, and Vuong (1992). In particular, Model 9-10 are based on our intuition that if a tacit collusion exists, it should be on both price and advertising and not just on either one of them. In fact, this conjecture is also supported empirically by the results from Model 1-6, which will be detailed in the next section. These two models are also of particular importance, as they represent the argument of collusion breakdown we initially discussed in this paper. Whether or not the price decline was triggered by a breakdown of collusive behavior between AIS and DTAC remains our primary interest and a very plausible argument, indeed. In addition to the idea of total collusion, we also establish an opposite model as a reference that assumes no collusion throughout both periods, namely Model 11-12 in which the behavioral changes are within the non-cooperative regime.

Apart from employing a dummy variable as a regime-switching instrument suggested above, an alternative approach to account for a new entrant is by adding the third firm in a derivation of game-theoretic structure in each model and solve for additional first-order conditions. Due to the scope and limitation of this paper, we will keep the model adequately simple and treat the new entry as an exogenous shifter by using a dummy variable rather than completely changing the structure of the competition to a full triopoly. As the third firm, namely TrueMove in this case, also never accounted for more than 20% of the market share[22] prior to 2007, it would be appropriate to treat it as a competitive fringe with relatively little significance in determining the shape of the competition.

VI. DATA DESCRIPTION

The primary interest of this paper is to explore whether or not the two major cellular carriers in Thailand, namely Advanced Info Service PCL (AIS) and Total Access Communications PCL (DTAC), tacitly colluded at any point since their inceptions. Therefore, as required by the models derived in the previous section, the necessary data are collected from various sources such as financial reports of both companies[23], equity research reports by brokerage firms, and the National Statistical Office of Thailand. The period spans from 1995, the earliest available data point since both firms' inception in 1990, until 2007. Data are collected quarterly for these 13 years, totaling 52 observations.

[22] Obtained from the Company data and brokerage analysts' estimates.
[23] AIS's Investor Relations only provides its quarterly financial statements from 2001-present, while DTAC's provides from 2002-present. Consequently, we also use the data from secondary sources such as research reports compiled by equity analysts.

Price

As discussed briefly in the model section, it is quite difficult to collect the data on prices and the other variables on a per-minute basis. There is a wide variety of cellular phone plans offered in the market these, especially in the past 5-6 years as the number of subscribers reached the threshold, beyond which the marketing flexibility became more feasible and cost-effective. Non-linear tariffs have subsequently been introduced, making it even more difficult to estimate the price per minute. As such, it would not be efficient to collect data on every single phone plans available and develop some sort of a weighted average to represent the overall strategic prices. In some academic publications, such as Parker and Röller (1997), an alternative method to estimate the per-minute price is to create a hypothetical subscriber with an average level of minute usage determined previously, then find a plan (supposedly unique) that best fits that particular subscriber. The drawback of this approach, however, is that several assumptions have to be made about this average hypothetical customer, which may eventually lead to inaccurate empirical results.

Hence, this paper proposes a measure of Average Revenue per User (henceforth “ARPU”) as a proxy for price instead. This measure is indeed widely recognized by researchers and analysts at brokerage firms to be a determinant for what the market perceives as the firm’s product quality. As the feature of this measure resembles that of the product price, it would be reasonable for this paper to use ARPU a substitute for price. Revenue and number of subscribers are then collected from the company reports and various equity research reports from Investext database[24]

It is worth noting that recent debates pay closer attention to the usage compatibility of ARPU as a proxy for price. McCloughan and Lyons (2006) state that ARPU has been used by some regulators as a measure for "market power," whereas others consider it as a representative of the amount of telephone usage by subscribers. They further argue that ARPU would be a good proxy if subscribers are not very sensitive to price per minute but rather to the overall cost of usage per month, otherwise RPM (Revenue per Minute) would perhaps be a better measure. Together with the fact that none of these measures are readily available or previously aggregated until only a few years ago, ARPU is perhaps the only measure that is practical enough for us to rebuild.

As such, it is important to know how exactly this paper calculates the ARPU in order to fully understand the analysis in the empirical section. The aforementioned method can be summarized below:

ARPU = (total revenue) / (number of subscribers)

Total revenue = (revenue from services) + (sales)
= (airtime charges + other revenues from International Roaming, Value-Added Services, etc.) + (Number of new subscribers * average price of a mobile phone)

Due to limited availability of the data, the airtime charges were not found as a standalone line item in the financial disclosures of both AIS and DTAC. The only measure available for all quarters since 1995 is the total revenue.[25] It also would not

[24] Formerly called "Research Bank Web," provided by Gale.
[25] Equity research reports for these two companies also provide only the summary of their quarterly financial statements. As companies are not required to disclose their quarterly statements to the Stock

be feasible to resolve this problem by extrapolating the total revenue with other additional information due to the difficulty in selecting appropriate proxies, not to mention the possible statistical errors associated with this approximation method.

As a result, this paper will not be reluctant to choose the originally provided total revenue as a proxy for product price. In fact, this approach is adequately justified when considering the fact that firms offer its products and services (i.e. cellular phone and the provision of network connections) together as a package. Their strategic decisions, namely pricing and advertising investment, will then take into account the total expected revenue and cost of each package, which makes it appropriate for us to include both sales and services together in our analysis. Together with the fact that the largest portion of the revenue for these cellular carriers comes from network provision[26], inclusion of mobile phone prices would not drastically affect the result of our analysis.

Furthermore, price of purchasing a mobile phone is also a key factor for customers in deciding what network operators they will use, as the operators often manipulate this price as a promotional instrument to attract customers and make them subscribe to their services. Factoring in revenues from sales of mobile phones to our calculation, therefore, would give a more complete picture of what goes into the decision making process of these cellular carriers. Kadiyali (1997) also briefly discusses the possibility of misspecification in the photographic film demand function

---

Exchange of Thailand, there is no historical record for the relevant documents to be retrieved. Also, quarterly statements do not have to follow GAAP accounting standards, nor do they have to be rigorously audited by an outside auditor. Thus, the figures in them would not be as reliable and subject to individual's interpretation.

[26] According to company information and recent years' financial disclosures, where the breakdowns of service revenue and sales revenue are provided.

caused by omitting the variable for camera prices. She suggests that such a treatment could have been problematic had those film companies also had significant market power in the camera retail sector, which would have allowed them to manipulate both prices simultaneously for a maximum profit. Thailand's mobile phone sector, however, functions fairly differently from the photographic film industry in that network operators were also the only major vendors in the mobile phone market until a few years ago.[27] This characteristic makes it appropriate to include mobile phone prices in the model, as is the practice this paper follows.

Cost

The empirical analysis will begin by using the direct observations on costs, which are obtained from the financial statements of the cellular carriers as well. Similar to the data on price, the cost used in this analysis is also in terms of total costs (i.e. a summation of cost of services and cost of mobile phones).

Alternatively, as the accounting-economic discrepancy is acknowledged as a potential problem, this paper also adopts the cost equation from Parker and Röller (1997) as previously mentioned. The components required to estimate the marginal cost per subscriber for AIS and DTAC are

- Number of subscribers: the total of pre-paid and post-paid subscribers, which will in a way reflect the quantity produced of each firm as a whole. This figure is generally obtained from brokerage analyst reports, with

[27] This is partly due to the implementation of International Mobile Equipment Identity (IMEI), which requires a mobile phone subscriber to use services exclusively from one network provider. As a result, mobile phones had also been mostly retailed through AIS or DTAC. Only until a few years ago, the government's policy to liberalize the cellular phone market successfully prompted all of the cellular carriers to subsequently unlock the IMEI so that a mobile phone can be used with any carriers. (With the exception of Hutch, a new entrant that operates on the CDMA technology, which makes its SIM card not compatible with other GSM mobile phones. Its market share, however, remains insignificant).

some additions from firms' quarterly disclosures and investor presentations.

- Cost of energy to run the operations: collected from *Quarterly Series, Thailand, Electricity, Gas & Water , Composite Index,* obtained via DataInsight
- Cost of capital for financing, construction, and network maintenance: used "prime rate offered by banks" as a proxy, collected from the Bank of Thailand via DataInsight
- Labor costs: used average wages for Thailand's manufacturing factor (baht per month), not seasonally adjusted[28]. Collected from the National Statistical Office's *Report of the Labor Force Survey* via DataInsight.
- Cost of rent: excluded from the model as no appropriate data is available at the moment, as well as because this type of cost generally highly correlates with other cost components.
- Cost of operations and SG&A overheads: as SG&A is a strategic variable in the equation, its appearance will not be repeated to avoid estimation bias.

Advertising Expense

As stated above, another strategic variable that reflects firms' market decisions is advertising expense. Due to the limited availability of the data, this paper is able to collect only the Selling, General and Administrative expenses (SG&A) as a lump sum from firms' historical financial statements. Secondary sources such as equity research reports also do not provide the breakdown of SG&A up until a few years ago As there are no better measures, it is inevitable for this paper to uses SG&A as a proxy for advertising costs. Nevertheless, it should be noted that the components of SG&A other than advertising expenses are fairly invariable in general, as can be seen how brokerage analysts also estimate them as fixed "overheads." As general and administrative costs do not change much, they could be treated as a constant for simplicity. One could also see them as a function (often with a linear relationship) of

[28] Seasonal variation would not significantly affect the operations as the nature of cellular phone industry does not depend upon seasonal factor, unlike the soft-drink industry Gasmi, Laffont, and Vuong (1992) use as their empirical illustration.

subscribers due to the fact that these costs do grow when subscriber base gets larger. These two propositions will be explored empirically in the next section.

Descriptive Statistics

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
DTAC					
dtacarpu	52	2,817	1,497	1,010	5494.4
dtacacpu	52	1,581	848	541	3071
dtacsga	52	1,304	601	179	2506.525
dtacsub	52	4,565,280	4,511,414	296,650	15,800,000
AIS					
aisarpu	52	3,220	1,642	966	5874.1
aisacpu	52	1,793	1,049	513	4181.5
aissga	52	1,923	974	568	3968
aissub	52	7,763,524	7,697,117	484,900	24,100,000
Exogenous variables					
electricity	45	103.37	17.71	78.48	136.42
avgwage	43	60.61	1.86	56.67	66.16
prime	52	8.68	3.02	3.80	14.51
realgdp	52	3,336,806	480,018	2,635,596	4,511,028

VII. RESULTS AND MODEL SELECTION

As introduced in the previous section, this paper employs three estimation techniques, namely 3SLS, Iterative 3SLS and FIML, to calculate the coefficients and data-fitting ability of each of the game-theoretically formulated model. The reason these two techniques are selected is mainly because they are full-information methods, which take advantage of solving all the equations simultaneously as well as imposing all available restrictions predicted by economic theory. This type of estimator is more suitable and efficient when the number of endogenous variables equals the number of equations in the system, as is the case in this analysis.

To establish a reference case, we first apply in our estimation the Full-Information Maximum Likelihood method, the technique suggested by Gasmi, Laffont, and Vuong (1992). We find that FIML only converges for Model 4 and Model 6-10, in which the coefficient estimates on the degree of collusion (λ) greatly exceed one and does not have any statistical significance. (All the estimation results can be found in Appendix A). Since all of these empirically-converged models are based on the assumption that collusion exists at some point during the period we study, neglecting the estimation result on λ and interpreting these models further would be self-contradictory. In fact, this type of result is not particularly unusual, as the FIML estimation do not always perform well especially when there is high multicollinearity between variables in the model. As mentioned earlier, Kadiyali (1996) also addresses this similar problem as she encounters non-convergence or singularity of the variance-covariance matrix.

Note that we did not refrain from employing the FIML method in our analysis for two reasons. First, since we enjoy the advantage of having the direct observations on costs available, there are fewer parameters to be estimated, which in turn alleviate the demand on our relatively small data set. Second, FIML is the most asymptotically efficient estimator for a system of nonlinear equations, which suggests that we should avoid using it only when the data also confirm non-convergence. Even with the presence of multicollinearity among variables, FIML does sometimes converge if the data demonstrate enough variations, which may compensate for the low marginal explanatory power each variable has in that case. Unfortunately, as the results indicate, FIML will not be an appropriate method to be used with our analysis.

Consequently, we next adopt the *iterative* 3SLS (IT3SLS) method, which is claimed by Kadiyali (1997) to be less affected by multicollinearity. This approach, however, still does not resolve the issue of non-convergence for some models. The results indicate that Model 4, 6, 9, and 10, 11 (AIS leads), and 12 (AIS leads) are the only ones that converge. And even so, among the converged models that incorporate some existence of collusion, only Model 4 provides a statistically significant estimate for the collusive parameter λ at 5% level (t-statistics of 17.42). The result for Model 4 can be found in Table 2 below (see Appendix B for the estimation results of other models):

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	9.06E+09	3.44E+09	2.63	0.0113
aisARPU	-5.39E+09	2.65E+09	-2.04	0.0472
dtacSGA	1081264	464815	2.33	0.0242
aisSGA	-4.15E+05	1.83E+05	-2.27	0.0276
constant	2.47E+07	9.62E+06	2.56	0.0135
realgdp	-19.0332	3.4321	-5.55	<.0001
AIS demand				
dtacARPU	1.62E+10	6.40E+09	2.54	0.0145
aisARPU	-9.53E+09	4.94E+09	-1.93	0.0596
dtacSGA	1918104	835097	2.3	0.0259
aisSGA	-7.26E+05	3.26E+05	-2.23	0.0304
constant	4.50E+07	1.69E+07	2.66	0.0106
realgdp	-34.6966	6.0277	-5.76	<.0001
Collusion	1.922515	0.1104	17.42	<.0001

Minimized Sums of Squared Errors = 67.71

Table 2: Estimation results for Model 4 (collusion in both price and advertising)

Note that an interesting observation of Model 4 is that the estimated value of λ does not lie within the theoretically possible range (i.e. 0 and 1). In addition, while all the coefficient estimates in this model are statistically significant under 95% confidence interval,[29] some of them still have the wrong signs. Namely, the coefficients for real GDP for both companies are negative with high statistical significance, and almost all of the coefficient estimates for AIS contradicts with the economic intuition. Therefore, all the estimates from these collusive models are not meaningful and cannot be interpreted with statistical confidence.

It should be made clear that we have already tried imposing restrictions from economic theory as well as from the second-order conditions of the profit maximization functions in each model. However, rather than helping the selected empirical techniques to perform better, this additional information causes some of the models to no longer converge since there are several variables to be constrained due to the wrong signs. Such results could be considered reasonable as these models barely converge even without any restrictions imposed[30]. Apart from the convergence issue, several coefficient estimates are also marked as biased as the model becomes singular. As such, we will only discuss the use of restrictions for the models in which they enhance the estimation results, and avoid the repetition of mentioning it for all other models.

Hence, we turn to purely non-collusive models, namely Model 11 and 12 with AIS being a leader. For Model 11, the majority of the coefficient estimates do not

[29] With the exception of AIS's own-price coefficient, which is statistically significant at 94% confidence.

[30] The number of iterations is unusually high in many models, which implies that it is increasingly difficult to find the converging point when starting the numerical iteration from the point calculated by OLS and SUR methods (default steps for FIML implementation in SAS).

demonstrate much discrepancy with economic intuition. AIS's own-price, cross-price, and own-advertising coefficients have the expected signs with p-value of less than 0.01% for all of these coefficients. The estimation for DTAC, the competitor, also produces the correct sign for the own-advertising coefficient, whereas the own-price and cross-price coefficients that have the wrong signs are not statistically significant at 5% level (p-value of 5.63% and 14%, respectively). The main concern with this model, however, is that the coefficients of GDP for both firms still give the wrong signs (i.e. negative) with statistical significance. The imposition of sign restrictions also results in non-convergence in this case. As such, although this model seems to perform better than the other models on which we previously discussed, the remaining wrong signs prevent us from invoking its results to explain the actual game structure of AIS and DTAC. Similarly, the coefficient estimates from Model 12 also have the expected signs except for those of GDPs, and imposing restrictions does not help. Despite a greater statistical significance of most individual estimates, Model 12 still cannot be considered superior to others.

We also explore the additional specification made in Kadiyali (1996): a time trend. This is done for a reason different from Kadiyali's rationale. In her study, she uses a time trend to represent technological progress and other trend variables affecting the marginal cost, while in this paper the time trend is included in the demand specification mainly to capture the network effect and consumer's product familiarity. It certainly is a sound proposal to use a lagged number of subscribers as a proxy for the network size and thus measure the network effect. Yet, it is worth noting that an inclusion of a lag variable will affect statistical properties of some econometric techniques and will also lead to much more complicated model with less "empirical tractability," as asserted by both Gasmi *et al.* and Kadiyali. In any case, the addition of a time trend did not turn out to be helpful in eliminating the sign mismatches in the estimation results or making the numerical iterations converge better. Considering the sheer number of coefficients to be estimated relative to the number of observations we have, it is appropriate to exclude the time trend from our demand equations.

Next, we propose the 3SLS method (non-iterative) as an alternative econometric technique in an attempt to re-estimate the 12 models and verify whether or not we can get any meaningful results. 3SLS may be a more suitable method for our data, since it is not computationally expensive and thus reduces the burden on our data. In terms of relative efficiency with respect to IT3SLS and FIML methods, Kennedy (2003) suggests that "Monte Carlo studies have not shown IT3SLS to be significantly superior to 3SLS." Moreover, "if there are lagged endogenous variable, FIML is asymptotically more efficient than 3SLS," which follows that our exclusion of the lagged variables is one of the reasons that justifies the use of 3SLS to replace FIML. It should be acknowledged, however, that the asymptotic efficiency gain may not imply similar superiority for a small sample size like ours, and the estimation results from this technique should be regarded with care.[31]

[31] Gasmi, Laffont, and Vuong (1992) also address a problem with 3SLS that it may not give the estimation for the collusive parameter. This is also the case in this paper, in fact. It is worth noting, however, that even though the method may not yield a statistically significant estimate for the collusive parameter, the goodness of fit should also be taken into account to interpret the overall results. Furthermore, Intriligator *et al.* (1996) also mentions that FIML has the advantage over 3SLS in terms of imposing *a priori* restrictions to several equations simultaneously. Yet, according to our results FIML does not give meaningful results for any model in this paper, making it necessary to opt for 3SLS where convergence is not a frequent problem.

According to the results produced by 3SLS for each case, Model 10 has the lowest minimized sums of squares (henceforth "MSSE") of all at 51.55 , which is the main selection criterion associated with the 3SLS method (See Table 3 below). However, the own-advertising coefficient for DTAC, as well as the own-price and cost-price coefficients for AIS all have the wrong signs. Imposing restrictions on these coefficients causes the model to become singular, which is not surprising as this is a known issue resulted from multicollinearity. Thus, we move on to consider Model 2A, which has the next lowest MSSE of all at 57.82 (see Table 4 below). Unlike Model 10, all of the statistically significant coefficient estimates from Model 2A have the correct signs, with the only exception of DTAC's cross-price coefficient which is not statistically significant even at 60% level. Although DTAC's own-advertising, cross-advertising, and AIS's cross-price coefficients are not statistically significant at 10% level either, the model is still considered acceptable as each coefficient is estimated jointly to fit the actual data.

Parameter	**Estimate**	**Approx Std Err**	**t Value**	**Approx Pr > |t|**
DTAC demand				
dtacARPU	-8.52E+09	2.71E+09	-3.15	0.0028
aisARPU	6.16E+09	2.20E+09	2.81	0.0072
dtacSGA	-241903	93410.7	-2.59	0.0126
aisSGA	179581.8	265270	0.68	0.5016
constant	-2.80E+07	21449352	-1.3	0.1988
realgdp	12.0573	4.8743	2.47	0.0170
AIS demand				
dtacARPU	-7.05E+09	2.63E+09	-2.68	0.0099
aisARPU	4.78E+09	2.15E+09	2.23	0.0306
dtacSGA	-277462	270260	-1.03	0.3095
aisSGA	289343.9	320482	0.9	0.3710
constant	-3.54E+07	20347937	-1.74	0.0880
realgdp	14.19774	4.8289	2.94	0.0050
Collusion	-3.99E+27	0	.	.

Minimized Sums of Squared Errors = 51.55

Table 3: Estimation results for Model 10B (Collusion in price and advertising until 2002q1, and AIS is a leader in price and advertising afterwards)

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-1.55E+09	5.66E+08	-2.73	0.0088
aisARPU	-5.09E+08	1.08E+09	-0.47	0.6400
dtacSGA	39460.54	133822	0.29	0.7693
aisSGA	-154903	205702	-0.75	0.4550
constant	52525.94	11690357	0.00	0.9964
realgdp	4.668227	2.1315	2.19	0.0334
AIS demand				
dtacARPU	1.08E+09	1.41E+09	0.77	0.4465
aisARPU	-2.40E+09	8.42E+08	-2.85	0.0063
dtacSGA	377670.3	169388	2.23	0.0304
aisSGA	32.50066	1.5024	21.63	<.0001
constant	-2.08E+07	6521728	-3.19	0.0025
realgdp	6.032493	1.6721	3.61	0.0007

Minimized Sums of Squared Errors = 57.82

Table 4: Estimation results for Model 2A (DTAC is a leader in price and advertising)

The next best-performing candidates are Model 4 and 5, where the MSSEs equal 59.06 and 65.02, respectively, while all other remaining models have this value higher than 70. Note, however, that in Model 4 almost all the individual estimates are not significant at 10% level, whereas in Model 5 the own-price coefficients for both firms are significant at 5% level but the coefficient for collusion is still neither significant or theoretically reasonable in magnitude. Accordingly, we can make a preliminary conclusion that Model 2A is the most “correct” model that best fits the actual data we have.

Using Model 2A to explain the strategic interactions between AIS and DTAC, the game-theoretic structure associated with it implies that DTAC might have been a leader in both price and advertising throughout both pre-entry and post-entry period.

One of the possible explanations for this interpretation is that DTAC as a smaller firm strives to reposition itself as a market leader. Its pricing and advertising behavior could be particularly aggressive in order to gain the leadership momentum of the market and the recognition from its adversaries. In addition, DTAC was able to successfully negotiate with the government for concession fees reductions,[32] giving it an increasing cost advantage over time relative to AIS. Even though AIS still has a stronger presence in the market, DTAC has been catching up fast in terms of market shares and could be perceived as a competitor capable of taking leadership in prices and advertising.

Now, one may wonder why the structural change in 2002 did not seem to have a significant impact on the interactive behavior between these two incumbents. We believe that, based on the results this paper finds, the entry may have urged DTAC to strengthen its presence in the market in order to remain perceived as a leader. In fact, DTAC was actually the firm that lost more market share to the entrant compared to AIS. This is potentially because upon the entry of the third firm, DTAC's in-between position was prone to being squeezed by the other two firms. DTAC's churn rate was shown to be high at the beginning of post-entry period, prompting it to pursue a leadership to discourage others from further aggressive price cuts and heavy investment on advertising.

[32] Partly because DTAC is a concessionaire of the Communications Authority of Thailand (CAT), which is often considered to have more political power than its counterpart, the Telecommunications Organization of Thailand (TOT), who grants a concession to AIS. Even though AIS was initially subject to less total regulatory fees, the trend has been favorable to DTAC.

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-2.15E+09	5.63E+08	-3.82	0.0004
aisARPU	1.70E+10	4.76E+09	3.56	0.0009
dtacSGA	4.79E+01	2.99E+00	16.00	<.0001
aisSGA	628508.7	209488	3.00	0.0043
constant	-2.09E+08	58930201	-3.54	0.0009
realgdp	41.37501	10.7761	3.84	0.0004
AIS demand				
dtacARPU	2.42E+09	1.06E+09	2.29	0.0266
aisARPU	-3.15E+09	8.40E+08	-3.75	0.0005
dtacSGA	3.93E+05	95342.5	4.12	0.0002
aisSGA	33.83463	1.496	22.62	<.0001
constant	-2.47E+07	10385783	-2.38	0.0215
realgdp	6.597255	1.8266	3.61	0.0007

Minimized Sums of Squared Errors = 73.13

Table 5: Estimation results for Model 2A (Nash competition in both prices and advertising)

It should be noted that there is a tradeoff when employing a model selection method to determine the best performing one. Specifically, while the MSSE as a main criterion measure for goodness of fit is easily understood and frequently compared across models, individual statistical significance also plays an important role in reflecting the explanatory power each component in the model has. The latter is especially important as it ultimately implies whether or not the model specification is adequately correct. A model that fits the overall data extremely well but does not show significance of its independent variables also does not lead to a very meaningful conclusion. Consider M1, for instance, it can readily be seen that all the coefficient estimates are significant at 3% level and have the expected signs (See Table 5 above). While its MSSE is discernibly higher than that of Model 2A, Model 1 has the desired, economically intuitive results and also should not be rejected right at the offset. Having addressed that issue, we can still arrive at a general conclusion that the best-fitting comprehensible model is Model 2A. Together with the acknowledgment of Model 1 as a possible alternative, our empirical investigation indicates that modeling Thailand's cellular telephone industry as a non-cooperative market gives superior results.

VIII. CONCLUSION AND FURTHER STUDY

In this paper, we have analyzed the game-theoretic structure of Thailand's two major cellular carriers from 1995 to 2007 through the framework of new empirical industrial organization. Relevant literature is addressed and serves as a background of study. Adopted from Gasmi, Laffont, and Vuong (1992), we modeled the demand as a dependent variable on prices, advertising expenses, and the GDP. We also specify cost specification from exogenous variables such as average wage, electricity price, and prime lending rate offered by banks (cost of capital) as well as using direct cost observations to obtain the profit function. Subsequently, we derive first-order conditions with respect to own-price, cross-price, own-advertising, and cross advertising. The two demand equations and four first-order conditions constitute a system of equations to be estimated simultaneously. The coefficients are in non-linear forms as a function of structural parameters, including those from the demand equation, the cost equation, and the collusive parameter. Several different non-nested models, each associated with a unique game-theoretic assumption, are postulated to be tested against one another. In general models can be separated into two categories: non-collusive and collusive. The non-collusive model is based on the assumption that both firms in the duopolistic market will try to maximize joint profit, the equation of which has a collusive parameter as a determinant for profit portion of each firm. After that, three econometric estimation techniques (namely FIML, IT3SLS, and 3SLS) are applied to all postulated models to indicate which of the competing models maximizes goodness of fit, measured by a calculated ratio associated with each technique. Formal pair-wise tests, including Vuong (1989), are also briefly introduced and discussed.

After estimating each model by the aforementioned econometric techniques, we found that Model 2A, where DTAC is a leader in price and advertising throughout both pre-entry and post-entry period, is the best-fitting model with regard to our data. All models that assume some degree of tacit collusion give inferior results, whether it be the unexpected signs of the coefficient estimates or the statistical insignificance of most individual coefficients. This result suggests that, contrasting to the intuition and what some researchers have said about the competition between AIS and DTAC, the competitive regime may have prevailed the cooperative structure in the Thai cellular telephone industry.

This paper has contributed to the development in the field of empirical industrial organization in several aspects. First, the carefully gathered data set used in this paper is unique and can be used conveniently to test other theories or hypotheses. Second, various characteristics pertaining to the cellular telephone industry are presented, which deviate the approach and result interpretation from those of Gasmi *et al.* (1992) and Kadiyali (1997). Different game-theoretic assumptions are also proposed and in some cases proven to perform better than other previously suggested models. Third, the estimation results our analysis generate help shed some light on the strategic interactions among firms in the Thai cellular phone sector, as well as present contrasting view against what has been said before by using empirical evidence as a support. However, due to some limitations of this paper, the game-theoretic assumptions presented in the analyzed models are simplified to the extent that there would not be too much burden on the limited amount of data we have, and that the empirical method can still provide meaningful, statistically significant estimates. Extensions and a more accurate specifications could be considered but should not be held strictly or exhaustively, as in reality there does not exist a model that is perfectly specified. It is only a subjective judgment that determines if the misspecification is serious enough to make the system unreliable.

Based on the estimation results our analysis produces, one of the major problems we have yet to overcome is the lack of a proper way to handle high multicollinearity between variables in our data set. This problem causes the FIML technique to be biased and sometimes not even estimable, while the 3SLS method which should be less affected also gives coefficient estimates with low significance or unexpected signs in many models. As Kadiyali, Sudhir, and Rao (2001) state in their meta-analysis research, most of the studies in empirical industrial organization also use 3SLS, and there are not many well-known alternatives for the estimation technique other than the General Method of Moments (GMM), which is used in only a few studies. Consequently, the problem of multicollinearity still remains a challenging obstacle in producing meaningful results.

In addition, throughout this paper the approach to formulating all of the profit-maximization models for various game-theoretical assumptions is based upon the static framework. In other words, it is first presumed that rational firms will try to maximize their profits of the current period for which they are required to make strategic decisions. As such, product prices and advertising expenses are determined accordingly without taking into consideration the expected future profits. This is unfortunately not always the case in the real world. In fact, strategists at each company generally look beyond the current period and also try to do what is best for the company in subsequent periods. As the static game theory framework rules out the possibility of planning ahead, it has to be noted that the results from our analysis will not necessarily work in a dynamic setting.

One alternative to resolve this issue, as this paper has initially considered, is to apply the dynamic settings and incorporate variables from other periods into the model. As suggested by Chen and Lee (2003), management executives make decisions based on both backward information and forward predictions, usually at the range of 2-4 quarters. Thus, an inclusion of the expected profit of a few adjacent quarters may enrich the likelihood and robustness of the estimates. This modification to the model is also in favor of the argument proposed by Simon and Sebastian (1987) earlier in this paper that advertising effect may reach its peak during 4-9 months after its first appearance. Having considered this result, it would be essential to include the lagged data on advertising expenses as well as the expected future effect of advertising discounted to present.

Additionally, as mentioned earlier, another important characteristic of the cellular phone industry is the existence of switching costs. As Klemperer (1989) discusses the impact of switching costs on the competition and the plausibility of a price war, this particular measure remains a key factor in shaping the interactive behaviors of competing firms. Consider a simple two-period profit maximization equation below:

$$V^F = \pi_1^F + \delta\pi_2^F(\sigma_1^F)$$

Where V^F is a notation for the total present value of the profits of firm *F* from both periods, π_i^F for the profit of firm *F* in period *i*, δ for the discount rate, and σ_1^F for the market share firm *F* has in period 1. As we move forward to the dynamic framework, this model will be an interesting theoretical background to explore.

In order to generalize this concept further, one may consider the reliance on a recursive model, defined for a certain number of quarters. Based on the perception that decisions firms make may depend upon several previous quarters and several following quarters, we may be able to allow the possibility of having a mixed strategy during specific period of time.

Another interesting point that may serve as a possible extension to this paper is the political influence on government-related competition. The cellular telephone industry is a good example for demonstrating how much control the government has in shaping the outcome of the competition. Cellular carriers need to win concessions in order to operate, and the terms of the concession is to a great extent dependent upon what the government decides. For instance, regulatory fees (sometimes called "excise tax") among firms can be different, making it advantageous for those that share a smaller portion of their revenues compared to the others. This argument is especially intriguing for the case of Thailand's cellular phone sector because AIS, the market leader, had been owned by the former Prime Minister Thaksin Shinawatra until very recently when he sold all of his shares to a Singaporean company called Temasek Holdings. As such, politically-influenced collusive behavior whether between companies or even with the government itself would be a perfectly legitimate subject to investigate further.

Finally, a formal derivation of a three-firm oligopolistic competition on price and advertising would also be necessary in order to ensure that we properly model their interactions with appropriate economic framework. As the third firm entered the industry only a few years ago, this paper decides not to pursue such an approach at this point due to the availability of the data. The triopolistic model will certainly be more complicated and involves more parameters, and thus adequate variations in the data are required to generate reliable estimates. However, we should note that it is not impossible to conduct empirical tests for the three firm settings even with a small data set. In the study on the U.S. photographic film by Kadiyali (1997), as referred to many times in this paper, models the structure of the competition with a strong emphasis on entry of a new firm and the incumbents' accommodation. Due to the fact that her data set was not very large and demonstrate high multicollinearity, as is also the case here, she alleviates these limitations by reusing some of the estimates from the pre-entry period, where there are less parameters to be estimated, to help reduce the number of parameters in the post-entry period. Although some predetermined conditions would have to be incorporated in the models in order to use this technique, it might not be a serious violation of relevant economic theory that would prevent us from implementing it. With the implications from this study, this approach would be quite an interesting path to pursue in the future.

APPENDIX - A

Full-Information Maximum Likelihood (FIML) method

<u>Model 4</u> Collusion in both price and advertising

M1 Parameter	**Estimate**	**Approx Std Err**	**t Value**	**Approx Pr > |t|**
DTAC demand				
dtacARPU	4.87E+08	4.18E+08	1.17	0.2487
aisARPU	-4.94E+08	3.81E+08	-1.3	0.2010
dtacSGA	176867.6	162378	1.09	0.2814
aisSGA	-147275	147550	-1	0.3231
constant	-2223016	3085657	-0.72	0.4748
realgdp	0.901725	0.8526	1.06	0.2955
AIS demand				
dtacARPU	4.13E+08	3.48E+08	1.19	0.2411
aisARPU	-4.33E+08	3.27E+08	-1.33	0.1913
dtacSGA	129393.4	148064	0.87	0.3864
aisSGA	-97149.4	134109	-0.72	0.4723
constant	-1941287	2487388	-0.78	0.4390
realgdp	0.68566	0.7024	0.98	0.3339
Collusion	2.455E+18	0	.	.
Log Likelihood	-1754			

<u>Model 6</u> Collusion in price and Nash in advertising

Parameter	**Estimate**	**Approx Std Err**	**t Value**	**Approx Pr > |t|**
DTAC demand				
dtacARPU	1.42E+09	9.50E+08	1.49	0.1420
aisARPU	-5.59E+09	1.21E+09	-4.62	<.0001
dtacSGA	51979.86	5160.5	10.07	<.0001
aisSGA	150768.5	40815.5	3.69	0.0006
constant	-6104296	11189010	-0.55	0.5879
realgdp	5.192141	3.0617	1.7	0.0964
AIS demand				
dtacARPU	1.05E+09	9.61E+08	1.09	0.2798
aisARPU	-5.20E+09	1.21E+09	-4.3	<.0001
dtacSGA	108308.2	21553.1	5.03	<.0001
aisSGA	62940.42	6594.9	9.54	<.0001
constant	-4953457	10184839	-0.49	0.6289
realgdp	6.136387	2.5342	2.42	0.0193
Collusion	-1.06E+29	0	.	.
Log Likelihood	-1753			

Model 7 Collusion in advertising until 2002q1, and collusion in both price and advertising afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	4.79E+05	5.17E+05	0.93	0.3579
aisARPU	-9.06E+07	3.36E+07	-2.7	0.0095
dtacSGA	1.87E+04	1.18E+03	15.9	<.0001
aisSGA	-16487.7	1220.1	-13.51	<.0001
constant	1.87E+05	1.95E+05	0.96	0.3406
realgdp	9.19E-02	5.78E-02	1.59	0.1184
AIS demand				
dtacARPU	-7.68E+05	8.22E+05	-0.93	0.3546
aisARPU	-2.80E+08	1.01E+08	-2.77	0.0078
dtacSGA	-1.68E+04	1.10E+03	-15.34	<.0001
aisSGA	24514.41	2208.3	11.1	<.0001
constant	572254.7	563050	1.02	0.3145
realgdp	2.70E-01	0.2329	1.16	0.2520
Collusion	6.21E+21	0	.	.
Log Likelihood	-1787			

Model 8A Collusion in advertising until 2002q1, and DTAC is a leader in price afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-5.21E+08	3.52E+08	-1.48	0.1455
aisARPU	-3.85E+09	4.44E+09	-0.87	0.3894
dtacSGA	547304.8	776034	0.71	0.4840
aisSGA	-470441	510166	-0.92	0.3609
constant	13011803	14462482	0.9	0.3727
realgdp	2.782152	4.789	0.58	0.5639
AIS demand				
dtacARPU	-1.04E+08	73459610	-1.41	0.1638
aisARPU	-5.34E+08	2.62E+08	-2.04	0.0471
dtacSGA	121334.9	86491.1	1.4	0.1670
aisSGA	-25258.2	7687.7	-3.29	0.0019
constant	11817.01	2532948	0	0.9963
realgdp	0.451792	0.5482	0.82	0.4138
Collusion	6.68E+32	0	.	.
Log Likelihood	-1775			

Model 8B Collusion in advertising until 2002q1, and AIS is a leader in price afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-3.82E+08	8.02E+07	-4.76	<.0001
aisARPU	9.14E+07	30204537	3.03	0.0039
dtacSGA	-37545	3887	-9.66	<.0001
aisSGA	22084.08	5869.4	3.76	0.0004
constant	169713.3	525298	0.32	0.7480
realgdp	-0.02736	0.179	-0.15	0.8792
AIS demand				
dtacARPU	6.02E+07	25594354	2.35	0.0227
aisARPU	-1.50E+07	7233403	-2.07	0.0432
dtacSGA	9383.254	2301.8	4.08	0.0002
aisSGA	-405.542	1074.2	-0.38	0.7074
constant	-158729	94585.2	-1.68	0.0997
realgdp	0.035193	0.0311	1.13	0.2626
Collusion	2.04E+31	0		
Log Likelihood	-1811			

Model 9 Collusion in price and advertising until 2002q1, and Nash competition in price and advertising afterwards

M9 Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	4.25E+08	4.54E+09	0.09	0.9258
aisARPU	-4.20E+09	5.44E+09	-0.77	0.4435
dtacSGA	1.81E+06	3.82E+05	4.73	<.0001
aisSGA	-1877222	1476713	-1.27	0.2097
constant	9666706	50260099	0.19	0.8483
realgdp	7.21309	7.4541	0.97	0.3381
AIS demand				
dtacARPU	4.41E+09	4.66E+09	0.95	0.3488
aisARPU	-7.95E+09	3.49E+09	-2.28	0.0271
dtacSGA	2.09E+06	4.31E+05	4.85	<.0001
aisSGA	-1271938	1002727	-1.27	0.2106
constant	-1.66E+07	34202355	-0.48	0.6301
realgdp	5.604863	7.1421	0.78	0.4364
Collusion	2.87E+22	0	.	.
Log Likelihood	-1797			

Model 10A Collusion in price and advertising until 2002q1, and DTAC is a leader in price and advertising afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	6.91E+08	4.69E+08	1.47	0.1466
aisARPU	-8.81E+08	2.54E+08	-3.47	0.0011
dtacSGA	348467.4	232547	1.5	0.1404
aisSGA	-1.29E+05	16572.6	-7.76	<.0001
constant	-5.74E+06	6991134	-0.82	0.4158
realgdp	5.19E-01	1.63E+00	0.32	0.7509
AIS demand				
dtacARPU	5.95E+08	4.24E+08	1.4	0.1669
aisARPU	-7.53E+08	2.51E+08	-2.99	0.0043
dtacSGA	299749.3	224276	1.34	0.1876
aisSGA	-8.59E+04	14453.3	-5.95	<.0001
constant	-5.58E+06	6433697	-0.87	0.3898
realgdp	3.63E-01	1.47E+00	0.25	0.8053
Collusion	5.69E+21	.	.	.
Log Likelihood	-1754			

Model 10B Collusion in price and advertising until 2002q1, and AIS is a leader in price and advertising afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-3.74E+08	77627546	-4.81	<.0001
aisARPU	1.06E+08	64071410	1.65	0.1056
dtacSGA	44136.73	4700.2	9.39	<.0001
aisSGA	-38803.8	5574	-6.96	<.0001
constant	1548980	1049011	1.48	0.1463
realgdp	0.231752	0.3363	0.69	0.4941
AIS demand				
dtacARPU	1.02E+08	54569517	1.86	0.0684
aisARPU	-3.17E+07	16179894	-1.96	0.0555
dtacSGA	10290.01	3054.8	3.37	0.0015
aisSGA	2625.587	3487.8	0.75	0.4552
constant	-556438	302467	-1.84	0.072
realgdp	0.059826	0.0934	0.64	0.5251
Collusion	7.32E+18	0	.	.
Log Likelihood	-1802			

APPENDIX - B

Iterative Three-Stage Least Squares (IT3SLS) method

Model 6 Collusion in price and Nash in advertising

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	1.48E+09	5.08E+08	2.91	0.0054
aisARPU	-7.36E+06	2.59E+08	-0.03	0.9774
dtacSGA	3.71E+04	4268.3	8.7	<.0001
aisSGA	82423.63	31745	2.6	0.0124
constant	3.56E+06	2306612	1.54	0.1294
realgdp	-3.83E+00	0.6053	-6.32	<.0001
AIS demand				
dtacARPU	7.60E+08	4.52E+08	1.68	0.0991
aisARPU	1.77E+08	2.14E+08	0.82	0.4135
dtacSGA	7.70E+04	16975.1	4.53	<.0001
aisSGA	44810.92	5315	8.43	<.0001
constant	9118266	1912218	4.77	<.0001
realgdp	-4.63763	0.5814	-7.98	<.0001
Collusion	-6.45E+24	0	.	.

Minimized Sums of Squared Errors = 78.18

Model 9 Collusion in price and advertising until 2002q1, and Nash competition in price and advertising afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	2.26E+09	1.92E+08	11.76	<.0001
aisARPU	-1.50E+09	1.65E+08	-9.09	<.0001
dtacSGA	3.47E+04	4.38E+03	7.93	<.0001
aisSGA	-22380.2	3362.4	-6.66	<.0001
constant	34958693	4390812	7.96	<.0001
realgdp	-12.8612	1.069	-12.03	<.0001
AIS demand				
dtacARPU	2.33E+09	1.95E+08	11.95	<.0001
aisARPU	-1.61E+09	2.53E+08	-6.36	<.0001
dtacSGA	3.39E+03	4.11E+03	0.83	0.4133
aisSGA	12854.51	2811	4.57	<.0001
constant	6.26E+07	6437818	9.72	<.0001
realgdp	-22.4428	1.5914	-14.1	<.0001
Collusion	1.19E+21	0	.	.

Minimized Sums of Squared Errors = 81.46

Model 10A Collusion in price and advertising until 2002q1, and DTAC is a leader in price and advertising afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	2.43E+09	2.14E+08	11.36	<.0001
aisARPU	-5.28E+08	1.50E+08	-3.51	0.001
dtacSGA	35516.4	3994	8.89	<.0001
aisSGA	-25286.3	4408.1	-5.74	<.0001
constant	8290705	2778193	2.98	0.0045
realgdp	-5.80926	0.676	-8.59	<.0001
AIS demand				
dtacARPU	1.81E+09	1.69E+08	10.7	<.0001
aisARPU	-3.08E+08	1.45E+08	-2.12	0.039
dtacSGA	4207.433	3677.9	1.14	0.2581
aisSGA	9937.663	3758.1	2.64	0.011
constant	8134922	2278683	3.57	0.0008
realgdp	-5.44748	0.5532	-9.85	<.0001
Collusion	-1.07E+26	0	.	.

Minimized Sums of Squared Errors = 77.91

Model 10B Collusion in price and advertising until 2002q1, and AIS is a leader in price and advertising afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	1.62E+09	1.93E+08	8.42	<.0001
aisARPU	-1.66E+09	1.41E+08	-11.75	<.0001
dtacSGA	3.62E+04	5370.1	6.73	<.0001
aisSGA	-22454.5	2925.8	-7.67	<.0001
constant	5.63E+06	2486363	2.26	0.0282
realgdp	-1.11E+00	0.6012	-1.84	0.0715
AIS demand				
dtacARPU	2.40E+09	1.84E+08	13.02	<.0001
aisARPU	-2.73E+09	1.86E+08	-14.73	<.0001
dtacSGA	5.57E+03	4991.2	1.12	0.2701
aisSGA	12444.68	2501.5	4.97	<.0001
constant	29637148	4009708	7.39	<.0001
realgdp	-8.33934	1.0106	-8.25	<.0001
Collusion	3.85E+21	0	.	.

Minimized Sums of Squared Errors = 81.72

Model 11B AIS is a leader in price and advertising until 2002q1, and Nash in both variables afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	3.64E+08	1.86E+08	1.95	0.0563
aisARPU	-5.12E+08	3.43E+08	-1.49	0.1414
dtacSGA	39.55246	2.4733	15.99	<.0001
aisSGA	-1.09E+00	1.01E+00	-1.08	0.2835
constant	3.39E+07	1.98E+06	17.1	<.0001
realgdp	-1.23E+01	5.57E-01	-22.11	<.0001
AIS demand				
dtacARPU	3.28E+09	7.01E+08	4.68	<.0001
aisARPU	-1.59E+09	3.08E+08	-5.16	<.0001
dtacSGA	625008.7	86610.4	7.22	<.0001
aisSGA	2.42E+01	3.2755	7.38	<.0001
constant	-2.39E+07	5564586	-4.29	<.0001
realgdp	-0.52108	1.1571	-0.45	0.6545

Minimized Sums of Squared Errors = 91.30

Model 12B Nash competition in price and advertising until 2002q1, and AIS is a leader in both variables afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	1.17E+09	1.89E+08	6.18	<.0001
aisARPU	-4.79E+08	1.05E+08	-4.56	<.0001
dtacSGA	35.9975	2.41E+00	14.93	<.0001
aisSGA	0.155917	0.988	0.16	0.8753
constant	36598066	5061248	7.23	<.0001
realgdp	-17.1486	1.1987	-14.31	<.0001
AIS demand				
dtacARPU	-8.06E+09	1.11E+09	-7.29	<.0001
aisARPU	2.04E+09	2.67E+08	7.65	<.0001
dtacSGA	-1385649	180746	-7.67	<.0001
aisSGA	27.4616	1.2182	22.54	<.0001
constant	1.29E+08	14942383	8.61	<.0001
realgdp	-28.1423	3.5612	-7.9	<.0001

Minimized Sums of Squared Errors = 99.52

APPENDIX - C

Results from Three-Stage Least Squares (3SLS) method

Model 2B AIS is a leader in price and advertising:

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-1.83E+09	5.67E+08	-3.22	0.0023
aisARPU	-1.27E+08	3.22E+08	-0.39	0.6946
dtacSGA	46.57027	3.0047	15.5	<.0001
aisSGA	-173655	86648.8	-2.00	0.0506
constant	-2996084	5418751	-0.55	0.5829
realgdp	6.105244	0.8344	7.32	<.0001
AIS demand				
dtacARPU	2.59E+09	2.38E+09	1.09	0.2819
aisARPU	-2.56E+09	9.31E+08	-2.74	0.0084
dtacSGA	396721.1	196564	2.02	0.0491
aisSGA	123324.4	169079	0.73	0.4692
constant	-3.39E+07	16570304	-2.05	0.0462
realgdp	7.030204	2.372	2.96	0.0047

Minimized Sums of Squared Errors = 73.19

Model 3A DTAC is a leader in price, and Nash in advertising

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-1.94E+09	6.53E+08	-2.97	0.0046
aisARPU	-1.16E+08	3.76E+08	-0.31	0.7586
dtacSGA	46.94743	3.0283	15.50	<.0001
aisSGA	-192624	91684.8	-2.10	0.0410
constant	-2170053	5338691	-0.41	0.6862
realgdp	6.189712	0.8986	6.89	<.0001
AIS demand				
dtacARPU	2.68E+09	1.36E+09	1.98	0.0535
aisARPU	-2.89E+09	8.27E+08	-3.49	0.0010
dtacSGA	620932.9	157507	3.94	0.0003
aisSGA	32.98145	1.4756	22.35	<.0001
constant	-3.02E+07	5954127	-5.06	<.0001
realgdp	5.38447	1.5195	3.54	0.0009

Minimized Sums of Squared Errors = 74.68

Model 3B AIS is a leader in price, and Nash in advertising

AIS leads Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-1.05E+08	3.25E+08	-0.32	0.7468
aisARPU	-1.87E+09	5.63E+08	-3.33	0.0017
dtacSGA	-1.80E+05	8.68E+04	-2.07	0.0434
aisSGA	4.67E+01	3.03E+00	15.41	<.0001
constant	-2.79E+06	5.44E+06	-0.51	0.6100
realgdp	6.145956	0.8457	7.27	<.0001
AIS demand				
dtacARPU	-2.65E+09	9.27E+08	-2.86	0.0063
aisARPU	2.40E+09	1.50E+09	1.6	0.1167
dtacSGA	3.28E+01	1.48E+00	22.16	<.0001
aisSGA	6.06E+05	1.74E+05	3.48	0.0011
constant	-2.99E+07	6.38E+06	-4.68	<.0001
realgdp	5.45398	1.6659	3.27	0.0020

Minimized Sums of Squared Errors = 72.93

Model 4 Collusion in both price and advertising

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	8.78E+08	2.03E+09	0.43	0.6673
aisARPU	-1.55E+09	1.98E+09	-0.78	0.4380
dtacSGA	-60642.5	300469	-0.20	0.8409
aisSGA	94983.12	195997	0.48	0.6301
constant	-2.38E+07	14465139	-1.65	0.1059
realgdp	8.921387	4.3052	2.07	0.0436
AIS demand				
dtacARPU	2.32E+09	2.25E+09	1.03	0.3067
aisARPU	-3.93E+09	2.93E+09	-1.34	0.1865
dtacSGA	-96586.8	295373	-0.33	0.7451
aisSGA	126915.4	172346	0.74	0.4650
constant	-4.19E+07	30246437	-1.38	0.1727
realgdp	16.66686	9.2798	1.80	0.0788
Collusion	4.88E+17	0	.	.

Minimized Sums of Squared Errors = 59.06

Model 5 Collusion in advertising and Nash in price

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-9.46E+08	4.08E+08	-2.32	0.0244
aisARPU	-1.52E+09	1.97E+09	-0.77	0.4453
dtacSGA	308697.8	383947	0.8	0.4253
aisSGA	-416995	471939	-0.88	0.3812
constant	2860720	25744127	0.11	0.9120
realgdp	4.815477	4.3085	1.12	0.2693
AIS demand				
dtacARPU	6.09E+08	2.97E+09	0.2	0.8386
aisARPU	-1.33E+09	5.88E+08	-2.26	0.0279
dtacSGA	84874.57	282199	0.3	0.7649
aisSGA	189110.9	673023	0.28	0.7799
constant	-3.03E+07	30968043	-0.98	0.3320
realgdp	8.865281	2.4732	3.58	0.0008
Collusion	1.71E+20	0	.	.

Minimized Sums of Squared Errors = 65.02

Model 7 Collusion in advertising until 2002q1, and collusion in both price and advertising afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-1.96E+09	6.82E+08	-2.88	0.0059
aisARPU	-5.94E+09	6.82E+08	-8.7	<.0001
dtacSGA	1351394	193683	6.98	<.0001
aisSGA	-1417144	169002	-8.39	<.0001
constant	63236124	15604851	4.05	0.0002
realgdp	-6.08E+00	4.8447	-1.26	0.2152
AIS demand				
dtacARPU	-1.09E+09	6.34E+08	-1.72	0.0923
aisARPU	-6.21E+09	6.57E+08	-9.44	<.0001
dtacSGA	1181841	176772	6.69	<.0001
aisSGA	-1053994	141818	-7.43	<.0001
constant	42034785	13742190	3.06	0.0036
realgdp	-2.14E+00	4.2808	-0.5	0.6194
Collusion	9.04E+29	0	.	.

Minimized Sums of Squared Errors = 86.30

Model 8 Collusion in advertising until 2002q1, and one firm is a leader in price afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-1.03E+09	3.12E+08	-3.30	0.0018
aisARPU	-7.47E+07	4.19E+08	-0.18	0.8591
dtacSGA	45739.36	75317.9	0.61	0.5465
aisSGA	-51170.7	59361.8	-0.86	0.3928
constant	-9617707	3982856	-2.41	0.0195
realgdp	5.32E+00	0.8995	5.92	<.0001
AIS demand				
dtacARPU	6.24E+08	2.79E+08	2.24	0.0299
aisARPU	-1.84E+09	3.56E+08	-5.18	<.0001
dtacSGA	109022.5	42807.4	2.55	0.0141
aisSGA	84081.56	7661.8	10.97	<.0001
constant	-2.10E+07	4393309	-4.78	<.0001
realgdp	7.631557	1.2144	6.28	<.0001
Collusion	-1.33E+18	0	.	.

Minimized Sums of Squared Errors = 93.00

Model 9 Collusion in price and advertising until 2002q1, and Nash competition in price and advertising afterwards

M9 Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-1.54E+09	3.49E+08	-4.41	<.0001
aisARPU	-5.19E+09	8.05E+08	-6.45	<.0001
dtacSGA	1276944	163688	7.8	<.0001
aisSGA	-1272726	182369	-6.98	<.0001
constant	49637919	15100801	3.29	0.0019
realgdp	-4.14605	3.9489	-1.05	0.2990
AIS demand				
dtacARPU	-2.84E+08	3.03E+08	-0.94	0.3522
aisARPU	-5.95E+09	6.77E+08	-8.79	<.0001
dtacSGA	1234086	153975	8.01	<.0001
aisSGA	-974530	158785	-6.14	<.0001
constant	31329290	12692024	2.47	0.0172
realgdp	-1.40866	3.424	-0.41	0.6826
Collusion	1.19E+21	0	.	.

Minimized Sums of Squared Errors = 82.28

Model 10A Collusion in price and advertising until 2002q1, and DTAC is a leader in price and advertising afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	7.33E+09	2.04E+09	3.60	0.0007
aisARPU	-9.43E+09	1.82E+09	-5.19	<.0001
dtacSGA	886136.7	367278	2.41	0.0196
aisSGA	-5.13E+05	1.17E+05	-4.39	<.0001
constant	2.87E+06	1.78E+07	0.16	0.8724
realgdp	9.96E-01	5.44E+00	0.18	0.8554
AIS demand				
dtacARPU	7.32E+09	1.67E+09	4.38	<.0001
aisARPU	-9.44E+09	1.53E+09	-6.15	<.0001
dtacSGA	761877.1	278274	2.74	0.0086
aisSGA	-3.42E+05	47956.4	-7.12	<.0001
constant	-1.03E+07	16010593	-0.64	0.5234
realgdp	4.948574	4.7179	1.05	0.2995
Collusion	3.85E+21	0	.	.

Minimized Sums of Squared Errors = 77.06

Model 11A DTAC is a leader in price and advertising until 2002q1, and Nash in both variables afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-8.90E+08	3.17E+08	-2.8	0.0072
aisARPU	4.58E+08	3.35E+08	1.36	0.1788
dtacSGA	-111801	42755.2	-2.61	0.0118
aisSGA	1.11E+05	3.18E+04	3.49	0.0010
constant	-1.80E+07	2.94E+06	-6.14	<.0001
realgdp	6.81E+00	6.76E-01	10.08	<.0001
AIS demand				
dtacARPU	-2.38E+08	5.39E+08	-0.44	0.6605
aisARPU	-7.54E+08	2.64E+08	-2.85	0.0063
dtacSGA	-41703.2	94371.7	-0.44	0.6605
aisSGA	5.33E+04	11278.9	4.73	<.0001
constant	-2.67E+07	5886347	-4.53	<.0001
realgdp	10.95684	1.1495	9.53	<.0001

Minimized Sums of Squared Errors = 111.86

Model 11B AIS is a leader in price and advertising until 2002q1, and Nash in both variables afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-2.27E+08	8.95E+07	-2.53	0.0145
aisARPU	5.39E+07	4.08E+07	1.32	0.1926
dtacSGA	23425.32	9446	2.48	0.0166
aisSGA	8.65E+04	3.47E+04	2.5	0.0160
constant	-2.11E+07	1.87E+06	-11.26	<.0001
realgdp	6.44E+00	6.17E-01	10.43	<.0001
AIS demand				
dtacARPU	9.97E+09	5.39E+09	1.85	0.0701
aisARPU	-1.18E+10	1.27E+09	-9.32	<.0001
dtacSGA	2334647	623811	3.74	0.0005
aisSGA	-1.31E+06	825785	-1.59	0.1194
constant	1.65E+07	54239773	0.3	0.7620
realgdp	-7.8952	7.1587	-1.1	0.2756

Minimized Sums of Squared Errors = 85.98

Model 12A Nash competition in price and advertising until 2002q1, and DTAC is a leader in both variables afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-1.02E+10	1.04E+09	-9.82	<.0001
aisARPU	1.26E+10	2.96E+09	4.27	<.0001
dtacSGA	-2980629	674578	-4.42	<.0001
aisSGA	1.99E+06	6.52E+05	3.05	0.0037
constant	-7.12E+07	3.61E+07	-1.97	0.0543
realgdp	2.50E+01	7.33E+00	3.41	0.0013
AIS demand				
dtacARPU	-3.47E+07	7.11E+06	-4.88	<.0001
aisARPU	-1.33E+09	2.28E+08	-5.82	<.0001
dtacSGA	341338.1	43662	7.82	<.0001
aisSGA	-6.98E+04	6267.7	-11.14	<.0001
constant	-2.14E+07	3272075	-6.53	<.0001
realgdp	7.31643	0.9577	7.64	<.0001

Minimized Sums of Squared Errors = 113.83

Model 12B Nash competition in price and advertising until 2002q1, and AIS is a leader in both variables afterwards

Parameter	Estimate	Approx Std Err	t Value	Approx Pr > |t|
DTAC demand				
dtacARPU	-1.97E+08	1.30E+08	-1.52	0.1357
aisARPU	-3.35E+08	2.69E+08	-1.24	0.2197
dtacSGA	2.70E+04	8.69E+03	3.10	0.0031
aisSGA	-8.33E+03	6.71E+03	-1.24	0.2201
constant	-1.56E+07	3.53E+06	-4.40	<.0001
realgdp	6.296007	0.7895	7.97	<.0001
AIS demand				
dtacARPU	-1.09E+09	7.97E+08	-1.37	0.1763
aisARPU	-9.86E+08	4.58E+08	-2.15	0.0362
dtacSGA	1.54E+05	9.94E+04	1.55	0.1278
aisSGA	-5.50E+04	1.63E+04	-3.37	0.0015
constant	-1.33E+07	4783407	-2.78	0.0078
realgdp	7.193262	1.0306	6.98	<.0001

Minimized Sums of Squared Errors = 94.82

BIBLIOGRAPHY

Beatty, A. L. (2007). How Does Changing Measurement Change Management Behavior? A Review of the Evidence, SSRN.

Bresnahan, T. F. (1987). "Competition and Collusion in the American Automobile Industry: The 1955 Price War." The Journal of Industrial Economics **35**(4): 457-482.

Chen, J. Q. and S. M. Lee (2003). "An Exploratory Cognitive DSS for Strategic Decision Making." Decision Support Systems **36**(2): 147-160.

Clarke, D. G. (1976). "Econometric Measurement of the Duration of Advertising Effect on Sales." Journal of Marketing Research **13**(4): 345-357.

Fabra, N. and J. Toro (2005). "Price Wars and Collusion in the Spanish Electricity Market." International Journal of Industrial Organization **23**(3-4): 155-181.

Feuerstein, S. (2005). "Collusion in Industrial Economics—A Survey" Journal of Industry, Competition and Trade 5:3/4, 163–198, 2005

Gasmi, F., Vuong, Q. (1991). "An Economic Analysis of Some Duopolistic Games" Advances in Econometrics: a Research Annual : Econometric Methods and Models for Industrial Organizations Greenwich: JAI Press, 1991.

Gasmi, F., Laffont, J.J., Vuong, Q. (1992). "Econometric Analysis of Collusive Behavior in a Soft Drink Market." Journal of Economics and Management Strategy 1 Ž2., 277–311.

Golan, A., L. S. Karp, et al. (2000). "Estimating Coke's and Pepsi's Price and Advertising Strategies." Journal of Business & Economic Statistics **18**(4): 398-409.

Hall, S. G. (1987). "A Forward Looking Model of the Exchange Rate." Journal of Applied Econometrics **2**(1): 47-60.

Harwood, J.H., Lake, W.T., Sohn, D.M. (1997). "Competition in International Telecommunications Services." Columbia Law Review **97**(4). (May, 1997), 874-904.

Hay, G.A., Kelly, D. (1974). "An Empirical Survey of Price Fixing Conspiracies" Journal of Law and Economics **17**(1). (Apr., 1974), 13-38.

Hossain, L., (2001). National Strategic Planning and Practice: the Case of Thailand’s Telecommunications Industry. Ashgate Publishing,UK.

Intriligator, M. D., Bodkin, R. G., & Hsiao, C. (1996). Econometric Models, Techniques, and Applications New Jersey: Prentice-Hall.

Kadiyali, V. (1996). "Entry, Its Deterrence, and Its Accommodation: A Study of the U. S. Photographic Film Industry." The RAND Journal of Economics **27**(3): 452-478.

Kadiyali, V., Sudhir, K., Rao, V.R. (2001). "Structural Analysis of Competitive Behavior: New Empirical Industrial Organization Methods in Marketing." International Journal of Research in Marketing **18**(1-2): 161-186.

Kennedy, P. (2003). A Guide to Econometrics, 5th edition, MIT Press, Cambridge, MA.

Klemperer, P. (1995). "Competition when Consumers have Switching Costs: An Overview with Applications to Industrial Organization, Macroeconomics, and International Trade." The Review of Economic Studies **62**(4): 515-539.

Lee, H.-Y. and S.-L. Chen (2006). "Why use Markov-switching models in exchange rate prediction?" Economic Modelling **23**(4): 662-668.

McCloughan, P. and S. Lyons (2006). "Accounting for ARPU: New evidence from international panel data." Telecommunications Policy **30**(10-11): 521-532.

Miravete, E. J., Roller, L.H. (2004). "Competitive Nonlinear Pricing in Duopoly Equilibrium: The Early US Cellular Telephone Industry," April 2004. mimeo.

Nikomborirak, D. (2005). "Transport Liberalization and Competition Concerns In ASEAN." TDRI Quarterly Review. December 2005.

Parker, P. M. and L.-H. Roller (1997). "Collusive Conduct in Duopolies: Multimarket Contact and Cross-Ownership in the Mobile Telephone Industry." The RAND Journal of Economics **28**(2): 304-322.

Pazo, M., a. z, et al. (1999). "An empirical oligopoly model of a regulated market." International Journal of Industrial Organization **17**(1): 25-57.

Roberts, M. J. and L. Samuelson (1988). "An Empirical Analysis of Dynamic, Nonprice Competition in an Oligopolistic Industry." The RAND Journal of Economics **19**(2): 200-220.

Simon, H. and K.-H. Sebastian (1987). "Diffusion and Advertising: The German Telephone Campaign." Management Science **33**(4): 451-466.

Slade, M.E. (1990). "Strategic Pricing Models and Interpretation of Price-War Data." European Economic Review **34**: 524-537.

Tangkitvanich S., Ratananarumitsorn, T. (2002). "Competition and Regulatory Reform in the Thai Telecommunication Markets" TDRI Report: Contract No. RDG4510001

Valletti, T. (2003). "Obligations that can be imposed on operators with significant market power under the new regulatory framework for electronic communications: Access services to public mobile networks." Prepared for DG InfoSoc.

Whitaker, R.M., Raisanen, L., Hurley, S. (2005). "The Marginal cost of Service Provision in Cellular Networks" *hicss*, p. 304b, Proceedings of the 38th Annual Hawaii International Conference on System Sciences (HICSS'05) - Track 9, 2005

Zimmerman, J (2002). "Business ethics and organizational architecture." Journal of Banking and Finance **26**(9): 1821-1835.