How to Alleviate the Electricity Scarcity in Guangxi

An analysis of electricity pricing

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Preface

Two years ago, I came to University of Oslo from Guangxi, China, and became a student studying for my master degree in Environmental and Developmental Economics. During these two years I learned much more advanced economic theory and I also benefited from the lectures and the literatures.

Guangxi, my hometown, located in the south of China, is a province with abundant hydropower resources. However, in recent years Guangxi has faced the problem of electricity scarcity, which made a huge impact on people's lives and Guangxi's economic development.

This awkward predicament raised my basic motivation for the thesis, which is to analyze Guangxi's electricity scarcity by my study of hydropower economics. My intention is not to judge the current electricity pricing policy, although it is one of factors causing the electricity scarcity. My main aim is to use the way of electricity pricing to alleviate or diminish the problem of electricity scarcity and I really hope that my thesis can provide the social planners in Guangxi a new vision to deal with the problem of electricity scarcity.

I appreciate that Dr. Zhang Tao, my supervisor for the thesis, gave me a lot suggestions and directions about how to finish the paper.

Xie Siping

11.2006

Summary

With the rapid economic growth and the increase of the population, Guangxi, a province with abundant hydropower resource, is facing a severe electricity shortage problem. This situation forces Guangxi's decision makers, the local government, to seek methods to alleviate the problem of electricity scarcity, and among the measures the way of re-pricing electricity seems a proper one.

Currently, in Guangxi, the prices of electricity are still set by the government, when the price regulators are setting the prices of electricity they do not fully think about the importance of the market, which results that the prices of electricity hold fixed for a long time and cannot fluctuate with the change of the demand and supply in the market. Moreover the current prices cannot reflect the true value of the electricity. These two factors are the main reasons for electricity scarcity from my point of view. Thus it is necessary to re-set prices of electricity in Guangxi.

To analyze how to set prices of electricity in Guangxi, I first adopt a hydropower economic model by Førsund (2005) to show how the prices should be according to the fact that the hydropower production is mixed with the thermal power. The results are the prices of electricity vary with the change of the water value and the operating cost of the thermal power plants.

Based on the result by the modeling analyses I will extend the analyses by adding some factors that influence the water value and the operating cost of the thermal power plants. In Guangxi it is regulated that the hydropower stations have to pay a proper amount of executive charge fees for the water use, which are charged by the water sector in local government and can be considered as the operating cost of the water sector, thus, I introduce this charge into my electricity pricing system. As for the operating cost of the thermal power plants, it is mainly focus on the environmental concerns, since it is well

known that thermal power plants generate electricity by burning coals, oils, etc., they inevitably emit pollutions. The thermal power plants should be charged a certain amount of tax for their emissions. If the price regulators take the environmental concerns into consideration then the cost of the thermal power plants will be higher, and consequently the prices of electricity will be higher as well. In addition I also introduce the optimal tax level-Pigovian tax. If both factors can be taken into account by the price regulators, the prices of electricity will be more accurate.

Since the main idea of this thesis is focus on the analysis of electricity pricing, besides the discussions of the electricity price system, some other topics related to the price setting, including natural monopoly, price structure, forecasting demand, are given by brief indications.

After the modeling analyses combined with some facts in Guangxi, it is clear that to alleviate the problem of electricity scarcity the current fixed prices of electricity are no more reliable. The prices should be flexible and more factors need to be considered.

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Section 1 Introduction

Since 2002 China has faced a severe electricity shortage problem. As a province with abundant hydropower resource, Guangxi has been immersed in this awkward predicament. The electricity scarcity inevitably makes huge impact on Guangxi's economic development, since the electricity is a sensitive product, which influences the stability of the society and the investment environment as well. As far as an increasing economy is concerned, how to avoid and solve the problem of electricity scarcity has become an important issue in China, both academically and politically.

The reason why Guangxi is short of electricity is mainly that demand exceeds supply. For the hydropower, the bad weather conditions force the stations to generate less, and the thermal power plants are lack of coals for productions. Moreover, rapid economic growth needs more electricity as a support. To reduce the electricity scarcity, the Guangxi's government has taken some measures, such as canceling the discount for main customers, power cutting in certain time or area, limiting the use of air conditioning and heating systems, asking for help from other provinces, etc. These measures are short-run remedies that maybe could lighten the scarcity in a short time span. They cannot be considered as long run reliable policies. Investment in new electricity power plants is of course the long run solution. But it will take at least five years to build an electricity power plant. Therefore investing on electricity capacities cannot weaken or deal with the problem of electricity scarcity in a rather short time. Even though the current investments on power plants would produce solutions in the future, could they make sure that there would be no electricity scarcity in the future? Thus it is necessary to seek a stable method to alleviate the problem.

Facing the problem of electricity scarcity, many claims to the solution are to increase the scale of supply, such as investments in new electricity plants. Fewer realize that the current prices of electricity are too rigid. In fact, the price of electricity in Guangxi is the primary issue in my view. In the science of economics, when there is perfect competition in the market, scarcity usually attributes to a low price, which means that price cannot reflect the true value of the goods such that the supply of goods does not cope with the demand that is characterized by consumers' willingness to pay. Price should fluctuate with the change of the demand and supply in the market. However, in Guangxi, prices of electricity are traditionally fixed by the government for a long time due to the planned economy in the past. The price setting in this sense does not take full consideration of the market demand and supply. Traditionally the electricity power plants were owned by government. And the prices of electricity were set much lower than the market price, should there be a perfect competition market. In the current rapid growth period, the demand and supply increase drastically. The traditional way of price setting by the government is no longer suitable for the electricity market.

It is impossible for the government to give up the right of price setting and let the price fluctuate freely in the market. But it is better that the government takes more market factors into consideration while setting the prices. To reflect the true value of the electricity, more factors about the production cost need to be considered, such as the charges on water use and the environmental concerns. To reflect the relationship between the market demand and supply, the prices of electricity in Guangxi should be flexible under the government's control. If the government can do both well, the problem of electricity scarcity will be alleviated, even solved, by the market.

Therefore, the main idea of this article is to analyze how Guangxi's prices of electricity should be, instead of the fixed prices, and derive a new electricity pricing system for Guangxi in for the case of electricity scarcity. The rest of the paper is organized as follows. Section 2 gives a background of Guangxi province including a short introduction of Guangxi, Guangxi's electricity industry, the phenomenon of electricity scarcity, reasons and some current measures. In section 3, I will attempt to use a hydropower model to show the prices of electricity should be flexible in Guangxi's case, where the hydropower is mixed with thermal power plants. Firstly, I will draw heavily on the paper by Førsund (2005) to develop a basic model for Guangxi's electricity market. Secondly, based on the results of the first part I will make some extensions to further discuss the Guangxi's cases. By adding an executive charge rate and a tax levied on the emissions into the electricity pricing system, the price settings are more accurate than before. In section 4 some other issues concerning the electricity pricing will be discussed. In section 5 concluding remarks will be given.

Section 2 Background

2.1 Introduction of Guangxi

Guangxi, a southern province of China, one of the five ethnic minorities' autonomous regions in China, has a population of around 48 millions. Geographically Guangxi is bordered by Yunnan to the west, Guizhou to the north, Hunan to the northeast, and Guangdong to the east. To the southwest Guangxi is bounded by Vietnam and to the southeast,with a 1,595 kilometers beach, it is Beibu Bay (Gulf of Tonkin). Since Guangxi is the only western province that has a coastline, Guangxi is playing an important role in Western Region Development Program. In May of 1992, Chinese government decided to make Guangxi as a gate for southwestern religions.

In recent years Guangxi's economy has developed at a higher rate than the whole China. In 2003 the increase of GDP was 11.39% and in 2004 the number went up to 21.39%. Since 2004, CAEXPO (China-Asean Expo) is held in Nanning, the capital of Guangxi province every year.

2.2 Electricity industry in Guangxi

At the end of 2002 Chinese government made a reform in electricity industry. The goal was to break traditional province-based electricity monopolies. Previously in Guangxi the provincial power corporation controlled both electricity production and the selling. After the reform the provincial power corporation was split by two sectors: One is the supply sector. This sector consists of hydropower and thermal power. The other one is the retail sector. There is only one retail-company in Guangxi, Guangxi Power Grid Corporation (GPGC), whose predecessor was the provincial power corporation. GPGC is in charge of buying electricity from suppliers and selling to consumers. In addition, GPGC has the responsibility for making trade between provinces. Nowadays it functions as an electricity distribution and trade center creating a competitive platform for electricity producers.

Although it has been three years since the reform took off, the effects of this ambitious reform are not significant for some reasons. The relationship between GPGC and suppliers are complicated. GPGC still has more power to influence the supply sector. Thus in reality Guangxi’s electricity industry is still monopolistic.

2.2.1 Hydropower

As Guangxi is located in mountain religion, many rivers are passing through the mountains. Besides Guangxi has a subtropical climate and a plenty of precipitation whose average annual level is 1250-1750 mm. These two conditions bring Guangxi a large amount of water resources. In theory the total volume of water resources is 17.52 million kw, and is ranking the fifth place in China. The exploitable amount of water resources is 14.18 million kw, ranking the sixth in China.

The HongShui River, which is known as the "rich ore" of water resources in China, has an average annual flow 2.8 times greater than that of the Yellow River and most of biggest hydropower stations were built along this river, such as Longtan, Qiaogong, Dahua, Yantan, Datengxia, etc. Among these, the third biggest hydropower station in China, Longtan hydroelectric power station is built on this river.

In Guangxi hydropower plays a very important role in providing electricity and the Guangxi's government has conducted a series of policies with the principle of keeping hydropower at a dominant place in electricity production. At the end of 2005 the total installed capacity of electricity is 10.94 million kw and there are around main 16 hydroelectric power stations with installed capacity of around 6.04 million kw, 55.2% of total installed capacity.

2.2.2 Thermal power

In Guangxi thermal power plants are built as replenishment for hydropower, meaning that when hydropower cannot supply enough electricity to meet the demand the thermal power plants have to produce in order to alleviate the gap between consumption and generation. There are 17 thermal power plants in Guangxi and their total installed capacity of thermal part is 4.9 million kw, 44.8% of total installed capacity.

Compared with the national situation, which is thermal power dominating one, Guangxi has its advantage in hydropower part.

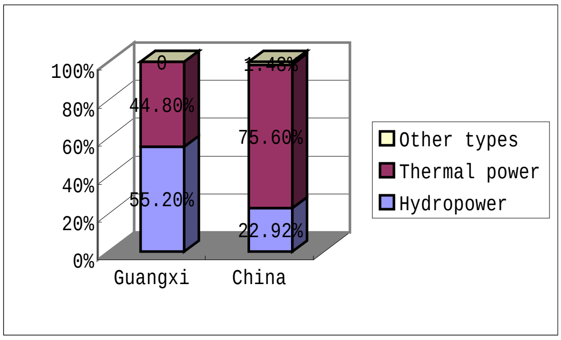

Figure 1 The structure of installed electricity capacity in China and Guangxi at the end of 2005

Source: Lin (2006), Hydropower electricity industry report in China (2005) and Thermal power electricity industry report in China (2005)

The figure indicates that thermal power is still main source of electricity supply in China, making up 75.6% of total installed capacity. The other types of electricity are mainly nuclear power and import.

2.3 Scarcity of electricity

2.3.1 Phenomenon

Although Guangxi is rich in hydropower and has a rather good ability to produce electricity from thermal power plants, since 2003 Guangxi has been facing a serious problem of electricity scarcity. Scarcity means that demand exceeds supply. The production cannot meet the consumption. For example, in March 2004, the total electricity available was 2.5 million kwh. If there were open consumptions, the load would go up to 4.5 million kwh that was much more than the supply. This kind of situation has continued for a long time.

Table 1 Production and Consumption of electricity in recent years in Guangxi

unit: 100 million kwh

Year	Production	Consumption	The gap between consumption and production
2003	362.91	414.93	52.02
2004	373.32	456.86	83.54
2005	445.47	509.58	64.11

Sources: Guangxi Statistical Yearbook 2004, 2005 and Lin (2006)

2.3.2 Reasons

The factors that cause scarcity of electricity in Guangxi are similar to that in other provinces in China and can be thought of both internal and external. The external factors can be increase of demand, relatively slower increase of supply, and bad weather conditions. In addition, rapid economic growth of Guangxi province makes electricity scarcity more severe. The internal factors might be some factors existing in electricity industry itself. In this context the internal factors could be managements inefficiency, unavoidable and unpredictable equipment breakdown, lose in net-transmitting, etc. These factors will not be discussed in detail here. Below I will discuss some main factors that cause scarcity of electricity in Guangxi.

Factor 1 Production side

The main source of scarcity is that the supply cannot catch up with the increase of consumption. Although both production and consumption are increasing the consumption is always greater than the production in recently years. This situation is shown in table 2. The lower supplies can be attributed to some factors.

Firstly, as indicated before the hydropower dominates in Guangxi's total installed capacity of electricity. It is well known that climate conditions play an important role in generating electricity, and hydropower depends heavily on water resources. Guangxi's hydropower relies on precipitation in summer and autumn, thus is easily affected by the seasons and the weather. Since 2003 Guangxi has been facing a droughty and hot climate. The less raining the less water stored in reservoirs, and the less electricity will be produced. The table below shows the water resources situation in Guangxi in recent years.

Table 2 Guangxi water resources situation

Year	Precipitation		Storage in main reservoirs (100 million m^3)
	Annul average (mm)	Compared with aggregate average level (%)	
1997	1854.2	19.5	107.8
1998	1673	8	91.5
1999	1604.2	4.4	94.43
2000	1350.8	-11.9	86.86
2001	1826	18.7	105.16
2002	1859	19.7	114.59
2003	1346	-12.4	90.43
2004	1366.9	-11.1	82.99
2005	1454.2	-5.4	89.26

Source: Water resources report 1997-2005

Note: The aggregate average level is calculated from 1956 to the latest year, for example, in 2005 the aggregate average level is the average from 1956 to 2005.

In addition the hydropower is distributed unevenly across seasons. Normally for the share of total amount of water, it accounts for 72% from April to August, during time from September to December it accounts for 21% and from January to March the share is only 7%. This causes a huge hydropower production difference between the period of water abundance and water scarcity.

In Guangxi hydropower is much more dependent on HongShui River. There is a chain effect on Guangxi's hydropower production since most of biggest hydropower plants are built on HongShui River. From the upper stream of HongShui River to the downstream district there are hydroplants Longtan, Yantan, Dahua, etc (see figure 2). These hydropower plants have the most installed capability in Guangxi. If Longtan plant is lack of water for producing then Yantan and Dahua will face the same problem.

Figure 2 Main hydropower plants on Hongshui River

Source: www.gxnews.com.cn

On the top of the figure Guangxi's location is shown and the thick line in the middle is Hongshui river.

Secondly, the thermal power in Guangxi is designed to replenish the supply of electricity during the period of water shortage. However in recent years less and less water has been used in generating electricity. The thermal power plants have been forced to supply more to cover the gap between production and consumption. It inevitably causes overloads of the thermal plants for a certain period of time. The more machines are used, the easier they break down and need maintenances.

Furthermore, the thermal plants rely on coals that are mostly come from Guizhou province. But in recent years Guizhou province has reduced its quota of exporting coals and raised the coal price, which results in a shortage of coals, hence increases the operating cost for the electricity production in Guangxi. After that Guangxi started to buy coals that were more expensive from other provinces. It also raises the cost of the thermal plants and directly reduces the production. In addition the coals from outside of Guangxi are transported by railway which are controlled by the railway department and the two main carrying coals railway routes Qiangui line and Nankun line are always on their peak load. It is hard to carry the coals when the thermal plants need them urgently. Moreover the coal price has been increasing and some plants cannot afford the higher price due to the high cost.

Thirdly, another issue on supply side is about the power net system of Guangxi. In China the grid in Guangxi is a part of China Southern Power Grid (CSPG) managing the electricity supply for five provinces: Guangdong, Guangxi, Yunnan, Guizhou and Hunan. For instance, when Guangdong is lack of electricity CSPG would consider whether and where to adjust some extra electricity that are not needed at the moment in other provinces to Guangdong. But these five provinces are facing the same problem: electricity scarcity. Because in these five provinces their electricity supplies depend not only on hydropower but also on other types of electricity, and all of them have been lack of water and fuels. The adjusting ability of CSPG on electricity use is lower and lower due to the scarcity in all provinces.

Factor 2 Consumption side

Economic growth is considered to be the most important determinant for electricity consumption. Economic growth and its impact on people's living standards are the main forces of the electricity consumption growth. Some empirical studies have shown that there should be a significantly positive correlation between GDP and electricity consumption. In recent years Guangxi's GDP has been increasing at a high speed. In 2003 GDP increased 11.39%, in 2004 it increased 21.39% and in 2005 the increase is surprisingly 22.38%.

With the rapid development of economy people's living standard has increased greatly. The per capita GDP increases from 4319yuan in 2000 to 7196yuan in 2004. (Yuan, RMB is Chinese currency, 1＄≈7.8RMB) Residents purchase more electronic and electrical appliances. In addition the continuously increasing of temperature and droughty weather seem to result that more air conditionings are used. This will call for a more usage of electricity. The following figure has shown that there is an increasing trend of household electricity consumption in Guangxi.

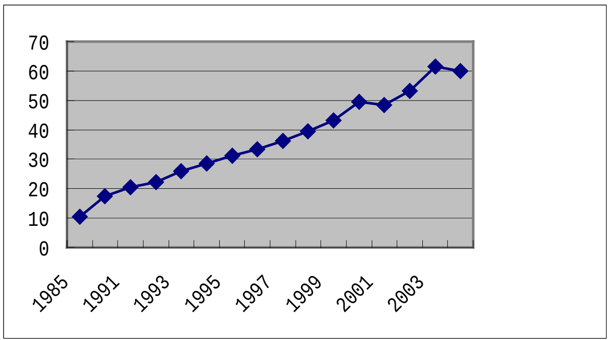

Figure 3 Household electricity consumption in Guangxi unit: 100 million kwh

Source: Guangxi Statistical Yearbook 2005

Factor 3 Prices

Beside the reasons from production and consumption parts, the most important one is the fixed prices of electricity. The fact that prices are fixed by government and cannot reflect the true value of the electricity and the status of the market is the basic reasons for electricity scarcity. In section 3 this factor will be discussed in more detail.

2.3.3 Measures to cope with scarcity

To deal with the electricity scarcity there are two general methods. One is supply enhancement and the other one is demand management. The former one increases the production scale and might call for use of new types of production methods, such as wind power. The latter one involves how to distribute the current supplies. Of course, jointly undertaking both methods is normally better. Some examples of each measure are listed below:

Table 3 Measures for scarcity of electricity

Supply enhancement	Demand management
1.Build more new power plants	1.Way of pricing
2.Infrastructure maintenance	2.Limit the electricity use
3.Enlarge the reservoirs or build up the dams	3.More precisely forecast demand
4.Make net-transmitting more effective	4.Educations about conservation
5.Develop new types of electricity	
6.Import	

Facing the scarcity problem, the Guangxi's government and the GPGC have taken some measures recently, such as increase the investments in electricity program, intensify the maintenances of power plants and net-transmitting, seek the probabilities of new sources of electricity, import electricity from some of adjacent provinces during their off-peak periods, etc.

However all the efforts above cannot solve the problem in a short period of time. Increasing the investment in infrastructure is to focus on the future, since it will take at least 5-7 years to complete a thermal power plant or a hydro one. On the other hand, more investments made in electricity industry would also create a potential problem of overproduction. As for import, if other provinces are facing scarcity at the same time it is not a feasible alternative.

For a short-term solution, as well as for a long term, demand management is much more important. At the beginning Guangxi's the government has taken some measures, such as canceling the discount of main customers, power cutting in certain time or area, limiting the use of air conditioners and heating systems, etc. They are all of ad hoc characteristics and cannot be government policies. For given supplies efficient management of the demand is more important, which raises the use of economic methods for electricity planning. Markets and prices are coherent concepts. Price should reflect the equilibrium of demand and supply in the market. If the electricity demand has exceeded supply for a longer period the electricity price must be adjusted to reflect the true value of electricity by the market. In Guangxi, although the decision makers have started to introduce market mechanisms into the electricity sector, the price is still set by the governing authorities not the market. As for the way of dealing with electricity scarcity by prices of electricity, fewer actions have been taken.

Section 3 Electricity pricing models for Guangxi

Among the methods discussed in section 2, price undoubtedly is important. From the economic theory point of view, price should reflect the equilibrium/disequilibrium of the market, and price mechanism can allocate the demand and supply such that the market moves from disequilibrium to equilibrium. However, in China price of electricity is fixed by government and they could not be changed immediately following the change of market yet. The invisible hand could not function well in this case.

Apparently scarcity means demand exceeds supply. To go deep into it, electricity scarcity also implies the social utilities by consuming electricity are not maximized. Førsund (2005) has studied this problem and pointed out that in a market of electricity when production of electricity is by hydropower mixed with thermal power or wind power, the prices of electricity should not be stable all the time. He also develops a hydropower model to study the price variations. In this section I will adopt Førsund's model to show how the prices of electricity should be set in Guangxi in order to alleviate the problem of electricity scarcity.

Before the analyses it is important to give a brief overview of the pricing system for electricity in Guangxi.

3.1 Brief introduction of the electricity price system in Guangxi

As a province of China, Guangxi's electricity pricing policies have to follow the Chinese governments'. Before 1979 during the highly central planned economy period, government set all the prices of goods and labors including electricity. If government did not change the prices they would hold fixed for a long time. At that time productions were determined by executive orders and consumption were limited by quota. There was no market for electricity. Electricity was merely treated as one kind of products allocated by government rather than a commodity.

Meanwhile hydropower was very rare at the whole country basis and most of electricity was generated from thermal plants. The government set price by mainly taking prices of coals and fuels into account and neglecting other factors in producing. Normally the price was too low to cover the cost of producing.

Since 1979 China started to reform its economy system by converting highly central planned style into market economy. The goal is to make price and market work. Government interferes in economy less and less and plays a role in administrative regulation only if necessary. Under these conditions in 1985 government conducted a series of policies to reform pricing system in electricity industry. Most of these policies were aimed to make profit to electricity industry and gained many positive effects. These reforms, to some extend, weakened the power of government to intervene the procedure of setting electricity price and took market power into considerations; especially at the end of 2002 the Chinese government broke its traditional electricity monopolies into six regional competitive markets. The electricity industry changes from a deficit industry into the most lucrative one in China.

In Guangxi the local government set up its own electricity price within the province. One of the unique properties of Guangxi's electricity price setting is to charge different prices during periods of water abundance (from May to October) and during periods of water shortage (from January to April and November, December) respectively. This policy is aimed to lighten the burden of electricity usage in water shortage period, but the effect are not manifested because the time period is relatively long and in the certain period the prices are the same all the time until the government set new prices. Anyway, although the current policy, time of seasonal tariffs, is somehow mechanical and cannot solve the problem of electricity scarcity efficiently, Guangxi's government has made a significantly important effort to seek methods to alleviate the gap between consumptions and productions by setting different prices to consumers. In the following parts I will utilize a highly stylized model to illustrate the time tariff policy.

3.2 Economic model for Guanxi's electricity pricing analyses

As talked before, intuitively using price as a lever to help weaken the scarcity problem seems effective in theory. I will set up a price-setting model for Guangxi mainly based on the model structure by Førsund (2005). A brief introduction of the model elements is shown in a table below.

Table 4 Introductions of hydropower economic model

Goal	To maximize social utilitiy by consuming electricity
Way	1. Dynamic analyses over discrete time periods by using non-linear programming 2. Bathtub illustrations
Results	Changes in water allocations and prices of electricity over time
Assumptions	1. Given the generating capacities 2. Hydropower plant opeartes without variable cost 3. No discount

In this part I will first introduce a basic model under the condition that hydropower is mixed with thermal plants, and make the analyses for the monopoly case which is a typical situation in Guangxi. Since the model is dynamic one, a time pattern is used, which means that a time subscript t will be added on the variables in the model. This time period t may be years, seasons, months, weeks even days and hours as well. As for a dynamic modeling analysis, a two-period case in multi-period is applied to explain it. After the introductions of the model, I will extend the model by continuing to discuss other factors affecting the prices of electricity. The main object is to develop a price-setting model for electricity and analyze implications under different circumstances.

3.2.1 Social optimum choice

Guangxi's electricity sector can be thought of that electricity is generated both by hydropower and by thermal power plants. The social planner, say Guangxi's provincial government, faces a social utility function $U_t\left(e_t\right)$ evaluated by how much electricity e_t is consumed in period t. This utility function is a standard concave function

$$U_t{}'\left(e_t\right) \geq 0, U_t{}''\left(e_t\right) \leq 0$$

and it has another property

$$U_t{}'\left(e_t\right) = p_t(e_t)$$

meaning that $\int_0^{e_t} p_t(z)dz = U_t\left(e_t\right)$.

Here $p_t(e_t)$, the electricity price and inverse demand function, is equal to the marginal utility and is interpreted as marginal willingness to pay as well.

The electricity consumed in Guangxi comes from hydro and thermal plants. For the hydropower stations, how much electricity is generated depends on how much water is in the reservoirs. The water in the reservoirs can be used, i.e. in irrigations, and for household usage, etc. The main use of the water is for hydropower generation. Here I assume that total water in the reservoir is used only for generating electricity. When the water r_t is released and runs into dams the turbines will transfer it into electricity e_t^H. There is a production specific coefficient *a* which measures the efficiency of the turbines. It may vary with the constructions and utilizations of the reservoirs. Their relationships can be given by a simple equation:

$$e_t^H \leq \frac{1}{a} r_t .$$

It is reasonably to assume that in period t the water in the reservoir is equal to the rest water of last period plus the inflows minus the released water. The inflows of water, in Guangxi, are mainly from the precipitation during May to October and most of inflows are stored in the reservoirs. Whether to release water is the management decision by the reservoir holders. We still assume that there is no lost of inflow and evaporations. Thus filling reservoir and releasing water in the reservoir are in a dynamic process. It can be expressed by:

$$R_t \leq R_{t-1} + w_t - r_t , t = 1,...,T . \quad (1)$$

here

R_t -- The total water remaining in Guangxi's reservoirs at the end of period t,

R_{t-1} -- The total water remaining at the end of the previous period t-1,

w_t -- The inflow water from rain during period t.

Assume all the water can be converted into energy units divided by production coefficient, the equation (1) changes into:

$$R_t \le R_{t-1} + w_t - e_t^H, t = 1, \ldots, T \ . \tag{2}$$

Furthermore there is an upper limit $\bar{R}$ for the reservoirs measuring the total water that can be stored. During each period the water in the reservoirs cannot be over $\bar{R}$ meaning that:

$$R_t \le \bar{R} \ . \tag{3}$$

Equations (1) and (2) are the water constraint for hydropower plants and show that the total water that can be used in hydro electricity generation.

For the thermal plants, there exist a variable cost $c(e_t^{Th})$ in generating electricity e_t^{Th}. For Guangxi's thermal power plants this variable cost includes tax, salary for labor, charges of fuels, transportation fees of fuels, costs of technology development, charges of installing de-sulfur equipments, etc. The cost function $c(e_t^{Th})$ is an aggregate function from whole 17 thermal power plants in Guangxi and has the standard properties of a convex function:

$$c'(e_t^{Th}) \ge 0 \quad , \quad c'(e_t^{Th}) > 0 \, .$$

The productivity has an upper limit $\bar{e}_t^{Th}$ in each period, which is ideally 4.9 million kw (total installed capacity in Guangxi). The reason why the upper limit is a dated one is that in each single period this upper can change due to the status of the machines in thermal power plants, as I have mentioned in **2.3.2**, not all of the generating units can operate at the same time. In Guangxi every thermal plant has a plan of unit maintenances.

Thus, to alleviate the problem of electricity scarcity, the optimum problem for Guangxi's social planners is to maximize the social utilities by consuming given amount of electricity, which is consumer surplus plus producer surplus, and given by:

$$
\begin{aligned}
& Max\sum_{t=1}^{T}[\int_{z=0}^{x_t} p_t(z)dz - c(e_t^{Th})] \\
& s.t. \\
& x_t = e_t^H + e_t^{Th} \\
& R_t \le R_{t-1} + w_t - e_t^H \\
& R_t \le \overline{R} \\
& e_t^{Th} \le \overline{e}_t^{Th} \\
& t = 1,...,T
\end{aligned}
\tag{4}
$$

where x_t is defined as total electricity produced by hydropower and thermal stations.

This optimization problem is a non-linear programming problem and we find the solutions by using the Kuhn-Tucker conditions. (Sydsæter, Strøm and Berck (1999)). Solving the maximization problem by Lagrangian method yields:

$$
\begin{aligned}
& L = \sum_{t=1}^{T}\left[\int_{z=0}^{x_t} p_t(z)dz - c(e_t^{Th})\right] \\
& -\sum_{t=1}^{T}\lambda_t(R_t - R_{t-1} - w_t + e_t^H) \\
& -\sum_{t=1}^{T}\gamma_t(R_t - \overline{R}) \\
& -\sum_{t=1}^{T}\theta_t(e_t^{Th} - \overline{e}_t^{Th})
\end{aligned}
\tag{5}
$$

and the necessary first order conditions for t=1,…,T are

$$
\begin{aligned}
& p_t(x_t) - \lambda_t \le 0 \perp e_t^H \ge 0 \\
& p_t(x_t) - c'(e_t^{Th}) - \theta_t \le 0 \perp e_t^{Th} \ge 0 \\
& -\lambda_t + \lambda_{t+1} - \gamma_t \le 0 \perp R_t \ge 0 \\
& \lambda_t \ge 0\left(= 0\, for, R_t < R_{t-1} + w_t - e_t^H\right) \\
& \gamma_t \ge 0(= 0\, for, R_t < \overline{R}) \\
& \theta_t \ge 0\left(= 0\, for, e_t^{Th} < \overline{e}_t^{Th}\right)
\end{aligned}
\tag{6}
$$

Before analyzing the solutions we need to make some further assumptions regarding the real situations in Guangxi. The first one is that both hydro and thermal plants produce electricity, which means $e_t^H > 0$ and $e_t^{Th} > 0$, even if the marginal cost of thermal power plants is greater than water value $c'(0) > \lambda$. The second one is that there is always some water in the reservoirs due to some environmental regulations, ($R_t > 0$), unless the weather is arid enough to make reservoirs dry. Given these two assumptions we can have

$$\begin{aligned} & p_t(x_t) - \lambda_t = 0 \\ & p_t(x_t) - c'(e_t^{Th}) - \theta_t = 0 \\ & -\lambda_t + \lambda_{t+1} - \gamma_t = 0 \end{aligned} \tag{7}$$

At the social optimum level the market electricity price is equal to water value during period t and equal to the marginal cost of thermal power plants plus the shadow price on thermal capacity constraint.

So far the reservoir capacity $R_t \le \overline{R}$ and the thermal capacity $e_t^{Th} \le \overline{e}_t^{Th}$ have not been discussed yet. In reality, according the water situation, Guangxi's government has separated the whole year into two periods that are periods of neither overflow nor scarcity and threat of overflow. Combined with the model I will make some discussions regarding with the basic model for the separated periods.

Case 1 Neither overflow nor scarcity

This here refers to that the water in reservoir has not reached its upper limit and less water can be used in generating electricity than normal. In Guangxi this situation is supposed to happen from November to next April. With the assumptions made before there is always some water in the reservoirs during period t we have

$$0 < R_t < \overline{R} \Rightarrow \gamma_t = 0 \Rightarrow \lambda_t = \lambda_{t+1} \tag{8}$$

This means in case of neither overflow nor scarcity, the water value is equal for all periods and from (7) it also implies the optimum market prices of electricity are constant for all time.

$$p_t(x_t) = \lambda_t = \lambda_{t+1} = p_{t+1}(x_{t+1}) \tag{9}$$

If the thermal power does not reach its capacity during certain period t the shadow price on thermal power capacity θ_t is equal to zero.

$$e_t^{Th} < \bar{e}_t^{Th} \Rightarrow \theta_t = 0 \Rightarrow p_t(x_t) = c'(e_t^{Th}) \qquad (10)$$

The social optimum market price of electricity is equal to marginal cost of thermal power plants.

If the thermal power capacity has been reach during period t, $e_t^{Th} = \bar{e}_t^{Th}$, the shadow price on thermal power constraint will have a positive value $\theta_t > 0$, from (7) we have

$$p_t(x_t) = \lambda_t = c'(e_t^{Th}) + \theta_t \qquad (11)$$

Now the effect of thermal power capacity enters the equation. The optimum market price of electricity is then equal to marginal cost of thermal power plants plus the shadow price on thermal power constraint but it is still equal to water value. The difference is that when thermal power is on full capacity, the marginal cost of thermal power is higher, the social optimum price and water value are higher accordingly.

Case 2 Threat of overflow

This situation means the water in the reservoir has reached its upper limit and sometimes there is a water spillage. It occurs during the time from May to October in Guangxi. In this case

$$R_t = \bar{R} > 0 \Rightarrow \gamma_t > 0 \text{ and } \lambda_t = \lambda_{t+1} - \gamma_t . \qquad (12)$$

The water value (market price of electricity) in the following period is greater than the current period.

If thermal power does not reach its capacity the optimum price is still equal the marginal cost of thermal power plants. If thermal power reaches its full capacity the shadow price on its constraint becomes positive. Two solutions are the same as (10) and (11).

In both case 1 and 2 the optimum market price of electricity is always equal to water value. With the presence of the thermal power plants, the prices of electricity vary with the conditions on whether the thermal capacity has been reached or not. If it has been reached, the shadow price on thermal constraint becomes positive and enters into the electricity pricing system; if not, the price keeps fixed and is equal to water value and marginal cost of thermal power plants. The difference between two cases here is that in case of neither overflow nor scarcity the water value holds for all periods, while in case of threat of overflow the water value in current period is less than the following period.

In Guangxi thermal power plants function as hydropower plants' backup. The probability that the thermal plants reach their upper limit during the period of neither overflow nor scarcity is higher than in the period of threat of overflow. The case that during the periods of neither overflow nor scarcity or threat of overflow thermal power reaches its full capacity means that there is a higher demand and consequently results in a higher price of electricity.

3.2.2 Monopoly

In Guangxi the electricity industry is, in reality, a monopoly industry. GPGC still controls hydro and thermal plants and all their operations, both in production and in transmission. Assume GPGC faces a demand function $p_t(x_t)$. Based on Førsund's model, GPGC's optimization problem is given by:

$$
\begin{aligned}
& Max\sum_{t=1}^{T}[p_t(x_t)x_t - c(e_t^{Th})] \\
& s.t. \\
& x_t = e_t^H + e_t^{Th} \\
& R_t \le R_{t-1} + w_t - e_t^H \\
& R_t \le \overline{R} \\
& e_t^{Th} \le \overline{e}_t^{Th}
\end{aligned}
\qquad (13)
$$

t=1,…,T ,

The target function and the constraints are almost the same as the case of social optimum one except that in the target function; the maximizing object is the monopolist's revenue $p_t(x_t)x_t$ instead of the social utilities $\int_{z=0}^{x_t} p_t(z)dz$ in perfect competition case, since the monopolist is only interested in perusing a maximized profit by providing certain amount of electricity.

The Lagrangian for the problem is

$$\begin{aligned} L = &\sum_{t=1}^{T}\left[p_t(e_t^H + e_t^{Th})(e_t^H + e_t^{Th}) - c(e_t^{Th}) \right] \\ &-\sum_{t=1}^{T}\lambda_t(R_t - R_{t-1} - w_t + e_t^H) \\ &-\sum_{t=1}^{T}\gamma_t(R_t - \overline{R}) \\ &-\sum_{t=1}^{T}\theta_t(e_t^{Th} - \overline{e}_t^{Th}) \end{aligned} \tag{14}$$

The necessary conditions are

$$\begin{aligned} &p_t'(e_t^H + e_t^{Th})(e_t^H + e_t^{Th}) + p_t(e_t^H + e_t^{Th}) - \lambda_t \le 0 \perp e_t^H \ge 0 \\ &p_t'(e_t^H + e_t^{Th})(e_t^H + e_t^{Th}) + p_t(e_t^H + e_t^{Th}) - c'(e_t^{Th}) - \theta_t \le 0 \perp e_t^{Th} \ge 0 \\ &-\lambda_t + \lambda_{t+1} - \gamma_t \le 0 \perp R_t \ge 0 \\ &\lambda_t \ge 0\left(= 0\, for, R_t < R_{t-1} + w_t - e_t^H\right) \\ &\gamma_t \ge 0(= 0\, for, R_t < \overline{R}) \\ &\theta_t \ge 0\left(= 0\, for, e_t^{Th} < \overline{e}_t^{Th}\right) \end{aligned} \tag{15}$$

The equation $p_t'(e_t^H + e_t^{Th})(e_t^H + e_t^{Th}) + p_t(e_t^H + e_t^{Th})$ is the marginal revenue (*MR*) for the monopolist and is equal to $p_t(x_t)(1+\eta_t)$, where $\eta_t = \frac{dp_t}{dx_t}.\frac{x_t}{p_t}$ is the demand flexibility that is the inverse of the demand elasticity. Since the inverse demand function is a decreasing function in x_t, η_t is negative. Its absolute value must be greater than or equal to zero, such that $(1+\eta_t) \ge 0$.

Simplify the conditions by assuming that both hydro and thermal generate electricity, and there is always some water in the reservoirs, i.e. $e_t^H > 0$, $e_t^{Th} > 0$, $R_t > 0$. The first three conditions change into:

$$\begin{aligned} &MR_t = p_t(x_t)(1+\eta_t) = \lambda_t \\ &MR_t = p_t(x_t)(1+\eta_t) = c'(e_t^{Th}) + \theta_t \\ &-\lambda_t + \lambda_{t+1} - \gamma_t = 0 \end{aligned} \qquad (16)$$

The *MR* is equal to water value and marginal cost of thermal power plants plus the shadow price on thermal capacity constraint. The monopoly market price is given by

$$p_t(x_t) = \frac{\lambda_t}{1+\eta_t} = \frac{c'(e_t^{Th}) + \theta_t}{1+\eta_t} \qquad (17)$$

which is different from the social optimum solution.

The analysis on the cases of the water situation is similar to that of the social optimum case. All we need to do is to replace the market price with marginal revenue. There is one thing need to be addressed. When monopolist experience a period of water abundance that is $R_t = \overline{R}$, the monopolist cannot do better than take the social optimum solution (Førsund, 2005).

3.2.3 Discussions

According to the simple modeling analyses above, it is clear that in order to maximize social utilities or the profit of the monopolist, the prices of electricity should be flexible, and the electricity pricing system is much more dependant on the water value and the operating cost of thermal power plants. In classical microeconomics theory, monopoly causes less output and higher market price than social optimal solutions. But here our solutions are different. During the period of neither overflow nor scarcity monopoly market price is less than social market price and in the following period monopoly price is higher than social one. This leads to a social inefficiency. This is further illustrated in the following bathtub figures.

The figure 4 below shows one case of neither overflow nor scarcity with both monopoly and social solutions. In the social planning situation, I assume in both periods thermal reach its full capacity; the demand curves (thick lines) start from the vertical line a_1 and d_1 that are the thermal limits, by result (11) as thermal capacity are exhausted, the shadow price on thermal constraint is greater than zero and also by result (8) the full thermal product are equal meaning $a_1A=Dd_1$. The market prices are equal to the shadow price on water and the marginal cost of thermal power plants. As for monopoly, less thermal output, the demand curves (thick and spotted lines parallel to the social ones) start from the vertical line a and d. By results (8) and (16) the thermal extensions are equal at each end meaning aA=Dd. The monopoly prices are determined by the intersection of marginal revenue curves (small spotted lines) and marginal cost up to the demand curves. We can see that in period 1, more usage of water is indicated and the monopoly market price is lower than the social optimum. This would potentially increase the electricity scarcity, since when market price is lower people tend to consume more. In the following period 2 the price is relatively higher and there is less electricity available for consumption.

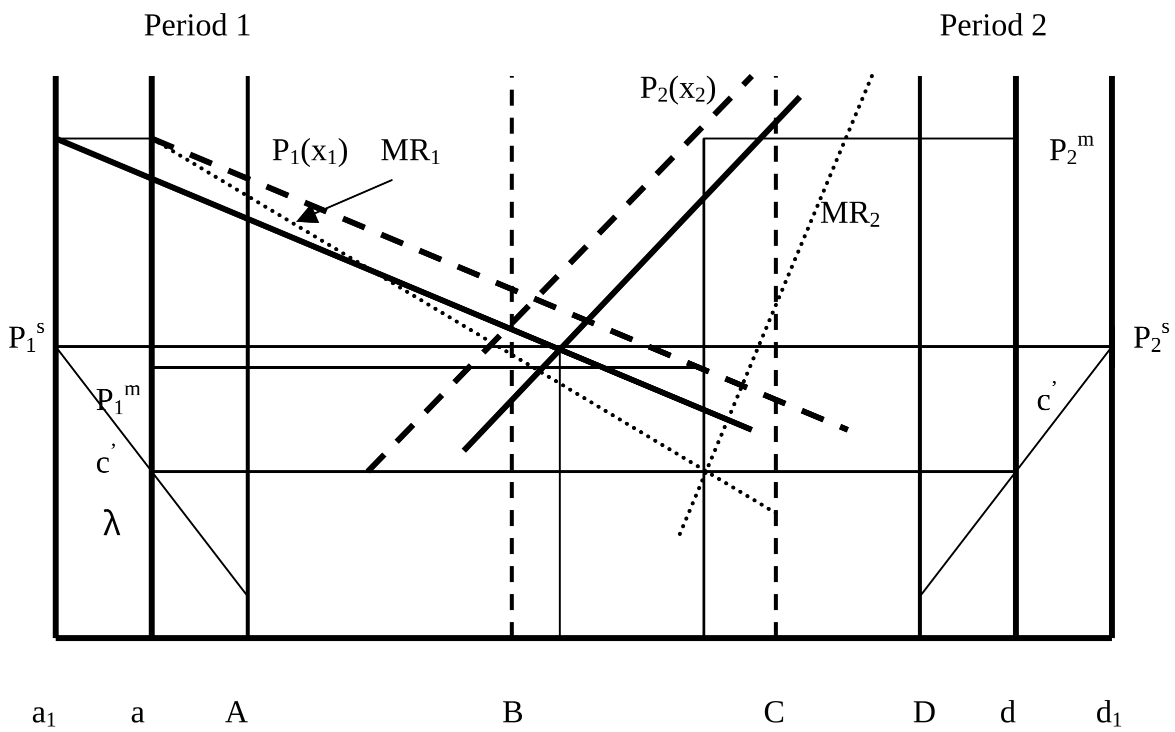

Figure 4 Bathtub for two periods in case of neither overflow nor scarcity

In the figure, aA , Dd - thermal extensions, a_1A, Dd_1- thermal capacity, AC and CD -inflows in both periods, BC reservoir; P^s is the price for the social optimum; P_1^m and P_2^m are the monopoly prices for period 1 and 2; c' is the marginal cost of thermal power plants; λ is the water value for monopoly; $P_*(x_*)$ is the demand of electricity; MR_* is the marginal revenue for monopolist.

The figure above maintains that a flexible price system is optimal, even though there exists market imperfection with monopoly. Actually in Guangxi the single price policy prevails. Although the time or seasonal tariffs are in practice, the season is relatively long and the price adjustment often falls behind. This means that in practice, the prices can be fixed for a long time. So in one period if prices are fixed it is impossible to get an optimum solution. In other words given the demands of whole society the prices set by government might not match solution of the optimal one. The way of alleviating the electricity scarcity by pricing probably fails. Suppose the time from May to October is threat of overflow (t) and the time from November to next April (t+1) is neither overflow nor scarcity. This is a close to real world assumption. According to the analyses above, when there is threat of overflow, the water value or the market price of electricity (social optimum or monopoly) in t is less than that in t+1, which matches the current price setting in Guangxi. However if we divide the so-called period of water abundance into smaller parts, say every month is one single period, the results will deviate the current pricing policy: single price. For instance, if June faces threat of overflow, then in July the price of electricity will be higher based on the (12). But in reality both June and July prices are set to be the same.

So far there are three kinds of prices mentioned: 1) government price that is the single price for Guangxi; 2) monopoly market price that can bring max profit to monopolist; 3) social optimum price that can maximize social utilities. Among these three prices first one is obviously inferior, since it is fixed and lack of adjusting ability. The second one at least can make monopolist better off. Of course if the government set the prices equal to the social optimum one, in given periods and with given installed capacity, the problem of electricity scarcity may be solved. This can be called first-best. The second-best may be that the government sets the electricity price equal to monopoly price. It can reach equilibrium between demand and supply by maximizing monopolist's profit. But the government price is still unreliable. Look at figure 4 in period 1, if the government price is higher than the optimum, less electricity would be consumed and the monopolist would lose some profit. Even worse is that some water might be released from reservoir without any use. This results in more loss of social efficiency in resource utilization. If the government price were lower than the monopoly price, the problem of electricity scarcity would become worse, since the consumers would tend to use more electricity. The cases that the government prices deviate the optimum, higher or lower, would also cause social inefficiency that is even worse than monopoly case.

The analyses above are focused on the optimal solutions under monopoly case that fits Guangxi's real situation. They involve some executive charges and the cost from thermal power plants. In the following part further studies on these two important factors will be given in more detail.

3.3 extensions

In this part, corresponding to Guangxi's realities, I will discuss two crucial factors that affecting the electricity pricing, in order to make prices reflect true value of the electricity.

3.3.1 Executive charge on water use

In the analyses shown before a key word "water value" has been mentioned. In case of social optimal model, one of the optimal solutions is that the market price is equal to the water value. In the monopoly model, the monopolist has to set his *MR* equal to water value so that he can maximize his profit. There is another factor relevant to water, which is an executive charge on water use in Guangxi.

In Guangxi it has been regulated that the hydropower stations have to pay some executive charges to the water sector in the local government for the right of using water to generate electricity. These charges are aimed to cover the operating cost of the water supplier sector, including labor costs, maintenance charges, investments for increase of the volume, etc. They are charged by how much electricity has been generated, the following table 5 shows that the charges' rate for hydro-use of reservoir water in Guangxi, for example, there is a large-scale hydropower plant yielding 9000 million kwh per year, then it has to pay 270,000yuan to the local government as for the use of the water. Furthermore, besides the charges for hydro-use, the irritation use water, industrial and commercial use water, etc are all charged by some fees.

Table 5 Charges for hydro-use of reservoir water in Guangxi

Scale of the hydro power plant	Charge fee for water (yuan/kwh)
Large (installed capacity ≥0.3 million kw)	0.003
Medium (0.05≤installed capacity≤0.3)	0.002
Small (installed capacity≤0.05)	0.001

Source: Regulations of charging water resources in Guangxi (1992) and P.R.C. Standard for blood control (1995)

According to this fact in Guangxi, in the highly stylized model a new factor will be added. Based on (13), the monopolist, GPGC faces a new profit maximization problem that is given by:

$$
\begin{aligned}
& Max\sum_{t=1}^{T}[\,p_t(x_t)x_t - c(e_t^{Th}) - E\cdot e_t^{H}\,] \\
& s.t. \\
& x_t = e_t^{H} + e_t^{Th} \\
& R_t \le R_{t-1} + w_t - e_t^{H} \\
& R_t \le \overline{R} \\
& e_t^{Th} \le \overline{e}_t^{Th}
\end{aligned}
\qquad (18)
$$

t=1,…,T ,

In the target function E is the executive charge rate that is regulated by the government. The necessary order conditions by the Lagrangian method are:

$$
\begin{aligned}
& p_t'(e_t^H + e_t^{Th})(e_t^H + e_t^{Th}) + p_t(e_t^H + e_t^{Th}) - \lambda_t - E \le 0 \perp e_t^H \ge 0 \\
& p_t'(e_t^H + e_t^{Th})(e_t^H + e_t^{Th}) + p_t(e_t^H + e_t^{Th}) - c'(e_t^{Th}) - \theta_t \le 0 \perp e_t^{Th} \ge 0 \\
& -\lambda_t + \lambda_{t+1} - \gamma_t \le 0 \perp R_t \ge 0 \\
& \lambda_t \ge 0\left(= 0\, for, R_t < R_{t-1} + w_t - e_t^H\right) \\
& \gamma_t \ge 0(= 0\, for, R_t < \overline{R}) \\
& \theta_t \ge 0\left(= 0\, for, e_t^{Th} < \overline{e}_t^{Th}\right)
\end{aligned}
\tag{19}
$$

Still assume both hydropower and thermal power plants produce electricity, $e_t^H > 0$ and $e_t^{Th} > 0$. The first two equations change into:

$$
\begin{aligned}
& MR_t = \lambda_t + E \\
& MR_t = c'(e_t^{Th}) + \theta_t
\end{aligned}
\tag{20}
$$

Here the executive charge rate enters into the electricity pricing system, the marginal revenue of the monopolist is equal to the water value plus executive charge rate, and it reduces the profit of the monopolist. So the executive charge should not be ignored by the price setting regulators while they set prices.

3.3.2 Cost of thermal power plants

In the previous part, the cost of thermal power plants is briefly mentioned. But at that moment the cost is merely the operating cost such as prices of fuels, labor costs etc. There is one thing that has not been discussed yet—pollution.

It is well known that thermal power plants generate electricity by burning coals, oils. This causes an environmental problem of the emission. The emissions from electricity productions consist of suspended particulates (TSP), sulfur dioxide (SO_2) and carbon dioxide (CO_2). They are doing damage to the environment. In Guangxi there are 17 thermal power stations emitting 38.86% of total emissions of SO_2 in 2004. The table following shows more detail about the pollution from thermal power stations in Guangxi.

Table 6 Emissions from thermal power industry in 2004

	Number of Industrial Enterprises	Total Discharged Volume of Industrial Waste Gas（10 000 cu．m）	Volume of Sulphur Dioxide Discharged（ton）	Volume of Soot Discharged （ton）
Total in Guangxi	1731	106573697	764224	467410
Total in thermal power industry	17	35493855	297014	104706
Percentages	1%	33.3%	38.86%	22.4%

Source: Guangxi Statistical Yearbook 2005

From the table 6 we can see that Guangxi’s thermal power industry contribute a major part of the waste gas emissions. The direct effects from the emissions are acid rain and climate warming. Now Guangxi (combined with Sichuan basin, Guangdong, Yunnan, Guizhou) is a part of the third biggest acid rain area (ranked after western EU and northern America) in the world. Every year the Guangxi government spends large amount of expenditures in controlling the pollutions and investment in abatement. But these expenditures cannot deal with the pollution effectively and also make government’s fiscal burden heavier. In fact, the government can regulate pollutions by two ways.

One is command and control. This might be a prevailing form of environmental regulation in the world. In Guangxi all the thermal power plants must install sulfur dioxide filters. As a compensation for this abatement cost, the government agrees to raise electricity price 0.002 yuan/kwh to those who install the sulfur-reducing facilities in order to cover the cost of these facilities. Without these facilities the plants cannot get the special price for their electricity and have to digest the cost themselves. This simplifies the way of pollution control and only involves inspections on whether the power plants have the installments or not.

The other one is the economic incentives. Take Guangxi as an example, the government only order the plants to install some certain abatement equipment, of course, it can reduce pollutions, but the plants can still emit whatever amount they can without concerning the environmental control. They do not bear the responsibilities to the emissions while government has to pay for reducing the pollution. In fact, the government can charge an emission tax on the plants according to how much electricity e_t^{Th} they generate. This will increase the operating cost of the power plants but control the emissions by reducing the productivity level.

Go back to equation (18) for Guangxi it is necessary to insert one more factor, tax, into the target function. Suppose the tax is the function of the electricity e_t^{Th} generated from thermal plants. The monopolist GPGC is facing his optimization problem

$$\begin{aligned}
&Max\sum_{t=1}^{T}[p_t(x_t)x_t - c(e_t^{Th}) - E\cdot e_t^{H} - t(e_t^{Th})]\\
&s.t.\\
&x_t = e_t^H + e_t^{Th}\\
&R_t \le R_{t-1} + w_t - e_t^H\\
&R_t \le \overline{R}\\
&e_t^{Th} \le \overline{e}_t^{Th}\\
&t = 1,...,T
\end{aligned} \tag{21}$$

Same assumptions and way of solving as before yield:

$$\begin{aligned}
&p_t'(e_t^H + e_t^{Th})(e_t^H + e_t^{Th}) + p_t(e_t^H + e_t^{Th}) - \lambda_t - E \le 0 \perp e_t^H \ge 0\\
&p_t'(e_t^H + e_t^{Th})(e_t^H + e_t^{Th}) + p_t(e_t^H + e_t^{Th}) - c'(e_t^{Th}) - \theta_t - t'(e_t^{Th}) \le 0 \perp e_t^{Th} \ge 0\\
&-\lambda_t + \lambda_{t+1} - \gamma_t \le 0 \perp R_t \ge 0\\
&\lambda_t \ge 0\left(=0\, for, R_t < R_{t-1} + w_t - e_t^H\right)\\
&\gamma_t \ge 0(=0\, for, R_t < \overline{R})\\
&\theta_t \ge 0\left(=0\, for, e_t^{Th} < \overline{e}_t^{Th}\right)
\end{aligned} \tag{22}$$

Look at the first two equations by assuming both hydro and thermal are producing electricity in period t ($e_t^H > 0$ and $e_t^{Th} > 0$).

$$\begin{aligned} MR_t &= \lambda_t + E \\ MR_t &= c'(e_t^{Th}) + \theta_t + t'(e_t^{Th}) \end{aligned} \tag{23}$$

It is obvious that new factor enters into the electricity pricing system and it raises the marginal cost of the monopolist. While setting prices of electricity in Guangxi the decision makers should take the executive charge rate and the new operating cost (including the tax levied on) of thermal power plants into considerations. The presence of the tax raises the cost of thermal plants.

Discuss emission tax further more. What tax level is the optimal one? The English economist Arthur C.Pigou studied this problem. He maintained that the government must levy a tax of emission to make pollution more costly to the polluter. This tax has been called a Pigovian fee or Pigovian tax that is defined as a fee or tax paid by the pollution per unit of pollution exactly equal to the aggregate marginal damage caused by the pollution when evaluated at the efficient level pollution and the fee is generally paid to the government. (Kolstad 2000)

Suppose the social damage by generating electricity e_t^{Th} can be expressed by a social damage function $D(e_t^{Th})$ and the optimal tax level is t^*. According the definition Pigovian tax is $t^* = D'(e_t^{Th})$. For simplicity assume tax function $t(e_t^{Th})$ has a linear form $t(e_t^{Th}) = te_t^{Th}$, so $t'(e_t^{Th}) = t$.

Thus equations (23) change into

$$\begin{aligned} MR_t &= \lambda_t + E \\ MR_t &= c'(e_t^{Th}) + \theta_t + t \end{aligned} \tag{24}$$

On the optimal tax level equations (24) can also change into

$$MR_t = \lambda_t + E$$
$$MR_t = c'(e_t^{Th}) + \theta_t + t^* \quad (25)$$

which is the same as

$$MR_t = \lambda_t + E$$
$$MR_t = c'(e_t^{Th}) + \theta_t + D'(e_t^{Th}) \quad (26)$$

Now the social damage part enters into my electricity pricing system. The government shifts the environmental burden upon monopolist by way of levying a certain amount of tax on thermal power plants.

Section 4 Other issues

In section 3 I introduce an electricity pricing system for Guangxi in order to alleviate or solve the problem of electricity scarcity by a hydropower economics model. There are still many factors related to the price setting. In this section I will give some brief indications of them.

4.1 Natural monopoly thoughts

In Guangxi's electricity market, if we let GPGC decide the prices of electricity, according to the analyses in previous parts, it will set its marginal revenue equal to marginal cost. This behavior raises the prices and reduces the output. Unfortunately the right of price setting is controlled by government. To maximize the social utilities all government has to do is to set price equal to marginal cost. If this is the case our monopolist GPGC might get a negative profit. Such a situation is referred as natural monopoly.

The situation of natural monopoly often arises with public utilities. The electricity industry involves a large fixed cost of building dams and reservoirs, buying and installing turbines. Although there are also operating costs, they are small relative to the fixed cost. Therefore if government regulators set price that is lower than the average cost of production, the monopolist would prefer to leave this market. Ideally these prices are supposed to be prices that just allow the firms to break even—produce at a point where price equals average costs (Varian 2003). The natural monopoly may happen to water suppliers as well. In previous section water value is used as an important part for determining the prices of electricity by way of marginal-cost pricing. Although it is a social optimum, it is necessary to consider average cost of supplied water like the natural monopoly case.

So when Guangxi's government is setting the prices of electricity, the average cost factor should not be ignored.

Take Longtan hydropower plant, the third largest hydropower plant in China, as an example. Its total installed capacity is 5.4 million kw and the annul average electricity output is 18.71 billion kwh, and the total investment is 28.2 billion yuan in 1998. This program will be completed in 2009. (Introduction of Longtan hydropower station 2005) Let us simply calculate the average cost in 2009. In 1998 the total fixed cost is 28.2 billion yuan but in 2009 the cost will be $28.2(1+10\%)^{11} \approx 80.46(billionyuan)$.

In China the discount rate used by electricity power sector is 10%. Then the average cost is equal to 18.71 kwh divided by 80.46 billion yuan, which is 0.2325yuan/kwh. So in the future if the price of electricity for Longtan plant is greater than 0.2325yuan/kwh then the plant can get enough to cover the average cost otherwise the plant will get negative profit.

4.2 Price structure

The term price structure can reflect how the amount of water consumed can be charged. In below I will study which kinds of the price structure is suitable for Guangxi. As the prices of electricity are set seasonally in Guangxi, the basic idea so far is to charge different prices during the water abundance period and scarcity period respectively. In each period there is a fundamental price, derived from the previous modeling analyses, which can change depending on how much electricity has been used.

Figures 5 depict the three basic price structures. First one is decreasing block prices. Each electricity consumer faces the same price level within certain used volume, as the volume increases price is going to a lower level. The opposite one is increasing block prices and if price holds fixed there is one called uniform price structure. In first two figures, $P_{1,}$ $P_{2,}$ P_3 are the prices for each volume level of electricity consumed, and $e_{1,}$ $e_{2,}$ e_3 are the amount of electricity consumed, and especially P_1 is the fundamental price mentioned. In case of uniform, price P is the constant price for the electricity used. For all three structures there is a small free amount of electricity consumption $e_{1.}$ For example if a user consumes e units of electricity, in first two price structures, his bill is $P_1(e_2- e_1)+ P_2(e- e_2)$, not P_2e, and in case of uniform he only need to pay $P(e- e_1)$.

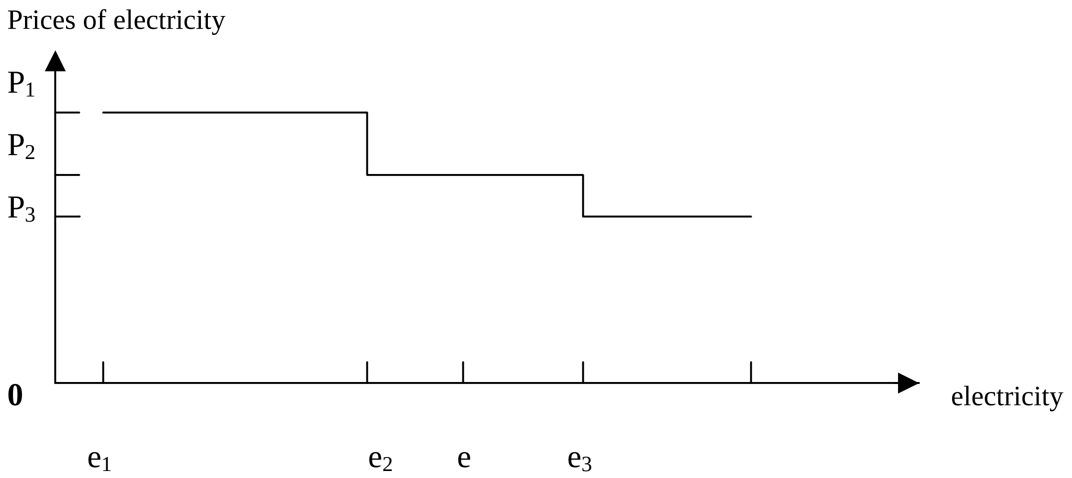

Figure 5-1 Decreasing price structure

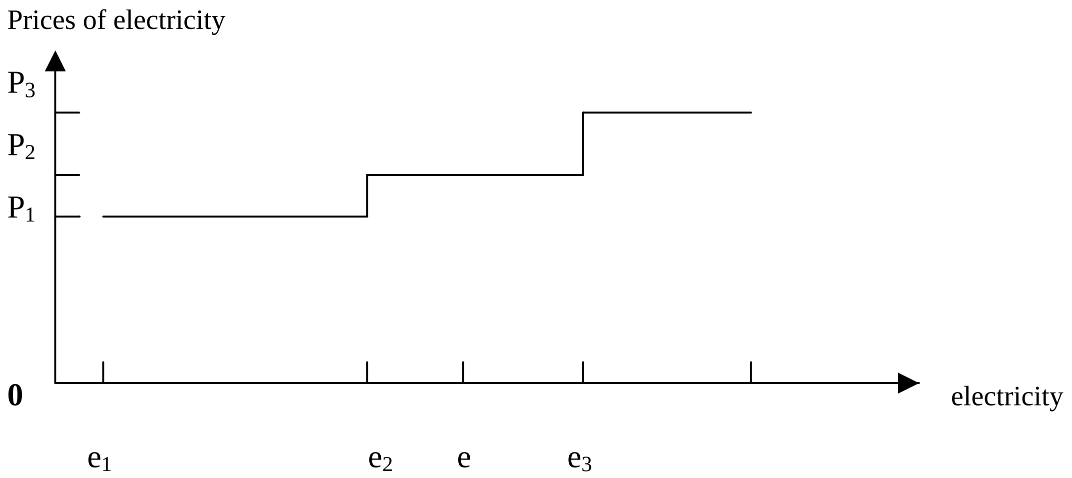

Figure 5-2 Increasing price structure

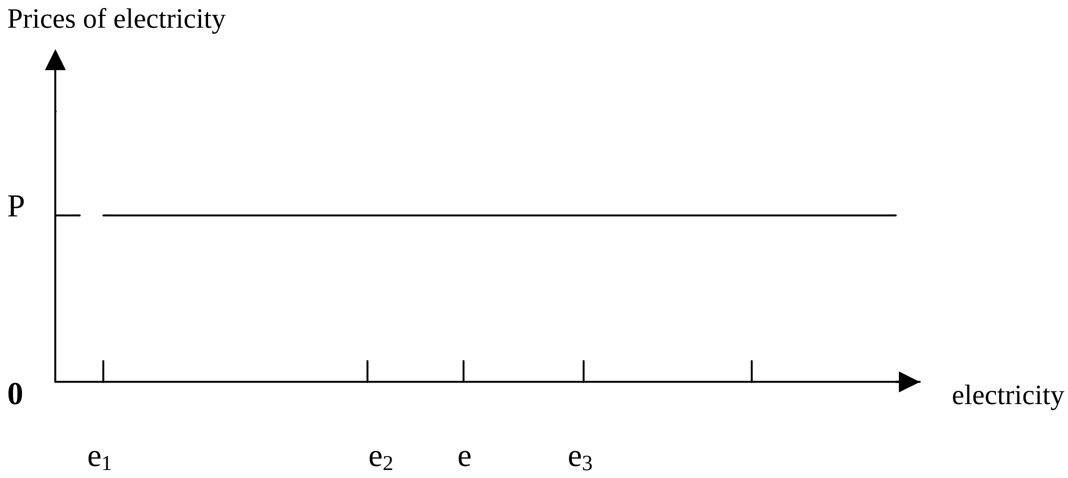

Figure 5-3 Uniform price structure

The uniform price structure is like the current one in Guangxi, which is during each periods, no matter if there is water scarcity or abundance, the prices of electricity are fixed. As talked before a uniform price cannot function as an invisible hand, regulating the demand and supply, alleviating the scarcity problem.

Regarding with the electricity scarcity in Guangxi the better one is increasing structure, the more usage the higher price and the more payment. The motivation for this kind of price structure is mainly from the electricity usage conservation, since the large electricity users need to be charged more for their behavior.

4.3 Forecasting

There have been some errors in Guangxi's electricity demand forecast. It was estimated that in 2005 Guangxi would lack 4000 million kwh, while the real gap between consumption and production was 6411 million kwh. Normally an underprediction can lead to undercapacity. A precise estimate of demand can serve both supply enhancement and demand management strategies. For supply side, it gives the signal to government whether to build more power stations; from the demand perspective it is important for the goal of setting prices and the development of management strategies.

Usually government takes statistical method to predict electricity demand by putting various independent variables into demand equation. These variables can be economic growth, population, prices of electricity, prices of fuels, etc. As for Guangxi's estimation I suggest a statistical model:

$$E_t^d = f(GDP_t, P_t^e, PG_t, T, I, GB_t), \tag{27}$$

where

E_t^d -- Demand of electricity

GDP_t -- Gross domestic product

P_t^e -- Price of electricity

PG_t -- Population growth

T -- Variable of technology

I -- Investment in electricity industry

GB_t -- Variable for government behaviors.

Since weather change is one of the reasons for the electricity scarcity in Guangxi, outdoor temperature changes will cause an increasing need for air-conditioning and more electrical heating equipments to be installed as a sign of people's higher living standard level. Here a possible weather model that is based on a temperature model derived by three Norwegian economists (Gabrielsen, Bye and Aune 2005) can be useful in predicting electricity demand. The model is given by:

$$E_t = f(P_e, P_f, GDP, H, Add, Hdd) \tag{28}$$

where

P_e --Price of electricity

P_f --Price of fuel oils and coals

GDP --Increase of gross domestic product

H --Holiday dummy variable

Add --Air-conditioning degree-days

Hdd --Heating degree-days.

In this model, the price of electricity and the demand are correlated undoubtedly. The presence of the price of fuel oils and coals shows that fuels and coals may function as substitutes for hydropower, because they can be used in producing electricity from thermal plants and used in heating. Holiday variable is something special here since in China there are 3 long-term holidays each lasts 7 days long. During the long holidays, the consumption of electricity may encounter a peak load. Air-conditioning degree-days is defined as the sum of the days whose temperature are over 30 degree and heating degree-days is for the days under 10 degree.

The impact of these factors on electricity demand and empirical studies on these two interesting statistical models will certainly cast lights on price settings for electricity and is beyond the scope of this thesis.

Section 5 Conclusions

The paper has demonstrated that, to alleviate or solve the problem of electricity scarcity in Guangxi, the way of flexible pricing is most suitable one. The current fixed prices policies can lead the electricity scarcity to a worse situation. The prices of electricity should fluctuate through the year according to available water resources, the status of thermal power plants and the market situations.

In the simple model analyses, to maximize the social utilities by consuming electricity, the prices of electricity are determined by water value and the operating cost of thermal power plants. The former one influences the prices because the total water that can be used in hydropower electricity production is uncertain, and there is a reservoir constrain that matters. How the latter one can affect the prices depends on whether the thermal power reaches its production capacity or not.

Based on the fact that the water use is charged by a certain amount of fees and thermal power plants emit a huge amount of emissions in Guangxi, I extend the simple model by taking the executive charge and environmental concerns, which could affect the electricity pricing system, into consideration. An executive charge rate on water use has been introduced, and as for the environmental concern, pollution issue has been discussed. The thermal power plants should bear the abatement cost of emission caused by their production, therefore, the cost for thermal power production is higher. After adding these two factors, as a consequence, the market prices of electricity should reflect this cost more accurate than before.

From the analyses above we have a clear idea on why the prices of electricity should be flexible and how to develop a new electricity pricing system for Guangxi. Some interesting and related topics as mentioned in section 4, will be interesting subjects and shall be studied in the future.

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