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This dissertation consists of three essays that evaluate various types of health care policies from the social welfare perspective. Chapter 1 introduces the main ideas and framework of this dissertation. Chapter 2 evaluates the new co-payment policy, enacted on July 15, 2005 under Taiwan's National Health Insurance (NHI). We show that this new policy is unlikely to change consumers' health care seeking behavior. The co-payment policy can reduce the financial burden of the NHI, but it may have a potentially harmful effect from the social welfare perspective. Chapter 3 simulates the impact of user-fee policies on the choice of health care under Taiwan's NHI. The pricing-out effect and welfare effect are estimated using a willingness to pay approach. Our empirical results suggest that the Taiwan government still has room to increase the NHI's premium since the willingness-to-pay rate (measured as percentage of household income) is much higher than the new premium proposed by the Taiwan government. Chapter 4 is a theoretical treatment of hospital competition under the Global Budget Payment System (GBPS) that explicitly responds to two

recent criticisms of the GBPS in the literature. These criticisms are the following: (1) the GBPS is inferior to the Prospective Payment System (PPS) because the GBPS fails to achieve the first best allocation that can be achieved by the PPS; (2) under the GBPS, hospitals will provide more health care services in accordance with a lower reimbursement payment due to a fixed budget, referred to as the treadmill effect. Prior research suggests that the treadmill effect often causes a lower quality of care. We show that the GBPS can approach the optimal levels of quality and slack generated by the PPS, and that the treadmill effect is a social welfare improvement outcome. Based on our theoretical analyses, we suggest that these two criticisms are highly suspect, and that further empirical studies are necessary to identify whether the GBPS is necessarily related to low quality of care. Chapter 5 presents the major contributions of this dissertation.

National Health Insurance in Taiwan: Welfare Analysis and Hospital Competition

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Wen-Yi Chen

Wen-Yi Chen, Author

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DEDICATION

To my parents Jenn-Jiang Chen and Jiin-Luan Lin

and

my wife Yu-Hui Lin

for their everlasting love, understanding, and support.

National Health Insurance in Taiwan: Welfare Analysis and Hospital Competition

1. Introduction

Health economics is a distinct specialty within economics inasmuch as health care policies are dominant economic and political issues in most western countries as well as in newly industrialized countries. With economic development, nearly every country around the world experienced rapid increases in health care spending in the past two decades. In order to stabilize the growth of medical expenditure, governments implement various types of health care policies to regulate health care market. In this dissertation, I consider any health care system as consisting of three players, which are consumers, providers, and payers. In order to study health care policy, three important relationships needed to be evaluated: (1) the relationship between consumers and providers, (2) the relationship between consumers and payers (the government in the NHI system), and (3) the relationship between providers and payers (the government in the NHI system). Based on these underlying relationships, three essays that explore health care policies from the social welfare perspective are presented in Chapter 2 thru Chapter 4.

Chapter 2 evaluates Taiwan's new co-payment policy, enacted on July 15, 2005. The co-payment policy is typical of demand-side regulation in the health care market and is intended to influence consumer behavior via a pricing mechanism. The demand for health care is carried out by a two-part decision making process, which is the

underlying relationship between consumers and providers in the health care market. The first part is characterized by the consumer initiating a physician contact in the event of an illness. After his/her first contact, the physician determines how extensive a treatment he/she should receive (the second part decision-frequency decision). Since health care utilization is often measured by a discrete number (i.e., zero usage or positive integer usage), the so-called hurdle count data model (or two-part count data model) is used to assess the discrete nature of health care utilization into the two-part decision making process. We show that the new co-payment policy is unlikely to change consumer behavior of seeking care, and we then go on to estimate the welfare effect due to the new co-payment policy.

Chapter 3 presents the impact of user fees on the choice of health care under Taiwan's health care system. This chapter is a sequel to Chapter 2. The nested multinomial logit model (NMLM) is used to simulate the potential pricing-out effect as well as the welfare effect due to various user-fee policies. The policy simulations performed in this chapter allow us to estimate the willingness-to-pay for a universal coverage health plan. Our estimate of the willingness-to-pay, which bridges the underlying relationship between consumers and payers (the government) in the health care market, can serve as a reference for instituting a premium policy if the government intends to implement a universal coverage health plan under its health care system.

Chapter 4 studies hospital competition under the Global Budget Payment System (GBPS). The GBPS is a reimbursement system which restricts medical

expenditure at a fixed level for a given period. Many European countries, as well as Canada and Taiwan, adopted this payment system to reimburse hospitals for the purpose of medical cost control. To study the reimbursement system is actually to analyze the underlying relationship between providers and payers in the health care market. Many previous theoretical studies criticize the GBPS in two ways: First, the GBPS fails to induce the first best allocation in terms of quality-enhancing and cost-reducing efforts that can be achieved by the Prospective Payment System (PPS). Second, the treadmill effect, describing a phenomenon in which hospitals provide more health care services in accordance with a lower reimbursement payment under the GBPS, would result in a worse welfare outcome because hospitals would lower quality of care in response to the lower reimbursement payment. We show that the GBPS can perform just as well as the PPS from the social welfare perspective, and the treadmill effect could be a sign of welfare improvement as long as competition (measured by the number of hospitals and the mobility of patients) among hospitals is sufficiently high in the health care market. In contrast with these two criticisms, our results suggest that the GBPS does not necessarily lead to a lower quality of care.

Chapter 5 presents the major contributions of this dissertation, and avenues for future research are also discussed.

2. The new co-payment policy under Taiwan's National Health Insurance: Welfare gain or Welfare loss?

2.1 Introduction

A National Health Insurance (NHI) program was implemented in Taiwan in 1995. Approximately 99% of Taiwan residents have benefited from this program, and public satisfaction with the program topped 81% at the end of 2004 (Chang, 2005). Due to the public's opposition to premium increases, the NHI's expenditures have outstripped its revenues since 1998. Thus, the question of financial sustainability moves to center stage for the NHI policy in Taiwan.

Since the launch of NHI program in 1995, ambulatory care medical expenditures have constituted the largest proportion of total medical expenditure. In 2004, approximately 65% of medical expenditures were spent on ambulatory care, of which 54% went to hospitals (Bureau of National Health Insurance, 2005a, Department of Health 2005a). There are two major reasons for the large reliance on the hospital sector. First, the residents of Taiwan have a strong belief that hospitals can provide better quality care than clinics because they have advanced equipment and better-trained physicians (Chen, 2003). Patients prefer to receive treatment from hospitals rather than from clinics, even when they only have a minor illness (Chen, 2003). Second, the reimbursement payments for ambulatory care to hospitals are around 2-4 times higher than those of the clinics (Bureau of National Health Insurance, 2005b). Given such a strong economic incentive, most hospitals in Taiwan now reward their staff physicians largely on the basis of the number of patients seen,

procedures performed, and lab tests ordered. It follows that physicians in hospital are willing to keep patients in ambulatory care, possibly triggering physician-induced demand (Cheng, 2005).

In order to reduce the NHI's medical expenditure, a new co-payment policy was implemented on July 15, 2005. The objective of this policy is to encourage patients with minor illnesses to seek ambulatory care at local clinics rather than at hospitals, which are more expensive. The new co-payment policy raises co-payment fees for ambulatory visits at hospitals, except in cases of referral by local clinics. The objective of this paper is to assess this co-payment policy from two perspectives. First, will this new co-payment policy provide sufficient incentive for patients to participate in a referral system? Second, how much welfare gain or loss will result from the implementation of this new co-payment policy?

Notwithstanding the Bureau of National Health Insurance (BNHI)'s claim that the new co-payment policy would reduce expenditures by creating a referral system, it appears that this policy is doomed to failure. The failure comes from insufficient incentives to induce patients to participate in the referral system. According to the new co-payment policy, if a patient were referred to the district hospital from a local clinic, his/her minimum total cost for ambulatory care would be NT$300[1], much higher than the cost would be if he/she went directly to the hospital and bypassed the referral system (NT$180) (see section 2.2 for details).

Since it is doubtful that this new co-payment policy will promote the referral

[1] 1 US dollar = 31.5 NT dollars

system in Taiwan, we largely focus on how much welfare loss (or gain) would be caused by the policy. To this end, we estimate the demand for ambulatory care.[2] This estimate allows us to evaluate the recent determinants of the health care utilization and calculate the potential welfare effects. The estimation of the demand for health care is different from that of the demand for other commodities. For example, whether or not to buy a computer and how much to spend if a computer is bought are decisions jointly made by the consumer. However, the patient's decision to utilize health care services is a two-part decision making process. Patients themselves first decide whether or not to visit the physician (hereafter referred to as simply contact decision), and second, the physician and the patient jointly determine the intensity of treatment (hereafter referred to as simply frequency decision).

Manning et al. (1981) propose a two-part model, incorporating contact and frequency decisions, to estimate the demand for health care. Since then, many empirical studies have utilized a two-part model to estimate demand. For instance, some research focuses on the impact of insurance on health care utilization (Manning et al., 1987; Nolan, 1993; Hurd & McGarry, 1997). Other research analyzes the factors affecting the demands for alcohol and tobacco (Manning et al., 1995; Chaloupka & Henry, 1997; Ross & Chaloupka, 2004). Donaldson et al.(1998) applied the two-part model to investigate the factors affecting willingness to pay for specific health care services in Norway. Bradford et al.(2002) use the two-part model as a

[2] "Utilization" and "demand" are used interchangeably throughout this paper. The data used in this paper cannot distinguish "demand" from "utilization", because we do not have information relating to either "an episode of medical service" or "an episode of illness" for each observation. For discussion of the discrepancy between "utilization" and "demand" see Stoddart and Barer (1981).

methodology[3] to estimate cost of treatment for benign prostatic hyperplasia, among others.

It is also important to consider the discrete nature of health care utilization when modeling the demand for health care. Since patients have either no use or a positive number of uses (i.e., non-negative integer value), the use of linear regression models to model health care utilization will result in inefficient, inconsistent, and biased estimates (Long, 1997). In light of these shortcomings, a number of studies emphasize the application of the count data models to analyze health care utilization. For example, Cameron et al. (1988) use a negative binomial model to analyze the impact of health insurance on health care utilization in Australia. The negative binomial model fits data especially well when overdispersion (variance is greater than mean) is exhibited in the raw data. For most empirical studies in health care utilization, the excess of zero counts is so great that the negative binomial model is not appropriate. However, if we treat zero counts and positive counts as two different stochastic processes within a hurdle model, the problem raised by the excess of zero counts is eliminated (Mullahy, 1986).

There are many empirical studies that use a hurdle model for count data to study health care utilization. Pohlmerier and Ulrich (1995), for example, use a negative binomial hurdle model to investigate the determinants of the demand for ambulatory care in Germany. They estimate a binary outcome model of the contact decision, and

[3] They first estimate the probability of receiving the transurethral resection of the prostate (TURP) given a benign prostatic hyperplasia diagnosis using a logit regression. The second step is to estimate the log of TRUP cost for the population that actually received the procedure.

then estimate a left truncated negative binominal model for the frequency decision. The parent distribution for the specification of the two-part decision making process is the negative binomial model. A similar specification is used in Gerdtham's (1997) study. He specifies the contact decision as a logit model and the frequency decision as a truncated negative binominal model for testing the hypothesis of horizontal inequality in the delivery of health care in Sweden. Gurmu (1997) introduces a semi-parametric hurdle model for count data to analyze the factors affecting health care utilization covered by Medicaid in the US. More recent health care examples of hurdle models for count data can be seen in Lahiri & Xing (2004), and Brown et al. (2005), among others.

Although the hurdle model for count data is strongly advocated and widely used in literature to model health care utilization, few studies in Taiwan have applied it for investigating the determinants of health care utilization. Cheng & Chiang (1998) use the Poisson hurdle model to analyze the disparity of health care utilization in the pre-NHI period. They use a scale parameter to correct overdispersion in their data. The scale parameter, however, will enlarge the covariance matrix of estimated coefficients, and hence make their estimates less likely to be significant (Cheng & Chiang,1998, p 615). The negative binominal model, fitted with a correction for sample selection bias, is used in Su (1999) to investigate medical cost-containment for implementing NHI in Taiwan. He finds that price (out-of-pocket payment) has a significantly negative impact on health care utilization, and therefore, a higher price imposed on the NHI is suggested to reduce the fiscal burden of the NHI.

Even with the two-stage estimation process, the implicit assumption in the sample selection model is that the decisions whether or not to visit a physician and how intensely to receive treatments are simultaneously made by the patients (Maddala, 1985). Liu & Chen (2001) apply the negative binomial hurdle model to analyze the effect of NHI on health care utilization in Taiwan. Their analyses mainly focus on examining the determinants of health care utilization under the NHI. The estimate of price elasticity for health care demand is not available in their study. Hence, they are not able to evaluate the impact of the new co-payment policy on health care utilization.

A very limited number of papers evaluates co-payment policy in Taiwan. Liu and Rome (2003, 2004) use a descriptive analysis and OLS regression analysis to evaluate the impact of drug co-payment policy enforced in 1999 on the elderly population. The 1999 drug co-payment policy imposed no charges for outpatient prescriptions costing less than NT$100. An additional charge of NT$20 was imposed for every increase in drug costs of NT$100 (lower bound of the drug co-payment schedule) until NT$500 (upper bound of the drug co-payment schedule). The main finding in Liu and Rome (2003, 2004) is that, in response to the drug co-payment policy, the physician tends to prescribe the drugs costing close to the lower bound (save the patient's out-of-pocket payment) and the upper bound (exploit the BNHI due to no further financial burden for patients beyond the upper bound) of the drug co-payment schedule. Non-essential drugs are more expensive than essential drugs in Taiwan. For those who need non-essential drugs, the physician will prescribe more

non-essential drugs in order to meet the upper bound of the drug co-payment schedule. For those who don't need non-essential drugs, the only way for a physician to meet the lower bound of the drug co-payment schedule is to prescribe less essential drugs. Liu and Rome conclude that the drug co-payment policy decreased the essential drug utilization but increased non-essential drug utilization for the elderly. The drug co-payment policy did not reverse the trend of prescription drug cost increases in hospitals. Although they do address the fact that the drug co-payments could have had adverse effects on patients, no further assessment was done in their papers.

In this study, we use the negative binomial hurdle model to estimate the demand for ambulatory care. The negative binomial hurdle model allows us to incorporate the two-part decision making process and the discrete nature of health care utilization in analyzing the determinants of health care utilization. Price elasticity, quality elasticity, and education elasticity are also estimated. Using price elasticity as a parameter, we then calculate the welfare effects of this new co-payment policy, as well as the social welfare cost due to the implementation of NHI. To the authors' best knowledge, this is the first research to evaluate the impact of this new health policy on social welfare in Taiwan.

This paper is organized as follows: Section 2.2 briefly describes the NHI co-payment policies since 1995; Section 2.3 introduces the empirical model; Section 2.4 describes the data used in the analyses; Section 2.5 explains the empirical findings; Section 2.6 presents social welfare analysis; and a brief conclusion as well as an avenue for future research are drawn in Section 2.7.

2.2 Background

Taiwan's NHI is a government-run, single-payer national health insurance plan financed by premiums (earmarked tax) collected from employees, employers, and the government. It offers all citizens equal access to comprehensive health care regardless of their financial status. The covered benefits include ambulatory service, in-patient service, emergency care, dental treatment, eye care, maternity delivery, rehabilitation service, preventive medical service, Chinese medicine, and prescription drugs. Since this program is very generous, the design of NHI includes a co-payment mechanism to provide an incentive for the beneficiary to limit health care use. However, even with co-payments, medical expenditures have grown rapidly since the NHI was launched in 1995. In 1998, the NHI began running a financial deficit that forced the BNHI to reconsider the effectiveness of the co-payment mechanism. As a result, the BNHI adjusted NHI's co-payment policies in 1999. The adjustments in co-payment policies, implemented in 1999, include a co-payment for prescription drugs and an increase in co-payment fees for excessive medical visits (over 24 visits per year).[4] The 1999 co-payment policy adjustments had the immediate effect of controlling over-utilization of health care services. A slight modification in co-payments for curbing excessive medical visits was made in 2000.

Nevertheless, the NHI's fiscal difficulties did not end yet. In fact, the main

[4] A Department of Health internal study in 1999 showed that around 95.74% of patients, whose number of annual ambulatory visits exceed 24, actually only had minor illnesses. Based on that study, the 24-visit limit is a criterion to define excessive medical visits. Due to the public's strong opposition to the co-payment policy in 1999, the BNHI did not use this criterion until 2000 (see Chen, 2003 for details). Note that the 24-visit limit does not apply to those who have certain chronic conditions (see Bureau of National Insurance, 2004).

reason for the NHI's financial difficulties was resistance to raising premium rates, voiced by the public and politicians. Over the entire period, from 1995 to 2001, NHI revenues increased at an average annual rate of 4.26 %, and expenditures increased at 6.26% (Cheng, 2003). During the same period, the NHI premium rates remained unchanged. Facing NHI's imminent bankruptcy, the government was able to increase both premiums and co-payment fees in 2002. The premium rates were increased from 4.25% of salary income, to 4.55%. For the majority of the insured public, the average premium was increased by, at most, NT$40 per month (Taipei Times, Aug 12, 2002). The 2002 co-payment policy raised co-payment fees for ambulatory visits at regional hospitals and academic medical centers from NT$100 and NT$150 to NT$140 and NT$210, respectively. Together with the comprehensive global budget payment system, implemented in 2002, the adjustment of co-payment fees and premium rates kept NHI at the edge of a financial breakeven level until 2004.

In order to prevent another financial crisis, the BNHI implemented a new co-payment policy on July 15, 2005. This new policy is designed to entice patients to choose health care providers at a clinic for their first ambulatory visit instead of at a hospital, thus reducing medical expenditures for ambulatory care. Specifically, the new policy increased co-payment fees for outpatients at district hospitals, regional hospitals, and academic medical centers to NT$80, NT$240 and NT$360, from NT$50, NT$140, and NT$210, respectively.[5] The co-payment fees for outpatients at

[5] The new co-payment policy also increased the co-payment fees for emergency room care at regional hospital and academic medical research center to NT$300 and NT$450, from the present NT$210 and NT$420, respectively.

local clinics remain NT$50. Patients who are referred to the hospital pay a NT$50 co-payment at local clinics in addition to the hospital co-payments, which are NT$50, NT$140, and NT$210 at district hospitals, regional hospitals, and academic medical centers, respectively. The co-payment policies for ambulatory care from 1995 to 2005 are displayed at Table 2.1-2.3.

Table 2.1 [a] : Co-payment Policy for Ambulatory Visits (NT $) [b]

Year	Clinic	District hospital		Regional hospital		Academic Med. Ctr.	
1995-1997	50	50		100		100	
1998-2001	50	50		100		150	
2002-2004	50	50		140		210	
2005	-----	Non-Referral	Referral	Non-Referral	Referral	Non-Referral	Referral
	50	80	50	240	140	360	210

[a] Source: Bureau of National Health Insurance and Liu and Chen (2002)

[b] Unit: 1US$=31.5 NT$

Table 2.2 [a] : Co-payment Policy for Excessive Utilization (NT $) [b]

Ambulatory Visits in 1999	Ambulatory Visits in 2000 and after	Co-payment /per visit
Start from the 49th Ambulatory visits	Start from the 25th Ambulatory visits	50 plus co-payment in Table 1
Start from the 157th Ambulatory visits	Start from the 157th Ambulatory visits	100 plus co-payment in Table 1

[a] Resource: Bureau of National Health Insurance and Liu and Chen (2002)

[b] Unit: 1US$=31.5 NT$

Table 2.3 [a] : Drug Co-payment Policy (NT $) [b]

Total drug cost	Below 100	101-200	201-300	301-400	401-500	Above 501
1995-1998	0	0	0	0	0	0
1999 and after	0	20	40	60	80	100

[a] Source: Bureau of National Health Insurance and Liu and Chen (2002)

[b] Unit: 1US$=31.5 NT$

Although the BNHI expected that this new co-payment policy would effectively promote the referral system in Taiwan, the pricing mechanism does not provide sufficient incentive for patients to participate. Analysis of the success of the co-payment policy needs to include the full out-of-pocket costs to the consumer, which are the co-payment plus registration fees. Registration fees are levied per contact with the provider. They are set by the relevant providers' associations with ceilings imposed by NHI law. In general, patients are charged NT$150 registration fees at regional hospitals and academic medical centers and NT$100 at district hospitals and clinics for each visit. By examining registration fees, we can illustrate the insufficient incentives provided by this pricing mechanism (see Figure 2.1 and Table 2.4).

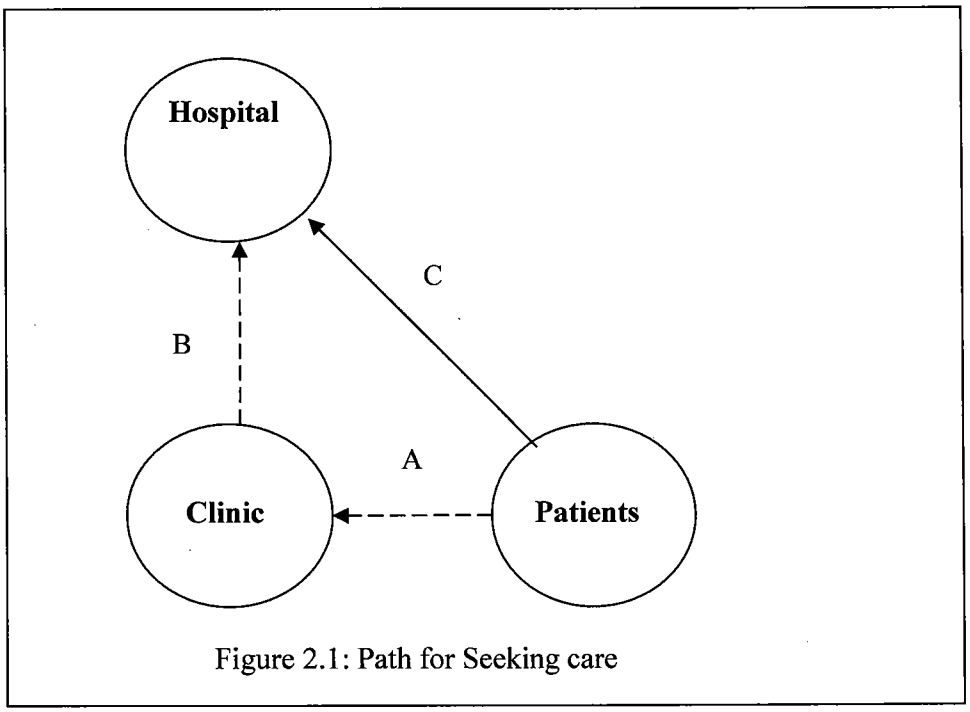

Figure 2.1: Path for Seeking care

Table 2.4: Costs comparison for ambulatory care (NT $) [a]

	Referral from Local Clinics			Non-Referral
Costs / Refer To	Clinic Level (A) [b c]	Hospital Level (B)	Total Cost (A)+(B)	Total Cost (C)
District Hospital [c]	150 (50+100)	150 (50+100)	300	180 (80+100)
Regional Hospital [c]	150 (50+100)	290 (140+150)	440	390 (240+150)
Academic Med. Center [c]	150 (50+100)	360 (210+150)	510	510 (360+150)

[a] Unit: NT$, 1US$=31.5 NT$.

[b] Co-payment fee in clinic level is NT$50.

[c] Regional hospitals and academic medical centers charge NT$150 for registration fees. District hospitals and clinics charge NT$100 for registration fees.

If a patient follows the referral system promoted by the BNHI, he/she first seeks ambulatory care at a local clinic. Provided that the patient's illness is serious, the physician at the local clinic will refer him to a hospital. The patient's path to seek ambulatory care is from A to B, as illustrated in Figure 2.1. If the patient does not follow the referral system, his/her path to seek ambulatory care is path C (Figure 2.1).

Since the NHI gives patients the right to freely choose their health care providers, the question is whether or not the patient will follow the referral system. Table 2.4 displays the minimum out-of-pocket payments under each alternative pathway A $\rightarrow$ B or pathway C. If the patient follows the referral system, he will have to pay at least NT$300, NT$440, and NT$510 at the end of each ambulatory visit to district hospitals, regional hospitals, and academic medical centers, respectively. The patient, who expects that treatment in a hospital is necessary, will not participate in

this referral system. The cost for ambulatory care with and without a referral is the same if he/she chooses care at academic medical centers, and it is NT$50 and NT$120 less if he/she chooses care at regional hospitals and district hospitals, respectively. Hence, this pricing mechanism will not generate the desired result, due to insufficient incentives for patients to participate in the referral system.

The incentive problem affecting whether or not a patient participates in the BNHI's referral system is a typical principal-agent problem in economics theory. Namely, the principal (BNHI) wants to induce the agent (patients) to take some actions (follow the referral system) which are not desired by the agent (patients). The principal (BNHI) has to impose two constraints on the agent (patients) to achieve his/her objective. The first is called participation constraint, meaning that the principal (BNHI) must design a pricing mechanism that insures the agent (patient) obtains at least some reservation level of goods or services in order to be willing to participate. The second is called incentive compatibility, meaning that the agent will take the best action (i.e., follow the referral system) from the viewpoint of the principal (BNHI). If the participation constraint is not satisfied, the options provided by the principal to the agent are not feasible, meaning that the incentive compatibility will never be satisfied (Varian, 1992).

As indicated in Table 2.4, the new co-payment policy does not satisfy the participation constraint in the principal-agent theory. The dissatisfaction of the participation constraint generated by this pricing mechanism will deteriorate further if non-monetary costs (such as the cost of transportation time, waiting time, and

complexity of referral paperwork) are added into the cost of participation in the referral system. In addition, this pricing mechanism relies most on the patient's expectation of whether or not he needs treatment in a hospital. Assuming risk-adverse behavior in seeking care, for a patient to minimize expected cost, he will first seek care from a hospital rather than from a clinic. Consequently, this new co-payment policy results in the anti-referral phenomenon currently prevalent in Taiwan.

Since the new co-payment policy is unlikely to promote the referral system in Taiwan, our focus is on the estimation of the welfare loss (or gain) resulting from the new co-payment policy in the following sections.

2.3 Model Specification

The hurdle model for count data is used in this paper to incorporate two aspects of health care utilization: the first one is that the distribution of the number of ambulatory visits can take only non-negative integer values; the second one is that the decision to utilize health care service is a two-part decision making process. To understand the econometric specification of the hurdle model for count data, we start with the introduction of basic count data models.

(1) Basic count data models

Let Y be a random variable indicating the number of ambulatory visits, and let μ_i represent the mean of the number of ambulatory visits. The probability that y follows the Poisson distribution with parameter μ_i $(\mu_i > 0)$ is

[1] $\Pr\{Y = y_i \mid \mu_i\} = \frac{e^{-\mu_i}\mu_i^{y_i}}{y_i!}$, $y_i = 0,1,2,3,\cdots\cdots$

Typically, y_i is regarded as an endogenous variable. To incorporate exogenous variables, μ_i can be specified by equation [2].

[2] $\ln \mu_i = x_i'\beta$, $i = 1,2,3,\cdots\cdots N$

where β and x_i are column vectors of parameters and exogenous variables, respectively.

Equation [1] implies equality of the conditional mean and the conditional variance. However, the equi-dispersion property rarely fits in practice, since the conditional variance is greater than the conditional mean in most applications. Furthermore, the negative binomial model is useful for predicting probability, not just modeling the mean. Hence, we assume that our dependent variable follows a negative binomial distribution which allows inequality of the conditional mean and the conditional variance. To derive the negative binomial model, the unobserved heterogeneity between individuals (ε_i) is included in equation [2]. Hence, we obtain

[3] $\ln \tilde{\mu}_i = x_i'\beta + \varepsilon_i$, $i = 1,2,3,\cdots\cdots N$

We define $\delta_i = \exp(\varepsilon_i)$ and assume $E(\delta_i) = 1$ for the purpose of identification. Note that $E(\delta_i) = 1$ implies $E(\tilde{\mu}_i) = \mu_i$. Hence, the distribution of Y given δ_i is as follows:

[4] $\Pr\{Y = y_i \mid \delta_i\} = \frac{\exp(-\tilde{\mu}_i)\tilde{\mu}_i^{y_i}}{y_i!} = \frac{\exp(-\mu_i\delta_i)(\mu_i\delta_i)^{y_i}}{y_i!}$