Should I Stay or Should I Go Now? (To the Hospital)

Modeling the Impact of Introducing a Telemedicine System in a Remote Amazonian Community

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Abstract

The health needs of rural and remote populations are often not fully addressed as health care professionals agglomerate in urban areas. Telemedicine utilizes modern telecommunications technology to extend health care resources to these populations, overcoming obstacles of time and space. Thus far, scholarly literature on the impact of telemedicine has been limited to weakly persuasive empirical evaluations of specific interventions. This paper constructs an economic model of the introduction of a telemedicine system to a remote Amazonian community. It finds that patients do not seek health care if the quality of care available in the village is below a threshold value, as the opportunity cost of receiving care outweighs its health benefits. This implies that government investments should only target health if this threshold value can be met.

JEL Classification: I; I1; I14; I15; I18; O; O38

Keywords: Telemedicine, Health Care, Remote Populations, Health Care Policy

1. Introduction

In a world afflicted with systemic structural inequalities, a large segment of the poor are the rural and remote.[1] In the United States, rural residents are in poorer health and have more difficulty receiving adequate health care compared to urban residents (Roh, 2008). The difference between urban and rural care can be even greater in other countries around the world (Loureiro et al., 2007). This disparity is largely due to challenges from distance, accessibility, and profitability, as health care professionals agglomerate in urban centers. With interest in global health and inequalities rising, the development of effective health care delivery methods for rural and remote regions has become a fundamental issue.[2]

Telemedicine attempts to address this problem by utilizing modern telecommunications technology to extend health care resources, overcoming obstacles of time and space. Through a satellite link or radio waves, rural health care providers are connected to urban physicians and specialists. The potential of these communication networks is vast, with applications in the continued education of health professionals in the field, the facilitation of patient transfer in health networks, and clinical use in diagnosis and consultation. Telemedicine, when applied appropriately, can improve the quality of health care and greatly extend access to limited health resources. Alongside

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[1] As of 2002, 16.8% of rural populations were living in poverty, compared to 11.2% of urban populations (USDA ERS, 2004)

[2] Many programs have emerged including USAID's Health Systems Strengthening (usaid.gov), UN Foundation's mHealth Initiative (unfoundation.org), and the U.S. Department of Health and Human Services' Health Resources and Services Administration (hrsa.gov).

these potential gains in patient welfare comes the possibility for reductions in overall health care costs as patients seek more preventative care and less emergency care. Despite this, telemedicine is not without critics, who claim that the technology does not allow for the transfer of diagnostic-quality information, and thus should not be used as a substitute for face-to-face health care. Other objections include speculation on the overall effect of telemedicine on cost as expensive technology is introduced to traditionally low-cost environments (Bashshur, 1995).

It is essential, then, to analyze and evaluate these telemedicine interventions for their effect on health care demands, costs, and patient outcomes. The resolution of these issues will ultimately guide important policy decisions that affect the health and well-being of millions around the world. Thus far, scholarly literature discussing telemedicine has been primarily comprised of weakly persuasive empirical evaluations of specific telemedicine interventions. Few papers have examined the changes in health care demand and costs brought about by telemedicine systems.

In this thesis, I will first discuss more thoroughly the existing literature surrounding telemedicine programs. I will then construct an economic model to examine the introduction of a telemedicine system to a remote Amazonian community and apply calibrations to perform simulations given my personal experience and field research in that particular community. Through this evaluation, I will be able to comment on the impact of introducing telemedicine on the decision making of patients in remote communities. Additionally, I will determine the effect on population welfare for the change in government expenditure, providing a simple cost-benefit comparison, thus leading to potential policy implications for health care delivery to remote populations.

2. Literature Review

Various telemedicine programs can be found across many countries in Africa, Asia, and the Americas, including the United States. Even so, telemedicine faces many barriers to widespread implementation. While one significant barrier is the lack of telecommunications infrastructure in remote areas of the world, another is the lack of conclusive evidence proving its efficacy, especially in terms of its economic costs and benefits. Surveying related literature shows that in the past twenty years, many of the telemedicine systems were simply implemented by administrative bodies trying to improve health systems. The implementation was not designed as a research tool to better understand the benefits of telemedicine. These implementations have focused on the use of telemedicine in very specific settings such as acute stroke care (Pedagrosa et al., 2009) and patient assessment for aeromedical retrieval (Mathews et al., 2008). While useful in describing the effects of the specific scenario, these studies do not significantly contribute to an overall evaluation of telemedicine.

The pitfalls common to these two studies are the same obstacles that almost all researchers face when trying to evaluate a telemedicine implementation. In nearly all analyses of telemedicine systems, the study is designed around the system's implementation, as opposed to having the implementation designed around the hypotheses of a study. Instead of carefully designing and planning a randomized intervention with targeted data collection, researchers seem to be retrospectively collecting data to compare usage and health outcomes before and after the provision of the telemedicine system. Another issue is the lack of observations. Especially when dealing with specialized medicine in rural areas, there are often too few cases to confidently conclude statistically significant results. Both the Pedragosa et al. (2009) and Mathews et al. (2008) studies would have benefitted from a larger sample size, but the communities they were operating in were simply too small. This is an intrinsic problem with rural and remote communities, as they are often smaller due to their isolation.

Beyond this, there is no established framework or methodology through which researchers can examine the economic effects of telemedicine implementations. There have been papers that analyze the changes in costs (Le Goff-Pronost & Sicotte, 2010) or demand (Berman & Fenaughty, 2005) using economic modeling and analysis, but I have yet to encounter a paper that successfully incorporates changes in both. The Le Goff-Pronost & Sicotte (2010) paper utilizes calculations of costs and savings based on the investments and variable costs required to establish the telemedicine link for pediatric cardiology consultation that they describe between a community hospital and a regional hospital in Canada. The investigators determine savings based on travel costs avoided by patients and doctors, as well as reductions in hospital stays and gains in productivity. Le Goff-Pronost & Sicotte take their evaluations a step further by calculating the breakeven point in terms of number of consultations required, as well as net present value of future benefits. However, they do not consider the benefits to patients derived from improved patient outcome, nor the changes in demand that arise due to the increase in health care access. In their case study, the telemedicine system performed more as a complement to the existing care.

In contrast, the Berman & Fenaughty (2005) paper contributes a model for health care demand in a managed care scenario. They construct a model of health that depends on the quality of care received, personal and household characteristics, as well as a random factor, noting that the elasticities with regards to this consumption are low. Given this model for demand, the authors calculate the value to the patient of a new option for care by using welfare analysis. Berman & Fenaughty calculate the compensating variation for both the change in quality of care and the opportunity to consume this new type of care. After defining utility through the Random Utility Model, leading to a linear health care demand equation based on the perceived quality and the personal characteristics, the authors applied this model to a case study in rural Alaska. There, a telemedicine program was installed to aid in the treatment of patients suffering from otitis, or ear inflammation. This telemedicine program was designed to supplement the existing care structure that involves a community health practitioner (CHP) consulting a regional clinic physician. With the telemedicine system, the physician was able to see digital images of the ear canal, leading to an increased amount and quality of information available to the consulting physician. Other benefits described were improved communication between the health care providers, as well as improved education for both the CHP and patient.

It is evident that work must be done to establish a standardized framework for evaluating telemedicine and its effects on the health of different communities. In other fields, there is an accepted methodology used to evaluate complex interventions. In health and development, this framework includes multiple steps that build upon one another to produce a rigorous analysis of the intervention and its effects (Campbell et al, 2000). The framework described includes five main steps in the development process. The first is the preclinical step, where the theory behind the intervention is established. In Phase I, modeling is completed to identify the components of the theory that will influence the outcomes and to predict how those components will interact with one another. Phase II consists of an exploratory trial where an actual experiment is designed and its feasibility is explored. Phase III requires the development of the main randomized control trial that will compare the intervention with a suitable control group in a manner that is theoretically justified and reproducible. Finally, Phase IV examines the implementation of the intervention into practice, keeping an eye on the rate of uptake and the expansion to new subject groups. Such a framework would be enormously beneficial to the field of telemedicine. The introduction of a standardized form would force investigators to carefully consider and control the interventions that they are bringing into communities.

It is my goal for this thesis to capture the first two steps of such a framework. I have synthesized the appropriate theory and will now create a model where I will seek to identify the key parameters that affect the consumption of health care in remote communities. As demonstrated in these papers, the specific circumstances into which telemedicine is introduced greatly influences both the approach in modeling and the manner in which telemedicine enters the model. Therefore, before establishing the theoretical framework of my own model, I must first describe the circumstances that surround this specific implementation of telemedicine. Unlike the studies where telemedicine is used for the treatment of a specialized field of medicine, the telemedicine intervention I examine was introduced into a remote community to improve general access to health care. Further details are now provided.

3. Institutional Details

In the Amazon River basin, there are many small riverside communities that exist in extreme isolation, where primary health care is sporadic and emergency care is costly and deficient. One such community is the Lake Cuniã community, on the shores of a lake near the Madeira River. The Lake Cuniã community has a population of 300-400 people living many kilometers and hours by boat from larger towns and cities. The community is serviced by a small health outpost consisting of two examination rooms, a basic laboratory with a microscope, and three community health agents living permanently in the community. Power lines providing a constant supply of electricity recently arrived to the community.

The community suffers mainly from acute health shocks such as respiratory infections and tropical infectious diseases, as well as chronic ailments such as diabetes and hypertension. Basic health care services are provided by the community health agents at the health outpost. Though the health center is understaffed, supply of pharmaceuticals is not a serious issue, as they receive deliveries of medicine once a month. In emergency cases, an ambulance boat brings the patient a couple of hours down the river to a clinic in a larger community, or the hospital in the capital city. Chronic illnesses and other ailments that cannot be immediately treated but do not warrant emergency transport are documented to be presented to doctors who visit the community once a month on a boat. During the dry season, however, the boat is often unable to pass through the shallow waters, and the doctors are unable to service the community. Once a year, a group of medical students spends a month at the community providing basic primary health and dental care. Outside of these services, the community receives no additional access to health care services.

By Brazilian law, health care is provided to all permanent residents of Brazil and is free at the point of service. Each state manages its own health care program, including investments in technologies and infrastructure such as telemedicine programs. The salaries of health professionals, including the community health workers in the Cuniã community, are provided by the government. Private health institutions are reimbursed by the government for care provided to patients.

In the summer of 2010, I traveled to the community to implement a telemedicine system that established a connection between the Cuniã health post and physicians in the state of São Paulo. This pilot project was developed and funded by the Edumed Institute, a Brazilian NGO, with support from the state government of the Lake Cuniã community. Utilizing a satellite link to provide both store-and-forward and real time consultations, the telemedicine program is geared towards assisting in triage, as well as managing chronic diseases such as hypertension and diabetes.

4. Theoretical Framework

Given this institutional scenario, I will base my theoretical framework around the decision of a member of the remote community whether or not to make the trip to the hospital to seek treatment. Following standard economics methodology, I will model this decision as a patient optimizing his utility subject to a particular budget constraint. I expect to show that with telemedicine, the overall health and utility of the community is improved. With these results, I will describe how the government should allocate its resources towards providing traditional health care or investing in programs such as telemedicine. I assume the government supplies health care through these two avenues in order to maximize the health or welfare of its population. Solving the optimal choices of the patient in this model will shed light on the factors that affect the patient's decision and indicate the appropriate amount of government investment in telemedicine. Insight will be gained on the effect of these investments on health outcomes and overall welfare for this remote community. Acknowledging the details that are specific to my community and addressing commonalities found elsewhere will allow me to generalize the results to other regions around the world.

Utility Maximization by Patients

The patients in the remote community can be described as maximizing utility based on their level of health and other consumption in each time period t. As in the Le

Goff-Pronost & Sicotte (2010) model, I will utilize an additively separable utility function where health (H) and other consumption (O) enter linearly. The simplicity of this model allows me to perform an analytical evaluation that provides a base for the patient's health care choice simulations.[3] In each time period t, an individual's utility function is

$$U_t = \alpha H_t + (1-\alpha)O_t,\ 0 < \alpha < 1 \quad (1)$$

For the interest of simplicity, I will examine a two period model and a three period model, where patients will maximize their total utility across time periods subject to their budget constraint.

$$max \sum_{t=1}^{T} \rho^{t-1} U_t\ , where\ T = 2\ or\ 3 \quad (2)$$

We can see that future utility is discounted at a rate of ρ and the present value of total utility is maximized.

A patient will choose optimal levels of H_t and O_t given the relative costs, as expressed in a budget constraint. Because of the simple nature of their employment, I assume that the income that the villagers are able to earn is directly proportional to the amount of labor they supply. Writing a budget constraint in units of time is appropriate and useful, as the cost of seeking medical care is also proportional to time. Patients traveling to the health care center to receive treatment lose time that they would otherwise have spent working. For simplicity, I assume that villagers provide labor

[3]To check for robustness, I perform the same simulations with a Cobb Douglas utility function and generate the same quantitative results. This can be found in Table 3 in the Appendix.

inelastically, aside from spending time to consume health care. This eliminates leisure time from the budget constraint. Therefore, the budget constraint will take the form of

$$L_t + p_V T_V + p_H T_H = 1, where \quad (3)$$

$$0 \leq p_V \leq 1 \; and \; 0 \leq p_H \leq 1$$

where L_t is labor supplied and p_V and p_H are the prices of the health care choices T_V and T_H, in terms of time. T_V represents treatment in the health outpost within the community, and T_H represents treatment at the regional hospital. Therefore, p_V should be relatively low and p_H should be much higher, capturing the relative cost of the two types of health care.

To translate labor provided into consumption, L_t enters into the utility function such that

$$\delta * L_t = O_t \quad (4)$$

Here, δ represents the relative value of labor in terms of utility. It is essentially a measure of the purchasing power or wage rate of the labor supplied by the villager. Thus, with reference to the utility function above, O_t is a simple function of L_t, while H_t is a more complicated function that depends on previous health as well as treatment sought, if any.

<u>The Health Stock</u>

An individual's health stock is a state variable that changes over time. Each villager is endowed with an initial level of health H_0, and this endowment is subsequently affected by possible health shocks and treatment decisions in each period. The current level of the health stock in a period t enters the utility function for that period, as people generally base their current levels of happiness on their current levels of health. If the health stock reaches zero, this is equivalent to death. The function is defined as

$$H_t = H_{t-1} S_t \qquad (5)$$

S_t modifies the health from the previous period by incorporating both any health shock ε_t experienced and the effect of any treatment pursued, represented by β_t in the equation

$$S_t = \min\left[\frac{\varepsilon_t}{1-\beta_t}, 1\right], where\ 0 \le \varepsilon_t \le 1\ and\ 0 \le \beta_t \le 1 - \varepsilon_t \qquad (6)$$

S_t is bounded at a maximum of 1 such that if the patient seeks full treatment, the result is no decrease in health stock in the next period. The bounds for ε_t imply that a health condition that yields an ε of zero equating to death and a health shock with no effect on health stock producing an ε of one. S_t is also influenced by β_t, the parameter that captures the effectiveness of any treatment that the patient seeks. It can be seen that a β_t of zero does nothing to mitigate the shock from ε_t, while a β_t approaching $1 - \varepsilon_t$ works to cancel the shock out entirely. As the shock becomes more serious, more treatment is necessary to counteract its effects.

The amount that treatment improves health depends on the type and quality of care received. Without telemedicine, there are four options presented to the villagers.

They can choose to visit the health outpost in the community at a low cost, travel to the state capital to visit the hospital at a much higher cost, do both, or choose neither. The quality of care received and therefore the improvement in health is different for each choice. The introduction of telemedicine should serve to improve the quality of care received at the health outpost and ultimately may increase utility. The effects of these various factors are captured in the equation for β_t.

$$\beta_t = \frac{1}{4}[\gamma_V T_V^t + \gamma_H T_H^t + 2\gamma_V T_V^t \gamma_H T_H^t], \quad (7)$$

$$where\ 0 < \gamma_V < 1, 0 < \gamma_H < 1$$

Here, T_V and T_H represent treatment sought in the village health post and treatment sought at the regional hospital, respectively. Their contributions to the effectiveness of treatment are mediated by the terms γ_V and γ_H, which represent the quality of care in each location. These gammas are influenced by the level of government investment in both traditional medicine (increasing γ_H) and telemedicine (increasing γ_V). An additional feature of the effect of treatment is the opportunity for complementarity between T_V and T_H.

The effect on health also depends on what type of health shock the patient is suffering. For this model, I am most interested in two types of health shocks (1) acute health shocks such as a dermatological lesion or a respiratory infection, and (2) chronic health conditions such as hypertension and diabetes. To capture this, I will analyze the model for each type of health shock. First, the health shock function for an acute condition is represented by

$$\varepsilon_t = 1 - a_t \quad (8)$$

Here, a_t represents the acute shock, and is bounded between zero and one. Thus, an acute shock can range in severity from mild to death as a_t increases. For the chronic analysis, the health shock is defined as

$$\varepsilon_t = 1 - c_t, where \quad (9)$$

$$c_{t+1} = c_t * (2 - \beta_t) \quad (10)$$

We can see that once the chronic condition begins, it will persist in future periods. Additionally, its negative effect on health will compound if it is left untreated.

The Decision

Given these functions, a villager will maximize his utility, weighing the expected increase in H from their decision to pursue T_V, T_H, both, or neither against the cost associated with that course of action. When a sick villager is making the decision whether or not to seek treatment, he will seek to maximize Equation 2, subject to Equation 3 for the current period. The patient may choose T_V and T_H, and will observe α, p_V, p_H, and perceived values of ε_t, γ_V, and γ_H. The decision to act, however, is bound to the current period. The patient cannot borrow against future income in an attempt to smooth the loss in consumption across periods. This situation is reinforced by the lack of a credit market. While the subject cannot borrow from future periods, he can still be myopic, considering his decisions in future periods when making a choice in the current period.

The allocation of government resources, which will be discussed next, will have an impact on this decision as the quality and uncertainty of care at each point is affected by investment in traditional medicine or telemedicine. The introduction of a certain threshold level of telemedicine may lead to an improvement in the quality of T_V via an increase in γ_V from government investment.

Investment by the State Government

Just as the villagers are the consumers of health care treatment, the state government is the producer. The government can choose to allocate its resources drawn from various sources such as taxes, federal money, and other revenues to maximize the "welfare" of the state population. This "welfare" could be seen as maximizing the utility of the population, or it could be seen as maximizing the health H of the population. At a base level, this may also simply mean the minimization of expenditure in order to achieve a targeted minimum level of health. These expenditures can be spent on either traditional medicine or telemedicine. Realistically, the expenditures should be divided within each between basic capital and labor inputs. In traditional medicine, capital would include purchases such as more boats to service remote communities and improved facilities at the points of service. Labor would include hiring more doctors, nurses, and community health agents. Investment in capital for telemedicine would include communications equipment such as a satellite dish, electricity, computers, and devices to digitally transmit biometric information. Labor for telemedicine would include technicians and the same health professionals that would typically act in traditional roles. In the model, however, I will assume investment in either traditional medicine or telemedicine to directly affect γ_V and γ_H.

One can begin to see the impact on the villager's health care decision that increased investment in telemedicine may encourage. The optimal allocation of government resources will depend on other aspects of the model such as the complementarity or substitutability of telemedicine and traditional medicine, as well as the impact of telemedicine on expected health gains from treatment. Ultimately, telemedicine may prove to increase population health while decreasing overall expenditure, or it may increase population health while increasing expenditure. This type of comparison will determine possible policy implications.

5. Results and Discussion

Acute Health Conditions: Analytics

To evaluate the model and generate results, I will analyze two scenarios of the patient's decision. The first will analyze the decision of T_V and T_H for a villager suffering from an acute health condition. The time frame for this analysis will be two periods, with the shock suffered in the first period. This way, we can see how the villager chooses to address the health shock in the first period in order to avoid the negative effects of diminished health in the second period. We can see that the utility trade off comes when the patient must decide whether to forgo consumption in the first period to maintain health for the second period. To assist my analysis, I have utilized the computational program Mathematica to simulate the patient's optimal choices of T_V and T_H in the first period.

Before introducing the results from the simulations in Mathematica, I will present the analytical results of the model. Of all the parameters of interest from Equations 1-10, some will be treated as universal in the health system and unvarying when I evaluate the model. These include α, the relative weight of health versus consumption; ρ, the discount factor; and H_0, the initial health stock. The scope of the health system in this model is representative of many independent and isolated communities in the Brazilian Amazon that all rely on the same regional hospital. Because of this definition, it is not unreasonable that the members of these communities would have similar preferences and initial health stocks.

Other parameters may be universal in the system but varying in the model, such as γ_H. The remaining parameters are village-specific, and include p_V and $p_{H,}$ δ and γ_V. With the exception of p_V, all of these parameters will vary within the model. I expect p_V, while formally village-specific, to be approximately universal across all villages, as the size of these villages and the accessibility of the health outpost within the village should not vary greatly. Therefore, in this model, I am most interested in examining the changes in the optimal consumption of T_V and T_H as γ_V and γ_H change, all within a village with a given p_V, p_H, and δ. I am also interested in how differences in village characteristics change those effects of γ_V and γ_H on T_V and T_H. Finally, I wish to see if the effects are different for an acute injury of varying levels of severity. This is controlled in the model by the value of a_t. The nature of these parameters is diagrammed in Figure 1.

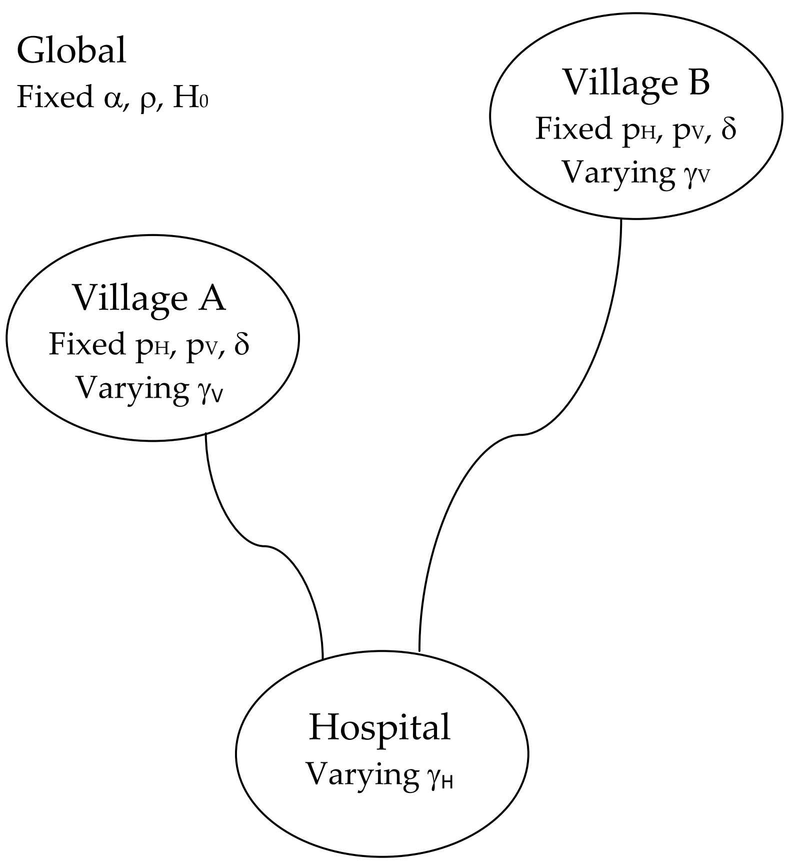

Figure 1 Diagram of parameters of interest

Turning back to the theoretical framework, we can begin to answer these questions. Maximizing the sum of the utilities across two periods (Equation 2) with respect to T_V and T_H subject to the budget constraint (Equation 3) and solving the first order equations yields the following implicit solutions for T_V^* and T_H^*

$$T_V^* = \frac{p_H\gamma_V - p_V\gamma_H}{2p_V\gamma_H\gamma_V} + \frac{p_H}{p_V}T_H^* \tag{11}$$

$$T_H^* = \frac{p_V\gamma_H - p_H\gamma_V}{2p_H\gamma_V\gamma_H} + \frac{p_V}{p_H}T_V^* \tag{12}$$

Further differentiation of these equations yields informative partial derivatives.[4]

$$\frac{\partial T_V^*}{\partial T_H^*} = \frac{p_H}{p_V} \tag{13}$$

$$\frac{\partial T_V^*}{\partial \gamma_V} = \frac{1}{2{\gamma_V}^2} \tag{14}$$

$$\frac{\partial T_V^*}{\partial \gamma_H} = -\frac{p_H}{2p_V{\gamma_H}^2} \tag{15}$$

$$\frac{\partial T_H^*}{\partial \gamma_V} = -\frac{p_V}{2p_H{\gamma_V}^2} \tag{16}$$

$$\frac{\partial T_H^*}{\partial \gamma_H} = \frac{1}{2{\gamma_H}^2} \tag{17}$$

From these partial derivatives, we can see how the optimal choice of T_V and T_H change with changes in the quality of care in the village and quality of care at the hospital. The result from Equation 13 shows a positive relationship, indicating complementarity between T_V^* and T_H^*. Equations 14-17 also give familiar results, as own demand for each type of health care is increasing in its own quality, and decreasing in the quality of the other. This last piece is interesting, as it shows that the two types of health care still

[4]Note that these partial derivatives are limited as they assume a fixed value of T_V^* or T_H^*.

possess come of the characteristics of substitutes in addition to compliments. Next, I further differentiate some of these equations to see whether the decision changes from village to village. The cross-partials of interest are

$$\frac{\partial^2 T_V^*}{\partial \gamma_V \partial p_H} = 0 \tag{18}$$

$$\frac{\partial^2 T_V^*}{\partial \gamma_H \partial p_H} = -\frac{1}{2 p_V {\gamma_H}^2} \tag{19}$$

$$\frac{\partial^2 T_V^*}{\partial \gamma_V \partial \delta} = 0 \tag{20}$$

$$\frac{\partial^2 T_V^*}{\partial \gamma_H \partial \delta} = 0 \tag{21}$$

$$\frac{\partial^2 T_H^*}{\partial \gamma_V \partial p_H} = \frac{p_V}{2 {p_H}^2 {\gamma_V}^2} \tag{22}$$

$$\frac{\partial^2 T_H^*}{\partial \gamma_H \partial p_H} = 0 \tag{23}$$

$$\frac{\partial^2 T_H^*}{\partial \gamma_V \partial \delta} = 0 \tag{24}$$

$$\frac{\partial^2 T_H^*}{\partial \gamma_H \partial \delta} = 0 \tag{25}$$

Most of the equations above show the cross-partial relationship to equal zero. This implies that the changes in T_V and T_H due to changes in γ_V and γ_H generally do not vary from one village to the next. Equations 18 and 23 imply that the change in consumption of each type of health care with respect to change in its own quality is independent of the price of the other type of care. Equations 20, 21, 24, and 25 show that the effects of quality of care on health care consumption are independent of the purchasing power of the villagers. This is not unexpected, as δ simply acts as a translator between amount of labor supplied and utility derived.

Equations 19 and 22, however, show some more interesting results. Equation 19 implies that as the cost of making the trip to the hospital increases (i.e. the village is farther away, gasoline prices increase, etc), the effect of the quality of care at the hospital on consumption of care in the village decreases. Because this effect was originally negative (Equation 15), this cross-partial represents the idea that as distance from the hospital increases, improvements in quality there are less likely to reduce your intake of care at the village outpost. Equation 22 provides a similar result, as it states that as the cost of travelling to the hospital increases, the effect of an improvement in quality of care in the village is magnified in its reduction of consumption of health care at the hospital (Equation 16). These results, while logical, give credibility to the model and are further supported by the following simulations.

Acute Health Conditions: Simulation

In simulating the model, I begin by defining parameters to match the environment. In this simulation, the a_t of interest will be .3, a moderate health insult. Next, I assume values for the universal, unvarying parameters. I adopt a value of .5 for α, giving equal weight to health and other consumption. For the discount rate ϱ, I assume a constant rate of 3.5 percent, a value taken from literature in the field (Moore et al, 2004). Next, I arbitrarily assign a value of 100 to both H_0 and δ, setting their maximum contributions to utility equal. Finally, I assume a value of .2 for p_V, meaning that a patient must sacrifice one fifth of potential labor supply in the period for each "unit" of care sought in the village. With these assumptions in place, I vary the remaining parameters γ_V, γ_H, and p_H while solving each time for the optimal choices of T_V and T_H in order to maximize the utility across the two periods. The results from the simulations can be seen in Table 1.1 and Table 1.2.[5]

From the simulation data, we see that there appears to be "threshold effects" taking place as the quality of health care in the village increases. Under these conditions, when γ_V is below 0.3, the patient chooses not to seek any care, electing instead to maximize utility by fully supplying labor in period one. While this result is optimal for the decision-maker maximizing utility, it is also concerning. Populations in these remote communities suffering from the low quality of care currently in place are sacrificing their health every day to continue working. As γ_V rises, the patient eventually chooses to seek care, primarily at the community health outpost. There is also evidence of the complementarity effect, as care within the community is consumed along with hospital care once the decision to treat has been made. On the other hand, there is little gain in utility from increasing the quality of care at the hospital, γ_H. This suggests that the cost of going to the hospital is so high that in cases of a moderate acute injury, there is little overall benefit in travelling to the hospital to seek care.

[5] Data tables can be found in the Appendix

To determine how these effects differ for different villages, Table 1.1 and Table 1.2 also include simulations run for villages with varying p_H. As the opportunity cost of traveling to the hospital decreases, the patients begin treating at a lower threshold level of γ_V. However, this effect is weak and requires a significant (30%) reduction in p_H. To better visualize these results, Figures 2-5 depict the changes in consumption of health care based on varying price. In Figure 2, we see that, as predicted by the theoretical model, there is little change in the slope of the T_v to γ_V line as the price of seeking care in the hospital changes. Figure 3 shows this as well with regards to the slope of the T_H to γ_V line. These results concur with Equations 18 and 23, which predict no cross-partial relationship. Figures 4 and 5, on the other hand, show the changes in the slopes as predicted by the theoretical analysis. In Figure 4, the lines flatten as p_H increases, showing the negative cross-partial relationship of Equation 19. Figure 4 depicts a positive cross-partial relationship as predicted by Equation 22.

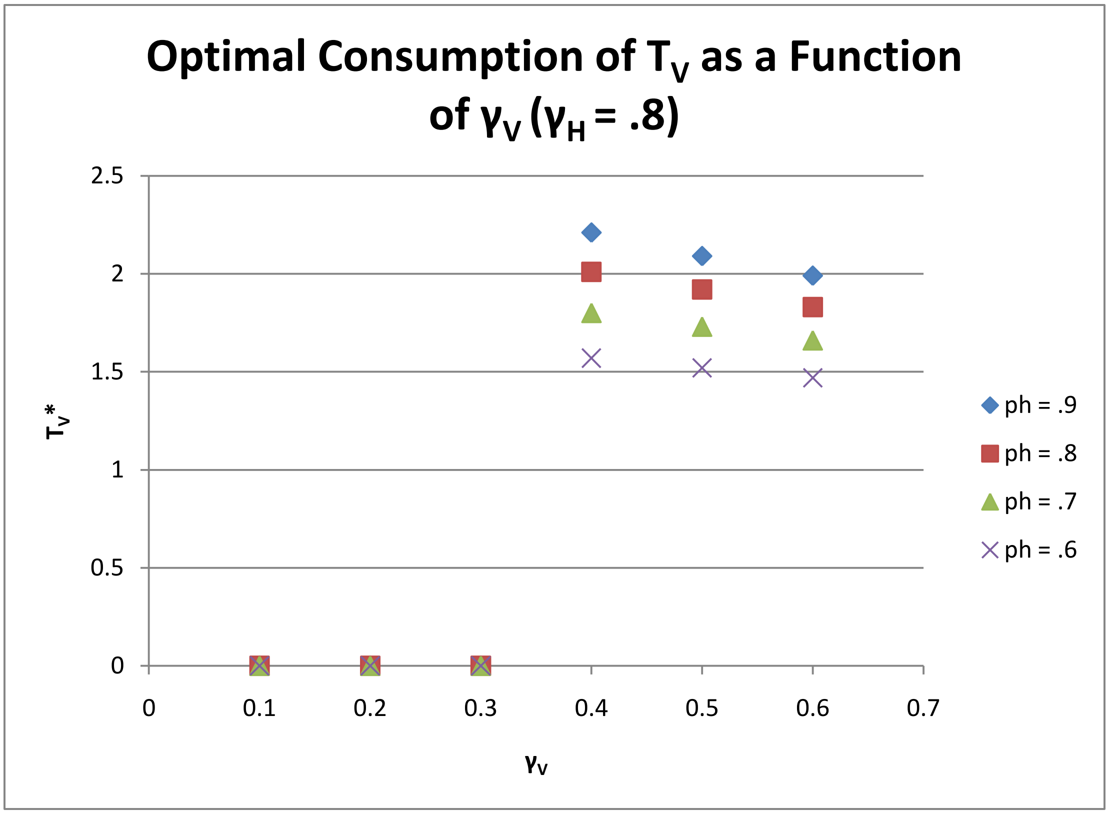

Figure 2

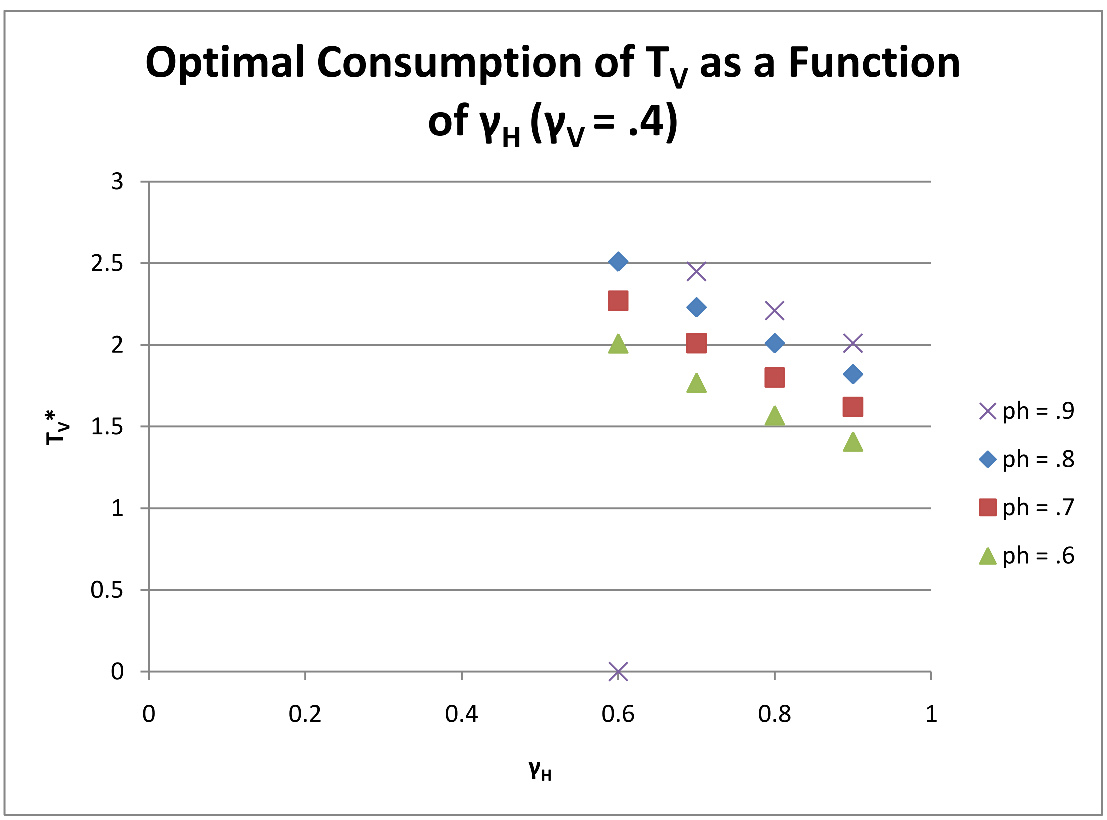

Figure 3

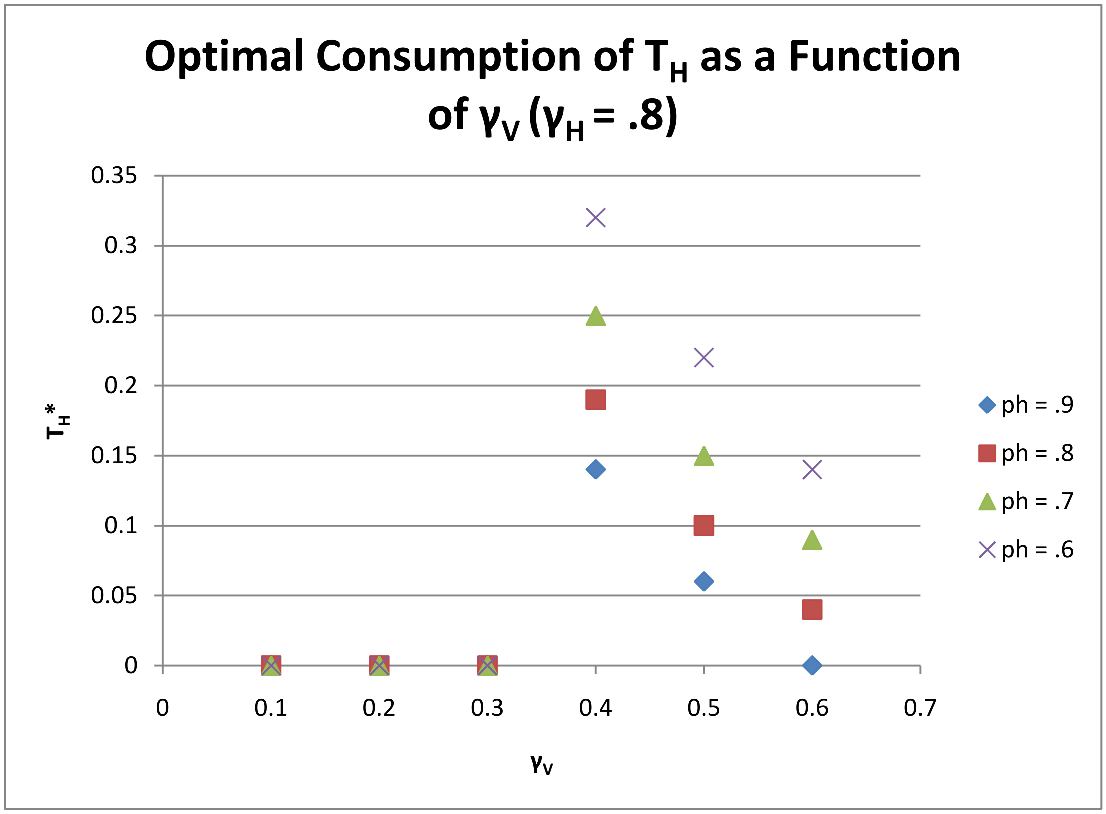

Figure 4

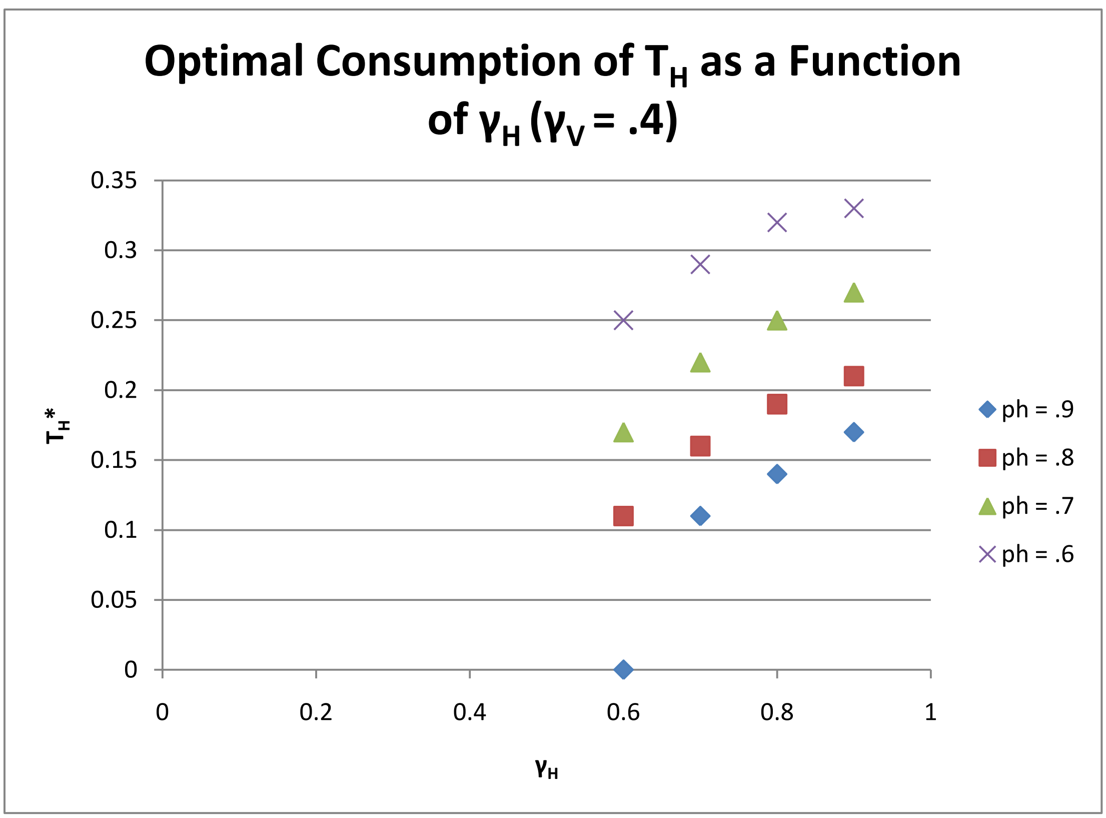

Figure 5

Chronic Health Conditions: Simulation

Given the predictions of the model in the acute case, I will next consider a chronic case, where the effects of the disease are compounded if treatment is neglected. In this evaluation, I use a three period time frame in an attempt to capture some of the longer term effects of the patient's health care consumption decision. Due to the complexity of the model, however, I am unable to derive any results analytically, as in the acute case. However, the model of the chronic condition is simply an extension of the model used in the acute condition, so I am confident in the results of the simulation. Once again, I utilize Mathematica to solve for the optimal choices of T_V and T_H across all three periods.

The results from the simulation with a chronic condition of .3 arising in the first period can be seen in Table 2.[6] Once again, it is evident that there are significant threshold effects. When the quality of health care available in the village is low, patients choose not to treat in any of the three periods as they sacrifice their health to maintain consumption. When γ_V does approach levels where treatment becomes the optimal decision, it is interesting to see that the patient begins by treating fully only in period one. As the quality continues to rise and the cost of traveling to the hospital declines, the patient begins to treat in both the first and second period, before finally treating in all three periods when the quality is substantially higher.

[6] Table 2 can be found in the Appendix

The results from the chronic disease simulations reinforce the results from the acute condition analysis. While some of the simulations returned odd results, with some simulations indicating that patients achieve a lower utility as quality improves marginally, the overall trend is the same.[7] Individuals are unlikely to seek treatment to offset moderate health conditions as long as the quality of care that is available within the community remains below a threshold level. Once treatment begins, village health care and hospital care are again generally consumed in conjunction, though the emphasis remains on care at the health outpost.

These results are also applicable to health shocks of greater or lesser severity. More serious health conditions will likely respond similarly, only with an increased sensitivity to the parameters of interest. On the other hand, patients will be even less inclined to treat minor health conditions when quality of care is low.

6. Conclusions

After constructing a theoretical model and deriving results from analytical evaluation and simulation, I have attained results that carry a number of implications for policymakers. The recommendations, however, depend on both the specific goal of the government and the extent of its budget. Due to the threshold effects revealed in the

[7] I take these anomalies to be shortcomings of the manner in which Mathematica performs the built-in maximization function.

simulations of the model, it is apparent that the consumption of health care by villagers in these remote communities will not be affected unless the quality of care available in the village increases. It is apparent that in cases where the quality of care available to patients at the health outpost in the community is sufficiently low, patients will not seek care of any kind. Therefore, investments to improve health outcomes are unlikely to have a significant effect unless they dramatically increase this quality parameter. Though reducing the opportunity cost of travelling to the hospital mitigates these threshold effects in some ways, the effect does not seem to take hold until the price has been cut by one third. Realistically, it would seem that investments in such high speed boats or helicopters to transport people so swiftly would be better served as an investment in the quality of care in the community. The model suggests that this is the most important factor in unlocking health care for these remote populations. It would seem that funding for telemedicine and other similar projects should be increased in an effort to find new, innovative solutions to deliver high quality care across great distances.

In cases where the government budget is too limited, however, it would be futile to invest insufficient funds into village medicine. All investments that fail to raise quality above the threshold level yield no effect on health consumption or utility. If the government is seeking to maximize the welfare of the populations in these remote locations, it will be better served to spend the resources on improving welfare through avenues other than health care. To translate these results to other environments, appropriate values of the various parameters of interest γ_V, γ_H, p_V, p_H, α, and δ must be applied to this model. The relative values of these parameters will influence the decision-making process of patients in different communities, and will help guide government policy.

In addition to these policy recommendations, I hope that my work will inspire others to take interest in telemedicine and other innovative health care solutions. These technological advances can truly improve the lives of underserved populations living in remote and rural communities. While my results certainly display the positive effects of telemedicine and encourage further investment and implementation, it must also be stressed that these interventions still need to be rigorously evaluated with randomized control trials. Such an experiment should compare utilization rates of health care and health outcomes longitudinally across multiple isolated communities that are randomized to control and experimental conditions. The experimental conditions should include graded levels of telemedicine investment. The results from this experiment would give evidence supporting or refuting the conclusions indicated by my theoretical model. Until then, we can only speculate the true effects of these health care programs. I believe that this paper can serve as an appropriate point of reference for the justification of further experiments in telemedicine and the health of isolated populations.

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Appendix

Table 1.1 Simulation of Optimal Health Care Consumption in Acute Case

p_H	γ_H	γ_V	T_V	T_H	U_{max}
0.9	0.6	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	0	0	167.03
		0.5	2.4	0	172.5
		0.6	2	0	176.5
	0.7	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	2.45	0.11	167.22
		0.5	2.31	0.02	172.53
		0.6	2	0	176.5
	0.8	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	2.21	0.14	167.98
		0.5	2.09	0.06	172.78
		0.6	1.99	0	176.5
	0.9	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	2.01	0.17	168.81
		0.5	1.92	0.09	173.19
		0.6	1.83	0.04	176.6
0.8	0.6	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	2.51	0.11	167.06
		0.5	2.37	0.01	172.5
		0.6	2	0	176.5
	0.7	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	2.23	0.16	167.88
		0.5	2.12	0.06	172.74
		0.6	2	0	176.5
	0.8	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	2.01	0.19	168.81
		0.5	1.92	0.1	173.19
		0.6	1.83	0.04	176.6
	0.9	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	1.82	0.21	169.76
		0.5	1.75	0.13	173.75
		0.6	1.68	0.07	176.87
0.7	0.6	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	2.27	0.17	167.75
		0.5	2.15	0.07	172.69
		0.6	2	0	176.5
	0.7	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	2.01	0.22	168.81
		0.5	1.92	0.12	173.19
		0.6	1.83	0.05	176.6
	0.8	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	1.8	0.25	169.89
		0.5	1.73	0.15	173.83
		0.6	1.66	0.09	176.92
	0.9	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	1.62	0.27	170.95
		0.5	1.57	0.18	174.52
		0.6	1.51	0.12	177.33
0.6	0.6	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	2.01	0.25	168.81
		0.5	1.92	0.14	173.19
		0.6	1.83	0.05	176.6
	0.7	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	1.77	0.29	170.07
		0.5	1.7	0.19	173.94
		0.6	1.63	0.11	176.98
	0.8	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	0	0	167.03
		0.4	1.57	0.32	171.29
		0.5	1.52	0.22	174.75
		0.6	1.47	0.14	177.49
	0.9	0.1	0	0	167.03
		0.2	0	0	167.03
		0.3	1.41	0.47	168.37
		0.4	1.41	0.33	172.44
		0.5	1.38	0.24	175.56
		0.6	1.34	0.17	178.04

<u>Table 1.2</u> Simulation of Optimal Health Care Consumption in Acute Case

p_H	γ_V	γ_H	T_V	T_H	U_{max}
0.9	0.1	0.6	0	0	167.03
		0.7	0	0	167.03
		0.8	0	0	167.03
		0.9	0	0	167.03
	0.2	0.6	0	0	167.03
		0.7	0	0	167.03
		0.8	0	0	167.03
		0.9	0	0	167.03
	0.3	0.6	0	0	167.03
		0.7	0	0	167.03
		0.8	0	0	167.03
		0.9	0	0	167.03
	0.4	0.6	0	0	167.03
		0.7	2.45	0.11	167.22
		0.8	2.21	0.14	167.98
		0.9	2.01	0.17	168.81
	0.5	0.6	2.4	0	172.5
		0.7	2.31	0.02	172.53
		0.8	2.09	0.06	172.78
		0.9	1.92	0.09	173.19
	0.6	0.6	2	0	176.5
		0.7	2	0	176.5
		0.8	1.99	0	176.5
		0.9	1.83	0.04	176.6
0.8	0.1	0.6	0	0	167.03
		0.7	0	0	167.03
		0.8	0	0	167.03
		0.9	0	0	167.03
	0.2	0.6	0	0	167.03
		0.7	0	0	167.03
		0.8	0	0	167.03
		0.9	0	0	167.03
	0.3	0.6	0	0	167.03
		0.7	0	0	167.03
		0.8	0	0	167.03
		0.9	2	0	167.03
	0.4	0.6	2.51	0.11	167.06
		0.7	2.23	0.16	167.88
		0.8	2.01	0.19	168.81
		0.9	1.82	0.21	169.76
	0.5	0.6	2.37	0.01	172.5
		0.7	2.12	0.06	172.74
		0.8	1.92	0.1	173.19
		0.9	1.75	0.13	173.75
	0.6	0.6	2	0	176.5
		0.7	2	0	176.5
		0.8	1.83	0.04	176.6
		0.9	1.68	0.07	176.87

p_H	γ_V	γ_H	T_V	T_H	U_{max}
0.7	0.1	0.6	0	0	167.03
		0.7	0	0	167.03
		0.8	0	0	167.03
		0.9	0	0	167.03
	0.2	0.6	0	0	167.03
		0.7	0	0	167.03
		0.8	0	0	167.03
		0.9	0	0	167.03
	0.3	0.6	0	0	167.03
		0.7	0	0	167.03
		0.8	0	0	167.03
		0.9	0	0	167.03
	0.4	0.6	2.27	0.17	167.75
		0.7	2.01	0.22	168.81
		0.8	1.8	0.25	169.89
		0.9	1.62	0.27	170.95
	0.5	0.6	2.15	0.07	172.69
		0.7	1.92	0.12	173.19
		0.8	1.73	0.15	173.83
		0.9	1.57	0.18	174.52
	0.6	0.6	2	0	176.5
		0.7	1.83	0.05	176.6
		0.8	1.66	0.09	176.92
		0.9	1.51	0.12	177.33
0.6	0.1	0.6	0	0	167.03
		0.7	0	0	167.03
		0.8	0	0	167.03
		0.9	0	0	168.81
	0.2	0.6	0	0	173.19
		0.7	0	0	176.6
		0.8	0	0	167.03
		0.9	0	0	167.03
	0.3	0.6	0	0	167.03
		0.7	0	0	170.07
		0.8	0	0	173.94
		0.9	1.41	0.47	168.37
	0.4	0.6	2.01	0.25	168.81
		0.7	1.77	0.29	170.07
		0.8	1.57	0.32	171.29
		0.9	1.41	0.33	172.44
	0.5	0.6	1.92	0.14	173.19
		0.7	1.7	0.19	173.94
		0.8	1.52	0.22	174.75
		0.9	1.38	0.24	175.56
	0.6	0.6	1.83	0.05	176.6
		0.7	1.63	0.11	176.98
		0.8	1.47	0.14	177.49
		0.9	1.34	0.17	178.04

Table 2 Simulation of Optimal Health Care Consumption in Chronic Case

p_H	γ_H	γ_V	T_V^1	T_H^1	T_V^2	T_H^2	T_V^3	T_H^3	U_{max}
0.8	0.6	0.1	0	0	0	0	0	0	193.32
		0.2	0	0	0	0	0	0	193.32
		0.3	0	0	0	0	0	0	193.32
		0.4	0	0	0	0	0	0	193.32
		0.5	1.94	0.13	0	0	0	0	193.81
		0.6	0	0	0	0	0	0	193.32
	0.7	0.1	0	0	0	0	0	0	193.32
		0.2	0	0	0	0	0	0	193.32
		0.3	0	0	0	0	0	0	193.32
		0.4	0	0	0	0	0	0	193.32
		0.5	1.96	0.11	0.02	0	0.01	0	194.14
		0.6	2	0	0	0	0.01	0	198.18
	0.8	0.1	0	0	0	0	0	0	193.32
		0.2	0	0	0	0	0	0	193.32
		0.3	0	0	0	0	0	0	193.32
		0.4	0	0	0	0	0	0	193.32
		0.5	0	0	0	0	0	0	193.32
		0.6	1.79	0.05	0	0	0	0	198.55
	0.9	0.1	0	0	0	0	0	0	193.32
		0.2	0	0	0	0	0	0	193.32
		0.3	0	0	0	0	0	0	193.32
		0.4	0	0	0	0	0	0	193.32
		0.5	0	0	0	0	0	0	193.32
		0.6	1.77	0.05	2.18	0.22	0	0	204.78
0.7	0.6	0.1	0	0	0	0	0	0	193.32
		0.2	0	0	0	0	0	0	193.32
		0.3	0	0	0	0	0	0	193.32
		0.4	0	0	0	0	0	0	193.32
		0.5	2.12	0.07	2.607	0.34	0	0	193.77
		0.6	1.97	0.01	2.88	0.17	0	0	202.49
	0.7	0.1	0	0	0	0	0	0	193.32
		0.2	0	0	0	0	0	0	193.32
		0.3	0	0	0	0	0	0	193.32
		0.4	0	0	0	0	0	0	193.32
		0.5	0	0	0	0	0	0	193.32
		0.6	1.84	0.04	2.37	0.23	0	0	203.72
	0.8	0.1	0	0	0	0	0	0	193.32
		0.2	0	0	0	0	0	0	193.32
		0.3	0	0	0	0	0	0	193.32
		0.4	0	0	0	0	0	0	193.32
		0.5	1.81	0.13	0.02	0	0.03	0	195.34
		0.6	1.88	0.03	1.96	0.32	2.89	0.36	201.06
	0.9	0.1	0	0	0	0	0	0	193.32
		0.2	0	0	0	0	0	0	193.32
		0.3	0	0	0	0	0	0	193.32
		0.4	0	0	0	0	0	0	193.32
		0.5	1.39	0.23	1.98	0.39	0	0	199.80
		0.6	1.88	0.03	1.86	0.32	2.77	0.35	203.82

Table 3 Cobb-Douglas Simulation Results

p_H	γ_H	γ_V	T_V	T_H	U_{max}
0.9	0.6	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	0	0	164.40
		0.5	2.4	0	168.61
		0.6	2	0	173.96
	0.7	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	0	0	164.40
		0.5	2.31	0.02	168.64
		0.6	2	0	173.96
	0.8	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	0	0	164.40
		0.5	2.09	0.06	169.00
		0.6	1.99	0	173.96
	0.9	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	0	0	164.40
		0.5	1.92	0.09	169.56
		0.6	1.83	0.04	174.09
0.8	0.6	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	0	0	164.40
		0.5	2.37	0.01	168.62
		0.6	2	0	173.96
	0.7	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	0	0	164.40
		0.5	2.12	0.06	168.94
		0.6	2	0	173.96
	0.8	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	0	0	164.40
		0.5	1.92	0.1	169.56
		0.6	1.83	0.04	174.09
	0.9	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	1.82	0.21	164.70
		0.5	1.75	0.13	170.32
		0.6	1.68	0.07	174.44

p_H	γ_H	γ_V	T_V	T_H	U_{max}
0.7	0.6	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	0	0	164.40
		0.5	2.15	0.07	168.84
		0.6	2	0	173.96
	0.7	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	0	0	164.40
		0.5	1.92	0.12	169.56
		0.6	1.83	0.05	174.09
	0.8	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	1.8	0.25	164.90
		0.5	1.73	0.15	170.43
		0.6	1.66	0.09	174.50
	0.9	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	1.62	0.27	166.43
		0.5	1.57	0.18	171.36
		0.6	1.51	0.12	175.03
0.6	0.6	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	0	0	164.40
		0.5	1.92	0.14	169.56
		0.6	1.83	0.05	174.09
	0.7	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	1.77	0.29	165.16
		0.5	1.7	0.19	140.59
		0.6	1.63	0.11	174.58
	0.8	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	1.57	0.32	166.92
		0.5	1.52	0.22	171.67
		0.6	1.47	0.14	175.22
	0.9	0.1	0	0	164.40
		0.2	0	0	164.40
		0.3	0	0	164.40
		0.4	1.41	0.33	168.52
		0.5	1.38	0.24	172.73
		0.6	1.34	0.17	175.92