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HOW MUCH IS A HEALTH INSURER WILLING TO PAY FOR COLORECTAL CANCER SCREENING TESTS?

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ABSTRACT

Colorectal Cancer (CRC) screening tests have proven to be cost-effective in preventing cancer incidence. Yet, as recent studies have shown, CRC screening tests are noticeably underutilized. Among the factors influencing CRC screening test utilization, the role of health insurers has gained considerable attention in recent studies. In this paper, we propose an analytical model for the market of CRC screening tests and show how the insurer can benefit from a computer simulation model to cope with the problem of *incomplete* and *asymmetric* information inherent in this market. Our estimates reveal that promoting CRC screening tests is not necessarily economically attractive to the insurer, unless the insurer's valuation of life is greater than a certain limit. We use the proposed model to estimate such a threshold - the insurer's willingness-to-pay to acquire one additional life year by covering the CRC screening tests.

1 INTRODUCTION

Colorectal Cancer (CRC) - cancer of the colon or rectum - is the second leading cause of cancer-related deaths in the US. An estimated 49,960 deaths (24,260 men and 25,700 women) from colon and rectum cancer are expected to occur in 2008, accounting for 9% of all cancer deaths (American Cancer Society 2008). Like many other cancers, the symptoms of CRC begin developing when the cancer is at an advanced level and consequently the chance of survival is significantly low. However, the identification of CRC at an earlier stage leads to improved survival and considerably lower treatment cost. CRC screening tests can find and remove precancerous polyps and early-stage cancer, thereby either preventing the development of cancer or detecting the disease at an early, and more treatable stage. According to Centers for Disease Control and Prevention (2008), if everybody aged 50 or older had regular screening tests, as many as 60% of deaths from colorectal cancer could be prevented. Common screening tests include Fecal Occult Blood Test (FOBT), Flexible Sigmoidoscopy, Combination of FOBT and Flexible Sigmoidoscopy, Double Contrast Barium Enema (DCBE) and Colonoscopy. The screening methods that are currently available vary considerably in terms of their performance characteristics, complication rates, acceptability, and cost. Many studies have been devoted to comparing the available screening tests based on cost, effectiveness (measured in life-years saved by undergoing screening tests) and cost-effectiveness (the ratio of cost over effectiveness); Two comprehensive sources on available CRC screening tests which describe and assess the available CRC screening tests from different perspectives are (Pignone et al. 2002) and (Levin et al. 2008).

It is generally recommended to begin screening for CRC soon after turning 50 and continue getting screened at regular intervals. But as the findings of 2000 National Health Interview Survey (Swan et al. 2007) and the recent report of American Cancer Society on cancer prevention and early detection (American Cancer Society 2007) show, there are many people who are at risk for colorectal cancer and still not being screened. Income, education, gender, race, coverage by health insurance, cost of screening, accessibility to primary care units and screening facilities, and the complication level of the screening tests can be considered important factors influencing the tendency of people to use screening tests (Peterson et al. 2007, Cokkinides et al. 2003, Wee et al. 2005, Ioannou et al. 2003).

Among these factors, however, the role of health insurance has gained considerable attention in recent studies. Evidence presented in recent research suggests that addressing insurance and cost-related barriers to care is a critical component of the effort to improve the cancer prevention and early detection practice (Ward et al. 2008). Analysis of the National Health Interview Survey 2005 survey found that the likelihood of receiving recommended cancer screening tests varies significantly by insurance status (Ward et al. 2008) and the widest disparity in CRC screening is also by health insurance status (American Cancer Society 2007). Among men and women aged 50 to 64 years with private insurance,

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48.3% had a recommended colorectal cancer screening test in the past 10 years and 39.6% of individuals with Medicaid insurance were appropriately screened, while only 18.8% of those who were uninsured were screened (Ward et al. 2008).

Although having health insurance increases the likelihood of having CRC screening tests, still half of the people covered by health insurance did not receive any form of CRC screening test during past 10 years. As noted by Pignone et al. (1999), the patient preference for CRC screening is strongly sensitive to out-of-pocket costs and therefore, one of the issues that may contribute to low utilization of these tests, is the lack of insurance coverage for the full range of CRC screening tests, especially the rather expensive ones (Klabunde et al. 2004, Cokkinides et al. 2003). Consequently, recent research on improving the utilization of CRC screening tests suggest the insurers offer coverage of a full range of CRC screening tests as well as eliminating the co-payments for preventive screening tests (Harvard School of Public Health - Harvard Center for Cancer Prevention 2008). The American Cancer Society in their 2007 report on Cancer Prevention and Early Detection assert that improving insurance coverage for the full range of CRC screening tests is a high priority for the society. It encourages passing legislation to ensure that private health insurance plans cover the full range of screening methods, which is believed could be done for little or no additional cost to health plans (American Cancer Society 2007).

Due to the recent attention to the importance of health insurance in the utilization of CRC screening tests, insurers may need (or may be required through legislations) to restudy or revise their health plans to cover the full range of CRC screening tests and set new co-insurance rates for the preventive CRC screening tests. In this paper, we present the problem that an insurer solves to revise its offered health plan, and how the insurer can benefit from a computer simulation model to cope with the problem of *incomplete* and *asymmetric* information when determining the optimal health plan. We further use the proposed model to estimate the insurer's willingness-to-pay to obtain an additional life-year by covering certain CRC screening tests.

2 THE INSURER'S MODEL FOR COVERING CRC SCREENING TESTS

Consider a population consisting of n different risk groups, each denoted by $i = 1,\ldots,n$. The risk groups differ in the probability of developing CRC and severity of cancer, if developed. People are assigned to risk categories based on their observable risk factors. For colorectal cancer, age, race, gender, family history of CRC, previous history of polyps and adenoma (adenoma is a benign tumor of a glandular structure, which over time may progress to become malignant) are often used to determine the risk level of a person. Assume there are m screening tests available, $j = 0,\ldots,m$, where "no screening" is represented by 0. A person is said to be in "class ij" if she is in risk group i and chooses screening alternative j. We assume *full compliance* for the members of each class; that is, if a person chooses screening test j, she will undergo the test regularly and according to the recommended guidelines during her life. To model the population, we assume that at a given age, say 50, an individual decides which screening alternative to choose for the next few years, say 10. We call this interval over which the individual intends to use a particular screening alternative the *decision period*. The entire population is assumed to have an equal annual remaining income denoted by w after all other expenses being deducted, and an accumulated Quality Adjusted Life Years (QALY) of q_0 at the beginning of the decision period; i.e., the entire population has the same financial and health status.

A colorectal cancer may progress in many different ways, which are theoretically assumed to be known, to facilitate modeling. The cancer progression can also be affected by screening tests interventions. Let S_{ij} denote all the possible time-based health-related pathways that a member of class ij may follow. As an example, consider a pathway in which a person starts colonoscopy at age 50 and expects to repeat it in 10 year intervals. However, she develops the first adenoma at age 58.2 which will later be detected at age 60 by screening and get removed. She experiences a natural death at age 64.9, concluding the pathway.

Let $t_{ij}(s)$ denote the expected CRC annual *treatment* costs for a class ij member subjected to pathway $s \in S_{ij}$. Note that $t_{ij}(s)$ does not include the cost of *preventive* screening tests, while it includes the cost of screening tests that are done for *diagnosis* purposes or as follow-ups to cancer treatment. The expected annual treatment cost incurred by a class ij member can be calculated as $T_{ij} = \int_{s\in S_{ij}} t_{ij}(s) f_{ij}(s) ds$, where $f_{ij}(s)$ is the probability that a member of class ij follows pathway s.

Let $p_{ij}(s)$ denote the annual cost of preventive CRC screening tests for a class ij member subjected to pathway $s \in S_{ij}$. The expected annual cost of preventive CRC screening tests incurred by a class ij member during her life due to undergoing regular screening tests according to a clinical guideline can be calculated as $P_{ij} = \int_{s\in S_{ij}} p_{ij}(s) f_{ij}(s) ds$.

We define $q_{ij}(s)$ as the resulting QALY if a member of class ij takes pathway $s \in S_{ij}$. Then the expected QALY for a member in class ij is calculated as $Q_{ij} = \int_{s\in S_{ij}} q_{ij}(s) f_{ij}(s) ds$.

We assume that the entire population is covered by a health plan which compensates for all the medical expenses due to CRC (including diagnostic CRC screening tests) with co-insurance β. The health plan, however, does not cover the *preventive* CRC screening tests. The insurer's problem is to determine a health plan, characterized by the amount of increase in the premium and co-insurance rates for each

screening test that covers the preventive CRC screening tests.

For the insurer, we assume he can estimate T_{ij}, P_{ij} and Q_{ij} for each class ij. The risk category of a certain person is, however, unobservable by the insurer, but the insurer has an approximation for the proportion of the population in each risk category i, denoted by α_i, where $\sum_{i=1}^{n} \alpha_i = 1$. Since the individual's types are not observable, the premium and the coinsurance rate must be independent of the individual's type, and so the insurer should set a single premium and coinsurance rates for all the risk categories.

We further assume that the insurer is risk neutral and seeks to minimize $C - \lambda \times Q$, where C is the expected total cost of population, Q is the population QALY, and λ is the amount of money the insurer is willing to pay to acquire one additional unit of QALY for the covered population. The insurer finds the optimum policy by determining the increase in premium (Δm) to cover the preventive screening tests and the coinsurance rate for each CRC screening test (β_j). We assume each person maximizes her expected utility function over her net income v, and the obtained QALY, q. The utility function represented by $u(v,q)$ satisfies the first and second derivative conditions $u_v(v,q) > 0$ and $u_{vv}(v,q) \leq 0$ for all (v,q) (subscripts here denote partial derivatives); and for any $q_1 > q_2$, $u(v,q_1) > u(v,q_2)$ for all v. That is, each person prefers more money to less, is weakly risk averse over income, and likes to be in better health.

The insurer's problem can be formulated as the optimization problem (1)-(5), presented below. Suppose that the insurer chooses the contract $(\Delta m, \beta_1, \cdots, \beta_m)$ to offer. Having observed the offered contract, each risk category in the population solves the sub-optimization problem (2) over the set of possible screening alternatives to select the best cancer screening alternative. If for the contract $(\Delta m, \beta_1, \cdots, \beta_m)$, the members of risk category i select the screening alternative $J_i \in \{0, 1, \ldots, m\}$, then for a given λ, the insurer's cost can be calculated as equation (1), where $I(J_i)$ equals 1 if the members of risk category i chooses to include the coverage CRC screening tests in their health plan (i.e., $J_i > 0$), and equals 0 otherwise (i.e., $J_i = 0$). Remember that a person should agree to an increase of Δm in her premium to include the coverage of CRC screening tests in her health plan. Constraint (4) eliminates the possibility of reduction in insurance premium, and constraint (5) assures that co-insurance rates are between 0 and 1.

$$\min_{\Delta m, \beta_1, \cdots, \beta_m} \pi = \sum_{i=1}^{n} \alpha_i \Big(I(J_i)\big((1-\beta_{J_i})P_{i,J_i} - \Delta m\big) + (1-\beta)T_{i,J_i} - \lambda(Q_{i,J_i} - Q_{i,0})\Big) \quad (1)$$

$$\text{s.t.} \quad J_i = \arg\max_{j=0,\ldots,m} \int_{s \in S_{ij}} u\Big(w - I(j)\big(\Delta m + \beta_j p_{ij}(s)\big) - \beta t_{ij}(s),\, q_0 + q_{ij}(s)\Big) f_{ij}(s) ds, \quad \text{for } i = 1, \ldots, m, \quad (2)$$

$$I(j) = \begin{cases} 0 & \text{, if } j = 0 \\ 1 & \text{, if } j > 0 \end{cases} \quad (3)$$

$$\Delta m \geq 0, \quad (4)$$

$$\beta_0 = 0, \text{ and } 0 \geq \beta_i \geq 1 \text{ for } j = 1, \ldots, m. \quad (5)$$

Careful investigation of optimization problem (1)-(5) shows that constraint (2) makes an unrealistic assumption that people have perfect knowledge about the CRC progression and its consequence; i.e., the probability of undergoing each pathway ($f_{ij}(s)$ for each $s \in S_{ij}$), as well as the associated cost and QALY. Such information is rarely available to any physician, let alone the patients. Yet, in practice one can elicit the necessary information to make an *informed* decision from different sources particularly from her physician. Consider a person who just turned into age 50 and would like to decide whether to use screening tests and if so, which screening test to undergo. To make the formulation more tractable, we assume the person fully complies with her decision made at age 50 for the next 10 years, unless she is diagnosed with cancer, which in this case, she changes her medical behavior according to the recommended treatment. To make an *informed* decision, she needs to know her present *risk category*, the possible *future states* she might reach if a certain screening alternative is taken, and the corresponding transition probabilities and outcomes. In common practice, she can identify her present risk category based on several *observable* risk factors such as age, race, family history of cancer, previous history of polyps, etc. For simplicity, we assume there are only two risk categories in the population: high and low risk. A person can be assigned to each according to her risk factors. For example, a person at age 50 with family history of cancer and Inflammatory Bowl diseases is considered being at high risk while a person at age 50 with no family history of cancer is considered being low risk. Regardless of the selected screening alternative at age 50, one may *perceive* one of the following possible future states at age 60:

1. Clean: where the person considers herself to be clean of any benign or malignant adenomas.
2. Adenoma: where at least one adenoma, detectable by her selected screening tests at age 50, has developed but has not yet become a cancer (remember that adenomas are benign tumors, but if not removed, they can progress over time to become malignant). Also note that this state cannot be reached by the individuals who have selected "no screening" alternative at age 50.

3. Cancer: where the individual is diagnosed with CRC.
4. Death: death due to Colorectal Cancer (we assume when deciding on using screening tests, the individual does not take into account the possibility of natural death or death due to other diseases in the decision period, which here is between ages 50 to 60 years).

Let $z_{ij}(s)$ denote the probability that a member of class ij reaches state $s \in \{1,2,3,4\}$ at the end of the decision period $[t_0,t_1]$. Let $\bar{T}_{ij}(s,t_0 \to t_1)$ and $\bar{T}_{ij}(s,t_1^+)$ denote the expected annual treatment cost due to CRC that a member of class ij might incur from age t_0 to t_1 and after age t_1, respectively, given being in state $s \in \{1,2,3,4\}$ at time t_1. Thus, the expected total annual cost of *treatment* for a member of class ij given being at state s at time t_1, can be calculated as $\bar{T}_{ij}(s) = \bar{T}_{ij}(s,t_0 \to t_1) + \bar{T}_{ij}(s,t_1^+)$. Likewise, the expected total annual cost of *preventive* screening tests for a member of class ij given being at state s at time t_1 can be calculated as $\bar{P}_{ij}(s) = \bar{P}_{ij}(s,t_0 \to t_1) + \bar{P}_{ij}(s,t_1^+)$, where $\bar{P}_{ij}(s,t_0 \to t_1)$ is the expected cost of preventive screenings for a member of class ij in period $[t_0,t_1]$ and $\bar{P}_{ij}(s,t_1^+)$ is the expected cost of preventive screenings for a member of class ij after time t_1, given being at state s at time t_1. Let $\bar{q}_{ij}(s,t_0 \to t_1)$ and $\bar{q}_{ij}(s,t_1^+)$ denote the expected total QALY of a member of class ij in period $[t_0,t_1]$ and after age t_1, respectively, if the person has reached state s at time t_1. Thus, the expected QALY for a member of class ij provided being at state s at time t_1, can be calculated as $\bar{q}_{ij}(s) = \bar{q}_{ij}(s,t_0 \to t_1) + \bar{q}_{ij}(s,t_1^+)$. Now we can replace constraint (2) with the following sub-optimization problem:

$$J_i = \arg \max_{j=0,\ldots,m} \sum_{s\in\{1,2,3,4\}} z_{ij}(s) u\Big(w - I(j)\big(\Delta m + \beta_j \bar{P}_{ij}(s)\big) - \beta \bar{T}_{ij}(s), q_0 + \bar{q}_{ij}(s)\Big), \text{ for } i = 1,\ldots,n. \quad (6)$$

To solve the new optimization problem, the insurer needs to know the outcomes (cost and QALY) for each population with specific risk factors when a certain CRC screening test is implemented; i.e. P_{ij}, T_{ij}, and Q_{ij}. The insurer uses this information to decide which screening test(s) to implement for each population. The parameters of this problem cannot often be estimated accurately by using the history data. First, it required a huge burden of data collection since the insurer should collect data for all combinations of risk-groups and available screening tests. These data are rarely available in practice. Second, using historical data usually leads to biased estimates, since the estimates are obtained based on only the *insured* portion of the population. That is, if the insurance company manipulates its covered population through some mechanism, the estimated parameters are no longer valid for the new situation where the insured population has changed.

One effective way to alleviate the information imperfection inherent in cancer screening environment is to create a model for the *natural history* of CRC. Such models, if validated and verified precisely, enable the analysts to obtain accurate estimates for the outcome of undergoing screening tests by each risk-specific population. In other words, such models provide accurate estimates for the outcomes of each pathway $s \in S_{ij}$, for class ij, as well as the probability of undergoing that pathway by a member of class ij.

To estimate the parameters of the optimization problem (1)-(6), we use a medical simulation model called Vanderbilt/NC State model (V/NCS Model), which is a stochastic, discrete-event simulation model of the natural history of colorectal cancer (CRC) (Roberts et al. 2007). This model simulates a population over time which may include a mixture of patients with different birth years, races, genders, and family histories of colorectal cancer. The model has been developed using an object-oriented simulation platform driven by an independent database to provide a complete representation of the potential stochastic impact of CRC. The discrete-event representation of the natural history models changes in the CRC state of an individual throughout her natural lifetime. Screening can intervene in the CRC process by detecting adenomas and early cancers. Removing these neoplasia changes the future outcomes, thus potentially extending life. This model produces discounted costs and quality-adjusted life-years (QALYs) for screening decisions as the primary outcomes although various natural history data may also be collected and reported. The model has been carefully verified, calibrated, and validated, and used to determine the cost-effectiveness of CRC screening alternatives (Tafazzoli et al. 2009).

In next section, we present an application of V/NCS Model in obtaining the necessary estimates for solving the proposed optimization problem.

3 NUMERICAL RESULTS

The optimization problem (1)-(6) poses interesting properties that provide better understanding for the market of CRC screening tests. Those characteristics as well as how to solve this optimization problem is the subject of future work. In this paper, we solely present a numerical example for this optimization.

We consider a population consisting of two risk groups. The low-risk group ($i = 1$) consists of white men of age 50 without a family history of cancer, and the high-risk group ($i = 2$) consists of white men of age 50 with a family history of cancer. For simplicity, we assume that there are only two screening tests available to the population: Fecal Blood Occult Test (FOBT) and Colonoscopy. At age 50, a person may decide to use FOBT ($j = 1$), Colonoscopy

($j = 2$), or not to use any screening tests ($j = 0$) for the next 10 years. Both groups comply with the screening regimen described below.

For a person who chooses FOBT, if the FOBT result is positive, the patient is recommended to obtain a Colonoscopy as a more accurate test, in the same year. However, we assume that only 70% of individual follows such recommendation. If a patient with positive FOBT result chooses not to use the recommended Colonoscopy, she will retake FOBT in one year. If the FOBT result is negative, the follow-up FOBT for a person with no history of adenoma or CRC is scheduled in 2 years. If the colonoscopy result is positive, a Polypectomy (with Biopsy) will be performed and the person goes under surveillance. Surveillance refers to the regular examination of the colon in patients with a prior history of colorectal adenoma or cancer history. Because a history of colorectal adenomas or cancer is a risk factor for future colonic neoplasia, surveillance regimens are more aggressive than standard screening strategies. Therefore, the frequency of the screening tests should be increased for a person under surveillance. If Colonoscopy finds advanced adenomas, or 3 or more non-advanced adenomas, the next Colonoscopy will be scheduled in 3 years after the initial Colonoscopy; and if the result is normal, the procedure will be repeated in 5 years. If the Colonoscopy finds non-advanced adenomas, the next Colonoscopy will be scheduled in 5 years after the initial Colonoscopy; and if the result is normal, the procedure will be repeated in 5 years. For a patient with a history of resection or colorectal cancer, the next Colonoscopy will be scheduled within 1 year of cancer resection; if the exam is normal, the procedure will be repeated in 3 years and if still normal, it will be repeated in 5 years. Surveillance tests halt after the cancer goes into the terminal stage or the patient reaches age 80.

If a person decides not to use any screening tests and becomes aware of the cancer through its symptoms, a Colonoscopy is performed to determine the extent of the cancer, and treatment of the cancer begins. As part of Colonoscopy, adenomas may be found and removed. Should surgery prove necessary, sections of the colon are resected and thus eliminating all the adenomas in those sections.

In the V/NCS Model, treatment cost includes the costs incurred when the cancer is diagnosed, such as the cost of resection surgery and the annual continuing care cost for follow-up treatment associated with the cancer. The treatment costs also include the costs required for pathology doing the biopsy on the polypectomy specimens, as well as the cost of surveillance tests. The FOBT and colonoscopy are assumed to cost \$4.54 and \$661.00, respectively. The model assumes that the quality of life diminishes as a person ages. Being diagnosed with cancer and undergoing cancer treatments including resection surgery and chemotherapy lowers the patient's quality of life. Also the model assumes that the inconvenience preceding colonoscopy and the associated complications cause a drop in the patient's utility for a short period of time. The detailed assumptions of V/NCS Model are discussed in (Roberts et al. 2007).

We simulated a population of 100,000 persons for each risk group with the screening regimen described above. The model starts gathering statistics when a person reaches age 50 and continues for 50 years or till the person dies, whichever occurs sooner. Table (1) and Table (2) show the resulting costs and QALYs for each risk groups when different screening alternatives are chosen at age 50. We should emphasize again that in these tables, "Screening Cost" excludes the cost of screening tests that are used for surveillance or to diagnose a symptomatic cancer. Those costs are included in "Treatment Cost."

Table 1: Cost and QALY* for low-risk group from the health insurer's perspective

Test	Screening Cost	Treatment Cost	Total Cost	QALY
NO	\$0.00	\$90.79	\$90.79	14.1776
FOBT	\$15.52	\$79.46	\$94.98	14.2087
COL	\$67.79	\$73.15	\$140.94	14.2438

*All costs and QALYs are discounted at 3% rate to year 2000.

Table 2: Cost and QALY* for high-risk group from the health insurer's perspective

Test	Screening Cost	Treatment Cost	Total Cost	QALY
NO	\$0.00	\$211.61	\$211.61	14.0528
FOBT	\$17.34	\$164.11	\$181.45	14.1274
COL	\$64.67	\$118.58	\$183.26	14.2067

*All costs and QALYs are discounted at 3% rate to year 2000.

Table (1) and Table (2) reveal why a cost-minimizing insurer might not be willing to cover the preventive CRC screening tests for the entire population. For the low-risk population, using FOBT and Colonoscopy increases the total annual cost by 4.6% and 55.2%, respectively; and for high-risk population, FOBT and Colonoscopy results in 14.2% and 13.4% decreases in the total cost, respectively. Therefore, assuming zero co-insurance rates, the insurer's preferred choice of screening is "No screening" for low-risk population, and FOBT for high-risk population, and hence Colonoscopy will not be promoted by the insurer, despite being one of the most effective CRC screening tests (Levin et al. 2008) and being widely recommended by physicians (Allison and Lawson 2006). To make it economically feasible, the insurer can set a nonzero co-

insurance rate for Colonoscopy and increase the premium for covering the prevention CRC screening tests (note that almost all health plans cover FOBT with co-insurance zero, since it usually costs less than $10). Changing the premium and co-insurance, however, changes the demand for each screening tests; therefore to find the optimum health plan, the insurer also needs to know how each risk group chooses among the available screening alternatives. This decision process is modeled by equation (6). To use this equation, the decision maker needs estimates for transition probabilities to future health states, and the expected annual screening and treatment costs if a certain screening alternative is chosen by each risk group. The required estimates are provided in Table 3 and Table 4. These two tables contain very interesting and useful information regarding the outcomes of adopting different screening alternatives by each risk category. We leave the detailed interpretation of the information in those tables to the reader, due to space limitation. Hence we solely use the estimates to present a numerical example of the optimization model.

We assume that the low-risk and high-risk groups constitutes 90% and 10% of the entire population, respectively. Both groups are assumed to have identical utility function of form $u(v,q) = \ln(w-v) + \gamma \ln(q+q_0)$ for $v < w$ and $q > 0$, and zero otherwise, where w is the annual remaining income after all other expenses being deducted, q_0 is the accumulated QALY at the beginning of the decision period, and γ is a constant. If we assume $w = \$200$, $q_0 = 46$, and each person is willing to spend $50 annually to obtain one additional quality of life year in the long-run, then γ can be estimated to be 11.5 (solving $dv/dq = -(u_q(v,q))/(u_v(v,q))|_{v=q=0} = 50$ results in $\gamma = 11.5$).

Assuming co-insurance rate of 20% for all treatment expenses and the co-insurance rate of zero for FOBT (which is close to reality) the feasible region for optimization problem (1)-(6) will have two dimensions: $(\Delta m, \beta_{\text{COL}})$, where Δm is the increase in premium due to covering CRC screening tests and β_{COL} is the co-insurance rate for Colonoscopy.

Figure 1 depicts the objective function (1) over its feasible region, when $\lambda = 0$. The optimum occurs at point $(\Delta m, \beta_{\text{COL}}) = (\$55.23, \%0)$ with minimum cost $75.80. Having observed the insurer's offered health plan, the low-risk group chooses not to participate in CRC screening plan and high-risk group decides to submit to Colonoscopy at age 50. For the population of this example, the insurer could reduce his annual cost from $82.29 to $75.80. If the insurer was a not-for-profit organization, it could potentially share the reduction in the annual cost to the population by reducing the offered annual premium.

Now assume that the insurer is willing to change his offered health plan, simply out of goodness, such that the low-risk group chooses Colonoscopy as their preferred screening alternative. In order to achieve that, the insurer should change his offered plan to $(\Delta m, \beta_{\text{COL}}) = (\$16.12, \%0)$,

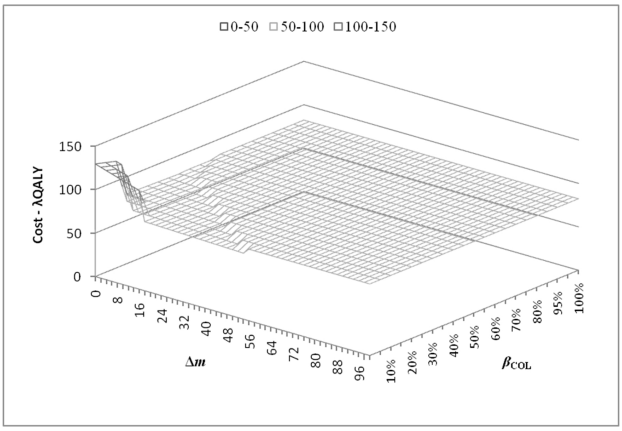

Figure 1: Schematic presentation of the optimum solution

which results in the expected annual cost $113.51. Thus, if the insurer offers such a contract, the minimum value of λ that the insurer is willing to pay to obtain one additional QALY for the low-risk population of our example can be estimated by:

$$\lambda = \frac{\text{Increase in Cost}}{\text{Additional QALY Obtained}} = \frac{(\$113.51 - \$75.80)}{0.9 \times (14.2438 - 14.1776)} = \$632.93/\text{QALY}.$$

For the contract $(\Delta m, \beta_{\text{COL}}) = (\$55.23, \%0)$ the insurer is willing to cover the CRC screening tests because it results in decrease in his annual cost. But for the second contract $(\Delta m, \beta_{\text{COL}}) = (\$16.12, \%0)$ the insurer is willing provide enough economic incentive to the entire population because he has a greater valuation for life. The minimum value of λ for the first contract is 0 and for the second contract is $632.93 per QALY.

4 CONCLUSIONS AND FUTURE RESEARCH

The important role of third-party payers have been promoted in recent studies as one of the determinant factors in improving the cancer screening utilization. Health insurers, however, are troubled by information imperfection existing in the cancer-care environments. The insurer can observe the overall cancer prevalence and incidence rate in historical data, but often they are not able to accurately estimate the outcomes of using different CRC screening tests by people in different risk categories. As a consequence, they tend to design their health plans based on average population risk, which according to microeconomic theories can result in so-

Table 3: Cost and QALY* for low risk population

Future State	Test	Prob.	Annual Treatment Cost			Annual Screening Cost			QALY		
			50-60	60+	Total	50-60	60+	Total	50-60	60+	Total
Clean	NO	0.9944	$0	$138	$138	$0	$0	$0	7.9836	10.1272	18.1108
	FOBT	0.9132	$7	$105	$112	$12	$15	$27	7.9837	10.1598	18.1435
	COL	0.7018	$13	$42	$55	$72	$79	$151	7.9837	10.1902	18.1739
Adenoma	NO	0.0000	$0	$0	$0	$0	$0	$0	0.0000	0.0000	0.0000
	FOBT	0.0816	$113	$324	$437	$78	$10	$89	7.9740	10.1059	18.0799
	COL	0.2953	$168	$245	$413	$87	$18	$105	7.9823	10.1831	18.1654
Cancer	NO	0.0031	$2,624	$1,553	$4,177	$0	$0	$0	7.5299	5.7343	13.2641
	FOBT	0.0030	$2,948	$2,481	$5,429	$20	$0	$20	7.4671	5.5690	13.0361
	COL	0.0017	$2,817	$2,710	$5,527	$77	$0	$77	7.4528	5.6043	13.0571
Death	NO	0.0026	$11,386	$0	$11,386	$0	$0	$0	4.2681	0.0000	4.2681
	FOBT	0.0022	$11,900	$0	$11,900	$74	$0	$74	4.0353	0.0000	4.0353
	COL	0.0012	$13,303	$0	$13,303	$88	$0	$88	2.7448	0.0000	2.7448

*All costs and QALYs are discounted at 3% rate to year 2000.

Table 4: Cost and QALY* for high risk population

Future State	Test	Prob.	Annual Treatment Cost			Annual Screening Cost			QALY		
			50-60	60+	Total	50-60	60+	Total	50-60	60+	Total
Clean	NO	0.9868	$0	$380	$380	$0	$0	$0	7.9756	10.0077	17.9834
	FOBT	0.8594	$14	$238	$252	$12	$17	$28	7.9764	10.0831	18.0594
	COL	0.5891	$20	$110	$130	$72	$80	$152	7.9750	10.1620	18.1370
Adenoma	NO	0.0000	$0	$0	$0	$0	$0	$0	0.0000	0.0000	0.0000
	FOBT	0.1291	$131	$455	$586	$76	$10	$86	7.9659	10.1090	18.0749
	COL	0.4053	$176	$316	$492	$87	$16	$103	7.9784	10.1706	18.1490
Cancer	NO	0.0074	$2,733	$1,548	$4,281	$0	$0	$0	7.5231	6.2387	13.7617
	FOBT	0.0068	$2,942	$1,913	$4,855	$22	$0	$22	7.4442	6.5027	13.9469
	COL	0.0033	$2,859	$3,000	$5,859	$79	$0	$79	7.4336	6.4394	13.8730
Death	NO	0.0058	$13,148	$0	$13,148	$0	$0	$0	4.0734	0.0000	4.0734
	FOBT	0.0048	$10,552	$0	$10,552	$14	$0	$14	3.6473	0.0000	3.6473
	COL	0.0024	$10,586	$0	$10,586	$67	$0	$67	2.7878	0.0000	2.7878

*All costs and QALYs are discounted at 3% rate to year 2000.

cial welfare loss and market failure. Imperfect information can in part be alleviated by modeling the *natural history* of CRC and screening interventions. The model can yield accurate estimates for the cost and life-year saved in each risk population that undergo screening tests. In this paper, we showed how the insurer can benefit from a simulation model to decide which screening test to implement for a certain risk group. We further showed, through a numerical example, that a cost-minimizing health insurer is willing to cover certain CRC screening tests only if they lead to reduction in the annual cost. Nonetheless, the insurer might still be willing to cover other screening tests if his valuation of life is greater than a certain value. In this paper, we presented an approach to estimate such a threshold.

People's decisions on using screening tests is also affected by other factors not captured by the model proposed here, such as level of education, discomfort caused by screening tests, other annual medical expenses, and access to cancer screening facilities. Moreover, one of the main assumptions of our model is that each risk group has estimates for their future expected costs and QALYs, as accurate as those possessed by the insurer. This assumption does not always hold in reality, and individuals usually decide based on *subjective* probabilities and estimates of future outcomes, generally provided by their physicians. Incorporating such possibilities into the proposed model is of great interest as future research.

In addition, the model discussed in this paper is a single-period decision making model, which suffers from over-simplification, since the decision of using screening tests can be made at any moment of lifetime and not necessarily at a certain age. Creating a multi-period model for the market of CRC screening tests will be of greater value to the cancer care communities.

REFERENCES

Allison, J. E., and M. Lawson. 2006. Screening tests for colorectal cancer: a menu of options remains relevant. *Current Oncology Reports* 8:492–498.

American Cancer Society 2007. *Cancer prevention & early detection facts & figures*. Atlanta, GA: American Cancer Society.

American Cancer Society 2008. *Cancer facts & figures 2008*. Atlanta, GA: American Cancer Society.

Centers for Disease Control and Prevention 2008. *Colorectal (colon) cancer*. Centers for Disease Control and Prevention. Available via <http://www.cdc.gov/cancer/colorectal/basic_info/> [accessed July 15, 2008].

Cokkinides, V. E., A. Chao, R. A. Smith, S. W. Vernon, and M. J. Thun. 2003. Correlates of underutilization of colorectal cancer screening among u.s. adults, age 50 years and older. *Preventive Medicine* 36:85–91.

Harvard School of Public Health - Harvard Center for Cancer Prevention 2008. *Tools and strategies to increase colorectal cancer screening rates: A practical guide for health insurance plans*. 5/04 ed. Harvard School of Public Health - Harvard Center for Cancer Prevention.

Ioannou, G. N., M. K. Chapko, and J. A. Dominitz. 2003. Predictors of colorectal cancer screening participation in the united states. *American Journal of Gastroenterology* 98:2082–2091.

Klabunde, C. N., G. F. Riley, M. T. Mandelson, P. S. Frame, and M. L. Brown. 2004. Health plan policies and programs for colorectal cancer screening: A national profile. *American Journal of Managed Healthcare* 10:273–279.

Levin, B., D. A. Lieberman, B. McFarland, R. A. Smith, D. Brooks, K. S. Andrews, C. Dash, F. M. Giardiello, S. Glick, T. R. Levin, P. Pickhardt, D. K. Rex, A. Thorson, and S. J. Winawer. 2008. Screening and surveillance for the early detection of colorectal cancer and adenomatous polyps, 2008: A joint guideline from the american cancer society, the us multi-society task force on colorectal cancer, and the american college of radiology. *CA: A Cancer Journal for Clinicians* 58:130–160.

Peterson, N. B., M. J. Harvey, N. M. Reid, and D. S. Robert. 2007. Colorectal cancer screening among men and women in the united states. *Journal of Women's Health* 16:57–65.

Pignone, M., D. Bucholtz, and R. Harris. 1999. Patient preferences for colorectal cancer screening. *Journal of General Internal Medicine* 14:432–437.

Pignone, M., M. Rich, S. M. Teutsch, A. O. Berg, and K. N. Lohr. 2002. Screening for colorectal cancer in adults at average risk: A summary of the evidence for the u.s. preventive services task force. *Annals of Internal Medicine* 137:132–141.

Roberts, S. D., L. Wang, R. W. Klein, R. M. Ness, and R. S. Dittus. 2007. Development of a simulation model of colorectal cancer. *ACM Transactions on Modeling and Computer Simulation* 18.

Swan, J., N. Breen, R. J. Coates, B. K. Rimer, and N. C. Lee. 2007. Progress in cancer screening practices in the united states: Results from the 2000 national health interview survey. *Cancer* 97:1528–1540.

Tafazzoli, A., S. D. Roberts, R. Ness, R. W. Klein, and R. Dittus. 2009. Probabilistic cost-effectiveness comparison of screening strategies for colorectal cancer. *ACM Transactions on Modeling and Computer Simulation*. Accepted for January, 2009.

Ward, E., M. Halpern, N. Schrag, V. Cokkinides, C. DeSantis, P. Bandi, R. Siegel, A. Stewart, and A. Jemal. 2008. Association of insurance with cancer care utilization and outcomes. *CA A Cancer Journal for Clinicians* 58:9–31.

Wee, C. C., E. P. McCarthy, and R. S. Phillips. 2005. Factors associated with colon cancer screening: the role of patient factors and physician counseling. *Preventive Medicine* 41:23–29.

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