

# Integrated Healthcare Delivery and Health Insurance Models for Studying Emergency Department Utilization

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## Abstract

*An important healthcare problem in the United States of America is that of emergency department overcrowding. A plausible explanation for such overcrowding is that the lack of access to primary care, which may be influenced by one's insurance status, leads to greater use of emergency departments. Additionally, it has been suggested that the inappropriate use of emergency departments, along with the phenomenon of cost-shifting, results in higher healthcare costs in the form of higher insurance premiums. Higher premiums may in turn influence one's insurance status. To study these relationships, we develop a system dynamics model that captures key interactions between population health state progression, healthcare economics, and population health insurance status. Two interventions are investigated: government subsidies to individuals for purchasing health insurance, and safety-net clinic capacity. We also explore the sensitivity of emergency department utilization to employment rate and population susceptibility to illness.*

**Keywords:** System Dynamics, Healthcare, Insurance Premium, Emergent Department Utilization

## 1. Introduction

In the midst of the heated debate on health reform that is going on in the United States, a problem that has received more than a little attention is the impact that rising health care costs and the number of people without health insurance has had on our nation's cities. A survey of 13 city mayors, conducted by Families USA, reveals that the burden of providing health services for an increasing number of uninsured is taking a toll on their ability to deliver even non-health related municipal services (e.g., family support services) effectively (Families USA 2008). In particular, all surveyed cities observed increased demand for safety net clinics, and 11 out of 13 cities observed crowding in hospital emergency departments (EDs).

An important consequence of being uninsured is that one is more likely to delay seeking care when ill and is generally sicker than someone who has health insurance (Kaiser Family Foundation 2002). Additionally, sick adults tend to be less productive at work (Davis, et al. 2005), and sick children are more likely to be absent from school (Hurwitz and Hurwitz 2000). Studies show that people with less access to primary care are more likely to utilize hospital

emergency departments for treatment (Newton 2008). The over-utilization of EDs for treatments that could be provided by a primary care provider (PCP) or for conditions that could have been avoided had primary care been sought in a timely manner, contributes to ED overcrowding. One important, everyday effect of ED overcrowding on city residents is the diversion of ambulances. That is, when a hospital's ED is over-utilized, ambulances are instructed not to bring patients to the hospital, and patients may need to travel farther for emergency care. From the point of view of city leaders, another significant implication of persistent ED overcrowding is the reduction in its capacity to deal with a major catastrophe, such as a terrorist attack, infectious disease outbreak or natural disaster (United States House of Representatives 2008).

We use system dynamics (Sterman 2000) to model the system consisting of health progression and care delivery, medical cost and insurance premium, insurance choice. We study the potential effects that city-provided health insurance subsidies and capacity constraints in a city's safety-net PCPs may have on the population of uninsured, access to primary care, and overcrowding in EDs. We also examine the sensitivity of ER utilization to changes in city employment rates, as well as to changes in the frequency of illness among city residents. The most notable existing efforts to use system dynamics to study public health issues include that of Homer and Hirsch (2006), Milstein, Homer and Hirsch (2009) and Milstein, Homer and Hirsch (2010). Additionally, Brailsford (2008) provides a perspective on the use of system dynamics for general analysis of health care systems. The Congressional Budget Office (2007) developed a simulation for health insurance in America. Gruber (2008) provides an economic perspective on the covering the uninsured in America. Our work places an emphasis on emergency department utilization, and combines the dynamics of health care delivery with those of public health policy and economics.

The paper is organized as follows. In section 2, we present an overview of healthcare model. Section 3 gives the formulation detail of the system dynamics model. Section 4 demonstrates some simulation results for certain scenarios. Section 5 concludes the paper and discusses future research directions.

## **2. Model Overview**

Our model comprises three main sub-models: 1) health progression and care delivery, 2) medical costs and insurance premiums, and 3) insurance choice. The health progression and care delivery sub-model captures how the population transitions between various health states: healthy, ill with non-emergent conditions and ill with emergent conditions. It also captures the dynamics associated with the use of primary care and emergency department services for preventive care, and treatment of non-emergent or emergent conditions. The sub-model for medical costs and insurance premiums captures the market dynamics that drive the price of health insurance. The insurance choice sub-model captures how individuals make choices regarding whether to purchase individual insurance plans, sign up for employee-sponsored insurance plans, or to remain uninsured. Figure 1 shows a schematic of the overall model with essential flows that capture the interactions among the three aggregate sub-systems. For the sake of clarity, certain details of the models are not shown.

These three sub-models interact in 3 main ways. The health progression and care delivery sub-model determines the ‘demand’ for various healthcare services, which influences the cost of care and the insurance premiums set by healthcare payers in the medical costs and insurance premiums sub-model. In turn, changes in insurance premiums influence individuals insurance purchasing decisions. Finally, as discussed earlier, the insurance status of an individual may influence his access to care, which may influence his health state and progression. We do not model births, deaths, or migrations. Therefore, the total population remains constant in our model.

In our healthcare model, people are primarily classified by their level of access to primary care. We assume that people with private insurance (either individually purchased or employee sponsored) and Medicare insurance have greater access to primary care than people without insurance, or who qualify for Medicaid. People with greater access to primary care (i.e., those with private/Medicare insurance) exclusively rely on private providers, while those with less access to primary care (i.e., those with no insurance or Medicaid insurance) exclusively rely on city-funded safety-net primary care providers. Therefore, private PCP capacity and safety-net PCP capacity are not shared among all residents. Meanwhile, emergency care is shared among all residents, regardless of insurance status. After all, the Emergency Medical Treatment and Active Labor Act passed in 1986 requires hospitals offering emergency services and participating in Medicare to provide screening exams and stabilizing treatment to any person who arrives in the ED, regardless of the person’s ability to pay. When given a choice between seeking care at a PCP or ED, convenience and access may play a large role. In our model, this choice is governed by the relative access times, or wait times, and weighted by insurance status. These dynamics are captured in the health progression and care delivery model. The mathematical expressions that drive the dynamics for two key variables in this sub-model are presented in the next section.

Uncompensated, or poorly compensated, care provided to uninsured/Medicaid insured individuals can be a drain on a hospital’s finances. Moreover, there is the potential for cost-shifting to occur, where the reduction in revenue associated with delivering uncompensated care is counter-balanced by an increase in ED fees charged to those who can pay for care. If cost-shifting occurs, then private insurance premiums may rise, causing a portion of individuals to drop or lose their insurance coverage. This dynamic is represented in the medical costs and insurance premiums sub-model. In this sub-model, the costs that drive insurance premiums include the claims paid for services provided by non-safety-net PCPs and emergency departments. We model the variable costs of providing these services. These costs may be significant, even in an emergency department (Bamezal, Melnick and Nawathe 2005).

While we assume that the number of people insured under Medicare is constant, the insurance status of the remainder of the modeled population is subject to change, according to the model dynamics. Insurance choice is influenced by whether or not an individual is offered employer-sponsored insurance (ESI), and by individual preferences to either take-up the ESI offer, purchase individual (i.e., non-group) insurance, or not purchase any insurance (Congressional Budget Office 2007). These probabilities are a function of the price of insurance premiums, less any available subsidies. In our model, we assume that each person is covered by only one form of insurance.



Our model was calibrated using reported statistics for NYC when available, and for the state of New York when city-level statistics were not available. Our calibration efforts focused on reasonably reproducing the reported distribution of insurance status in New York state (Kaiser Family Foundation), NYC emergency department utilization as categorized by use for emergent and non-emergent care (Billings and Parikh 2000) and emergency department utilization as categorized by patient insurance status in America (Delia and Cantor 2009). The expected frequency of primary care and ED visits was calibrated using data from the Centers for Disease Control and Prevention (CDC) (Centers for Disease Control and Prevention 2009).

### 3. Formulation of System Dynamics Model

In this section, we present mathematical formulations for the variables in each of our sub-models.

#### 3.1. Notation and Abbreviation

It should be noted that all variables presented here are functions of time, unless otherwise stated. However, this time dependency is not explicitly noted in the formulations to minimize the use of notation. The letter  $i$  is used to index the insurance status of a person and is defined as follows:

$$i = \begin{cases} 0, & \text{if person(s) has private or Medicare insurance} \\ 1, & \text{if person(s) has no insurance or Medicaid insurance} \end{cases}$$

In order to easily describe the formulation for each view of model, we introduce some abbreviation for variables and parameters used in the model. First, stock variables in the model view are listed as follows,

$P_h(i)$ : Healthy Population with insurance status  $i$

$P_s(i)$ : Population with Non - Emergent Illness with insurance status  $i$

$P_e(i)$ : Population with Emergent Condition with insurance status  $i$

$V_{pr}(i)$ : Preventive PCP Visitors with insurance status  $i$

$V_{ps}(i)$ : Non - Emergent PCP Visitors with insurance status  $i$

$V_{es}(i)$ : ED Visitors from Non - Emergent Illness with insurance status  $i$

$V_{ee}(i)$ : ED Visitors from those with Emergent Condition with insurance status  $i$

$V_{tr}(i)$ : Patients with non - emergent condition and insurance status  $i$  who receive treatment

$WT_{pcp}(i)$ : Perceived Waiting Time for PCP care with insurance status  $i$

$WT_{er}(i)$ : Perceived Waiting Time for ED care with insurance status  $i$

$M_{pcp}(i)$ : PCP Service Fee per Patient with insurance status  $i$

$M_{er}$ : ED Service Fee per Patient

$S_{in}$  :Insurance Premium per member (annually)  
 $P_{esi}$  :Number with Employer - Sponsored Insurance (ESI)  
 $P_{ind}$  :Number of Individually insured  
 $E_{esi}$  :Number with people who are eligible for ESI  
 $F_{ind}$  :Probability of enrolling in individual insurance plan

The parameters (non-time dependent) are listed as follows:

$F_p(i)$  :Frequency of Seeking Preventive Care with insurance status i  
 $F_s(i)$  :Frequency of Developing Non - emergent Illness with insurance status i  
 $F_i$  :Frequency of Injury  
 $F_e$  :Frequency of Escalation (from non - emergent to emergent illness)  
 $T_{rt}$  :Recovery time for non - emergent people who receive treatment at PCP or ED  
 $T_{ru}$  :Recovery time for non - emergent people who do not receive treatment at PCP  
 $T_{ap}$  :Acceptable PCP Waiting Time  
 $T_{ae}$  :Acceptable ER Waiting Time  
 $T_{wt}$  :Response Time for Waiting Time  
 $T_{pcp}$  :Response Time for Adjusting PCP fee  
 $T_{er}$  :Response Time for Adjusting ED fee  
 $T_{in}$  :Response Time for Adjusting Insurance Premium  
 $T_{esi}$  :Response Time for Modifying Insurance Plan/Status in ESI group  
 $T_{ind}$  :Response Time for Modifying Insurance Plan/Status in Individually Insured group  
 $Q_{pcp}(i)$  :PCP Provider Cost per Patient  
 $Q_{er}(i)$  :ED Provider Cost per Patient  
 $Q_{fpcp}(i)$  :PCP fixed cost associated capacity  
 $Q_{fer}$  : ED fixed cost associated capacity  
 $F_{pcp}(i)$  : Percentage of PCP service fee covered by payer  
 $F_{er}(i)$  : Percentage of ED service fee covered by payer  
 $MP_{profit}$  : Desired Profit for PCP Service  
 $ME_{profit}$  : Desired Profit for ED Service  
 $S_{profit}$  : Desired Profit for Insurance  
 $\lambda_{esi}$  : Employer offer elasticity  
 $\lambda_{ind}$  : Price Elasticity for Individual Plan  
 $G$  : Government Subsidy Percentage

Pertinent auxiliary variables are listed as follows

$X(i)$  :Total exchange rate between population that is privately/Medicare insured and uninsured/Medicaid insured  
 $R_{pr}(i)$  :PCP Service Rate for Preventive Care with insurance status i  
 $R_{ps}(i)$  :PCP Service Rate for Non Emergent with insurance status i  
 $R_{es}(i)$  :ED Service Rate for Non Emergent with insurance status i  
 $R_{ee}(i)$  :ED Service Rate for Emergent with insurance status i

$F_{sc}(i)$ : Fraction of people with non-emergent illness and insurance status  $i$  seeking either primary or ED care  
 $F_{ue}(i)$ : Fraction of people with insurance status  $i$  who seek care for non-emergent condition and choose to use the ED  
 $M_{dpcp}(i)$ : Desired price for PCP service, based on insurance status  $i$   
 $M_{der}$ : Desired price for ED service  
 $S_{din}$ : Payer desired premium per member  
 $P_{in}$ : Total Number of insured  
 $F_{emp}$ : Employee take-up probability of ESI

### 3.2. Health progression and care delivery

Consistent with the eight flows in and out of the stock “Healthy Population” in Figure 1, equation (1) expresses the number of people with insurance status  $i$  who are in the “Healthy Population” state. The integrand in Equation (1) comprises eight terms. Note that the healthy population is separated into those who are privately/Medicare insured and those who are uninsured/Medicaid insured. The eight terms in Equation (1) may be interpreted as follows: i) number of healthy people preventive care, ii) number of healthy people developing non-emergent illness, iii) number of people who develop emergent injuries, iv) number of healthy people who have received preventive care, v) number of people recovering non-emergent illness without treatment, vi) number of people recovering from non-emergent illness after treatment and vii) the number of healthy people who have switched their insurance status from being privately/Medicare insured to being uninsured/Medicaid insured. Since people who go for preventive care are considered healthy, the total healthy population includes those who are in the “Healthy Population” state, as well as those who are ‘in the queue’ to visit a PCP for care.

$$P_h(i) = \int_0^t \left( -P_h(i) \cdot F_p - P_h(i) \cdot F_s - P_h(i) \cdot F_i + R_{pr}(i) + \frac{P_s(i) \cdot (1 - F_{sc}(i))}{T_{ru}} + \frac{V_{tr}(i)}{T_{rt}} + P_h(i) \cdot X(i) \right) d\tau + P_h^0(i) \quad (1)$$

Equation (2) represents the “Population with Non-Emergent Illness,” for people with insurance status  $i$ . The integrand in this equation comprises the following terms: i) number of healthy people developing non-emergent illness, ii) number of people recovering from non-emergent illness without treatment, iii) number of people with non-emergent illness who condition escalates to an emergent condition, iv) number of people with non-emergent illness who visit the PCP or the ED and v) the number of people with non-emergent illness who have switched their insurance status from being privately/Medicare insured to being uninsured/Medicaid insured. Since people who are seeking care for their non-emergent condition are still sick, the total population with non-emergent illness includes those who are in the “Population with Non-Emergent Illness” state, as well as those who are ‘in the queue’ to visit a PCP or ED for care.

$$P_s(i) = \int_0^t \left( P_h(i) \cdot F_s - \frac{P_s(i) \cdot (1 - F_{sc}(i))}{T_{ru}} - P_s(i) \cdot F_e(i) + R_{ee}(i) - P_s(i) \cdot F_{sc}(i) + P_s(i) \cdot X(i) \right) d\tau + P_s^0(i) \quad (2)$$

Equation (3) presents the evolution of the “Population with Emergent Condition,” for people with insurance status  $i$ . The terms in the integrand include: i) number of healthy people who develop emergent conditions due to injury, ii) number of people with non-emergent illness whose condition escalates to an emergent condition, iii) number of people with emergent conditions who seek emergent care and iv) the number of people with emergent illness who have

switched their insurance status from being privately/Medicare insured to being uninsured/Medicaid insured. Since people who are seeking care for their emergent condition are still with emergent conditions, the total population with emergent illness includes those who are in the “Population with Emergent Condition” state, as well as those who are ‘in the queue’ to visit the ED for care.

$$P_e(i) = \int_0^t (P_h(i) \cdot F_i + P_s(i) \cdot F_e - P_e(i) + P_e(i) \cdot X(i)) d\tau + P_e^0(i) \quad (3)$$

Equation (4) represents the number of “Preventive PCP Visitors,” for people with insurance status  $i$ . Its value is affected by i) the number of people seeking preventive care, ii) the number of people returning from preventive care, and iii) the number of preventive PCP visitors who have switched their insurance status from being privately/Medicare insured to being uninsured/Medicaid insured. In Equation (4),  $R_{pr}(i)$  is the PCP service rate for preventive care for patients with insurance status  $i$ , and  $P_h(i) \cdot F_p(i)$  is the arrival rate at which patients visit the PCP for preventive care.

$$V_{pr}(i) = \int_0^t (P_h(i) \cdot F_p(i) - R_{pr}(i) + P_{pr}(i) \cdot X) d\tau + V_{pr}^0(i) \quad (4)$$

We have similar equations for expressing the number of “Non-Emergent PCP Visitors” (see Equation (5)), “ER Visitors from Non-Emergent” (see Equation (6)) and “ER Visitors from Emergent” (see Equation (7)), but with different formulas for the respective arrival rates and service rates.

$$V_{ps}(i) = \int_0^t (P_s(i) \cdot F_{sc}(i) \cdot (1 - F_{ue}(i)) - R_{ps}(i) + V_{ps}(i) \cdot X(i)) d\tau + V_{ps}^0(i) \quad (5)$$

$$V_{es}(i) = \int_0^t (P_s(i) \cdot F_{sc}(i) \cdot F_{ue}(i) - R_{es}(i) + V_{es}(i) \cdot X(i)) d\tau + V_{es}^0(i) \quad (6)$$

$$V_{ee}(i) = \int_0^t (P_e(i) - R_{ee}(i) + V_{ee}(i) \cdot X(i)) d\tau + V_{ee}^0(i) \quad (7)$$

We assume that patients with non-emergent conditions who are treated by a PCP or in the ED have different recovery rates from those who are untreated, before joining the “Healthy Population” state. Equation (8) represents the number of “Treated Patients”. Its value is changed by i) leaving PCP after treatment, ii) leaving ER after treatment and iii) proportionally exchanging between insured and uninsured

$$V_{tr}(i) = \int_0^t \left( R_{ps}(i) + R_{es}(i) - \frac{V_{tr}(i)}{T_{rt}} + V_{tr}(i) \cdot X(i) \right) d\tau + V_{tr}^0(i) \quad (8)$$

The mathematical expressions for the service rates used in equations (4)-(7) are provided in Equations (9) - (12):

$$R_{pr}(i) = \min \left( \frac{V_{pr}(i)}{T_{ac}}, \frac{C_{pcp}(i) \cdot V_{pr}(i)}{V_{pr}(i) + V_{ps}(i)} \right) \quad (9)$$

$$R_{ps}(i) = \min \left( \frac{V_{ps}(i)}{T_{ac}}, \frac{C_{pcp}(i) \cdot V_{ps}(i)}{V_{pr}(i) + V_{ps}(i)} \right) \quad (10)$$

$$R_{es}(i) = \min\left(\frac{V_{es}(i)}{T_{ae}}, \frac{C_{er} \cdot V_{es}(i)}{\sum_i V_{es}(i) + \sum_i V_{ee}(i)}\right) \quad (11)$$

$$R_{ee}(i) = \min\left(\frac{V_{ee}(i)}{T_{ae}}, \frac{C_{er} \cdot V_{ee}(i)}{\sum_i V_{es}(i) + \sum_i V_{ee}(i)}\right) \quad (12)$$

where  $C_{pcp}(i)$  and  $C_{er}$  are constants representing the PCP capacity and ED capacity respectively. The PCP capacity depends on insurance status. That is, people with private or Medicare insurance do not utilize the same PCP resources as those people without insurance, or with Medicaid insurance. The ED capacity, on the other hand, is shared by all patients, regardless of insurance status.

$T_{ap}$  and  $T_{ae}$  are constants representing the acceptable waiting times for PCP and ED care, respectively. When there is ample capacity, the service rate is determined by the regular processing time ( $V_{pr}/T_{ac}$ ). Otherwise, the service rate is constrained by the available capacity. Since patients seeking preventive care and non-emergent care share the same PCP capacity, the PCP capacity is split proportionally, according to the ratio of the population that is seeking preventive care and the population that is seeking non-emergent care (i.e.,  $V_{pr}/(V_{pr} + V_{ps})$ ). Since ED capacity is shared, the available capacity is split between patients with non-emergent and emergent conditions in proportion to the ratio of these two populations (i.e.,  $V_{es}(i)/(\sum_i V_{es}(i) + \sum_i V_{ee}(i))$ ).

Before presenting expressions for the auxiliary variables  $F_{sc}(i)$  and  $F_{ue}(i)$  in Equations (1-8), we first define the perceived waiting time for PCP and ER visits, as follows,

$$WT_{pcp}(i) = \frac{1}{T_{wt}} \int_0^t \left( \frac{V_{ps}(i)}{R_{ps}} - WT_{pcp}(i) \right) d\tau + T_{ap} \quad (13)$$

$$WT_{er}(i) = \frac{1}{T_{wt}} \int_0^t \left( \frac{V_{es}(i)}{R_{es}} - WT_{er}(i) \right) d\tau + T_{ae} \quad (14)$$

In Equation (13),  $T_{wt}$  is the response time for patients to perceive, and react, to the new waiting time according to current service rate ( $V_{ps}(i)/R_{ps}$ ).  $F_{sc}$ , the fraction of patients with non-emergent condition who seek care from either a PCP or ED, and  $F_{ue}$ , the fraction of patients with non-emergent condition seeking care, who seek care from the ED, are defined as follows:

$$F_{sc}(i) = \frac{T_{ru}}{(T_{ru} + T_{rt} + WT_{pcp}(i))} \quad (15)$$

$$F_{ue}(i) = \frac{WT_{pcp}(i)/T_{ap}}{(WT_{pcp}(i)/T_{ap} + WT_{er}(i)/T_{ae})} \quad (16)$$

Equation (15) implies that fewer people will seek care for a non-emergent condition if the perceived waiting time to receive care, either through a PCP or ED, is greater than the time it would take for them to recover without professional treatment. Equation (16) implies that more people choose to use ED for non-emergent care if the perceived waiting time for visiting the PCP

is longer than the perceived waiting time for visiting the ED, taking into account the acceptable wait times at the different care provider types.

### 3.3. Medical costs and insurance premiums

For the medical costs and insurance premiums model, we present formulations pertinent for determining the annual ‘insurance premium per member’. Briefly, we assume that insurance premiums are driven by the desire of payers to maintain a targeted level of profit. Therefore, when reimbursements paid by the payer increase on a per member basis, so will premiums. Changes in the reimbursements paid are affected by the fees charged by providers, which in turn depends on the proportion of their services that are compensated for. Although in reality there are multiple payers, we represent them in our model as an aggregated payer ‘entity.’

We assume that medical costs to the payer consist of two parts: the first part is the variable service costs at the PCP or ED, and the second part is the fixed capacity costs at the PCP or ED. The daily costs for PCP and ED care are expressed in equations (17) and (18), respectively.

$$Cost_{pcp}(i) = (R_{pr}(i) + R_{ps}(i)) \cdot Q_{pcp}(i) + C_{pcp}(i) \cdot Q_{fpcp}(i) \quad (17)$$

$$Cost_{er} = \sum_i ((R_{es}(i) + R_{ee}(i)) \cdot Q_{er}(i)) + C_{er} \cdot Q_{fer} \quad (18)$$

The expected pricing per service for both PCP and ER services covers the total cost plus desired profit, as shown in equations (19) and (20).

$$M_{dpcp}(0) = (Cost_{pcp}(0) + MP_{profit}(0)) / ((R_{pr}(0) + R_{ps}(0)) \cdot F_{pcp}(0)) \quad (19)$$

$$M_{der} = (Cost_{er} + ME_{profit}) / (\sum_i (R_{es}(i) + R_{ee}(i)) \cdot F_{er}(i)) \quad (20)$$

In Equation (20),  $F_{er}(i)$  is the percentage of the ED service fee covered by the payer for patients with insurance status  $i$ . If we assume that  $F_{er}(0) = 0.9$ , this means that the payer will reimburse the ED provider 90% of the costs incurred for private/Medicare insured patients. Similarly, if we assume that  $F_{er}(1) = 0.1$ , then the payer will reimburse the ED provider 10% of the costs incurred for uninsured/Medicaid patients. Due to the differences in reimbursement rates, Equation (20) captures the effects of cost-shifting.

$$M_{pcp}(0) = \frac{1}{T_{pcp}} \int_0^t (M_{dpcp}(0) - M_{pcp}(0)) d\tau + M_{pcp}^0(0) \quad (21)$$

$$M_{er} = \frac{1}{T_{er}} \int_0^t (M_{der} - M_{er}) d\tau + M_{er}^0 \quad (22)$$

The expression for the insurance premium per member is given by Equation (23).

$$S_{in} = \frac{1}{T_{in}} \int_0^t (S_{din} - S_{in}) d\tau + S_{in}^0 \quad (23)$$

According to Equation (23), insurance premiums are modified, with some delay, whenever there is a discrepancy between the current premium and the desired premium per member. The payer desired premium per member is the premium level that maintains a fixed profit for the payer, and is given by Equation (24).

$$S_{din} = \int_{t-365}^t \frac{\sum_i (R_{es}(i) + R_{ee}(i)) \cdot F_{er}(i) \cdot M_{er} + (R_{pr}(0) + R_{ps}(0)) \cdot F_{pcp}(0) \cdot M_{pcp}(0)}{P_{in}} d\tau + S_{profit} \quad (24)$$

The first term in the numerator of the integrand in Equation (24) corresponds to daily charge from ER and the second term corresponds to daily charge from regular PCPs (i.e., PCPs that serve those who have private/Medicare insurance). According to this equation, the desired premium per member covers all charges occurred by providers in the last 365 days, plus the desired profit.

### 3.4. Insurance choice

Finally, for the insurance choice model, we present formulations representing the variable “Number with Employer-Sponsored Insurance (ESI),” which is a function of the changes in insurance premiums and the size of any government subsidy,  $G$ .

$$P_{esi} = \frac{1}{T_{esi}} \int_0^t (E_{esi} \cdot F_{emp} - P_{esi}) d\tau + P_{esi}^0 \quad (25)$$

According to Equation (25), the number of people with ESI is modified, with some delay, whenever there is a change in either the number of people who are eligible for ESI or the level of ‘take-up’ (i.e., acceptance) of ESI ( $F_{emp} = f(G)$ ). The number of people who are eligible for ESI is determined by equation (26), below.

$$E_{esi} = \int_0^t \left( \lambda_{esi} \cdot \frac{(S_{dp} - S_{in})}{T_{in} \cdot S_{in}} \cdot E_{esi} \right) d\tau + E_{esi}^0 \quad (26)$$

A 2007 Congressional Budget Office report estimates the overall, average offer elasticity for firms in the United States to be around -0.28 (Congressional Budget Office 2007). This estimate generally varies by firm size. This same report also estimates the employee take-up probability of ESI is a function of the size of the government subsidy.

The number of individuals who are not insured by Medicare or an employer sponsored plan may choose to purchase individual insurance. The probability that they will purchase an individual plan is given by  $F_{ind}$ , which is expressed in Equation (27). This probability is also affected by the size of the government subsidies provided.

$$F_{ind} = \int_0^t \left( \lambda_{ind} \left( \frac{(S_{dp} - S_{in})}{T_{in} \cdot S_{in}} - \Delta G \right) \right) d\tau + F_{ind}^0 \quad (27)$$

The number of individuals who are individually insured is given by Equation (28).

$$P_{ind} = \frac{1}{T_{ind}} \int_0^t \left( (P_{tot} - P_{pub} - E_{esi}) \cdot F_{ind} - P_{ind} \right) d\tau + P_{ind}^0, \quad (28)$$

Finally, in Equation (29), we provide the formula for the rate at which people transition between private/Medicare insurance and Medicaid or no insurance. This rate is equal to the sum of rate of change for the number of eligible people who take-up ESI and the rate of change for the number of individually insured.

$$X(0) = \frac{1}{T_{esi}} (E_{esi} \cdot F_{emp} - P_{esi}) + \frac{1}{T_{ind}} \left( (P_{tot} - P_{pub} - E_{esi}) \cdot F_{ind} - P_{ind} \right), \quad X(1) = -X(0) \quad (29)$$

#### 4. Simulation Scenarios and Results

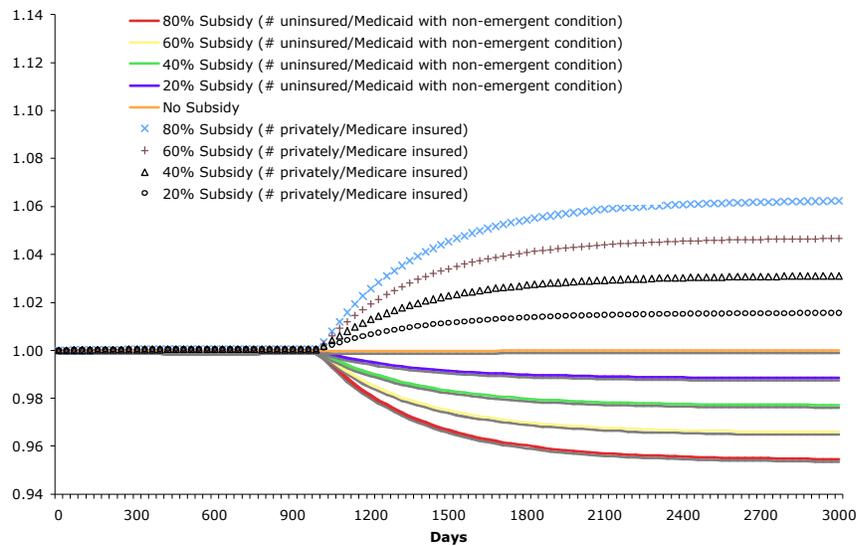
The results presented in this section represent an exploratory analysis of some of the key relationships between the health status, health delivery, health economics, and health policy, as formulated in our model. The reported results have not been validated. We explore four relationships via simulation.

In our first analysis, we study the impact that five different levels of health insurance subsidies from the government would have on the insurance status of the population and the health status of the uninsured. The reason that we were interested in the health status of the uninsured/Medicaid insured is that city governments are responsible for ensuring adequate access to primary care for this group of people through safety-net facilities. We ran 5 simulations (one for each subsidy level), for 3000 (simulated) days per simulation, for a representative population of one million people. In each simulation, we increase the level of the subsidy from 0% (i.e., no subsidy) to 80%, in increments of 20%. The subsidy is applied on day 1000. Prior to day 1000, there is no subsidy. The results from this analysis are shown in Figure 2, which plots two sets of data. The first set of data, represented by solid lined curves, shows the relative change in number of uninsured/Medicaid insured people who have non-emergent conditions. The second set of data, represented by various marker symbols, shows the relative change in the number of people who are privately insured. These changes are relative to the case in which there is no government subsidy. In Figure 2, the effect of the subsidy is seen after day 1000.

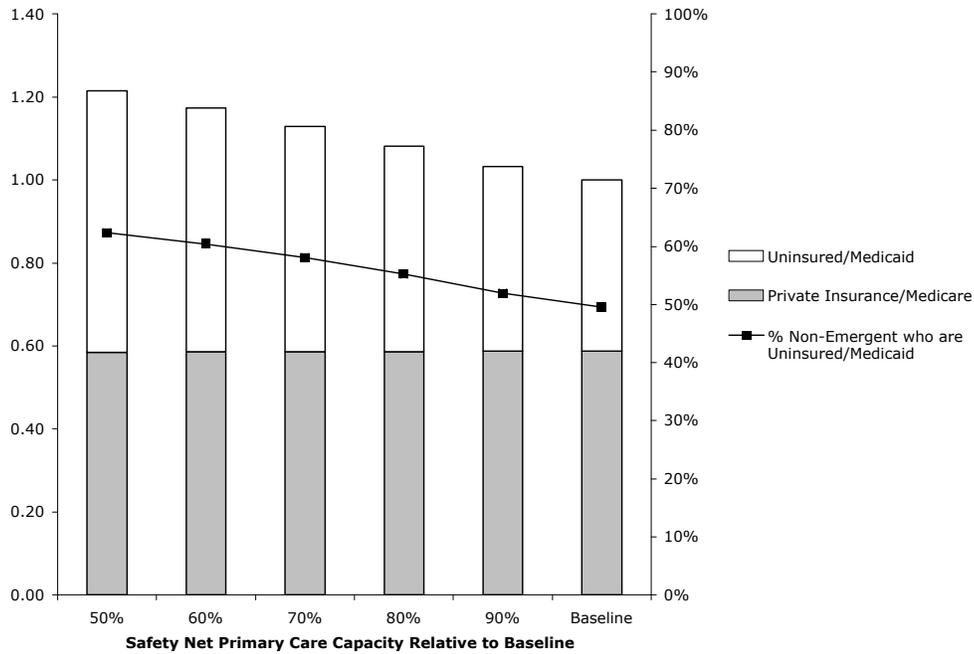
As shown in Figure 2, larger subsidies result in a larger number of privately insured people. Medicare insurance levels are assumed to be constant. As one might expect, the number of people with private/Medicare insurance increases with the level of government subsidy. At the same time, the demand for safety-net primary care, which is largely represented by the number of uninsured people with non-emergent conditions, decreases as the level of subsidies increases. In this example, a 5% reduction in demand for safety-net primary care is associated with an 80% government subsidy over around 5 years, with most of the benefits experienced within 3 years of the subsidy being implemented. Within a time frame of a year, an 80% subsidy would produce a 3% reduction in demand, a 60% subsidy would produce a 2% reduction, and a 20% subsidy would produce a 1% reduction in demand. To determine if subsidies were beneficial overall,

city leaders would need to perform a broader cost-benefits analysis, which is beyond the scope of this paper.

In our second analysis, we wanted to study how the number of visits to the emergency department changed as the level of access to city-funded safety-net PCPs was changed. Therefore, we ran 6 simulations in which we varied the available capacity of safety-net PCPs with each simulation run, from 50% of the baseline capacity, to 100% of the baseline capacity, in increments of 10%. The results from these simulations are presented in Figure 3. These results show that as access to safety-net PCPs falls, the number of ED visits rises relative to the baseline. This increase is due primarily to an increase in the number of uninsured/Medicaid insured people who visit the ED, since the number of ED visit from the privately and Medicare insured population remains steady. Additionally, from the data curve plotted on the secondary axis of Figure 3, we observe that the additional people visiting the ED are primarily presenting with non-emergent conditions that could have been treated by a PCP. In this example, city leaders who wish to control ED overcrowding can expect the level of non-emergent visits to the ED by uninsured/Medicaid insured patients to increase by approximately 4% for every 10% reduction in available safety-net PCP capacity relative to the baseline capacity.



**Figure 2: Impact of Government Subsidies on Insurance Status and Demand for Safety Net Primary Care**



**Figure 3: Impact of Safety Net Primary Care Capacity on Emergency Department Visits**

In our third analysis, we explore the sensitivity of the distribution of ED visits to changes in the employment rate in the city. In Table 3, we see that as the employment rate is increased from 80% to 100%, the number of ED Visits per day falls by around 7%. More interestingly, the fraction of visits to the ED from the uninsured/Medicaid insured population falls by around 25% as the employment rate increases to 100%, since more people become eligible for employee-sponsored insurance. However, the fraction of patients presenting in the ED with non-emergent conditions falls only slightly. This is because the reduction in non-emergent ED visits from the uninsured/Medicaid insured was offset by the impact that the increase in the population of privately insured people had on the utilization of resources in the non-safety-net PCP system. Given a fixed PCP capacity, the increased demand for care in the non-safety-net PCP system increases wait times and increases the likelihood that a privately insured patient with a non-emergent condition will find it more convenient to present at the ED instead of waiting for a PCP.

Employment Rate	ED Visits (Per Million People Per Day)	Fraction of Visits to ED from Uninsured/Medicaid	Fraction of Visits to ED for Non-Emergent Conditions
0.80	1151	0.47	0.66
0.85	1130	0.44	0.66
0.90	1110	0.41	0.65
0.95	1090	0.38	0.64
1.00	1070	0.35	0.64

**Table 3: Sensitivity of Distribution of ED Visits to Employment Rate**

In our fourth and final analysis, we explore the sensitivity of the distribution of ED visits to changes in the frequency of illness onset in the healthy population. This may be brought about, for example, by a degradation of the air quality in a city. Our results are presented in Table 4.

Frequency of Illness (as a proportion of healthy population, per day)	ED Visits (Per Million People Per Day)	Fraction of Visits to ED from Uninsured/Medicaid	Fraction of Visits to ED for Non- Emergent Conditions
0.005	1110	0.41	0.65
0.006	1172	0.39	0.67
0.007	1232	0.37	0.69
0.008	1292	0.36	0.70
0.009	1350	0.34	0.72
0.010	1407	0.33	0.73

**Table 4: Sensitivity of Distribution of ED Visits to Frequency of Illness**

The results in Table 4 show that as the frequency of illness is gradually increased up to two-fold, from 0.005 to 0.01, the fraction of visits to the ED increases by around 25%, where an increasing proportion of these visits comprises privately and Medicare insured people. Of the population presenting to the ED, we observe an increasing number presenting with non-emergent conditions. Since the majority of the population has private or Medicare insurance, the increase in frequency of illness results in larger numbers of people becoming ill. Although these people do not utilize safety-net PCPs, the capacity of private PCPs starts to become constrained, and lower access to primary care encourages some proportion of them to use the ED rather than waiting for a PCP for non-emergent care.

## 5. Conclusion

We use system dynamics to model how healthcare delivery and health insurance status interact to affect population health status and emergency department utilization. In our model, we capture how people choose between PCP or ED care based on their levels of access to care. In particular, we assume that when the wait time for accessing primary care providers is higher than is acceptable relative to the wait time for accessing emergency care, patients will prefer to visit the emergency department, even if emergency care is not required. We track the choice of PCP or ED care based on insurance status. We model the phenomenon of cost-shifting, which occurs when providers compensate for inadequate reimbursement from one class of patients by raising service fees, and subsequently, insurance premiums. Premiums will, in turn, influence the mix of insurance status and health states observed within the population, and the demands on the various care providers.

Through simulation, we explored the potential impact that different levels of government subsidies on insurance premiums may have on population insurance status and the mix of patients in the ED. We showed how government investments in safety-net PCP capacity could enable greater access to care and result in less use of the ED for non-emergent care. We also

showed how employment levels and the vulnerability of a population to illness may impact the mix and volume of patients in the ED. While the initial conditions for our model were calibrated using various reliable and publicly available data sources, our results have not been validated and represent an exploration of some of the relationships in the modeled system. Future studies will involve further refinement of the model assumptions, tighter calibration of the model against other data sources, and an appropriate degree of model validation.

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