Verifying and Documenting a System Dynamics Model of the US Healthcare System

A Major Qualifying Project

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Abstract

Advancing understanding of the dynamics in the health care industry promises great rewards from both business and public policy perspectives. This paper introduces a previously formulated but as yet unpublished model that can be useful from either angle. Designed according to system dynamics methodology, the model has been used successfully to promote mutual understanding and improve forecasting in the operating context of a major health insurance provider. The emphasis in this paper is on providing detailed model documentation, both as an aid to future users and as a method for building confidence in model validity and hence in model output. The discussion concludes with suggestions for future improvements.

Acknowledgements

There is no appropriate way to begin my acknowledgements other than by thanking Jim Thompson. Without him, of course, this project would not have existed, so I must say thank you for providing me with an opportunity that was both enjoyable and educationally valuable. Despite sometimes difficult circumstances, he provided his best effort to help me be as successful as possible with this MQP.

A big thank you as well to Professor Mike Radzicki for advising me throughout the process, from helping me connect with Jim initially all the way to submission.

I, at least, will miss the weekly advisory meetings for their intellectual stimulation and the many stories shared by both advisors.

Certainly, I must also thank my family and friends for their support and encouragement not only during this project but throughout my college years.

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Chapter 1: Introduction

Healthcare is not only an enormous and lucrative industry in the United States, but has been a focus of fierce public debate over the last few decades. Thus, there has been great effort put into understanding and predicting trends, on one side from those seeking business opportunities and on the other those trying to improve care quality and equity while limiting costs. In both cases, system dynamics modeling can help make sense of the extraordinary complexity at play.

This project presents a model of the US health care system developed by James Thompson. Originally developed for use in the business operations of a medical insurance provider, sectors of the model have also been used for other projects. It simulates visit rates and prices in physician office and hospital venues, managed care organization initiatives, hospital capacity, medical technology, and medical malpractice insurance, all in an endogenous manner. It was designed not only to produce forecasts but also to have an equilibrium mode for use in policy testing.

In early 2020, Mr. Thompson approached WPI and offered to donate the model in the hope that it could be useful to the institution and its partners. This project represents the initial effort to accept the model and begin to prepare it for new uses. The principal goals of the project were twofold: document Thompson's model and return it to equilibrium. The documentation effort was focused not only on describing *how* the model operated but also *why* the system was modeled as it was. This required working closely with Jim Thompson, the model's creator, who also verified that the observed relationships matched his intentions. Each sector was placed into isolated dynamic equilibrium for testing purposes. The final stages of the project involved producing a full model equilibrium and testing the model's reaction to exogenous shocks.

There is great value in having a detailed public catalogue of the assumptions on which a model is based. This documentation should aid future users without requiring them to rely so heavily on Jim

Thompson. It also serves as an example of the value of replicating other’s work. Despite an alleged “replicability crisis” in many social science disciplines, often too little attention is payed to this type of work, doubtlessly because system incentives discourage doing so.

Chapter 2: Background

2.1 System Dynamics

System dynamics (SD) is a comprehensive modeling methodology that uses continuous time computer simulation. Over six decades of practice, SD has been applied to address wide-ranging problems in business, social science, public policy, and more. The discipline emphasizes the importance of informational, behavioral, and physical feedback loops and adopts the view that system behavior is a result of system structure. Accordingly, SD models differ from their econometrically-derived cousins which predict behavior based on past statistical relationships. This allows system dynamics to be used in system redesign, even when past statistical correlations are no longer valid due to structural changes.

The basic building blocks of any SD model are stocks, flows, and the feedback loops they can form[1]. A common example of a stock is the water in a bathtub. The corresponding inflow is the faucet, while the outflow is the drain. A simple population structure is shown in Figure 1 as an example of the visual representation of stocks, flows, and feedback loops in Vensim, a common SD software package.

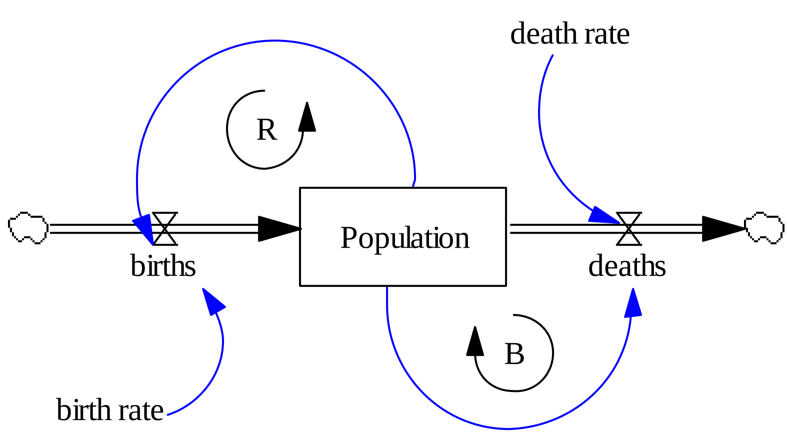

Figure 1: Example population structure

[1] Stocks are sometimes called levels or state variables, while flows are also known as rates.

Population[2] is a stock, usually represented by a box. *Births* and *deaths* are flows. *Birth rate* and *death rate* are auxiliary variables; choosing whether to model a particular variable as a stock or an auxiliary often comes down to the purpose of the model and the speed of variable adjustment relative to model time span. The blue arrows connect variables to others they modify. This may create a feedback loop, like the two in the diagram labeled **R** (for reinforcing feedback) and **B** (for balancing feedback).

2.2 Previous Healthcare Modeling Endeavors

Given the significant human and economic impact of healthcare provision and costs, it is no surprise that a great deal of effort has been invested in modeling related topics, ranging in scope from the spread and treatment of a virus to the organization of national healthcare delivery structures. System dynamics has contributed substantially to this field. One 2020 study found 207 published journal articles where SD was used to examine health or healthcare topics, with an increase in publishing frequency in the last several years (Davahli, Karwowski, & Taiar, 2020). They report that the most common subcategories were patient flows, HIV/AIDS, obesity, and workforce demand. Using different criteria, another 2020 report identified 301 distinct studies combining system dynamics and healthcare (Darabi & Hosseinichimeh, 2020). Of these, they categorize forty-three as addressing "healthcare system modeling" on a scale larger than a single organization.

System dynamics methodology is well-suited to the investigation of many areas of healthcare research due to the importance of feedback mechanisms and delays (J. B. Homer & Hirsch, 2006). SD modelers recognize the importance of modeling a system holistically, as an excessively narrow model boundary may ignore important feedback structures or produce adverse changes elsewhere in the system (Vanderby, Carter, Noseworthy, & Marshall, 2015). Another valuable feature of SD models is the ability to perform "what-if" analyses. Last but certainly not least, the model building process can be

[2] Throughout the paper, italicized names represent variables.

instrumental in promoting stakeholder understanding and consensus. Hirsch and Immediato (1999) have demonstrated successful use of participatory system dynamics in the healthcare space to help stakeholders develop understanding of system behavior and promote positive change.

Even within the domain of "Regional Health Modeling," past efforts have encompassed a wide range of objectives, scope, geographic scale and focus. Many models aim to predict demand, whether for long-term care in Singapore (Ansah et al., 2013), hospital bed capacity in Ireland (Rashwan, Abo-Hamad, & Arisha, 2015), or osteoarthritis treatment resources in Alberta (Vanderby et al., 2015). Others were created primarily for the purpose of testing policy changes or variations in care delivery in a single sector or applied to a single disease (see Bayer, Barlow, and Curry (2007), Bhojani et al. (2014), or Rees, Y. Cavana, and Cumming (2018)).There is a subset of SD models that deal with pharmaceuticals, often in the corporate development strategy domain, but also including national-level (Bulgaria) modeling of drug cost and access (Kunc & Kazakov, 2017).

Nearly all the published "healthcare organization" models are what I term "health models," meaning that health status is one of the primary concerns of the model in both structure and measure of success. Often, this means modeling several population stocks divided according to disease or condition status. Of course, the healthcare sector is represented as well; medical intervention can influence the course and outcome of a condition. Many models represent physicians and other healthcare resources (both human and physical infrastructure) to account for possible resource shortages and bottlenecks. They may also represent insurance coverage.

When restricting the search to regional or national-level comprehensive healthcare modeling (in other words, not restricted to a single condition or category of conditions), the pool of published work narrows considerably. Five of the six identified papers model the American healthcare system, although it is not out of the question that some could be adapted to other settings. The one exception, Yu et al.

(2015), discusses how to realize potential medical demand in China; it will not be discussed in detail mainly due to the limited endogenous feedback structure. Though there are substantial differences between the remaining models, this fact should not be construed to suggest that they are necessarily in conflict. With such a broad scope, detail must be pared down both in the interest of development time and ease of conveying model principles; the necessity of including a given detail often depends on the purpose of the model.

Ratanawijitrasin (1993), for example, conducts an in-depth examination of healthcare payment and finance. This requires detailed modeling of insurance coverage and reimbursement decisions, provider treatment and service provision, and patient visit decisions. Medical malpractice is included as an exogenous input, both as a provider cost and a driver of defensive medicine practice, as is medical technology. The author acknowledges that the latter is likely semi-endogenous to the issue of healthcare costs; she recommends a potential model extension to address this linkage. Notably, there are no modeled measures of population health; healthcare visit rates vary solely based on the cost to the patient. Model structure and effect magnitudes were largely extracted from the literature. The primary insight of the paper is the identification of the important role physician price setting and insurance reimbursement structure has on rising costs. The "moral hazard" phenomenon where insurance coverage reduces the cost disincentive to seek care, as well as technological and malpractice factors, were also identified as contributors to this issue. Ratanawijitrasin suggests a shift in insurance reimbursement policy towards prepaid arrangements, with a fixed cost per case or per patient.

J. Homer, Hirsch, and Milstein (2007) take a much different route when building their model in their paper "Chronic illness in a complex health economy: the perils and promises of downstream and upstream reforms." As the title suggests, the focus is on chronic illnesses, which account for the majority of medical expenditures in the United States and the developed world in general, but the model encompasses all conditions. An important area of inquiry in this paper is the relative effectiveness of upstream vs. downstream reforms on limiting health care spending growth. As Homer et al. (2007) define the terms, “upstream” policies aim to reduce incidence of disease –by, for instance, modifying lifestyle choices or addressing socioeconomic risk factors – while “downstream” measures focus more directly on curbing the cost of treating chronic illnesses. In order to address this research questions, the model must treat population health endogenously, which it does by dividing it into three categories: not at risk, at risk, and with disease. Because at risk individuals and especially those with disease require more medical care than not-at-risk persons, health spending depends in part on endogenous population characteristics. The level of healthcare assets – divided into disease management and urgent care classifications – and health insurance coverage, both of which are modeled endogenously, contribute to quality and cost of care.

Homer et al.’s (2007) headline finding asserts the greater opportunity for cost control through upstream strategies. They also evaluate the effectiveness of various downstream scenarios, though they do not go into detail as to the type of policies that would accomplish such effects. Drawing in part on Ratanawijitrasin (1993), they identify the most important cause of rising per visit costs to be the back-and-forth struggle between providers and insurers to maintain and reduce reimbursement, respectively. However, this insurance and physician price-setting structures are extremely basic, largely consisting of a single nonlinear function by which a larger healthcare fraction of GDP (and with it, presumably, a stronger desire from insurers to cut reimbursements) is specified to increase healthcare costs (representing providers raising prices). This simplicity may reduce confidence in the findings with regards to downstream reforms.

For scope, no other published US healthcare model can match the HealthBound / ReThink Health Dynamics Model, variants of which are presented in Milstein, Homer, and Hirsch (2010), Milstein, Homer, Briss, Burton, and Pechacek (2011), and J. Homer, Milstein, Hirsch, and Fisher (2016). The population health portion of the model is similar to that described above for Homer et al. (2007), with distinct stocks accounting for individuals who are healthy, have an asymptomatic disorder only, and who have a disease or injury, and where the flows between these categories are influenced by medical care quantity and quality, personal behaviors and environmental conditions. An important addition is the disaggregation into “Advantaged” and “Disadvantaged” populations; health equity is also added as an outcome benchmark. There are a number of divisions by care type – e.g. outpatient, inpatient, emergency, PCP, specialist, long term care, and more – for which usage is tracked separately. Emergency or specialist visits are imperfect substitutes for primary care visits if PCP supply is insufficient. Notably, physician supply is influenced by reimbursement rates. When reimbursement rates drop, physician supply contracts over time as the medical field appears less financially rewarding. Although hospital elective capacity is influenced by reimbursement rates, the model does not appear to represent physician-induced demand or the price struggle described in Ratanawijitrasin (1993) or Homer et al. (2007).

Milstein et al. (2010) introduce the HealthBound model and conduct a number of policy tests after calibrating the simulation using historical data. The most promising scenario, when considering cost, health outcomes, and equity, combines expanded insurance coverage, improved healthcare quality, expanded primary care capacity, and promotion of healthy living and behaviors. Milstein et al. (2011) extend the model to include population and price trends. These modifications do not change the major recommendations of the earlier work, with the 2011 paper emphasizing the necessity of “upstream” reforms. Homer et al. (2016) present a derivative of the earlier model (now called the ReThink Health Dynamics Model) which narrows the focus to the regional scale.

All the above papers are created primarily or exclusively for policy testing rather than precise forecasting. Diaz, Behr, and Tulpule (2012), conversely, built a system dynamics model as a proof-of-concept for the ability of SD models to forecast ambulatory healthcare demand over a period of five years, both aggregately and for subgroups divided by age, race, sex, and insurance coverage status. After initializing the model with data from 2003 and running it until 2008, the model's forecasted medical demand aligned closely with actual data. There is a caveat, however, when using Diaz et al.'s (2012) finding to support predictive SD simulation: there do not appear to be any feedback structures, and the model is heavily actuarial; it thus differs greatly from the other national healthcare models, which adhere more closely to traditional SD methodology.

Stepping outside of system dynamics, there are other modeling techniques used for healthcare projections and policy testing, but there do not appear to be any other models as comprehensive in scope and thus capable of capturing interactions between different parts of the industry. The Centers for Medicare and Medicaid Services (CMS), for instance, publishes yearly projections for healthcare utilization and costs with a forecast horizon of one decade. Because these projections use actuarial and econometric techniques, the predictions are fundamentally tied to historical relationships, though adjustments are made if the authors have good reason to believe there has been a notable change in the expected direction or magnitude of a relationship (Sisko et al., 2019). There are also many healthcare models made according to Agent-Based or Discrete Event methodologies – as well as hybrid models combining one of these methods with system dynamics – but none with a national-level scope.

2.3 The Health Care System Model

The Health Care System (HCS) model covered in this paper was developed by James P. Thompson beginning 2001 for use in the business operations of a major health insurance provider. The primary purpose was predicting medical visits rates and prices over a three-year horizon, with a disaggregation into four venues: physician offices, emergency departments, outpatient care,[3] and inpatient care. It was also adapted to other roles, such as planning for a hypothetical influenza pandemic or planning business strategy in response to changes in insurance regulation. Though its predictive accuracy compared favorably with more traditional forecasting techniques, Thompson did not cast it as an authoritative source but rather a valuable “voice in the conversation.” Moreover, he notes that part of the model’s value lay in its capacity to build mutual understanding and consensus about the healthcare system among company decision-makers. The model was designed with two modes: forecasting and policy-testing. The latter required the model to be initialized in equilibrium.

The model structure was based predominantly on information shared by MCO managers, physicians, and other healthcare industry participants. Thompson (n.d.) described the model building process as follows:

> In the first meeting, the manager was introduced to the idea of building a system dynamics model of the health care system. We reviewed graphs of measured data familiar to the manager who was asked to explain why conditions changed. The manager’s explanations were noted, and after the first meeting, a small model – a piece of the health care system – was developed to simulate the manager’s explanation.
>
> In the second meeting, the manager reviewed simulation output and asked for his reactions and criticism. …For the third meeting in the series, the small models were combined into a larger model of the U.S. health care system. (p. 2)

Because the model was intended primarily for short-term forecasting, no measures of population health were included. Instead, the main driver of care utilization is technology. This relationship is based on the

[3] Care is classified as outpatient if no overnight stay is required.

observation that people are more likely to visit their doctor if they believe there is a drug or treatment that can address their ailments.

2.4 Validating and Building Confidence in System Dynamics Models

Regardless of the methodology followed or the tools used to create a model, it cannot successfully represent the real world in every detail or under every circumstance. Furthermore, just as a scientific theorem cannot be proven beyond all doubt, a model cannot be proven right – it can only be demonstrated to provide useful insight or output for the purpose for which it is designed. Forrester and Senge (1979) argue that "the ultimate objective of validation in system dynamics is transferred confidence in a model's soundness and usefulness as a policy tool" (p. 8). Unless decision-makers and stakeholders develop faith in a model, it will be powerless to effect change.

Confidence in model usefulness rests both on a recognition that the assumptions and structure of a model are sound and that this structure can produce model behavior that reasonably mirrors the behavior of the real-world system in question. Building confidence can be accomplished in many ways, but there are some tests that have proven generally valuable. Forrester and Senge (1979) specify nineteen tests, divided into tests of model structure, of model behavior, and of policy implications.

Morecroft (1985) develops different a method to simultaneously verify and impart understanding about model structure and behavior. This is accomplished by breaking a model into smaller components and verifying the components individually. The emphasis is on verifying at a scale where the results can be compared with the decision-making processes of the entities being modeled (or aggregates of those entities, assuming all are believed to make decisions in a nearly similar manner). SD methodology tends to emphasize modeling as people actually behave, including decision-making shortcuts and cognitive limitations, rather than as a fully rational *homo economicus*. Thus, it is vital to specify the assumptions incorporated in the modeling of these decision-making process. Confirming that the individual decisions are modeled appropriately builds confidence in the combined result for both modeler and reader, even if the complete model produces complex and counter-intuitive behavior.

Chapter 3: Methodology

The great bulk of this project involved verification and documentation of model substructures – termed sectors – examined in isolation from the rest of the model. This section provides an overview of this process.

3.1 Isolation by Sector

As originally received, Thompson's Health Care System model was divided into over thirty-five sectors. The division has no effect on model structure, but aids in ease of understanding by visually breaking the structure into logical components. The sectors also provided ideal divisions by which to demonstrate and verify the assumptions and relationships expressed in the model, using a similar process to Morecroft (1985). Though there are 30 different sectors,[4] there are only fourteen distinct generic structures, termed "modules;" the discrepancy is a result of the division of the model by care venue. For instance, the "visit rate" structure is duplicated in five sectors – one for each venue (physician office (PO), emergency department (ER), outpatient (OP), and inpatient (IP)), plus one sector tracking inpatient length of stay (LOS). Though parameter and initial stock values may be different between venues, structural differences are minor or nonexistent. Though each sector was tested individually to ensure conformity with expected module behavior, documentation is only presented once per module.

For initial testing, the sector was isolated from the remainder of the model. All inputs from other sectors were initially changed to plausible constants; inputs were occasionally scaled down to make the numbers easier to work with, but the relative size of variables was preserved. Next, the dynamic equilibrium requirements were calculated algebraically. In SD terminology, dynamic

[4] This total does not include the three data and calculation sectors (Major Effects, Source Data, and Source Data 2)

equilibrium is present when cumulative inflows equal cumulative outflows for all stocks. In other words, stock values will remain constant, even though the theoretical “stuff” in them is constantly turning over. Generally, equilibrium requirements specify the initial values for stocks, but in some cases, there are parameter inputs that have required values – for instance, some sectors cannot be in equilibrium if the inflation input is non-zero. After putting the model into equilibrium, verification was carried out by “shocking” the model by varying sector inputs, usually through a step change in the input. To qualify as verified, the sector must exhibit behavior in line with the micro-level decision making assumptions. As stated above, the formulations in the HCS model are largely derived from consultation with stakeholders. Thus, when isolated, the simulation behavior should match the behavior they described.

Using testing classifications developed by Forrester and Senge (1979), this process encompasses aspects of both the Structure-Verification and Behavior-Prediction Tests. In the course of verifying a sector, it was ensured that all parameters had a real-world meaning and were not used to artificially affect the output – the Parameter-Verification Test. There was also an effort made to test the modules under extreme conditions, though this test was not applied as comprehensively.

If testing produced an unexpected response, further investigation was prompted. In a few cases, results that initially appeared to be wrong were determined to correctly reflect assumptions Thompson had temporarily forgotten. Other times the model formulation was determined to be incorrect. Many of these errors were fixed during the course of the project. Some identified issues remain but are noted in Appendix C: Appendix C: Detailed Model Documentation. Finally, there are several other instances where updated or more exhaustive research is needed.

3.2 Sample Verification

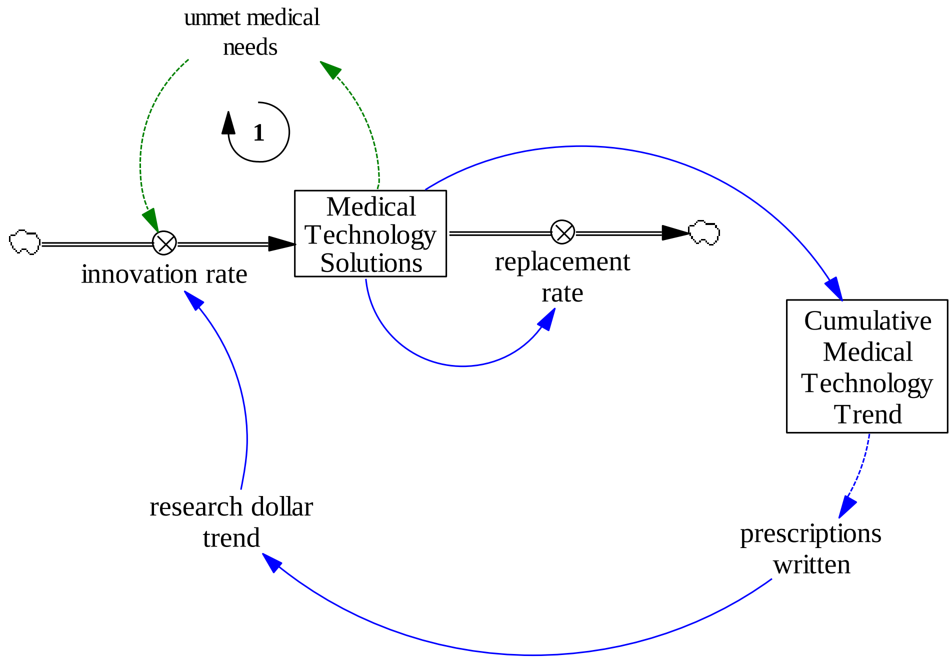

Figure 2: Simplified Medical Technology Structure - Sample Verification

Employing an example may aid understanding of the module verification process. Consider the structure shown in Figure 2, and suppose that the feedback loop in blue has already been tested in isolation and verified, with the outcome graphed in Figure 3. Observe that a step increase in *prescription written* produced behavior of *Medical Technology Solutions* similar to a right-skewed bell curve. Next comes the test of Loop 1 from the diagram (green dashed lines). This loop is added under the belief that medical technology research is subject to the "low-hanging fruit" effect: the more possible problems (unmet medical needs) to solve, the faster the average progress. Equivalently, when the number of problems dwindles, presumably the more difficult ones remain, resulting in slower innovation. Thus, the addition of this loop to the model should slow growth in *Medical Technology Solutions* compared to the previous run. Running both loops together produces the results shown in Figure 4. The new run is graphed in dark red, and the cyan line tracks the previous run for comparison purposes.

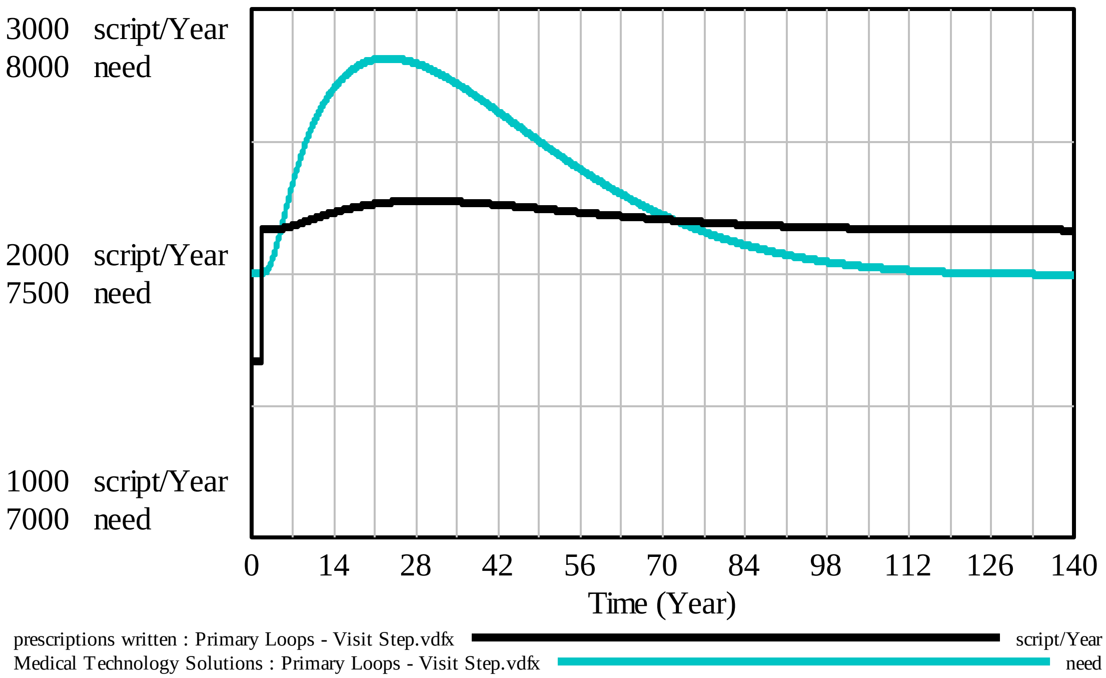

Figure 3: Sample Verification - step 1

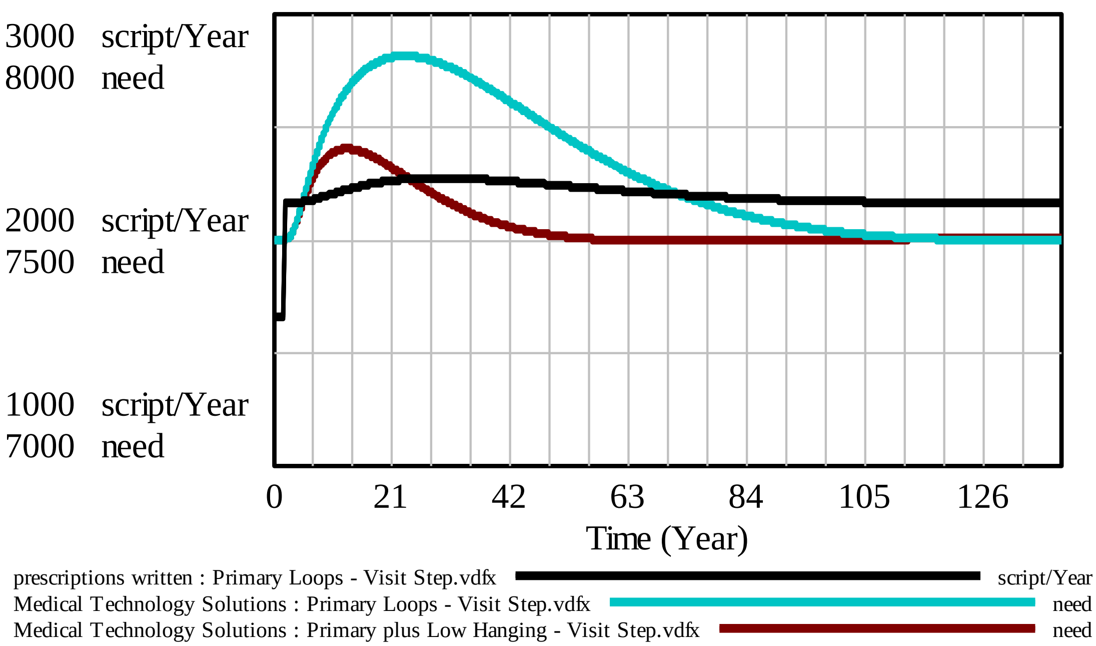

Figure 4: Sample Verification - step 2

As predicted, the second run resulted in less growth of *Medical Technology Solutions*. Because these tests were run with the structures of interest isolated from the rest of the model, we can conclude that the observed change in behavior occurred solely due to the addition of Loop 1. Therefore, the loop 1 sub-module has been verified as reproducing the behavior it was intended to model.

3.3 Combining Sectors

The first step when recombining sectors is ensuring equilibrium is maintained. Because of circular dependencies (e.g. the initial value of *PO Visit Rate* depends on *PO Visit Initiatives*, but the initial value of the latter also depends on the former), attaining full equilibrium required additional algebraic work.

Chapter 4: Model Overview

As noted, the HCS model is divided into fourteen distinct structures. This report covers thirteen; the fourteenth, MCO [Managed Care Organization] Premiums, was never fully incorporated into the model, so the decision was made to leave that sector for later examination. The thirteen remaining modules are summarized here. Much more detail, along with testing results, are included in Appendix C.

4.1 Visit Rate and Length of Stay

The Visit Rate module tracks medical visit rates in units of visits per person per year for the physician office (PO), emergency department (ER), outpatient (OP), and inpatient (IP) venues. A nearly identical structure is used to track inpatient length of stay (LOS) in units of days per visit. Visits rates are somewhat of an abstraction in that they combine the notions of visits per year and services provided per visit. This must be kept in mind when comparing or calibrating against reported visit rates.

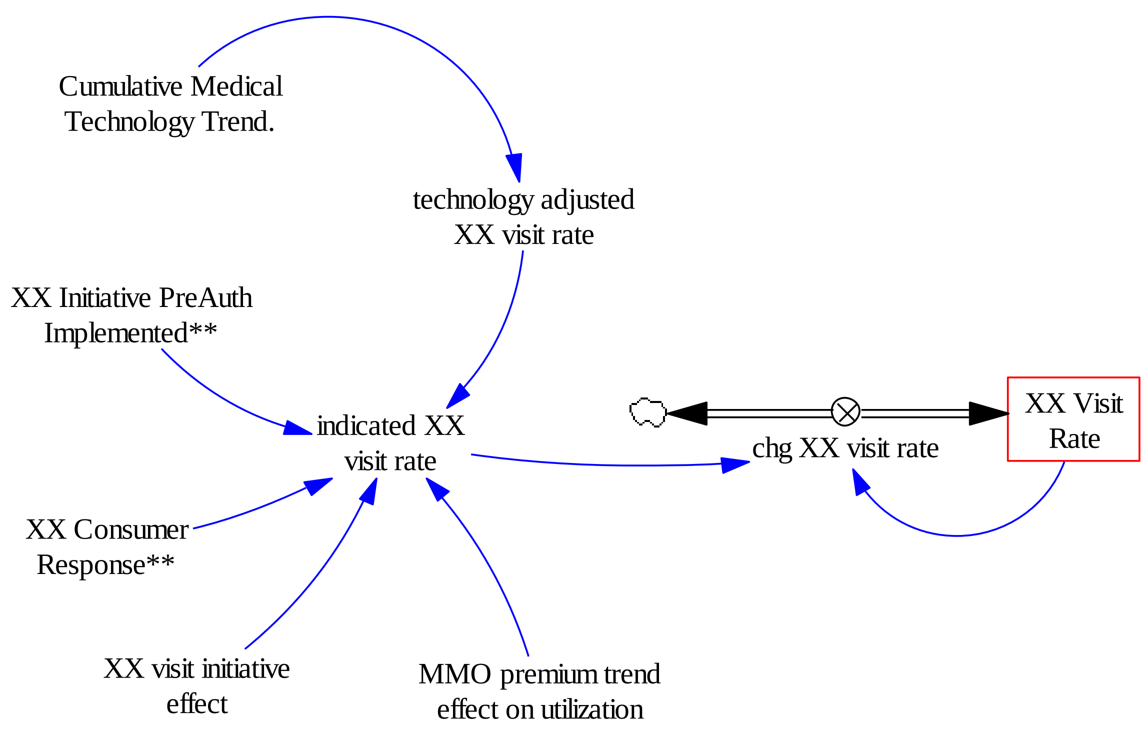

Figure 5: Diagram of XX Visit Rate / LOS sectors

** denotes variables that do not appear in all sectors

The sector calculates an instantaneous indicated visit rate by adjusting the initial rate with factors accounting for changes in the aggregate level of medical technology, the effect of managed care (MCO) initiatives to limit visit rates, and changes in medical malpractice premiums. Improvements in technology encourage visits by those who may be afflicted by newly-treatable ailments, while also decreasing the required inpatient length of stay and shifting some previously inpatient procedures to outpatient venues. MCO visit initiatives attempt to limit visit rates, but may face consumer and provider pushback. Note that the current model structure does not include an endogenous linkage between initiatives and pushback. When malpractice premiums are rising, doctors increase the standard of care both to defend against lawsuits and to offset costs. By increasing the standard of care, they perform more tests and procedures, which increase the visit rate.

The indicated rate is harmonized with the measured *XX Visit Rate* over time. In the physician office venue only, the actual visit rate cannot exceed the physician supply-limited rate.

4.2 Visit and Length of Stay Initiatives

As cost-conscious organizations, managed care organizations (MCOs) would like to control the number of medical visits made by their policyholders – they certainly want to avoid paying for unnecessary care. They have a number of methods to limit visit rates, including the standard HMO requirement for a primary care physician to serve as a “gatekeeper” to specialist access. Other strategies include increasing copays and case management for high-use patients. Policies denying coverage of certain expensive treatments or physicians may also reduce visits, as patients will often only visit their physician if they anticipate receiving their desired care. In this way, a single initiative can influence both visit rates and prices. This module is used to track these visit initiatives and duplicated for the major healthcare venues, while a nearly identical structure monitors initiatives targeting the average inpatient length of stay.

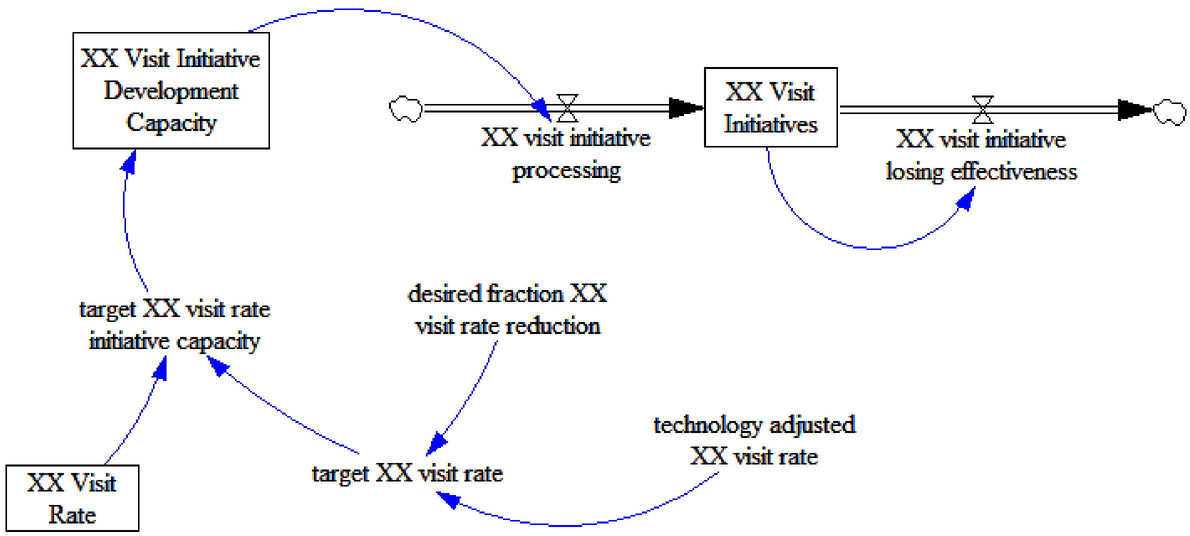

Figure 6: Diagram of XX Visit Initiatives structure

All five sectors include a variant of the initiatives/development capacity structure shown in Figure 6. MCOs determines a target visit rate or length of stay, and then adjust their initiative development capacity to meet that target. The model simulates initiative development as reactionary rather than proactive; insurers allocate resources to develop initiatives when increasing medical prices result in higher-than-anticipated payouts. However, no development capacity is allotted to replace initiatives which are “losing effectiveness”, meaning that initiatives rarely accomplish their full targeted price reduction. Development capacity takes time to adjust, and initiatives take time to be implemented. Initiatives also lose their effectiveness after a period of time, representing, among other possibilities, patients or providers finding work-arounds or the insurer terminating an initiative due to unpopularity or a large administrative burden.

A variety of specific MCO initiatives, along with a consumer response stock, are also modeled in some venues, but these are completely separate from both each other and the above structure. These factors take one of two structures: a single stock with an exogenous inflow and a proportional outflow, or a two-stock aging chain, again with an exogenous inflow. Due to their exogenous nature, these structures are primarily used for data fitting, whether for calibration or forecasting. In the updated model, a number of additional examples representing specific policies (e.g. capitation initiative) have been removed. (See 0 for full list of changes)

4.3 Capacity

The capacity module calculates the national hospital capacity in the emergency department (ER), outpatient (OP), and inpatient (IP) venues. These sectors primarily measure infrastructure and capacity – physician count is tracked separately, and all other resources are assumed to be available in non-constraining quantities.

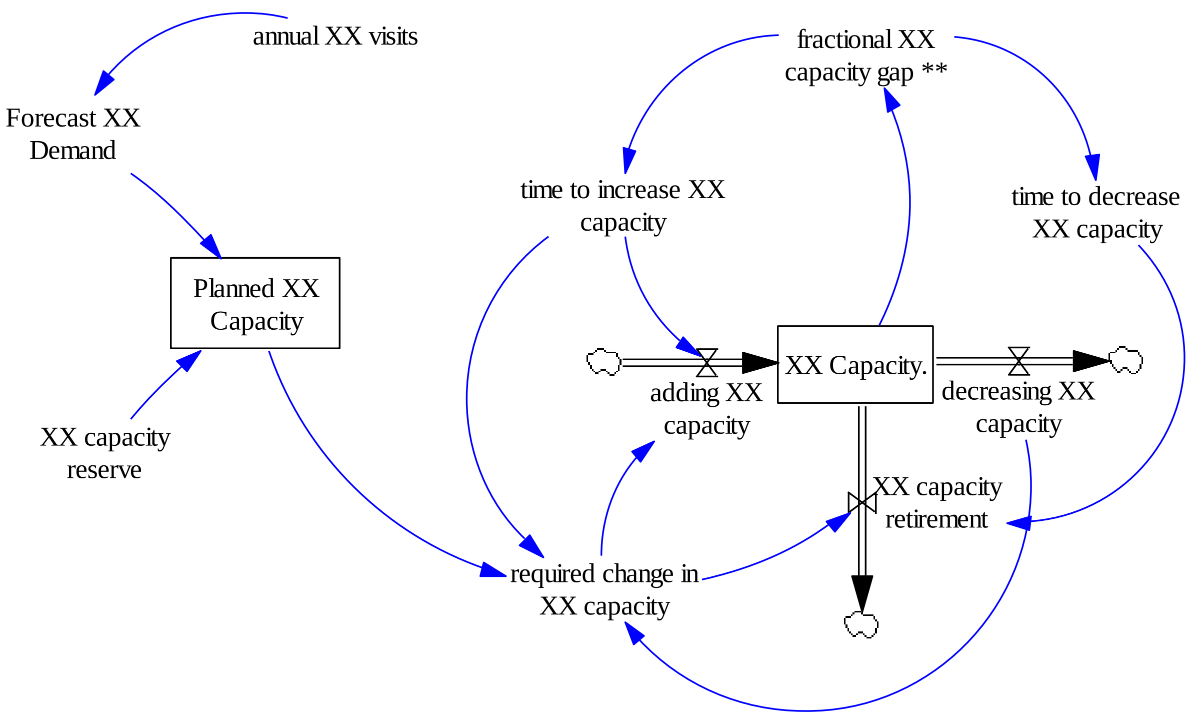

Figure 7: Diagram of the basic structure of the XX Capacity module.

** denotes a variable excluded from the IP CAPACITY formulation.

Due to the delays involved with planning, funding, and constructing capacity, healthcare facilities must forecast demand – formally or not – when projecting capacity requirements. In addition to adjusting for expected changes in future demand, facilities must account for infrastructure and equipment aging or becoming obsolete. Therefore, this model has one way to add capacity (appropriately named *adding XX capacity*) but two ways for it to be removed: d*ecreasing XX capacity* accounts for infrastructure that has reached the end of its lifespan and/or become obsolete, while *retiring XX capacity* denotes capacity retired "early" due to oversupply. As reflected in historical data, ER and OP capacity adjustment times decrease when the relative capacity gap is larger, but IP adjustment times are fixed. In the model, the *Planned XX Capacity* is determined by a combination of forecasted and historical demand, augmented by a capacity reserve for handling surges and seasonal demand fluctuations.

4.4 Asset Value

The Asset Value module tracks the aggregate value of infrastructure and equipment used in the three hospital venues. All assets are treated as proportional inputs– in other words, if there is zero capacity, there are zero assets. Moreover, there is no overlap between venue assets: each unit of assets can only belong to one venue.

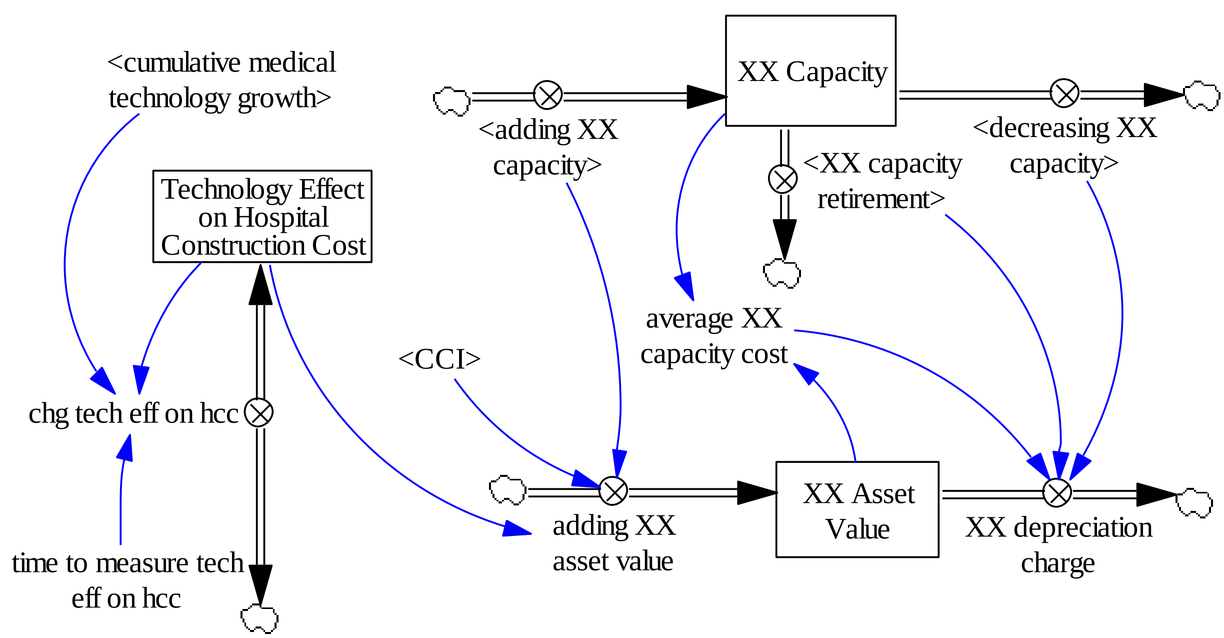

Figure 8: Diagram of the basic structure of the XX Asset module.

The basic operation of the sector is quite simple: asset value is added to by newly built capacity, and it is subtracted from by the removal of capacity. The book value of new capacity is the initial value modified by a construction cost index (*CCI*) and by cumulative growth in medical technology, as measured by *Technology Effect on Hospital Construction Cost*. More technology leads to a higher book value for each new unit of capacity. The book value of each removed unit of capacity is the average value of all capacity (Capacity ÷ Asset Value). As a result, if the stock of technology is increasing, even a constant capacity will exhibit increasing aggregate asset value.

4.5 Hospital Cost

The hospital cost module estimates average per visit operating costs for the outpatient and emergency venues and the average per day cost for inpatient visits.

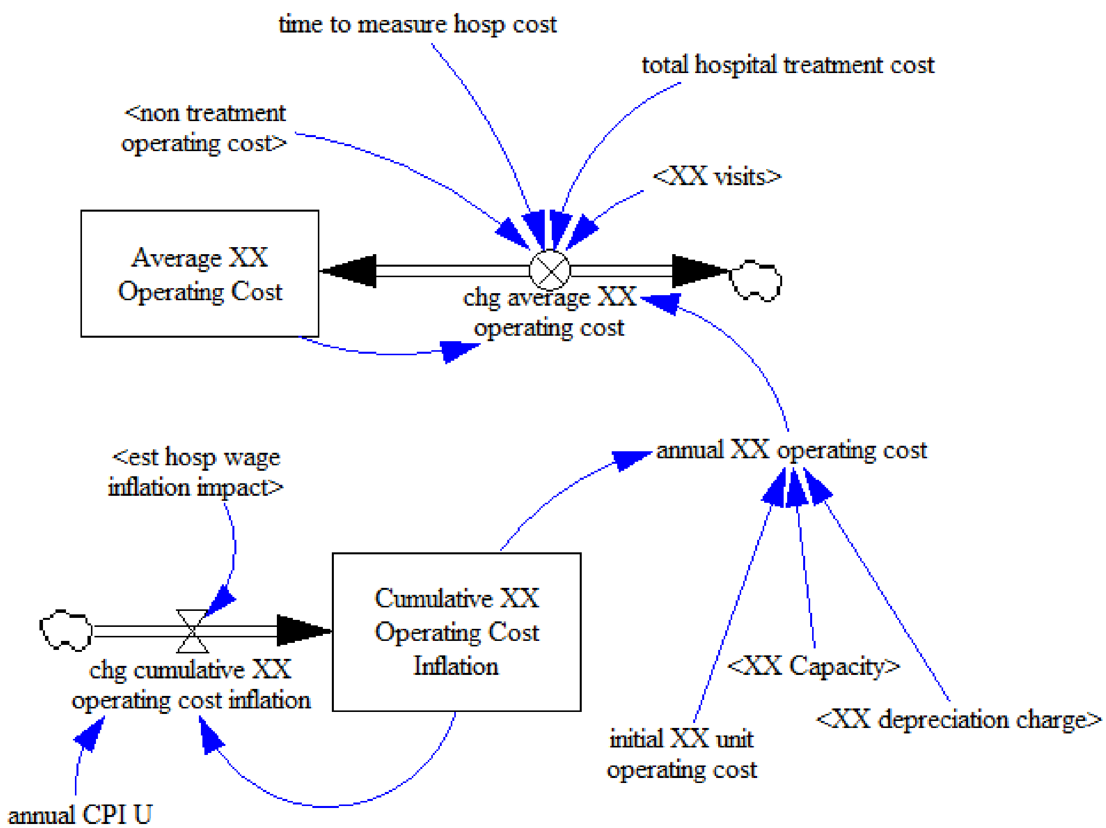

Figure 9: Diagram of XX Cost module structure

This sector is mostly computational, with similar calculations for ER, OP, IP, and non-treatment operating costs. Cost changes due to general inflation and labor cost fluctuations are tracked through the *Cumulative XX Inflation Index* stock, while the specified initial venue operating cost provides an anchor. In the manner of balance-sheet accounting, long-term asset costs are accounted for through depreciation charges. Among other factors (see module guide for more detail), asset cost depends on medical technology level, with a higher relative value increasing average asset costs. All units of venue capacity incur the same costs, whether they are utilized or not. Non-treatment operating costs (e.g. administrative overhead, facilities maintenance) are distributed among the emergency, outpatient, and inpatient venues proportional to each venue's share of total hospital costs. This division was perhaps more realistic in the era when nearly all outpatient procedures were done in hospitals, but it likely remains to be an reasonable abstraction at this level of aggregation.

4.6 PO Price

As the name implies, the PO Price module tracks physician office visit price. Because of the diversity in payment setups (insurance reimbursement, full or partial out-of-pocket), not to mention the variation among regions and even individual physicians, the price stock here denotes the national average in the most basic sense: total spent on physician visits divided by the number of annual visits. Thus, it incorporates payments made by both insurers and individuals.

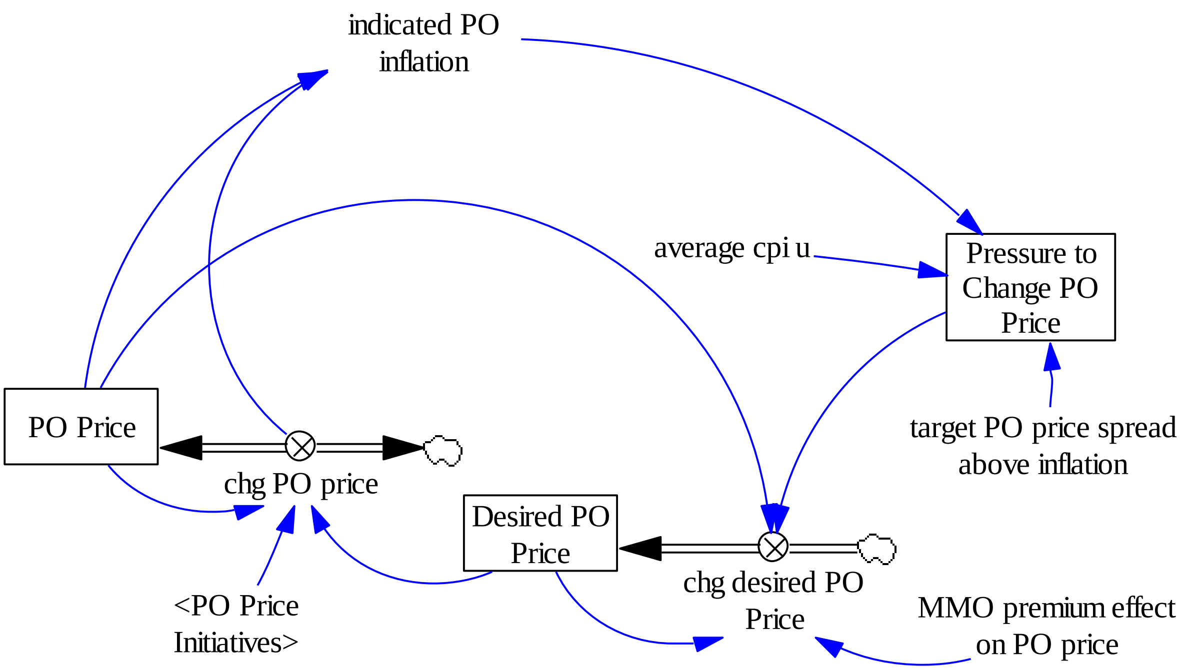

Figure 10: Diagram of PO Price structure

This structure can be divided into two sub-structures: the physicians' desired price and the actual average price paid, accounting for the downward price pressure exerted by insurers. This setup allows representation of disparate incentives for MCOs and providers.

Particularly given the level of aggregation, *Desired Price* necessarily represents a theoretical or unstated value that accounts for the markup physicians would like to receive for their services. The billed price is perhaps similar in concept, though there should be no expectation that the magnitude of the sticker markup is a reflection of the desired value as tracked by the model. Physicians are assumed to desire reimbursement that increases slightly faster than general inflation. If, for instance, the percentage increase in *PO Price* over a period (*indicated PO inflation*) is less than the sum of *average cpi u* and *target PO price spread above inflation*, *Pressure to Change PO Price* will grow. The trend in MMO premiums also influences desired price – if premiums are rising, *Desired PO Price* will rise as well, and the reverse.

4.7 Hospital Price

The Hospital Price module tracks price for the three hospital venues: emergency department, outpatient, and inpatient. As in the PO Price sector, the price stock here denotes the national average in the most basic sense: total spent in the given venue divided by the number of annual venue visits (or annual bed days, in the case of the IP venue).

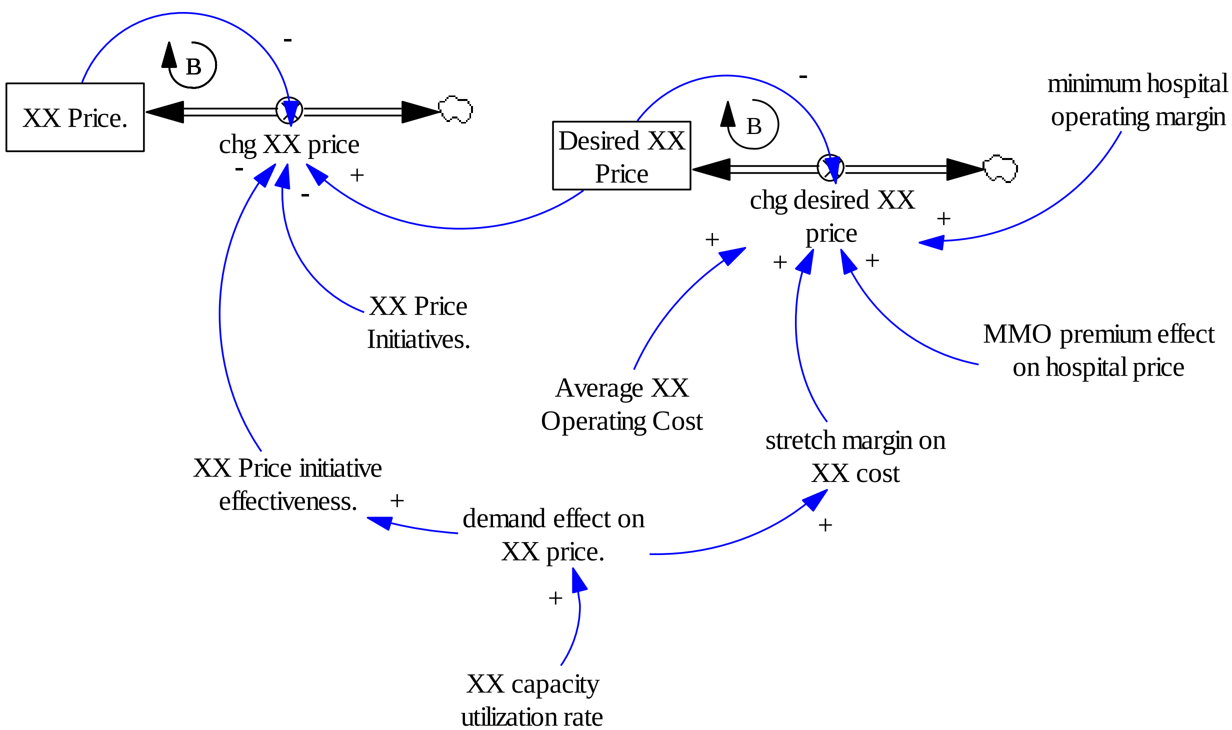

Figure 11: Diagram of XX Price structure

The Hospital Price module is structured similarly to the PO Price module, but there are three important differences. Whereas the desired physician price depends on the current price, the desired price in the hospital venues is anchored on the calculated costs for the respective sector. Cost is multiplied by the total desired margin – composed of constant and demand-sensitive elements. Second, initiative effectiveness is inversely proportional to demand – when demand is high and reimbursement costs grow, MCOs enforce restrictions more stringently – as is the stretch margin. Finally, Because the

Desired XX Price has a semi-exogenous anchor, *chg desired XX price* must be modified by the cumulative (not instantaneous) MMO premium trend.

4.8 Price Initiatives

Managed Care Organizations (MCOs) would like to decrease the average price they reimburse for a health care visit. They employ a number of tactics in pursuit of this goal, including step therapy – requiring use of a generic drug before authorizing a patented medicine – excluding high-priced physicians from coverage networks, implementing a capitation payment scheme instead of fee-for-service. The Price Initiatives sectors track such initiatives by venue.

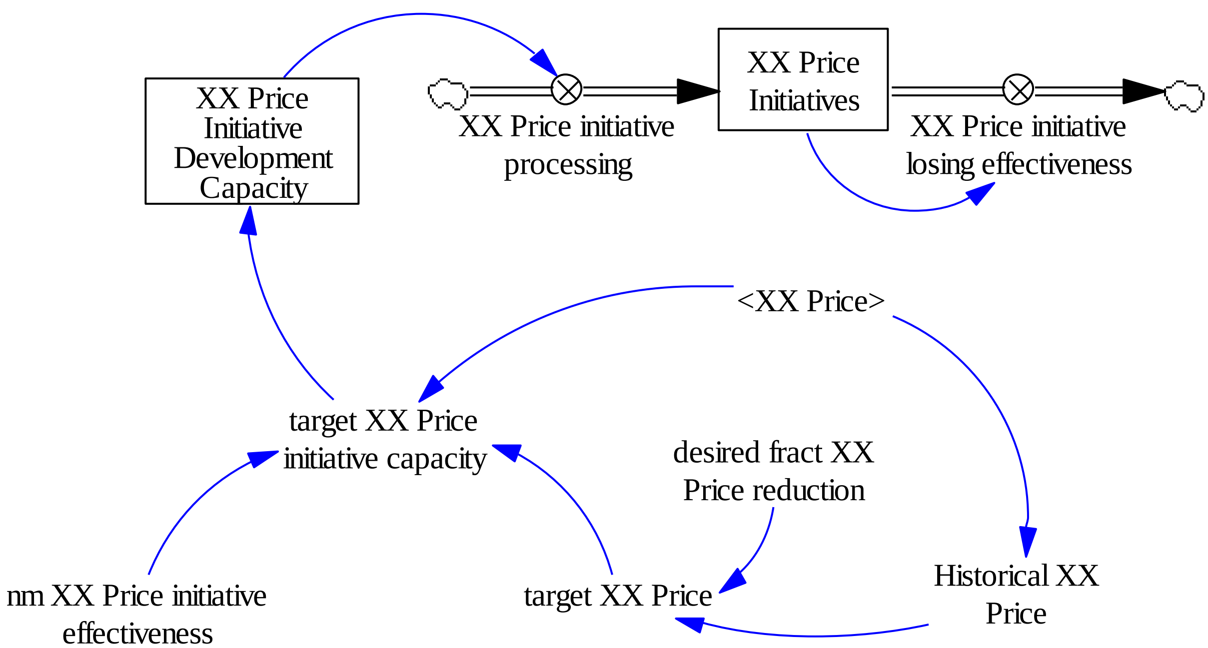

Figure 12: Diagram of XX Price Initiatives structure

MCOs determines a target price based on a fixed percentage reduction of an exponential smooth of historical prices. Otherwise price initiatives work in the same way as visit initiatives

4.9 Hospital Revenue

The Hospital Revenue sector produces national aggregate values for hospital costs and revenue. This sector is almost purely computational, with no decision or behavior modeling. All costs are summed to produce *total hospital cost*, all income sources contribute to *total hospital revenue*, and the difference is *hospital net revenue*. Related to these are *Average Hospital Operating Cost*, *Average Hospital Revenue*, and *net average hospital revenue*, respectively, which correspond to the delayed "measured" values. All these values represent totals, not per visit or per bed day figures.

4.10 Physicians

The physicians module tracks the number of practicing physicians. There is one stock – *Physicians in Practice*. Physicians can enter either by graduating from medical school or by immigrating. As the name of the stock implies, both these inflows only include those individuals who go into practice – the model does not include people with medical degrees who are not practicing. The single outflow accounts for all physicians leaving active practice. All flows in this sector are fully exogenous.

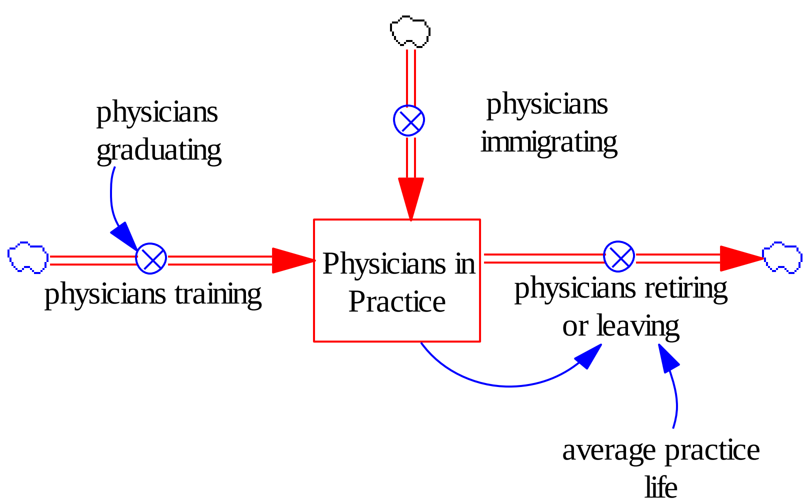

Figure 13: Diagram of the Physicians sector

4.11 Medical Technology

Technology is one of the most important dynamic influences on health diagnosis, care delivery and outcomes. This sector tracks "Medical Technology Solutions," both pharmacological and non-pharmacological in nature. While the value of *Medical Technology Solutions* is not meaningful in and of itself, the cumulative trend can be tracked to create an index of technological progress.

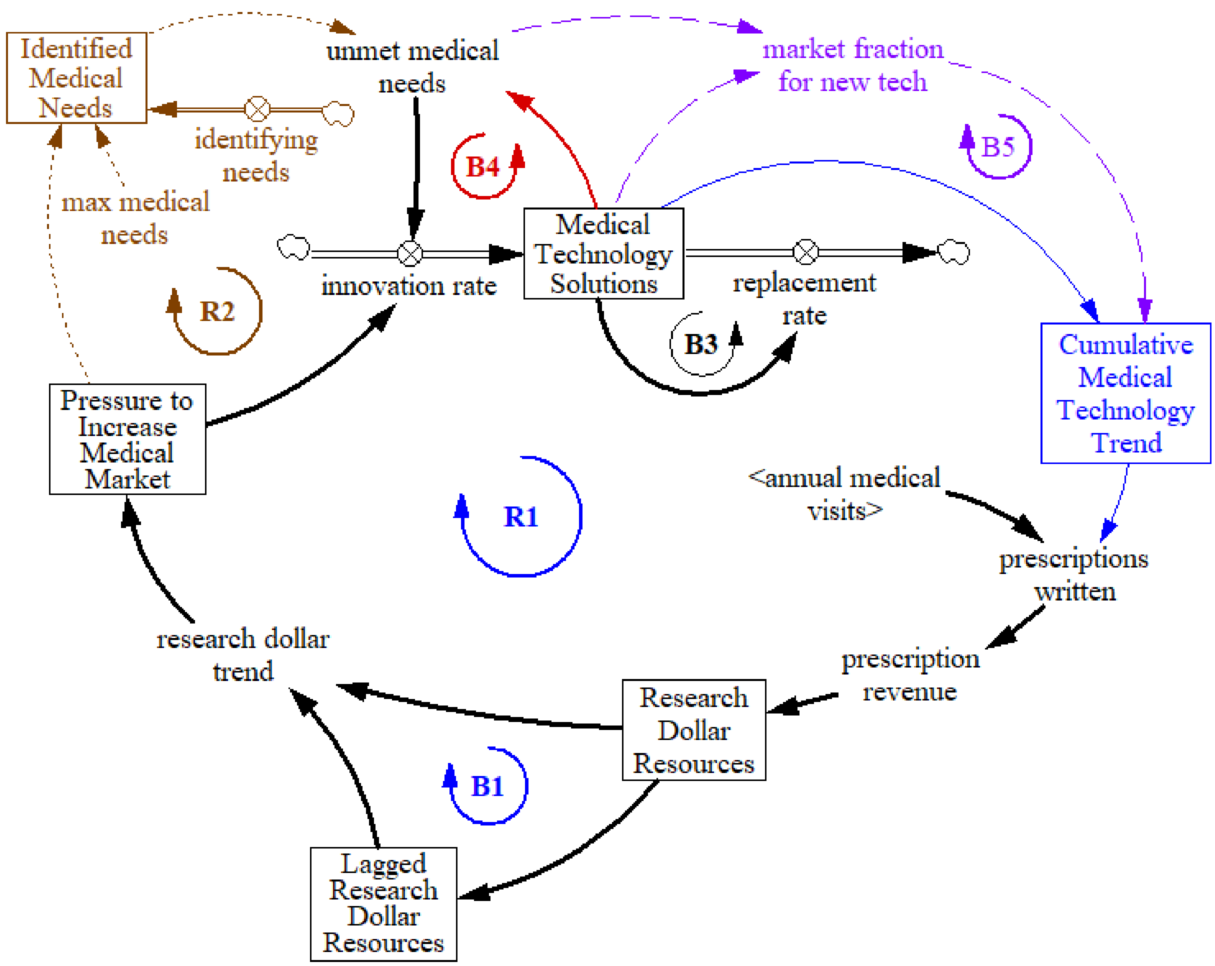

Figure 14: Simplified diagram of the Medical Technology sector, with selected feedback loops labeled

At its core, the medical technology sector is driven by the trend in prescription revenue (here, prescriptions refer to doctor's orders, whether for pharmaceuticals or other tests or procedures). Moreover, because the number of prescriptions written is proportional to *Medical Technology Solutions,* a pair of feedback loops is created within the sector (**B1** & **R1**).[5] More prescriptions produce more industry revenue, some of which is re-invested in research and development. As industry revenue grows, more players join and there is a greater reward for innovation, speeding up the rate of new discoveries and development. It is worth emphasizing that industry size has **no** effect on innovation rate – only the trend matters. To illustrate the difference, consider that a one-time step increase in revenue will initially produce in increases in both revenue value and trend, but will eventually settle into a new equilibrium where the amount of revenue remains elevated but the trend returns to zero. In this scenario, both the innovation rate and the level of technology would return to their original values – the latter because the stock of technology depreciates over time (**B3**).

In the model, there are three categories of medical needs: "unidentified", "unmet" but identified, and those both identified and addressed by medical technology solutions. The more identified unmet needs, the faster the innovation rate (**B4**). This represents the declining efficiency of innovation as "low hanging fruit" becomes progressively rarer, an effect documented in the real world (McConaghie, 2018). The pool of unmet needs can be replenished by identifying new needs (**R2**), a process whose rate is affected by the industry revenue growth trend in a similar manner to the innovation rate. The sum of all medical needs (identified and not) is modeled as finite via the *max medical needs* parameter.

As the medical market becomes more saturated, the average new technology is assumed to target a more specialized market and thus have a smaller impact on aggregate medical decisions (**B5**). Market saturation is determined by the ratio of medical technology solutions to unmet medical needs.

[5] **R1** and **B1** are identical except that **B1** "detours" through *Lagged Research Dollar Resources*. Because the link between *Research Dollar Resources* and *Lagged Research Dollar Resources* is negative, the loop polarity is reversed. Loops **R2** and **B5** also have corresponding loops of opposite polarity that are unlabeled in Figure 14.

The latter is chosen over *max medical needs* to represent the new market opportunities produced by needs identification.

It is important to note that loop **R2** cannot be active if the model is to achieve equilibrium.

4.12 Malpractice Premiums

The Malpractice Premiums module tracks medical malpractice premiums by modeling the basic financial structure of medical malpractice insurers or organizations (MMO). When the model was constructed, malpractice premiums had been growing rapidly for several years and were thus a significant focus of efforts to forecast (and reduce) medical cost growth.

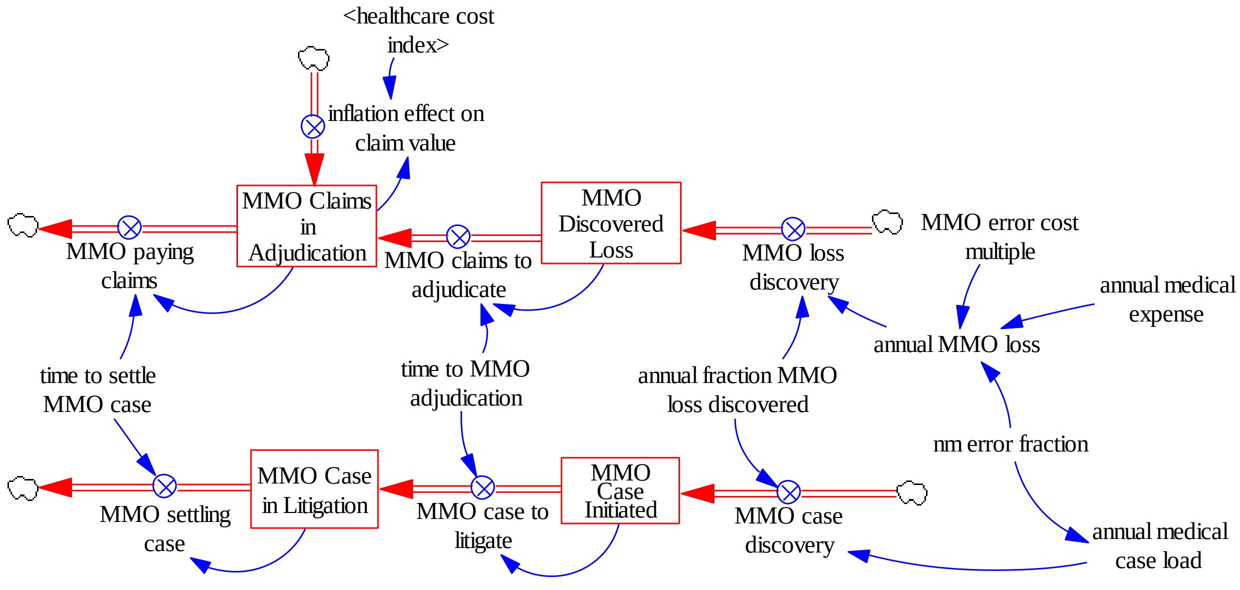

Figure 15: Diagram of part 1 of the MMO Premium module

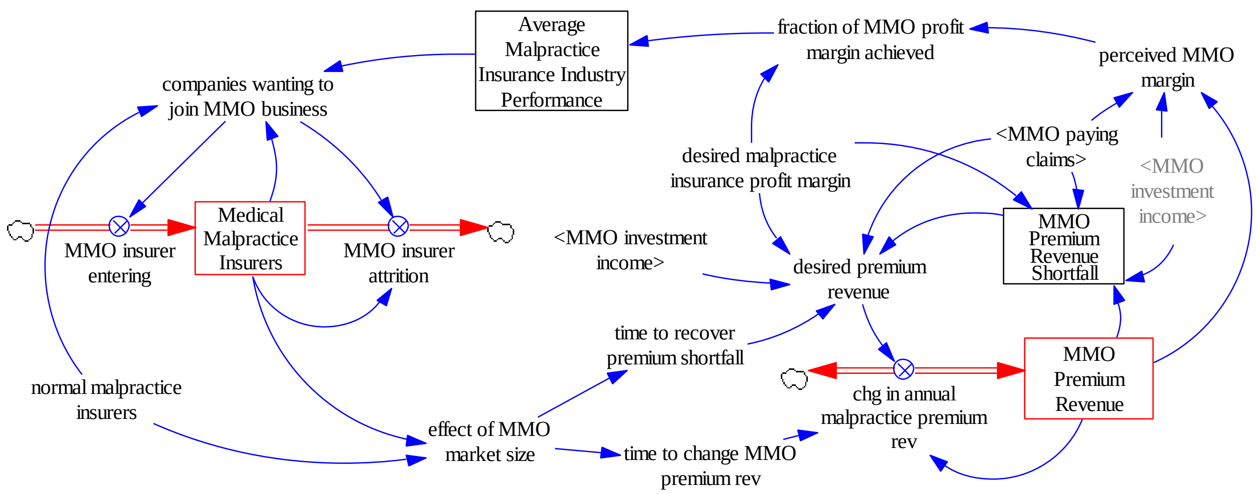

Figure 16: Diagram of part 2 of the MMO Premium module

In the model, malpractice claims are determined by the product of annual medical spending, the normal error fraction, and the error cost multiple. Because the model does not represent unsuccessful claims, the *nm error fraction* is the fraction of medical visits which result in successful malpractice suits.[6] *MMO error cost multiple* is the estimated ratio of the average claim value to the original visit cost. In other words, for every dollar's worth of negligent care, "*MMO error cost multiple"* dollars are claimed. Claim value is also modified by *healthcare cost index*, a measure of aggregate medical cost inflation, as measured by the aggregate*.* Furthermore, claims take time to be processed, adjudicated, and settled. The number of malpractice claims is also tracked (bottom chain in Figure 15), but only for the purpose of calculating the average claim value; for the purposes of MMO premium setting, only total claim value matters.

[6] Though this may seem like a major omission, especially given the relatively small percentage of malpractice claims settled in favor of the plaintiff, it is simply a calibration decision and does not change model behavior when compared to a structure where a fixed percentage of claims were dismissed. Modeling claim success rate endogenously would add considerable complexity in return for questionable gain.

Malpractice insurers are assumed to set premium rates at a level which covers claim payments as well as a desired profit margin. Administrative costs are abstracted in claim payouts. Insurers also maintain an actuary reserve of invested assets which not only serves a cushion against a down period but also generates a return used to help fund operations. Because premiums cannot be changed instantaneously to account for shifts in claim payments, it is possible to have an imbalance between costs and income. Though claim payments can be covered by the actuary reserve, MMOs are assumed to attempt to recoup any cumulative shortfall by increasing future premiums. Conversely (despite the variable name), excess income reduces future premiums.

This sector includes a basic structure tracking the number of medical malpractice insurers. When MMO profits exceed targets, the industry becomes attractive and more players join. If profits are subpar, the opposite happens. Larger numbers of insurers increase the time required to adjust premiums and extends the desired time to recoup past revenue shortfalls. Smaller numbers do the opposite. When costs experience sustained growth and premium revenue shortfalls appear, a decrease in *Medical Malpractice Insurers* allows premiums to adjust more quickly, narrowing the shortfall. When costs are decreasing, the increase in MMO numbers results in a slight larger profit margin as premiums take longer to fall.

4.13 Malpractice Equity

The MMO Equity tracks the value of assets in the MMO Actuary Reserve and the income derived from those assets. Like other types of insurers, malpractice insurers must maintain a reserve in case of claim costs exceeding premium income over a certain period of time. Though they can make up the loss by raising future premiums, they need an immediate source for paying the claims. In many places, governments require malpractice insurers to keep a certain fraction of annual costs in a reserve. In the model, the target value of the actuary reserve is one year’s worth of claims value. A notable simplification is that the money going in (or out) of the actuary reserve does not have to come from (or go) anywhere; *MMO Actuary Reserve* simply adjusts over time to equal *MMO Claims in Adjudication*.

Though the interest rate is set as a constant for equilibrium-based runs, it can be set up to be driven using historical data or another type of input.

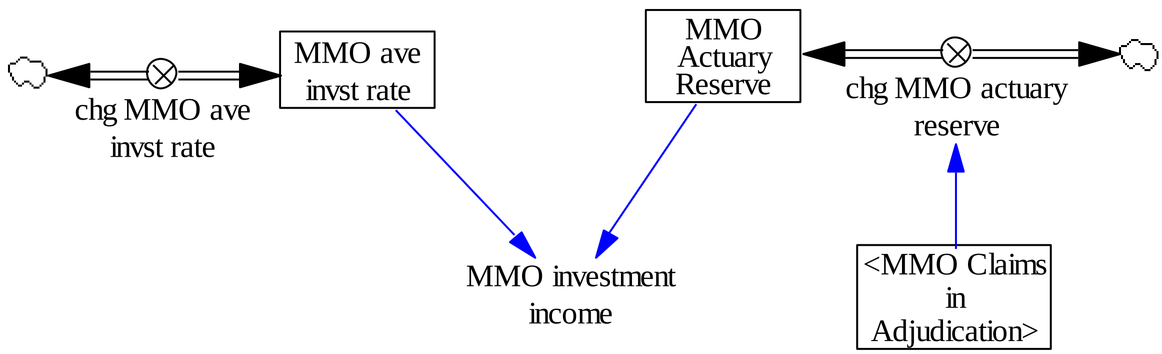

Figure 17: Diagram of the basic structure of the MMO Equity module.

Chapter 5: Discussion

While sector isolation is useful for testing and building confidence in a model, it cannot begin to simulate the complexity of the real health care system until the pieces are combined. This chapter will present some simple examples that demonstrate how joining multiple sectors can significantly alter behavior due to the formation of additional feedback loops. Starting with two sectors in combination, more will be added until the full model is linked together.

5.1 ER Price & ER Price Initiative

This example demonstrates the behavior of the linked ER Price and ER Price Initiatives sectors. The structure is duplicated for the OP and IP venues, which means that those sector pairs will exhibit the same behavior patterns, dependent on parameterization. The PO Price sector behaves somewhat differently, but is not shown. As described above, the desired hospital prices are anchored off the respective venue cost. Suppose there is a step increase in *Average ER Operating Cost* from 100 to 1500 at time = 2 (cost is exogenous to this sector pair). If price initiatives are held constant, it seems clear that *Desired ER Price* and *ER Price* should both increase. If initiatives are endogenized, however, will prices still increase?

Figure 10 displays the results; note that the *ER Price* equilibrium value is identical whether the modules are run together or not. When *ER Price Initiatives* is constant – the “ER Price Only” runs – a 50% step increase in *ER Operating Cost* leads to a smooth asymptotic adjustment to a new equilibrium value approximately 70% larger. In the “ERPrice + ERPI” runs (ERPI = ER Price Initiatives), price initiatives are free to adjust in response to changes in price. Because *target ER price* is based off the historical *ER Price,* this change produces oscillatory behavior in *ER Price*; Figure 19 helps explain why.

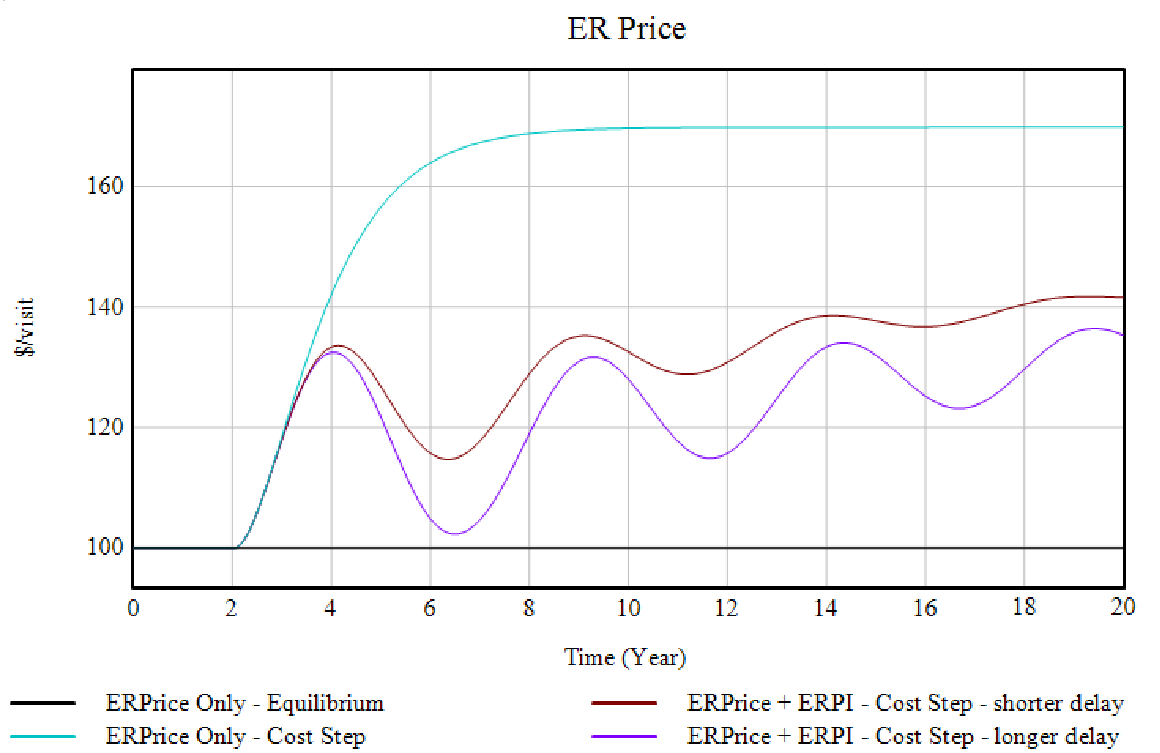

Figure 18: *ER Price* scenario comparison (ERPI stands for ER Price Initiatives sector)

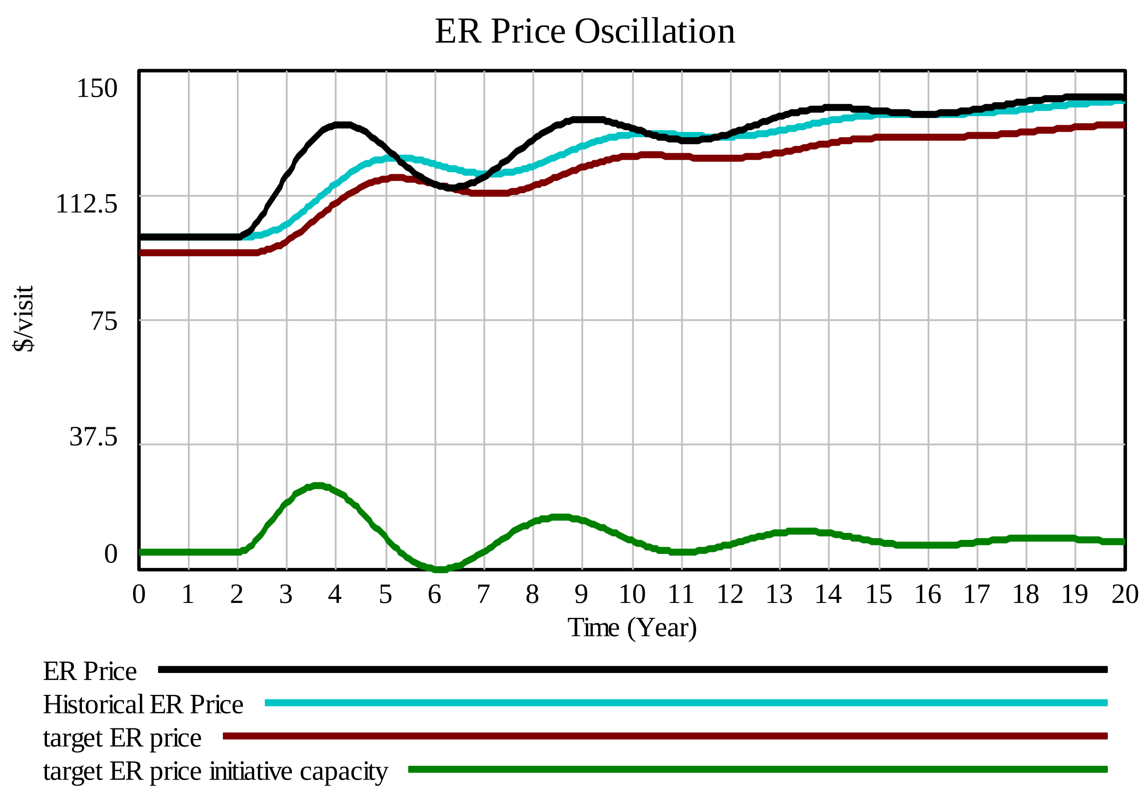

Figure 19: Oscillatory Behavior of *ER Price* in response to step increase in *Average ER Operating Cost*

When *ER Price* begins to increase, so does *target ER price initiative capacity* – because initiatives have an additive impact on price, a higher price requires more initiatives as long as the desired fractional reduction is constant. At the same time initiative strength is growing, the MCO *target ER price* is increasing in line with the smoothed historical price. These twin effects force *ER Price* towards the target price. Though this may seem to be the end of the story, it is not: as the gap between actual and target prices shrinks, the immediate urgency for MCOs to control prices disappears, and the *target ER price initiative capacity* falls. In response, the trend in *ER Price* reverses and begins to climb again. This starts the cycle all over again. Depending on adjustment time parameters, this oscillatory behavior may be barely noticeable – test values were chosen to emphasize the behavior – but the system can even produce exploding oscillation if the time delays to develop and implement initiatives are very short. Note that in all cases, the new *ER Price* equilibrium remains above *target ER price*, another consequence of the reactive initiative development process.

It may seem plausible that increasing the delay time for *Historical ER Price* may tame oscillation in *target ER price* and therefore actual *ER Price*. Comparing the “shorter delay” and “longer delay” runs in Figure 18 shows that the reverse is true, as a longer delay leads to more pronounced oscillation, all else being equal. Because the target price adjusts more slowly, the gap between actual and target price grows larger, leading to stronger peak initiatives in the “longer delay” run. Though it may appear that *ER Price* will remain permanently lower in the “longer delay” run, it eventually reaches the same equilibrium value of approximately 160 as in the “shorter delay” run, representing an increase of roughly 60% over the initial value.

An important note: though this behavior may seem irrational, that is not enough to dismiss it out of hand as a realistic model of real-world decision-making. The individual decision-making structures were confirmed by MCO initiative managers, and the oscillatory behavior may also exist in a more subtle fashion.

5.2 PO Visit Rate & PO Visit Initiative

Though the visit rate initiative and price initiative modules are very similar, the former uses the *technology adjusted PO visit rate* as the anchor for *target PO price*.[7] When running the model without the Medical Technology sector, these variables are both fixed. This produces notably different behavior compared to the previous price initiative examples.

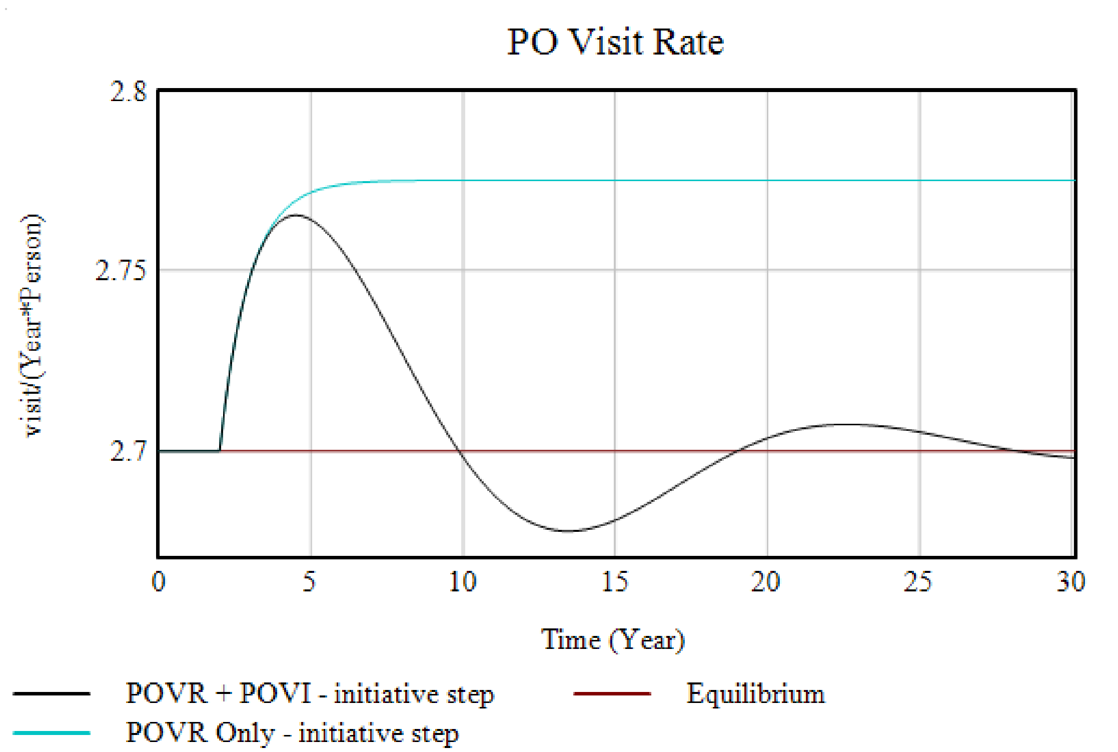

Figure 20: *PO Visit Rate* scenario comparison (POVR stands for PO Visit Rate sector, POVI for PO Visit Initiative sector)

The scenario in this example supposes a sudden 25% decrease in *PO visit initiative effectiveness*. Imagine, for instance, new legislation that required insurers to cover a certain class of expensive drugs, taking away one tool they use to control reimbursement costs. With constant price initiatives, *PO Visit*

[7] Or the corresponding variable from the relevant venue.

Rate (hereafter abbreviated *POVI*) increases asymptotically until it reaches a new equilibrium. When *PO Visit Initiatives* are endogenized, however, *POVI* experiences an initial surge but eventually returns to its original value by way of damped oscillation. As with the previous sector, the amplitude and type of oscillation depends on parameter values.

5.3 Adding Technology

In many ways the technology module is the most important one, not least because it ties all venues together. This test uses the same input shock as the previous section, a step decrease in *PO visit initiative effectiveness*. Because the relative change in *PO Visit Rate* is quite small, all other variable movement is also small. In fact, comparing the trajectory with and without technology in Figure 21 shows scarcely any difference. The importance of this runs instead lies in the demonstration that a change in one parameter in a single sector influences the entire model. As explained in more detail under the relevant module, this is because technological growth is based off the revenue trend, which always returns to zero except in the case of an exponentially growing input.

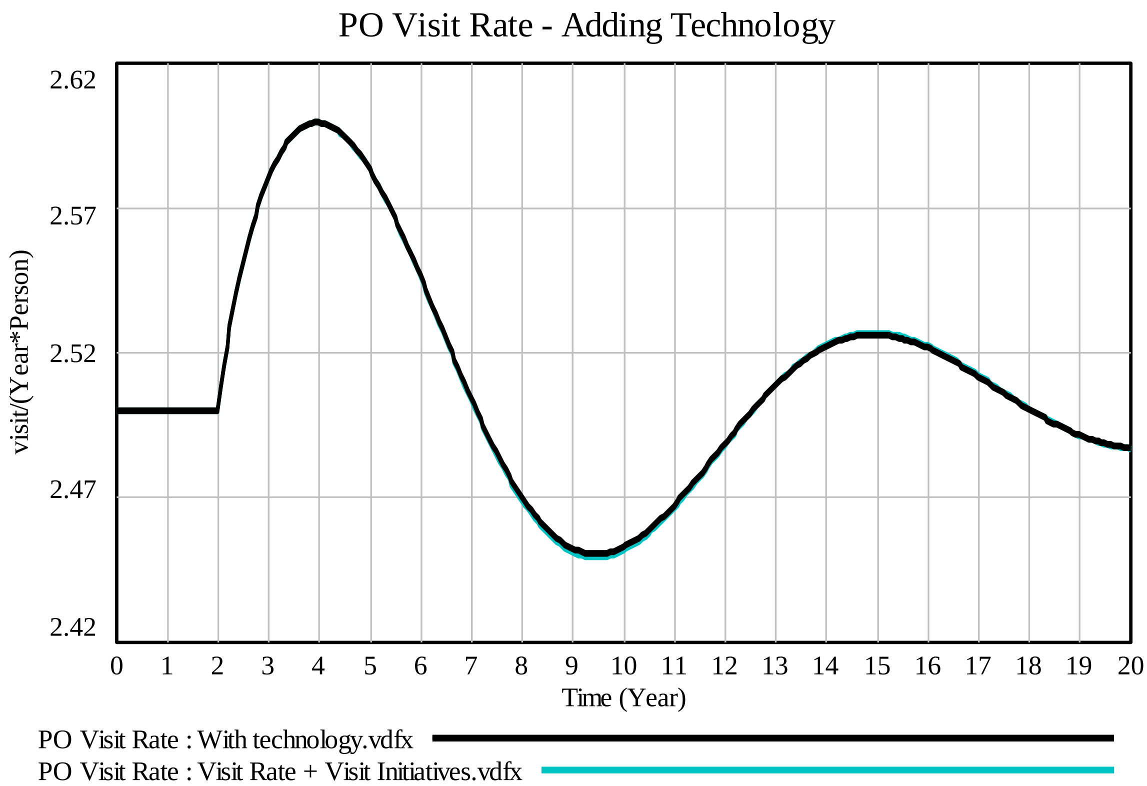

Figure 21: Comparison of *PO Visit Rate* with and without technology sector

An increase in *PO Visit Rate* translates to an increase in *Medical Technology Solutions*. This in turn increases visits rates and asset values for all sectors. Increasing visit rates require more capacity, while growth in asset values increases hospital operating costs and subsequently prices. Moreover, there are many active feedback loops, making causal tracing extremely time-consuming. The many delays in the system are also important contributors to behavior; although all variables shown in Figure 22 and Figure 23 exhibit oscillation, their periods are not in sync. For instance, the addition of *Medical Technology Solutions* actually dampened oscillation in *POVR* because the peak in *Cumulative Medical Technology Trend* came when *POVR* was in a trough, and vice versa. The final important observation is that all stocks eventually return to their original values after a shock. In other words, the model exhibits stable equilibrium behavior, like a marble at the bottom of a parabolic track.

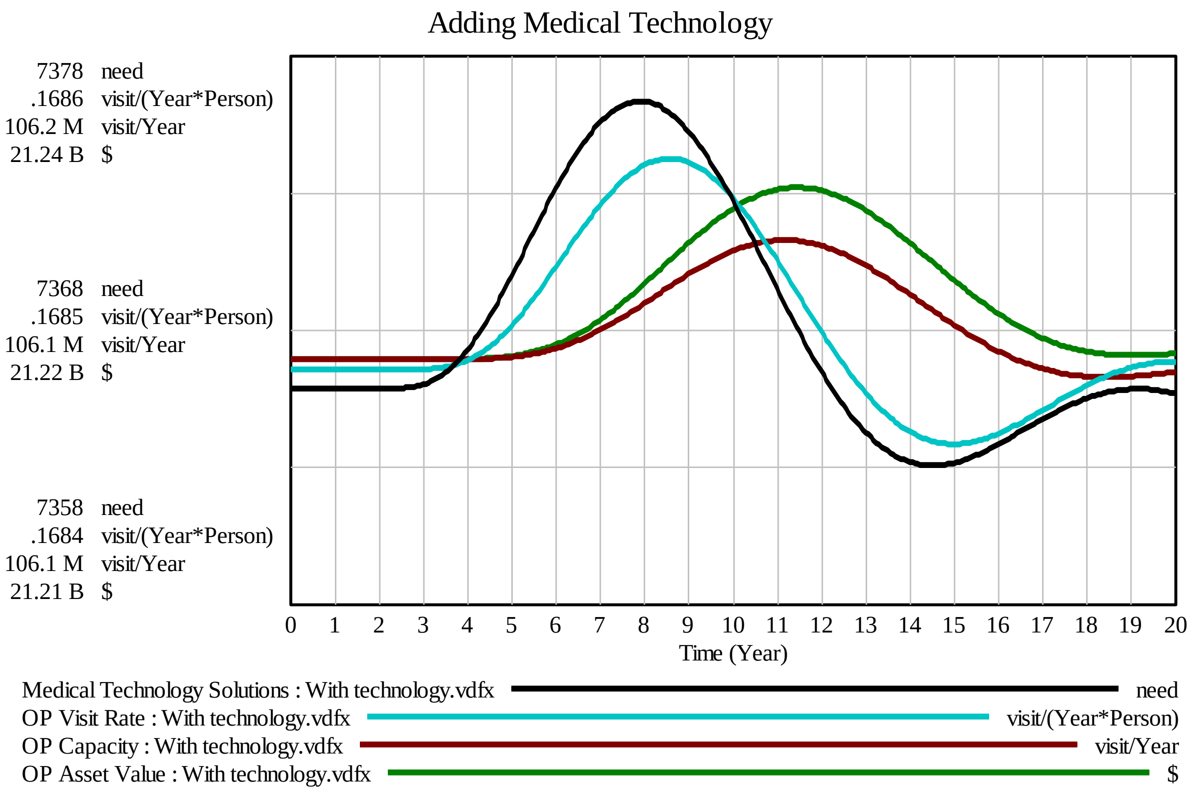

Figure 22: Effect of step change in PO visit initiative effectiveness on *Medical Technology Solutions*, *OP Visit Rate*, *OP Capacity*, and *OP Asset Value.*

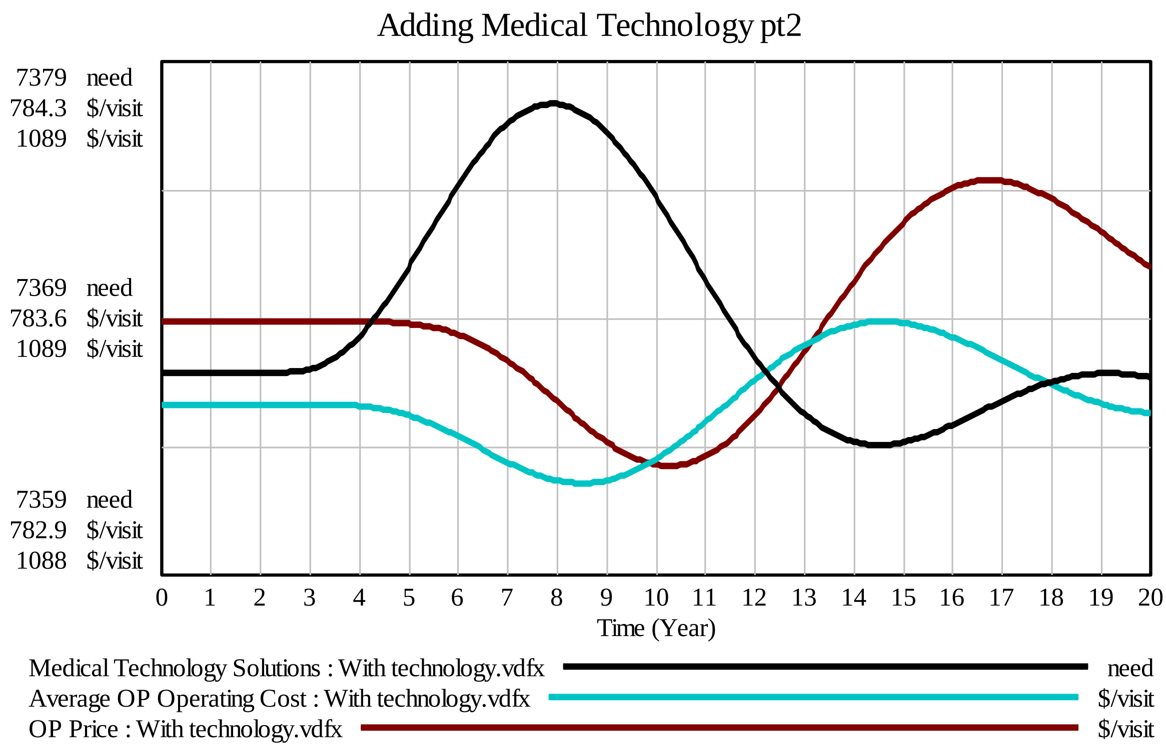

Figure 23: Effect of step change in *PO visit initiative effectiveness* on *Medical Technology Solutions*, *Average OP Operating Cost*, and O*P Price.*

5.4 The Needs Identification Structure

Unfortunately, it is quite evident that a stable equilibrium does not describe the behavior of medical technology development in the real world. Does this make the model useless in its current configuration? Not necessarily. After all, all models are wrong, but some are still useful. Nevertheless, it seems reasonable to hypothesize that the model may better serve a variety of purposes if technological progress could be modelled more accurately. Fortunately, there is a formulation already in the model that can help do this: the needs identification structure highlighted in blue in Figure 24. Because *identifying needs* can only be positive, there is no outflow from *Identified Medical Needs*. This is logical – specific medical technologies may come and go, but knowledge persists. In terms of model behavior, the consequence is that *Medical Technology Solutions* can exhibit permanent growth. The downside is that the sector (and thus the model as a whole) cannot be placed in equilibrium when *identifying needs* is non-zero, which only happens when *Identified Medical Needs* is less than *max medical needs*.

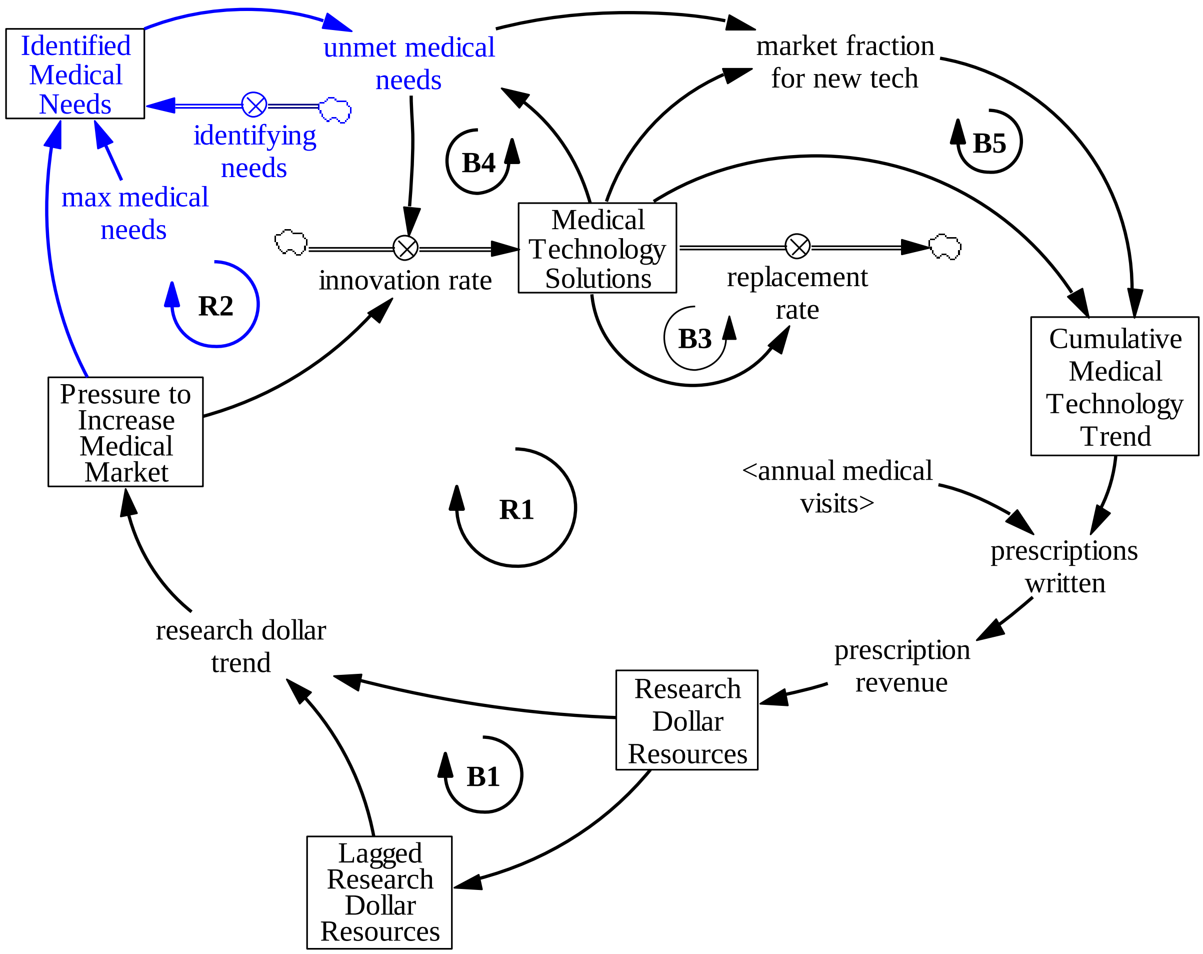

Figure 24: Simplified diagram of Medical Technology Sector, highlighting variables involved in Needs Identification

Figure 25 is not particularly interesting, but it shows an exponential increase in *Medical Technology Solutions* when *identifying needs* is active. The small boost to the *Pressure to Increase Medical Market* from the step change in *PO visit initiative effectiveness* causes technology to increase slightly more rapidly for a couple years, but it soon merges with the standard run.

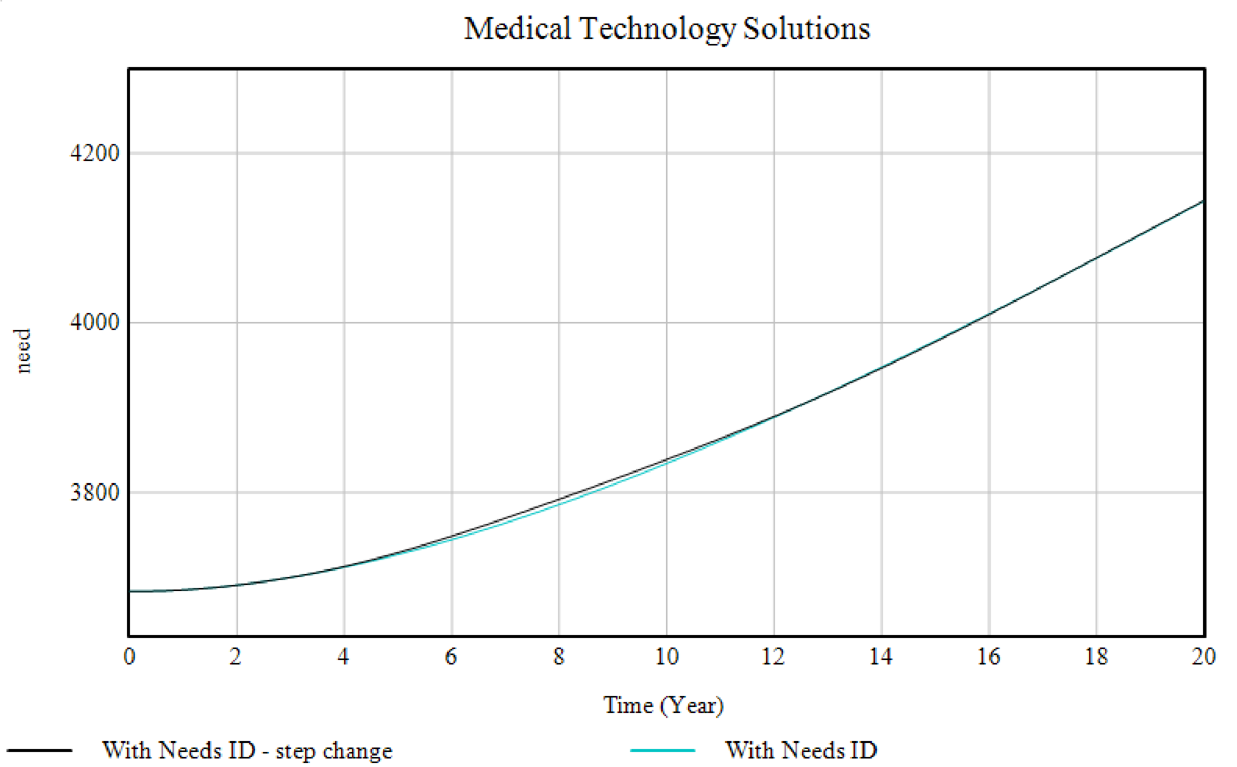

Figure 25: *Medical Technology Solutions* run with needs identification structure active

Chapter 6: Future Work

Although the primary goals of this project were fulfilled and significant progress has been made refining the HCS model, a substantial amount of work remains. As discussed in Section 5.3 of this paper, the inability to run the model in equilibrium without inactivating the needs identification structure limits the model's ability to simulate real-world scenarios. In my view, this is the most pressing shortcoming with the model. Otherwise, as noted in the detailed documentation, the PO Price sector has considerable shortcomings. Fortunately, there is little feedback from that module to the rest of the model, so any problems remain isolated. Both Medical Malpractice (Premiums and Equity) modules would also benefit from further effort. That being said, malpractice insurance costs have experienced an extended period with level or declining trends (Belk; Jones, Minetti, McCullaugh, & Page, 2019), so depending on what phenomenon the model is next used to examine, it may make sense to simplify the MMO representation.

Aside from structural modifications, the data inputs need updating, considering the information is at best thirteen years out of date. "Hard" data, like figures for visit rates, average prices, hospital capacity, and inflation rate are necessary both for initializing the model and to perform calibration. It is certainly possible that more abstract parameters – desired margins, adjustment times, etc. – have also changed over a decade and a half. Without access to the type of embedded system actors who originally supplied these kind of values, a review of the medical literature may be the best path forward. The more accurate the non-calibrated values, the better results calibration will produce. Before that process is undertaken, all parameters should be re-examined to determine suitability for calibration. All variables included in the most recent parameter input file (allvar73.cin) are noted in the documentation tables as calibration sourced, but there were at least a few previously left out that should have been included, so it bears reviewing again.

Possibilities for further modifications are limitless but will largely depend on the problems the model is next used to address. Nevertheless, the documentation file lists a number of possibilities, some specific suggestions and others prompts for future inquiry. Finally, I hope that with any and all future modifications the documentation is maintained and updated.

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Appendix A: Glossary

Managed Care Organization: In this model, the term encompasses entities that administrate and implement insurance plans and initiatives, whether private or public. For the purposes of this documentation, “insurer” is sometimes used as a synonym for “managed care organization,” though technically the term also includes other organizations contracted by insurers for various purposes.

MCO: see **Managed Care Organization**

Medical Malpractice Organization: An entity providing insurance coverage against malpractice suits.

MMO: see **Medical Malpractice Organization**

Appendix B: Model Changelog

Kahuna 59:

- Changed input of "pharma market size trend" from "annual IP bed days" to "annual IP visits" on the basis that prescriptions are more closely related to the latter.
- Removed "demand effect on ER price trend", "demand effect on OP price trend", and "visit limit per physician" - no purpose
- Resolved 90% of unit errors (5 remaining)

Kahuna 58 v1.9:

- In MEDICAL TECHNOLOGY: "specialization effect" incorporated into "Cumulative Medical Technology Trend" and eliminated old specialization effect on "prescriptions written"
- "cumulative medical technology growth" - simple current/initial ratio - removed from "prescriptions written" - had no known purpose besides mathematical balancing - no longer needed after previous change
- Tech effect on visit rate & hosp construction cost now depend on cumulative trend that accounts for specialization and tech diffusion delay
- Fixed disequilibrium if XX visit initiative effectiveness was not 1
- Removed outdated or unnecessary comments

Kahuna 58 v1.8:

- Returned MEDICAL TECHNOLOGY sector to original structure
- Changed "init zero trend" to 0
- "chg desired PO price" is now based off "PO Price" rather than "Desired PO Price" - allows for equilibrium

- Severed link between PO utilization and both "target PO price spread above inflation" and initiative effectiveness - more research needed
- Created separate trend and cumulative MMO effects on price - latter is stock, former is flow
- Changed PO PRICE to take trend effect on price
- In hospital price (NOT PO price) "desired XX price" calculation, MMO effect modifies op cost rather than "Desired XX Price" directly
- Full Model Equilibrium achieved

Kahuna 58 v1.7:

- Redesigned HOSPITAL COSTS structure

Kahuna 58 v1.6:

- Re-adjusted MMO effect on price to incorporate SMOOTH and lookup function.
- Separated delay time for "Historical XX Price" in PRICE INITIATIVE sectors from "time to chg hosp cost" also used in HOSPITAL COST to new variable "MCO accounting horizon" and also changed fixed delay to 1st-order exponential delay
- In PRICE INTIATIVE sectors, changed input to target development capacity from demand-influenced effectiveness to nm effectiveness

Kahuna 58 v1.5:

- Reworked MEDICAL TECHNOLOGY sector
- Removed calibration and data influences from PHYSICIANS sector
- Corrected units of price effectiveness variables
- Added MMO premium trend influence to ER sector.

Kahuna 58 v1.4:

- Changed MMO effect on price from trend to cumulative change in premium revenue / cumulative change in total hospital cost

Kahuna 58 v1.3:

- Reworked PO PRICE sector to share major structure with other price sectors.
- Changed multiplication of initiative effectiveness to division (see earlier effectiveness change)
- Visit initiatives now operate all the time, rather than being activated by a STEP input at a given year.
- Modified IP CAPACITY to more closely match other sectors' "required change in available XX capacity" in order to simplify equilibrium conditions
- Removed "IP Capacity in Progress" from IP CAPACITY to facilitate equilibrium
- Removed ER UTILIZATION and OP UTILIZATION, as they were copies of parts of the respective Capacity sectors - no variables lost
- Merged "annual emergency visits" with "annual ER visits" and other pairs which were duplicates
- Renamed XX ASSET COST sectors to XX ASSET VALUE
- Standardized asset value inflow as "adding XX asset value"
- Renamed "time to decrease XX capacity" to "time to retire XX capacity" to improve clarity
- "fraction market affected" changed from "1 - nm fraction market affected * MTS / MMN" to "nm fraction market affected * MTS / MMN"

Pre-kahuna 58 v1.3:

- Changed initiative effectiveness to make logical sense
    - An increase in effectiveness will now make initiatives more effective
    - Required changing division into multiplication (and vice versa) wherever effectiveness was used (visit rate, initiative, and price sectors)

- Removed PHARMACEUTICAL PIPELINE and GOV-COMM COVERAGE sectors (for predictive use and unfinished, respectively)
- Removed Capitation Initiative (IP PRICE INITIATIVE), BBA (Balanced Budget Amendment) initiative (LOS INITIATIVES), IP MCO initiative, and IP Consumer Response 2 (already unused). All were initiatives with an exogenously defined strength and timing for use in data fitting.
- Adjusted various variable names in the interest of standardization, accuracy, and ease of understanding
- Standardized formulation of XX visit rate trend
- Changed PO PRICE and PO PRICE INITIATIVES sectors to more closely match structure of hospital price sectors

Appendix C: Detailed Model Documentation

The detailed documentation has been copied below, but the transfer resulted in a number of formatting difficulties.

For a well-formatted version of this same documentation, please reference the document attached to the MQP submission: JPThompsonModel.SectorDocumentation.docx

- **Documentation Notes:**
- Variable names are italicized (Example: *Medical Technology Solutions*)
- View/Sector names are all caps (Example: PO VISIT RATE)
- Parameter tables have “last updated” date
- In Recommendations, number in parenthesis is estimated difficulty of modification on a scale of 1-10. Recommendations which involve significant research are not rated.

- **Module: Visit Rate**
- **Purpose:**

The Visit Rate module tracks medical visit rates in units of visits per person per year for the physician office (PO), emergency department (ER), outpatient (OP), and inpatient (IP) venues. A nearly identical structure is used to track inpatient length of stay (LOS) in units of days per visit. Visits rates are somewhat of an abstraction in that they combine the notions of visits per year and services provided per visit. This must be kept in mind when comparing or calibrating against reported visit rates.

- **Uses:**
- PO VISIT RATE
- ER VISIT RATE
- OP VISIT RATE
- IP VISIT RATE
- LENGTH OF STAY
- **Diagram:**

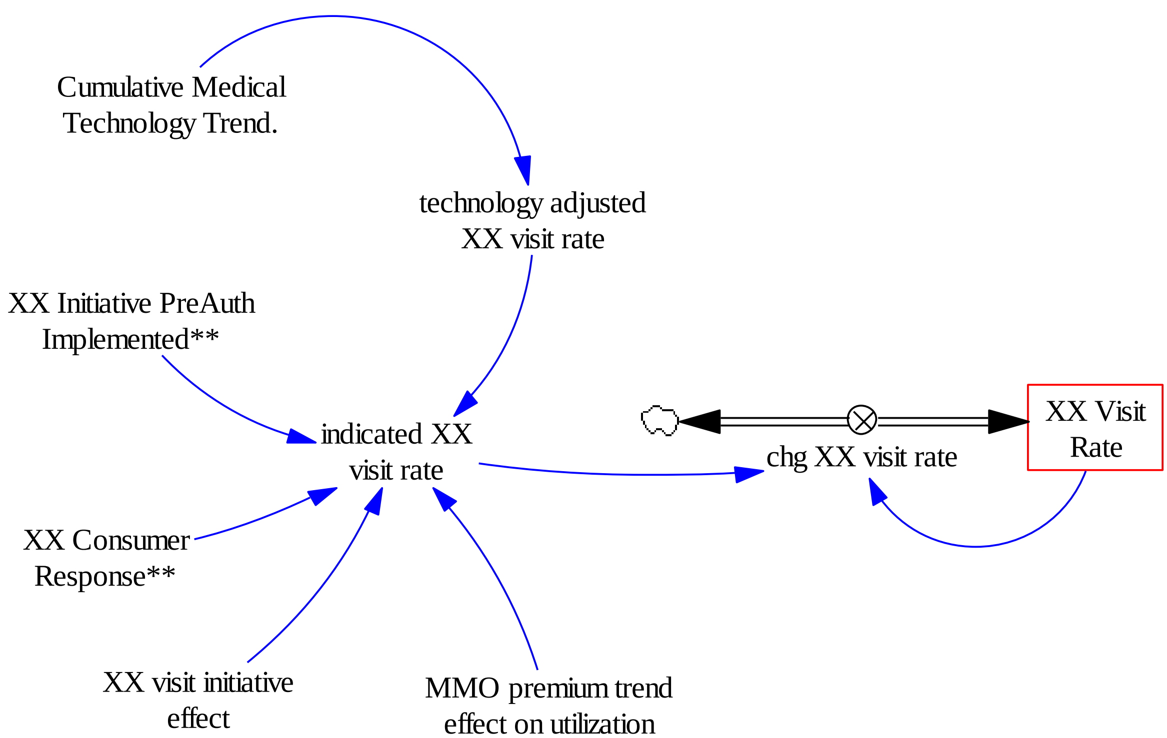

Figure 26: Diagram of Visit Rate / LOS sectors
** denotes variables that do not appear in all sectors

- **Summary:**

The sector calculates an instantaneous indicated visit rate by adjusting the initial rate with factors accounting for changes in the aggregate level of medical technology, the effect of managed care (MCO) initiatives to limit visit rates, and changes in medical malpractice premiums. Improvements in technology encourage visits by those who may be afflicted by newly-treatable ailments, while also decreasing the required inpatient length of stay and shifting some previously inpatient procedures to outpatient venues. MCO visit initiatives attempt to limit visit rates, but may face consumer and provider pushback. Note that the current model structure does not include an endogenous linkage between initiatives and pushback. When malpractice premiums are rising, doctors increase the standard of care both to defend against lawsuits and to offset costs. By increasing the standard of care, they perform more tests and procedures, which increase visit rate.

The indicated rate is harmonized with the measured *XX Visit Rate* over time. In the physician office venue only, the actual visit rate cannot exceed the physician supply-limited rate.

The indicated visit rate is determined in the following manner:

indicated XX visit rate[8] = (1 + *MMO premium trend effect on utilization* * *weight on MMO premium trend effect on XX visit rate*) * MAX ((*technology adjusted XX visit rate* – (*XX visit initiative effect* – *XX Consumer Response*[††] – *XX Initiative PreAuth Implemented*[††]) * *XX visit initiative effectiveness*) , *minimum XX visit rate*)

For policy-testing purposes, minimums will generally be set so as not to interfere with system behavior.

[††] denotes variables that are not present in all sectors and/or whose sign differs by sector. See below for details.

The dynamic influences on the *indicated XX rate* are the following:

Cumulative Medical Technology Trend [MEDICAL TECHNOLOGY] – There are many health conditions for which there is no treatment or the remedy is judged to be less desirable than the condition itself. As medical technology (pharmaceutical or otherwise) improves, more conditions can be effectively treated. This spurs some affected individuals to visit the doctor for treatment. In this way, technological progress encourages higher visit rates across most of the health care industry. On the other hand, medical advances decrease the invasiveness and required healing time of many procedures, decreasing average length of stay and allowing some inpatient procedures to shift to outpatient care.

In three of four venues modeled (PO/ER/OP), a change in *Cumulative Medical Technology Growth* produces a change in the *technology adjusted XX visit rate* and the *indicated XX visit rate* in the <u>same</u> direction.

---

8 Where applicable, references to … *XX visit rate* variables encompass the equivalent LOS variable.

- A change in *Cumulative Medical Technology Trend* produces a change in technology adjusted IP visit rate / LOS and indicated IP Visit Rate / indicated LOS in the opposite direction.

(PO/ER/OP/IP visit/LOS) initiative effect – In order to limit reimbursement costs, insurers implement policies and restrictions to reduce patient visits and billed procedures. Tactics include copay/co-insurance increases and restrictions on specialist visits without PCP approval. Many initiatives that limit coverage of high-priced drugs, procedures, or physicians may also curb visit rates, as users will not bother going to the doctor if they do not expect to have their desired treatment covered by insurance.

- A change in *XX initiative effect* should produce movement of the visit/LOS rate in the opposite direction.
- Influenced by instantaneous level of *XX Initiatives* [from XX VISIT INITIATIVES] and delayed *Perceived XX Initiatives*, weighted according to *weight on XX initiative delay*.

MMO premium trend effect on utilization [MMO PREMIUM] – Higher medical malpractice insurance premiums strengthen the incentive to avoid malpractice claims, increasing pressure on physicians to improve the standard of care when premiums increase (defensive medicine). This may manifest in physicians ordering more tests and procedures, which is abstracted as an increase in visit rate. Physicians also make an effort to increase patient load in order to offset the financial cost of higher premiums. All these factors are assumed to work in the opposite direction if premiums decrease. Note that providers are assumed to decide on the standard of care based on the trend rather than level of MMO premiums. This means that it is possible to indefinitely maintain equilibrium in the *XX Rate* despite a constant non-zero premium trend. An alternate assumption replace this formulation with a relationship based on cumulative MMO premium change.

- A change in *MMO premium trend effect* should cause a movement of the visit/LOS rate in the same direction.
- All sectors share a single *MMO premium trend effect* variable.
- *MMO premium trend effect on utilization* utilizes a SMOOTH of the output of the graphical lookup function *MMO premium revenue trend effect on utilization f*, shown in Figure 27.
- The lookup takes *MMO premium revenue trend* as input. The range is [-0.1, 0.66]. The graph shape suggests that providers react more strongly to premium increases than decreases. This follows on the assumption that if MMO premiums are stable, physicians generally follow best practices (i.e. low incidence of defensive practice), meaning that there is little excess to eliminate if premiums decline.

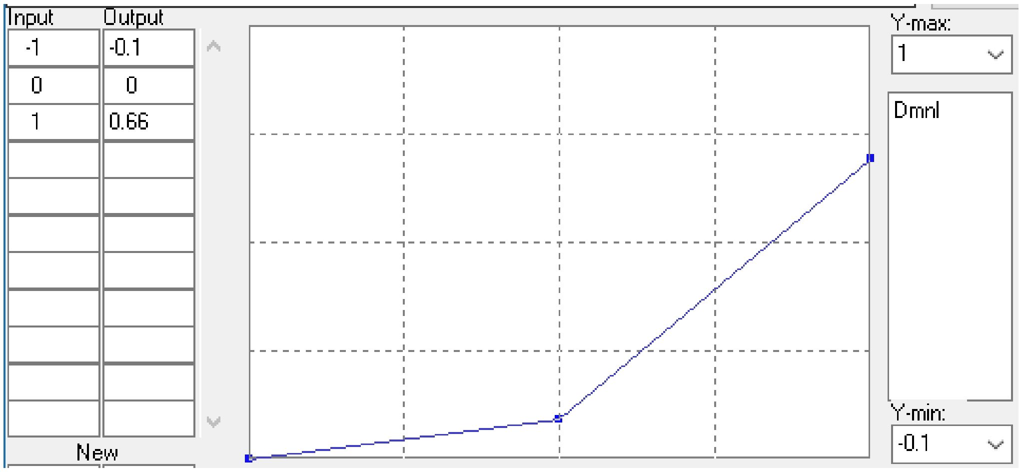

Figure 27: Lookup function *MMO premium trend effect on utilization f*.

(PO/ER/OP) Initiative PreAuth Implemented [XX VISIT INITIATIVES] – This variable mainly exists to account for historical movements in visit rates due to changes in insurance policies requiring pre-authorization as a prerequisite for the indicated visit types.

- There is no preauthorization initiative in the inpatient sector because inpatient referral is considered a sacred physician privilege.
- A change in *XX Initiative PreAuth Implemented* should produce movement of the visit rate in the opposite direction in the ER VISIT RATE sector but in the same direction in the PO VISIT RATE and OP VISIT RATE sectors.
- When pre-authorization initiatives were implemented, patients still desired the same treatment options. Rather than be deterred by a pre-authorization rejection for further treatment, they would often return to their physician to get another referral/prescription that would be approved by their insurer. This had the aggregate effect of increasing physician visits in both office and outpatient settings.
- On the other hand, ER preauthorization requirements had the intended effect of reducing the visit rate – it was effective enough, in fact, to prompt legislative action restricting the practice.
- Note that the model does not explicitly demonstrate any particular chain of events – the *PO Initiative PreAuth Implemented* stock is somewhat of a "black box." Furthermore, the strength and timing of such pre-authorization initiatives is fully exogenous.
- Variable chain is largely unused in policy testing mode due to exogenous nature.

(PO/IP) Consumer Response [XX VISIT INITIATIVES] – As MCOs impose restrictions on coverage of physicians, pharmaceuticals, and procedures, consumers and providers try to find work-arounds which preserve their original level of care and provider income as much as possible. This should tend to increase visit rates above what they would be otherwise. Note that the model structure does not require *XX Consumer Response* to operate in conjunction with *XX Visit Initiatives* – the strength and timing of the former is determined separately and exogenously.

- The *XX Consumer Response* variable only appears in the PO VISIT RATE and IP VISIT RATE sectors.
- A change in *XX Consumer Response* should produce movement of the visit rate in the same direction.
- As with the preauthorization initiative, this variable is primarily used to improve data calibration and account for historical events in forecasting mode – because of its exogenous nature, it will generally not be used in policy-testing mode.
- Could be made endogenous – see sector recommendations.

In the PO VISIT RATE sector only, there is a switch to limit visit rate to available physician capacity. Because personnel can be drawn away from private practice to address hospital shortages, the hospital venues are less likely to be impacted by physician scarcity and thus lack this switch.

physician limited office visit rate – *PO Visit Rate* is determined by either *indicated PO visit rate* or *physician limited office visit rate* – whichever is larger. The latter variable calculates the maximum visit rate so that the dynamic ratio of total annual visits to practicing physicians cannot exceed the initial value of this ratio. A side effect of this formulation is that the system cannot be initialized with a physician shortage. Due in part to the lack of modeled population health status, a physician supply shortage has no effect on any other variables, though the ratio of *indicated PO visit rate* and *physician limited office visit rate* can be considered a system performance metric.

- switch on physician supply constraint: 1 = ON; 0 = OFF
- Takes crude physician supply constraint [PHYSICIANS] as input.

- **Sector Inputs:**
- From other sectors:

See variables listed under Summary heading.

- **Parameters & Exogenous Inputs**:

Variable	Values / Restrictions		Source	Notes
	PO	**Other**		
initial actual XX visit rate	positive		Data	Vensim Data-type variable.
minimum XX visit rate	positive		Calibration	Minimum rate before MMO trend effect.
switch on physician supply constraint	1 OR 0	N/A	N/A	1 = ON. 0 = OFF
time to measure XX visit rate	positive		Calibration	
time to perceive XX visit initiative				
tune effect of technology on XX visits				
XX visit initiative effectiveness				Within a sector, all initiatives (e.g. PreAuth, Consumer Response, Visit Initiatives) use the same effectiveness parameter.
weight on MMO premium trend effect on XX visit rate				
weight on XX visit initiative effect delay	[0, 1]			Controls relative influence of *XX Visit Initiatives* and (delayed) *Perceived XX Visit Initiatives*.

- **In Isolation (Example sector: PO VISIT RATE):**
- Physician supply constraint switched off (switch set to zero)
- *minimum PO visit rate* set to 0
- Equilibrium Requirements:

PO Visit Rate = indicated PO visit rate = (1 + MMO premium trend effect on utilization * weight on MMO premium trend effect on PO visit rate) * MAX ((technology adjusted PO visit rate - (PO Visit Initiatives - PO Consumer Response - PO Initiative PreAuth Implemented) * PO visit initiative effectiveness), minimum PO visit rate)

Perceived PO Visit Initiatives = PO Visit Initiatives

- Test 1: Effect of medical technology
- *Expectations:*

New technology spurs visits by potential beneficiaries. *PO Visit Rate* should move in the <u>same</u> direction as *Cumulative Medical Technology Growth*.

- *Testing:*

Cumulative Medical Technology Growth = 1 + STEP(±0.1, 2)

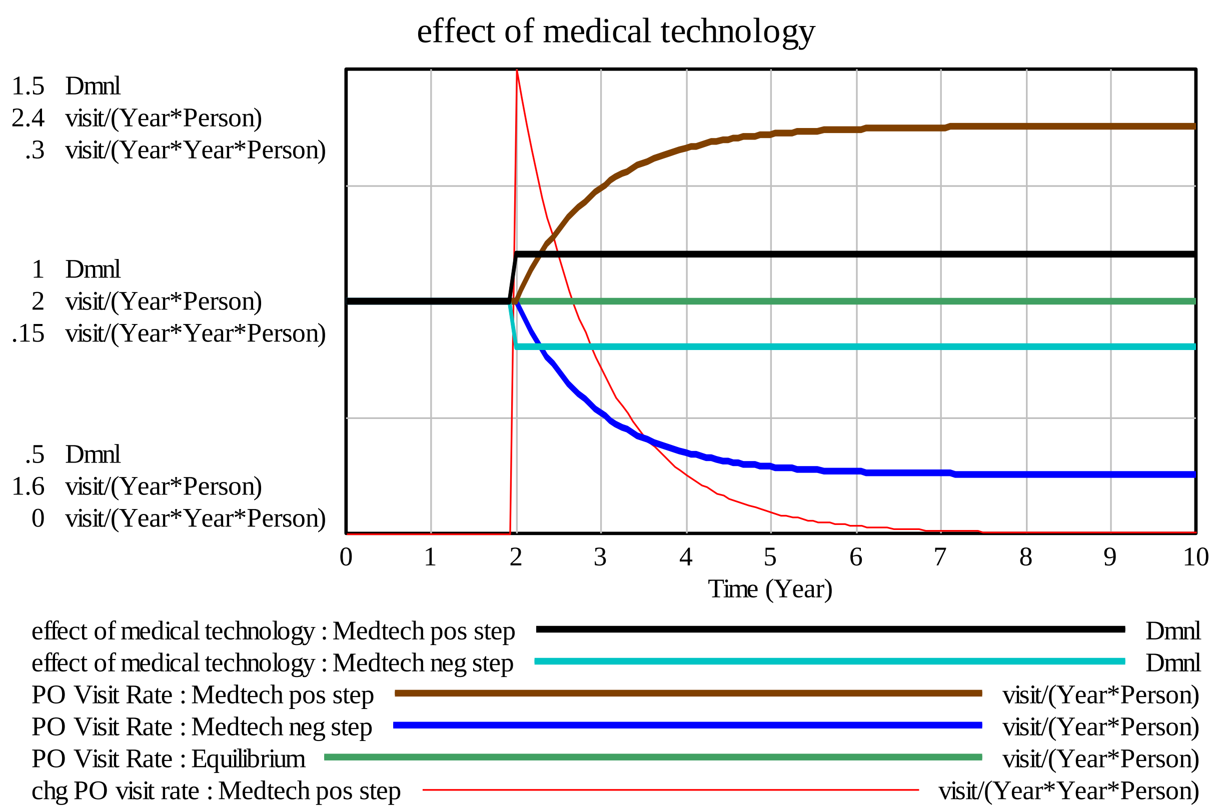

Figure 28: effect of step changes in *Cumulative Medical Technology Growth* on *PO Visit Rate*

- *Results:*

Increase in *Cumulative Medical Technology Growth* → increase in *technology adjusted PO rate* → increase in *indicated PO visit rate* → **increase in *PO Visit Rate***. *PO Visit Rate* exhibits asymptotically behavior.

- Test 2: *MMO premium trend effect on utilization*
- *Expectations:*

Doctors adjust level of care to protect themselves from malpractice claims. *MMO premium trend effect on utilization* and *PO Visit Rate* should move in the same direction.

- *Testing:*

MMO premium trend effect on utilization = STEP(±0.05, 2)

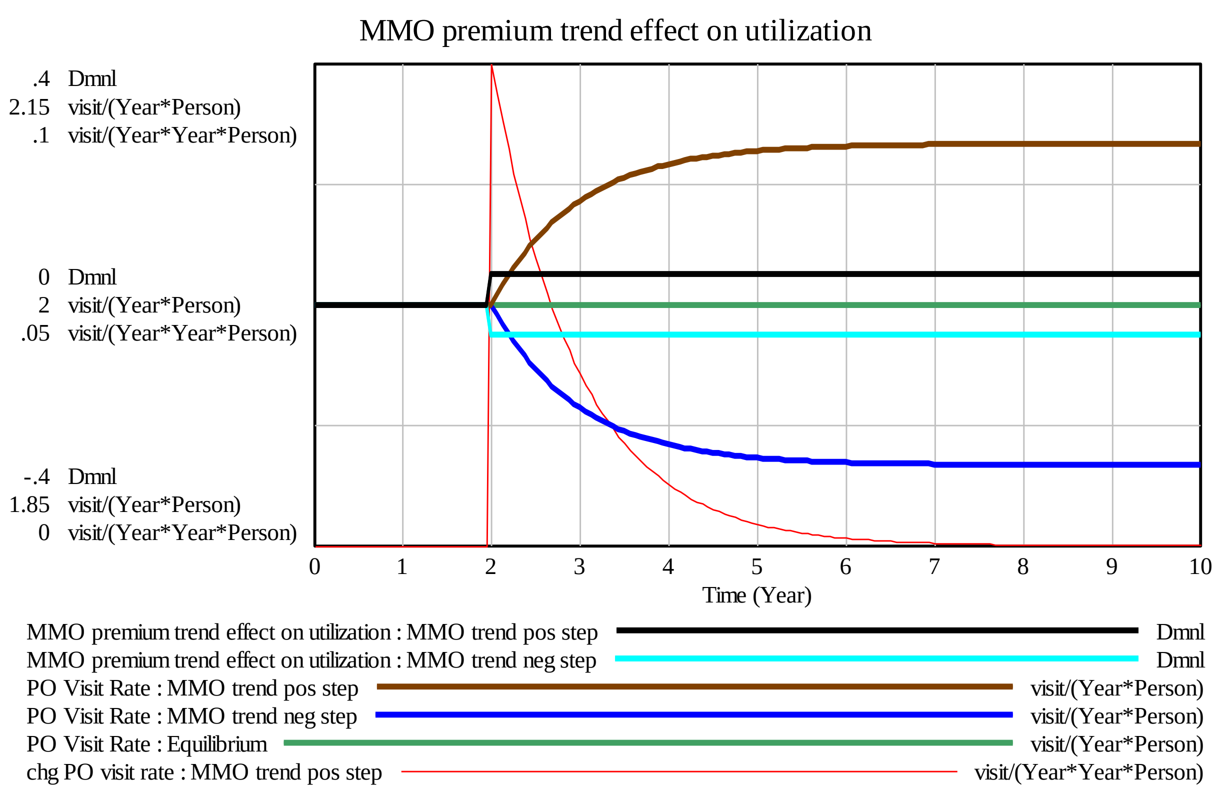

Figure 29: Effect of step changes in *MMO Premium Trend Effect* on *PO Visit Rate*

- *Result:*

Increase in *MMO premium trend effect on utilization* → increase in *indicated PO visit rate* → **increase in *PO Visit Rate***. The response is immediate and behavior is asymptotic.

Note: *PO Consumer Response* and *PO Initiative PreAuth Implemented* are not shown due both to their lack of usage in policy testing mode and the similarity of their effect on system behavior to that of *MMO premium trend effect on utilization*.

- Test 3: *PO Visit Initiatives*
- *Expectations:*

Initiatives are implemented for the purpose of decreasing visit rate. *PO Visit Rate and PO Visit Initiatives* should move in <u>opposite</u> directions.

- *Testing:*

PO Visit Initiatives = 1 + STEP(±0.1, 2)[9]

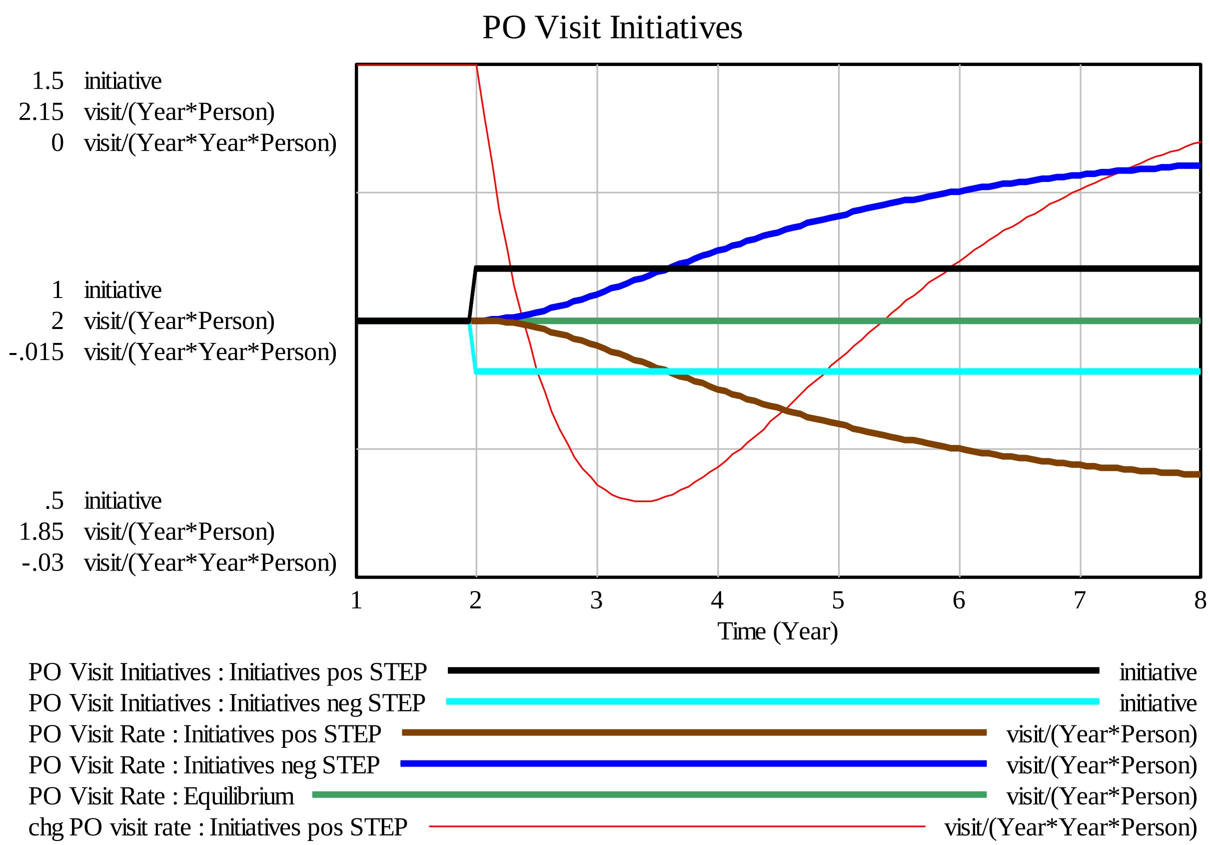

Figure 30: Effect of step changes in *PO Visit Rate Initiatives* on *PO Visit Rate*

- *Results:*

Increase in *PO Visit Initiatives* → increase in *Perceived PO Visit Initiatives* → decrease in *indicated PO visit rate* → **decrease in *PO Visit Rate***. Because a change in *PO Visit Initiatives* is transmitted through a separate stock of *Perceived PO Visit Initiatives,* the effect on *POVR* does not peak until a short period after the shock (see *chg PO visit rate* plotted in red). After that point, *POVR* follows an asymptotic/exponential decay path.

9 Converted from level to auxiliary type variable.

- Conclusion:

All expectations were confirmed – this sector operates according to its intended design.

- **Verification of Other Sectors:**
- ER VISIT RATE: ☑
- OP VISIT RATE: ☑
- IP VISIT RATE: ☑
- LENGTH OF STAY: ☑
- **Recommendations and suggestions for further work:**
- The *initial actual XX visit rate* translates to the initial *technology adjusted XX visit rate*, not the measured *XX visit rate*. Because the initial rate is presumably the data-derived measured rate, adjustments accounting for MMO and initiative impact should be made to produce the initial technology adjusted rate so that the initial *XX visit rate* = *initial actual XX visit rate*. (2)
- Re-examine assumption that providers set level of care dependent on MMO price <u>trend</u> rather than level.
- Consider linking the *physician limited office visit rate* to a separately specified ideal value rather than the initial visit : physicians ratio. This would allow initiating the model with a physician shortage. While the structural change would be easy, verifying that the model behaves when starting with a shortage would be more time-intensive. (2-4)

- **Module: Visit & LOS Initiatives**
- Purpose:

As cost-conscious organizations, managed care organizations (MCOs) would like to control the number of medical visits made by their policyholders – they certainly want to avoid paying for unnecessary care. They have a number of methods to limit visit rates, including the standard HMO requirement for a primary care physician to serve as a “gatekeeper” to specialist access. Other strategies include increasing copays and case management for high-use patients. Policies denying coverage of certain expensive treatments or physicians may also reduce visits, as patients will often only visit their physician if they anticipate receiving their desired care. In this way, a single initiative can influence both visit rates and prices. This module is used to track these visit initiatives and duplicated for the major healthcare venues: the physician office (PO), emergency (ER), outpatient (OP), and inpatient (IP) settings. A nearly identical structure monitors initiatives targeting the average IP length of stay (LOS).

- **Uses:**
- PO VISIT INITIATIVES
- ER VISIT INITIATIVES
- OP VISIT INITIATIVES
- IP VISIT INITIATIVES
- LOS INITIATIVES
- **Diagram:**

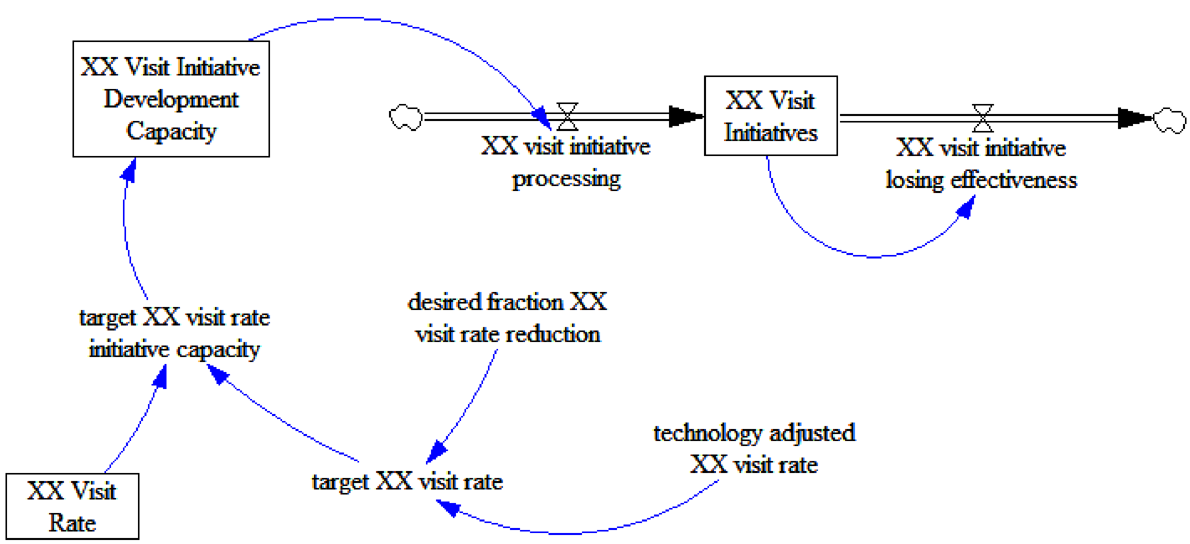

Figure 31: Diagram of *XX Visit Initiatives* structure

- Summary:

All five sectors include a variant of the initiatives/development capacity structure shown in Figure 6. MCOs determines a target visit rate or length of stay, and then adjust their initiative development capacity to meet that target. The model portrays initiative development as reactionary rather than proactive; insurers allocate resources to develop initiatives when increasing visit rates engender higher-than-anticipated payouts. However, no development capacity is allotted to replace initiatives which are "losing effectiveness", resulting in a chronic shortfall of initiatives. Development capacity takes time to adjust, and initiatives take time to be implemented, though there is no ongoing administrative requirement modeled. Initiatives also lose their effectiveness after a period of time, reflecting, among other possibilities, patients and providers learning how to effectively circumvent restrictions.

A variety of specific MCO initiatives, along with a consumer response stock, are also modeled in some venues, but these are completely separate from both each other and the above structure. These factors take one of two structures: a single stock with an exogenous inflow and a proportional outflow, or a two-stock aging chain, again with an exogenous inflow. Due to their exogenous nature, these structures are primarily used for calibration purposes in the data fitting and forecasting tasks. In the updated model, a number of additional examples representing specific policies (e.g. capitation initiative) have been removed. (See Appendix Y for full list of changes).

- **Primary structure:**
- Decision Points:

target (XX visit rate / LOS) – Medical care organizations are assumed to target visit rates and inpatient length of stay by anchoring on the *technology adjusted XX rate*[10]. In other words, MCOs do not try to push back against tech-driven increases in care usage.

target XX rate cannot fall below *minimum XX rate* (MAX function).

Because *technology adjusted XX Rate* is unaffected by initiatives, there is no reinforcing feedback loop where success in limiting *XX Rate* leads to a further fall in *target XX Visit Rate*.

An alternative formulation for visit rate initiatives could assume MCOs do not make adjustments to their "target" based off technological advances but are always trying to limit visit rates to historical levels , similar to how the price initiative sectors are structured.

target XX initiative capacity – Developing and implementing initiatives requires organizational resources, represented by the *XX Initiative Development Capacity*. Target capacity is determined by the gap between the target and actual system states (visit rates/length of stay). Target capacity is translated into actual capacity over time, as MCOs adjust the amount of resources directed towards initiatives. It is

10 In the interest of readability and concision, "… *XX rate*" (in this case, *technology adjusted XX rate*) may be used to encompass similarly named variables from all venues listed in the "Uses" section. Unless explicitly stated otherwise, this includes the relevant length of stay variable (here, *technology adjusted LOS*) even though the name is not an exact fit.

important to note that target capacity does not take into account existing initiatives and the capacity that will be needed to replace expiring programs. This is intended to model the reactive nature of these initiatives: if an initiative is successful and reimbursement costs decline, the loss of financial urgency will tend to cause the insurer to lose focus on sustaining the initiative, even if it is responsible for the improvement.

target XX initiative capacity cannot be negative (MAX function). A negative initiative capacity would represent insurers making efforts to increase the overall cost of care, whether through more frequent visits or longer inpatient stays. Because insurers pay the majority of these costs, such a scenario is unlikely.

XX initiative processing & XX initiative losing effectiveness

- *XX initiative processing = XX Initiative Development Capacity / time to develop XX visit initiative*
- The simplifying assumption is made that initiatives do not take resources to implement once they have been developed; if development capacity instantly dropped to zero, initiatives would still remain in effect for their normal lifespan.

- Inputs:
- ***XX Visit Rate / Length of Stay*** [XX VISIT RATE / LOS]
- ***technology adjusted (XX visit rate / Length of Stay)*** [XX VISIT RATE / LOS]
- **Parameters & Exogenous Inputs:**

Variable Name	Value / Restrictions	Source	Notes
desired fract XX visit reduction	[0,1]	Calibration	Positive values target reductions
XX initiative life	positive		
time to change XX visit initiative development capacity	positive		
time to develop XX visit initiative	positive		

last updated 12/9/20

- **Secondary structures:**
- *Single stock:*
- *(PO/ER/OP/IP/LOS) Consumer Response*
  - patient and provider push-back against MCO efforts to limit visits or length of stay
- *ER Initiative PreAuth*

- MCO initiative requiring pre-approval before some ER visits

- *Two-stock aging chain:*
- PO Initiative PreAuth
  - requirement for pre-approval for many pharmaceuticals and/or specialist visits
- OP Initiative PreAuth
  - requirement for pre-approval for outpatient visits and/or procedures.
- *Notes:*
- *ER Initiative PreAuth* is a single-stock structure, compared to a two-stock aging chain for the PO & OP preauthorization initiatives. The effectiveness of these initiatives depends on consumer awareness of the policy, and knowledge of the ER initiative spread more quickly thanks to the negative publicity. This is reflected in as a decreased implementation delay, modeled as one stock vs. two.
- Example Stocks:
- Two-stock aging chain: *PO Initiative PreAuth* and *PO Initiative PreAuth Implemented*

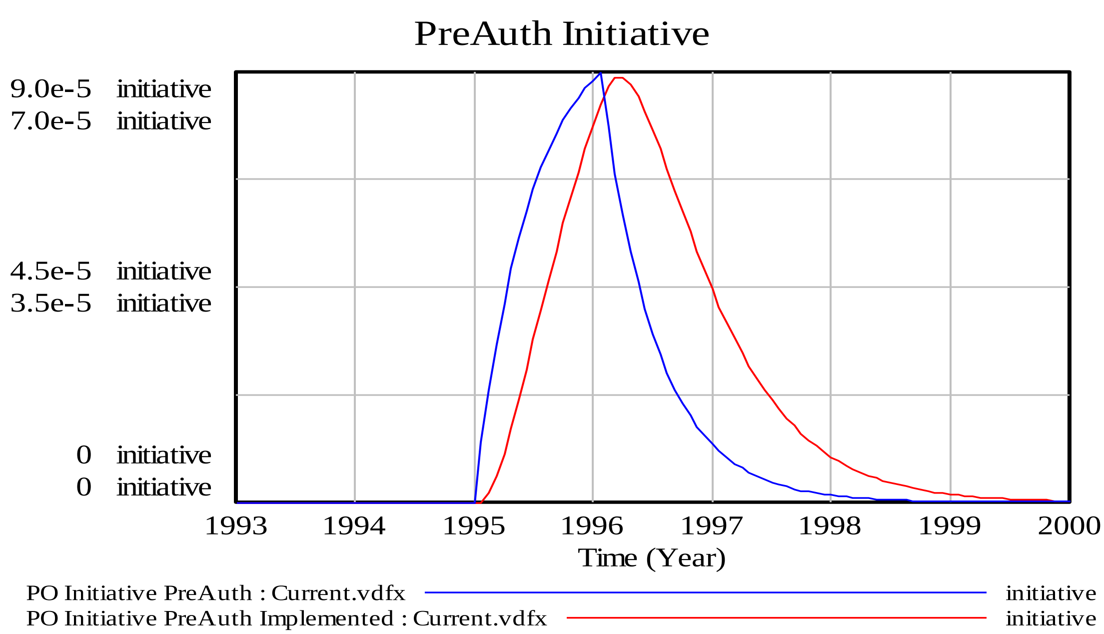

Figure 32: Visualization of pulse moving through aging chain including PO Initiative PreAuth and PO Initiative PreAuth Implemented stocks

Single Stock: PO Consumer Response

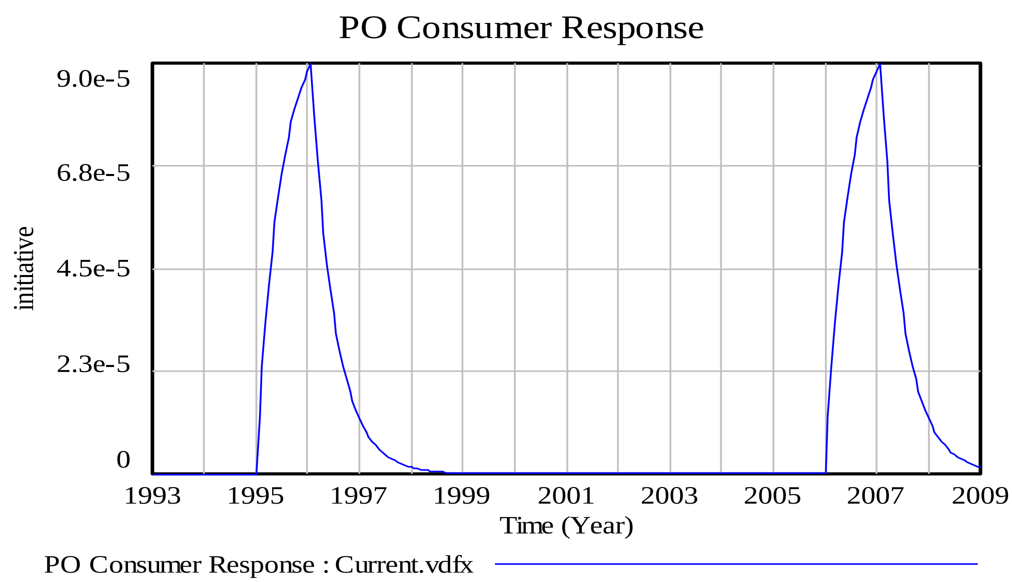

Figure 33: Example PO Consumer Response stock with pulse years 1995 & 2006

- **In Isolation:**
- All the secondary structures have flows that stop and start based on IF THEN ELSE statements. Setting them in equilibrium can be done in a number of ways with trivial difficulty.
- For equilibrium:
- *PO Visit Initiatives* [Initial] = *PO visit initiative effectiveness * PO visit initiative life **

MAX (*PO Visit Rate* - MAX (*technology adjusted PO visit rate* * (1 - *desired fract PO visit reduction*), *minimum PO visit rate*), 0) */ time to develop PO visit initiative*

- *PO Visit Initiative Development Capacity* [Initial] = *target PO visit initiative capacity*

- Test 1: *PO Visit Rate*
- *Expectations:*

The model assumes that insurers target a fixed percentage decrease in visit rates, meaning they desire larger absolute decreases when the visit rate is higher. Because initiatives have an additive effect on the visit rate, the required quantity of initiatives is proportional to the desired absolute decrease. Alternately stated, *PO Visit Initiatives* will respond to a change in the *PO Visit Rate* with movement in the same direction.

- *Testing[11]:*

PO Visit Rate = 3 + STEP(±0.3, 2)

Note: *PO Visit Rate* must remain at or above the *target PO visit rate* for the following behavior to be observed.

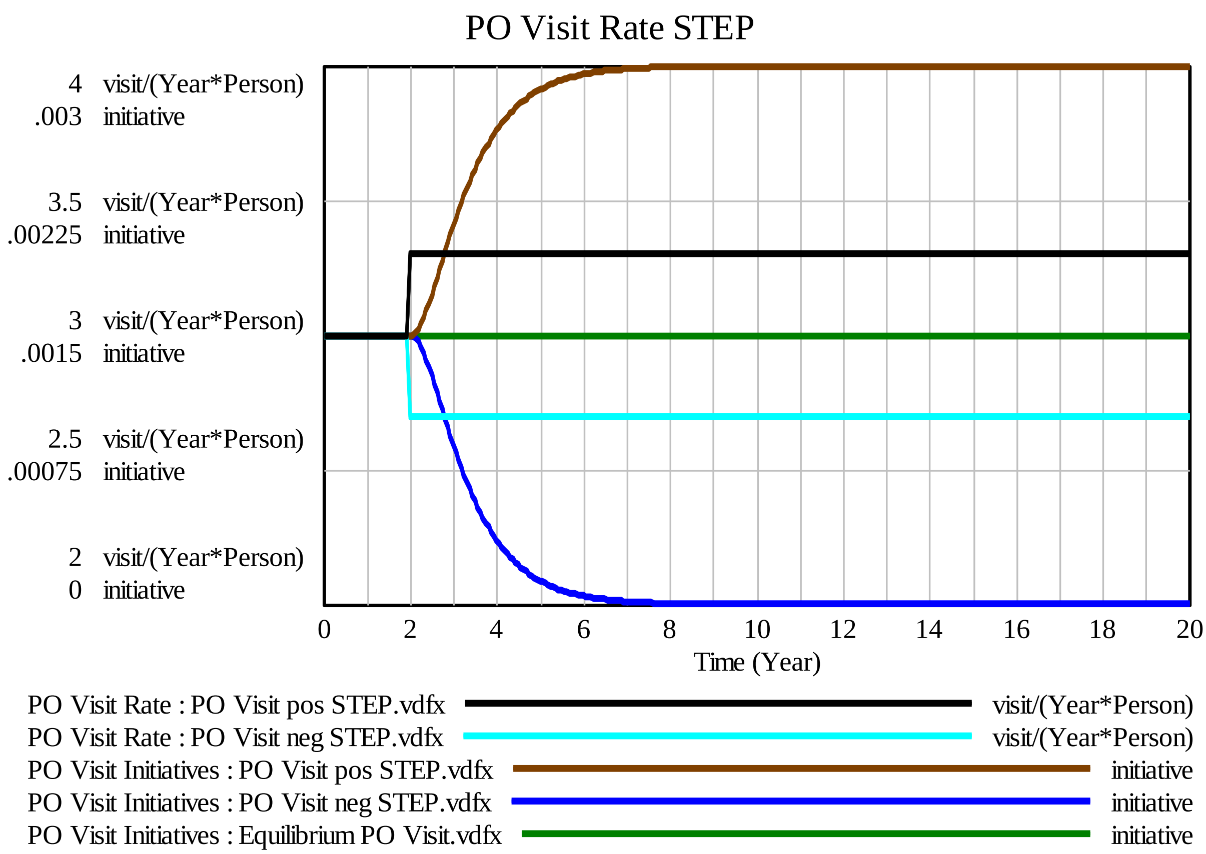

Figure 34: Effect of STEP in *PO Visit Rate* on *PO Visit Initiatives*

- *Result:*

11 Converted from Level to Auxiliary

Increase in *PO visit rate* → increase in *PO Visit Initiative Development Capacity* → increase in *PO Visit Initiatives*. Asymptotic growth.

- Test 2: *technology adjusted PO visit rate*

- *Expectations:*

Because MCOs are assumed to adjust their visit rate expectations based on technological developments, an increase in *technology adjusted PO visit rate* should result in a concurrent rise in *target PO visit rate*. With *PO Visit Rate* remaining constant, fewer initiatives will be required to reach the target rate. Therefore, a change in *technology adjusted PO visit rate* should result in movement of *PO Visit Initiatives* in the opposite direction.

- *Testing:*

technology adjusted PO visit rate = 3 + STEP(±0.3, 2)

Note: *PO Visit Rate* must remain at or above the *target PO visit rate* for the following behavior to be observed.

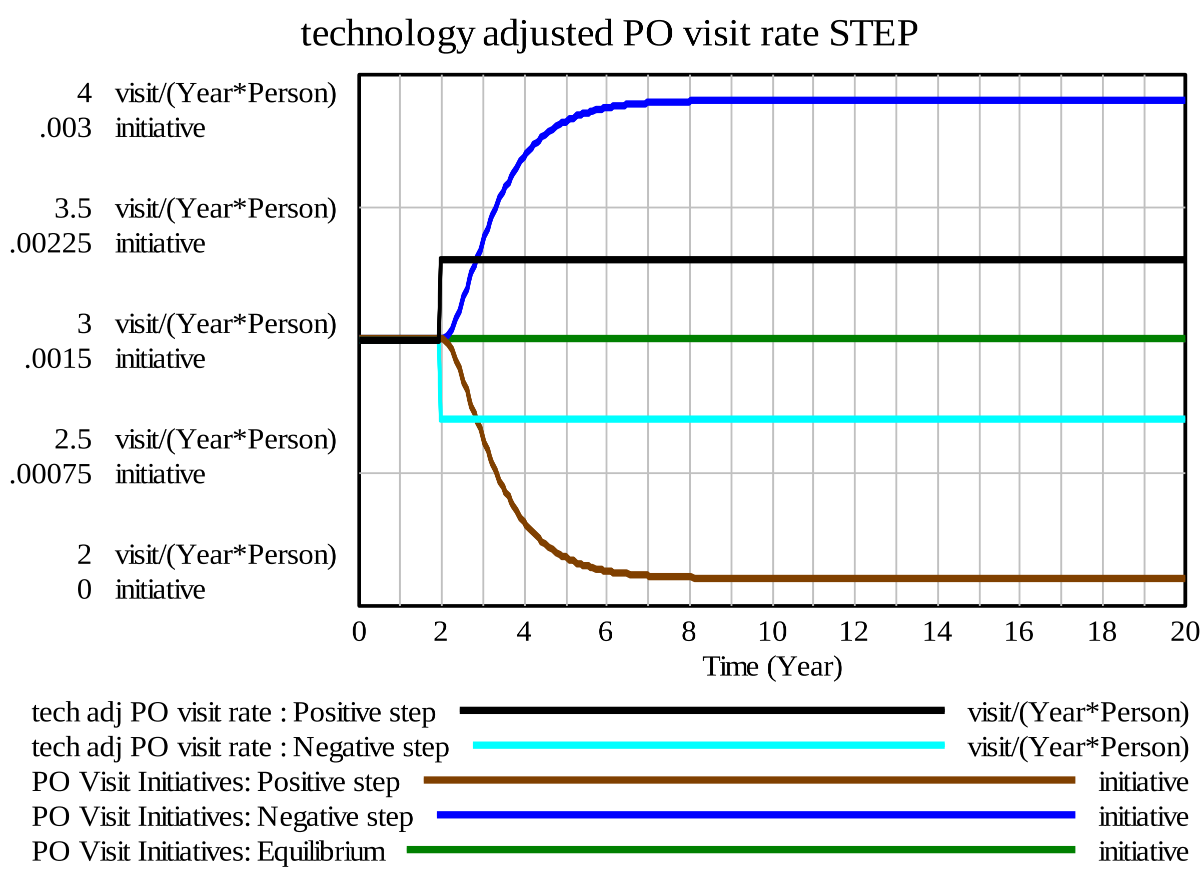

Figure 35: Effect of STEP in *technology adjusted PO visit rate* on *PO Visit Initiatives*

- *Result:*

With the qualification that the *PO Visit Rate* is sufficiently high relative to *technology adjusted PO visit rate*, an increase in the latter narrows the gap between targeted and actual rates. As a result, *PO Visit Initiative Development Capacity* is relatively too large and therefore decreases to compensate. A decrease in *PO Visit Initiatives* must follow.

- Conclusion:

All expectations were confirmed – this sector operates according to its intended design.

- **Verification of other sectors:**

ER Visit Initiatives: ☑

OP Visit Initiatives: ☑

IP Visit Initiatives: ☑

LOS Initiatives: ☑

- **Recommendations and suggestions for further work:**
- Scrutinize the assumption that MCOs account for tech changes directly when targeting visit rate (rather than simply picking up the influence on historical rates).
- Integrate Consumer Response structure into Visit Initiatives (2)

- **Module: Capacity**
- **Purpose:**

The capacity module calculates the national hospital capacity in the emergency department (ER), outpatient (OP), and inpatient (IP) venues. These sectors primarily measure infrastructure and capacity – physician count is tracked separately, and all other resources are assumed to be available in non-constraining quantities.

- **Uses:**
- ER CAPACITY
- OP CAPACITY
- IP CAPACITY
- **Diagram:**

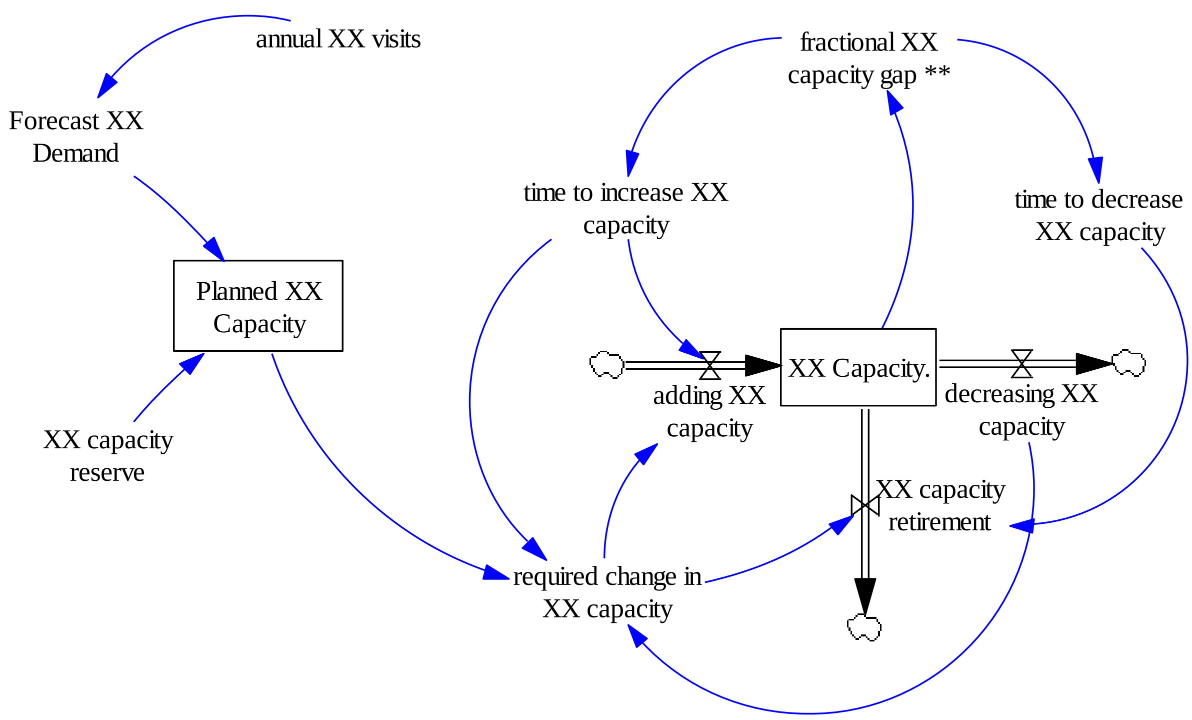

Figure 36: Diagram of the basic structure of the *XX Capacity* module.
** denotes a variable excluded from the IP CAPACITY formulation.

- **Summary:**

Due to the delays involved with planning, funding, and constructing capacity, healthcare facilities must forecast demand – formally or not – when projecting capacity requirements. In addition to adjusting for expected changes in future demand, facilities must account for infrastructure and equipment aging or becoming obsolete. Therefore, this model has one way to add capacity (appropriately named *adding XX* *capacity*) but two ways for it to be removed: d*ecreasing XX capacity* accounts for infrastructure that has reached the end of its lifespan and/or become obsolete, while *retiring XX capacity* denotes capacity retired "early" due to oversupply. As reflected in historical data, ER and OP capacity adjustment times decrease when the relative capacity gap is larger, but IP adjustment times are fixed. In the model, the *Planned XX Capacity* is determined by a combination of forecasted and historical demand, augmented by a capacity reserve for handling surges and seasonal demand fluctuations.

- Decision points:
- ***Forecast XX Demand –*** Long delays in capacity adjustment require forecasting visit rates. This variable takes two inputs: *forecast annual XX visits*[12], which uses a FORECAST function, and *average annual XX visits*, which is a first-degree SMOOTH of *annual XX visits*. The relative weights are determined by the parameter *weight on forecast XX demand* and (1 – *weight on forecast XX demand*), respectively.
- ***Planned XX Capacity –*** Because immediate medical demand is variable, with peaks and valleys, facilities need to maintain a "cushion" of excess capacity above normal utilization rates. *Planned XX Capacity* accounts for this reserve.
    - Reserve capacity is a fixed percentage of forecasted demand.
- ***required change in available XX capacity*** – This variable calculates the difference between available and planned capacity. It accounts for capacity depreciation; thus, even if *XX Capacity* equals *Planned XX Capacity*, the *required change in available XX capacity* is still positive to account for capacity that must be replaced, although there is no model differentiation between replacement and new additional capacity.
    - Specifically, in an equilibrium scenario where *Planned XX Capacity* always equals *XX Capacity*, *required change in available XX capacity* = *decreasing XX capacity* * *time to increase XX capacity*.
- ***adding XX capacity / XX capacity retirement –*** These flows represent the variable-rate input and output, respectively, of the *XX Capacity* stock (*decreasing XX capacity* is the fixed-rate end-of-life depreciation stock). They are controlled by IF THEN ELSE statements:
    - IF (*required change in available XX capacity* > 0),

THEN (*adding XX capacity* = *required change in available XX capacity*).

- IF (*required change in available XX capacity* < 0),

THEN (*retiring XX capacity* = -1 * *required change in available XX capacity*).

- In both cases: ELSE (0)

---

12 Unless explicitly noted otherwise, the information given applies to the equivalent IP variable;

here, *forecast annual IP bed days*

  - Depending on parameterization, most or all capacity reductions are handled by a decrease in *adding XX capacity* below *decreasing XX capacity*, with *XX capacity retirement* remaining at zero.

- ***average fractional XX capacity gap*** – A significant gap between desired and actual capacities is undesirable. In the case of a shortage, facilities are overcrowded and cannot treat all prospective patients, presumably resulting in negative health consequences. If there is excess capacity above that needed for handling expected surges, facilities are needlessly spending money. In either case, greater deviations from the ideal encourage quick action. This is reflected in the model by a decrease in *time to increase XX capacity* if the gap is less than zero (shortage) or a fall in *time to retire XX capacity* in the case of a positive gap (excess). These effects create a pair of potential (i.e. not always active) balancing loops.
  - This variable is absent in the IP CAPACITY sector, as data did not indicate a significant change in IP capacity adjustment times dependent on differences in utilization
  - In the ER CAPACITY sector, *ER Capacity* is compared to *Desired ER Capacity*, which is based on immediate utilization levels plus reserve capacity.
  - In the OP CAPACITY sector, *IP Capacity* is compared to *Planned OP Capacity*, which is based on forecasted and averaged utilization plus reserve capacity, and also has its own delay.
  - The reason for this difference in ER and OP formulations is unclear (JPT, Oct. 2020).
  - In the ER and OP sectors, there are minimum adjustment times (MAX function).

- **Sector Inputs:**
- From other sectors:
- ***annual (ER/OP visits / IP bed days)*** [XX Visit Rate]: *forecast (XX visit rate / bed days)* & *average (XX visit rate / bed days)*
  - *annual ER visits* and *annual OP visits* (as well as *ER/OP Capacity*) are measured in visits per year (visit rate * population)
  - *annual IP bed days* / *IP Capacity* are measured in [bed] days per year (visit rate * population * length of stay).
- Parameters & Exogenous Inputs:

Variable Name	**Value and/or Restrictions**			**Source**	**Notes**
	ER	**OP**	**IP**		
XX capacity depreciation rate	0.125	0.1	0.0625		Percent of capacity reaching end-of-life annually

XX capacity planning delay	5	5	5		
XX capacity reserve	1.1	1.1	0.7		Desired reserve capacity to handle surges
(XX visit / IP bed days) forecast horizon	3	3	3		How far out demand is planned for.
max fract IP retirement	N/A	N/A	0.1		Maximum fraction that can be removed **in addition to** normal depreciation. IP only.
min time to increase XX capacity	1	1	N/A		*time to increase IP capacity* is fixed.
min time to retire XX capacity	0.5	0.5	N/A		*time to retire excess IP capacity* is fixed.
(nm) time to increase XX capacity	2	2	5		
(nm) time to retire excess XX capacity	1	1	5	Calibration??	
time to average XX capacity gap	1	1	N/A		Not used in IP venue
time to average XX visit rate / time to average IP bed days	1			Calibration??	Shared by *forecast XX* and *average XX* variables
weight on forecast XX demand	[0,1]			Calibration	The closer to 1, the more weight on forecast and less on historical average visit rate

last updated: 12/7/2020

- **In Isolation (Example Sector: ER CAPACITY):**
- For equilibrium:
- *ER Capacity* [Initial] = *Planned ER Capacity*
- *Planned ER Capacity* [Initial] = *Forecast ER Demand* * (1 + *ER capacity reserve*)
- Test 1: *annual ER visits*

- *Expectations:*

Because capacity exists to accommodate utilization, a change in visits will cause a change in *ER Capacity* in the <u>same</u> direction, though the adjustment will take time.

- *Testing:*

annual emergency visits = $3x10^9$ + STEP($-6x10^8$, 2) + RAMP($3x10^8$, 4, 10)

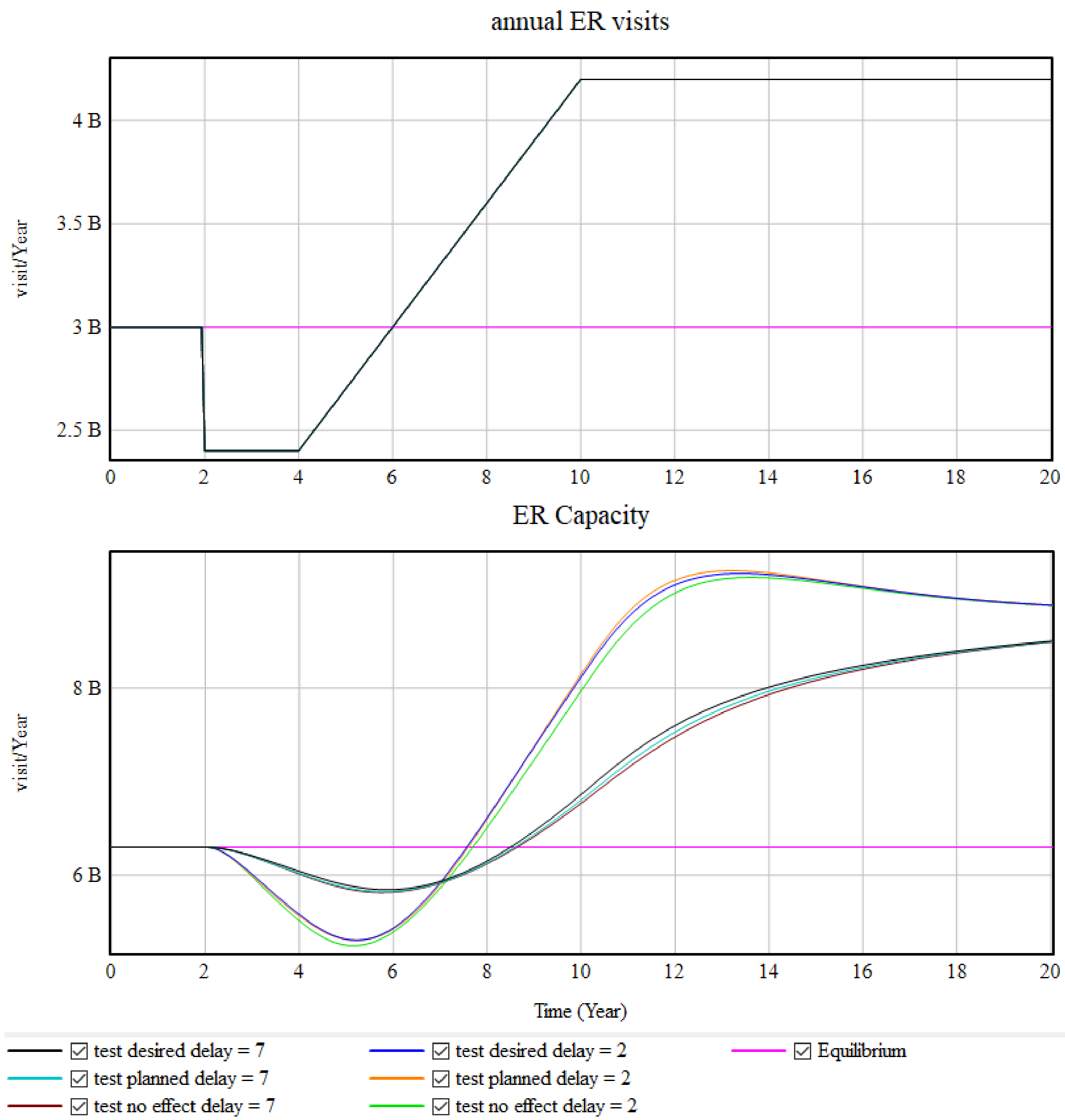

Figure 37: Effect of changes in *annual ER visits* on *ER Capacity*, comparison of several runs

- *Results:*

Figure 37 demonstrates the differences in sector formulation regarding *fractional XX capacity gap*. Although all tests were run in the ER sector, the runs titled “test no effect” mirror the IP CAPACITY sector, “test planned” mirror OP CAPACITY, and “test desired” represent ER CAPACITY. There are “delay = 2” and “delay = 7” versions of each, denoting the value for the *ER capacity planning delay*. In all cases, *ER Capacity* moves in the same direction as *annual ER visits*, as expected. The differences are generally quite minor, but the “no effect” (IP) runs, where fractional gap has no effect on adjustment times, react most slowly. When *ER capacity planning delay* is longer, the “desired” (ER) version adjusts most rapidly, but there is a threshold value for the delay under which “planned” (OP) version adjusts most quickly (this essentially happens because *Planned ER Capacity* may “overreact” to sharp changes if *ER capacity planning delay* is short).

As shown in all the “delay = 2” runs, it is possible for capacity changes to “overshoot.” This becomes more likely as *weight on forecast XX demand* moves closer to one.

- Conclusion:

All expectations were confirmed – the sector operates according to its intended design.

- **Verification of other sectors:**
- OP CAPACITY: ☑
- IP CAPACITY: ☑
- **Recommendations and suggestions for further work:**
- Is there a valid reason for ER and OP venues to have different fractional capacity gap formulations?
- Should *XX Capacity planning delay* be influenced by fractional capacity gap?
- Is there a difference in planning horizon for an increase vs. a decrease in capacity?

- **Module: Asset Value**
- **Purpose:**

The Asset Value module tracks the aggregate value of infrastructure and equipment used in the emergency department (ER), outpatient (OP), and inpatient (IP) venues. All assets are treated as proportional inputs– in other words, if there is zero capacity, there are zero assets. Moreover, there is no overlap between venue assets: each unit of assets can only belong to one venue.

- **Uses:**
- ER ASSET VALUE
- OP ASSET VALUE
- IP ASSET VALUE
- **Diagram:**

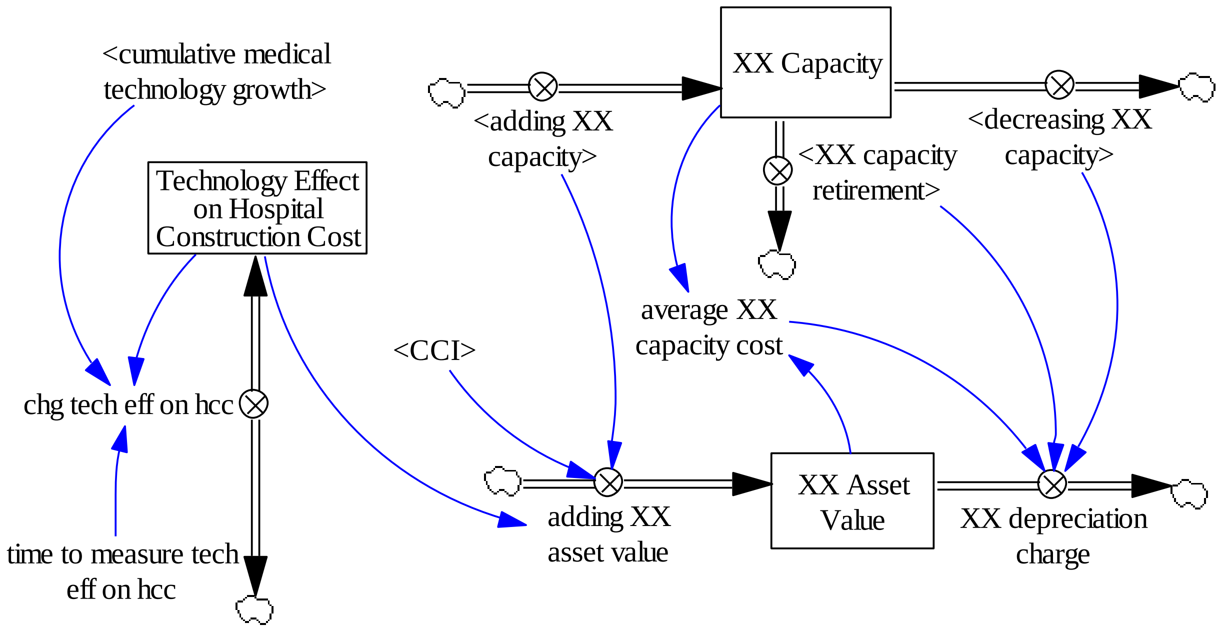

Figure 38: Diagram of the basic structure of the *XX Asset* module.

- **Summary:**

The basic operation of the sector is quite simple: asset value is added to by newly built capacity, and it is subtracted from by the removal of capacity. The book value of new capacity is the initial value modified by a construction cost index (*CCI*) and by cumulative growth in medical technology, as measured by *Technology Effect on Hospital Construction Cost*. More technology leads to a higher book value for each new unit of capacity. The book value of each removed unit of capacity is the average value of all capacity (Capacity ÷ Asset Value). As a result, if the stock of technology is increasing, even a constant capacity will exhibit increasing aggregate asset value.

Although the modeling is technically only counting depreciation of removed units, the usage of the average value results in a value for *XX depreciation charge* that well approximates the annual depreciation cost reported on an income statement. This becomes less true the larger *XX capacity retirement* is relative to *decreasing XX capacity,* assuming the oldest units are favored for premature removal. It also means that *XX Asset Value* will take longer to adjust to changes in new asset unit values than it "should." See Test 1: *cumulative medical technology growth* (& *CCI*) for an example.

- From other sectors:
- ***cumulative medical technology growth*** [Medical Technology]
- ***adding XX capacity*** [XX Capacity]
- ***decreasing XX capacity*** & ***XX capacity retirement*** [XX Capacity]
    - *decreasing XX capacity* tracks end-of-life / obsolete capacity removal
    - *XX capacity retirement* tracks premature capacity removal in response to oversupply (see Capacity module documentation for more detail)
- Decision points:
- ***adding XX asset value –*** unit value is initial value * (*CCI* + *Technology Effect on HCC*)
    - *Technology Effect on Hospital Construction Cost* is shared among all venues.
- **Parameters & Exogenous inputs:**

Variable Name	**Value**			**Source**	**Notes**
	ER	**OP**	**IP**		
CCI	Data type variable				*Engineering News-Record* Construction Cost Index. Tracks cumulative price change over base year. Must be formulated such that initial index value equals one (1).
bed day per year	365			N/A	Used to convert between IP beds and IP bed-days.
initial XX asset unit cost / initial cost per IP bed	100	200	30,000		
time for tech to affect hcc	1				hcc = hospital construction cost. Time for new technology to be adopted. Shared.

Last updated: 10/20/2020

- **In Isolation (Example Sector: OP Asset Value):**
- For equilibrium:
- *adding OP capacity* = *decreasing OP capacity* + *OP capacity retirement*
- *OP Asset Value* = *OP Capacity* * *initial OP asset unit cost* * (*CCI* + *cumulative medical technology growth*)
- *Technology Effect on Hospital Construction Cost* [Initial] = *cumulative medical technology growth*

To make the sector behave as if the entire model is in equilibrium, set *OP capacity retirement* = 0, *CCI =* 1, *cumulative medical technology growth* = 0, and ensure the above conditions are also met.

- Test 1: *cumulative medical technology growth* (& *CCI*)
- *Expectations:*

When more medical technology is in use, a larger quantity of and/or more expensive equipment must be purchased. A change in *cumulative medical technology growth* should produce movement of *OP Asset Value* in the <u>same</u> direction, with a delay.

A change in *CCI* will propagate in a similar manner.

- *Testing:*

cumulative medical technology growth = 0.2 + STEP(±0.1, 2)

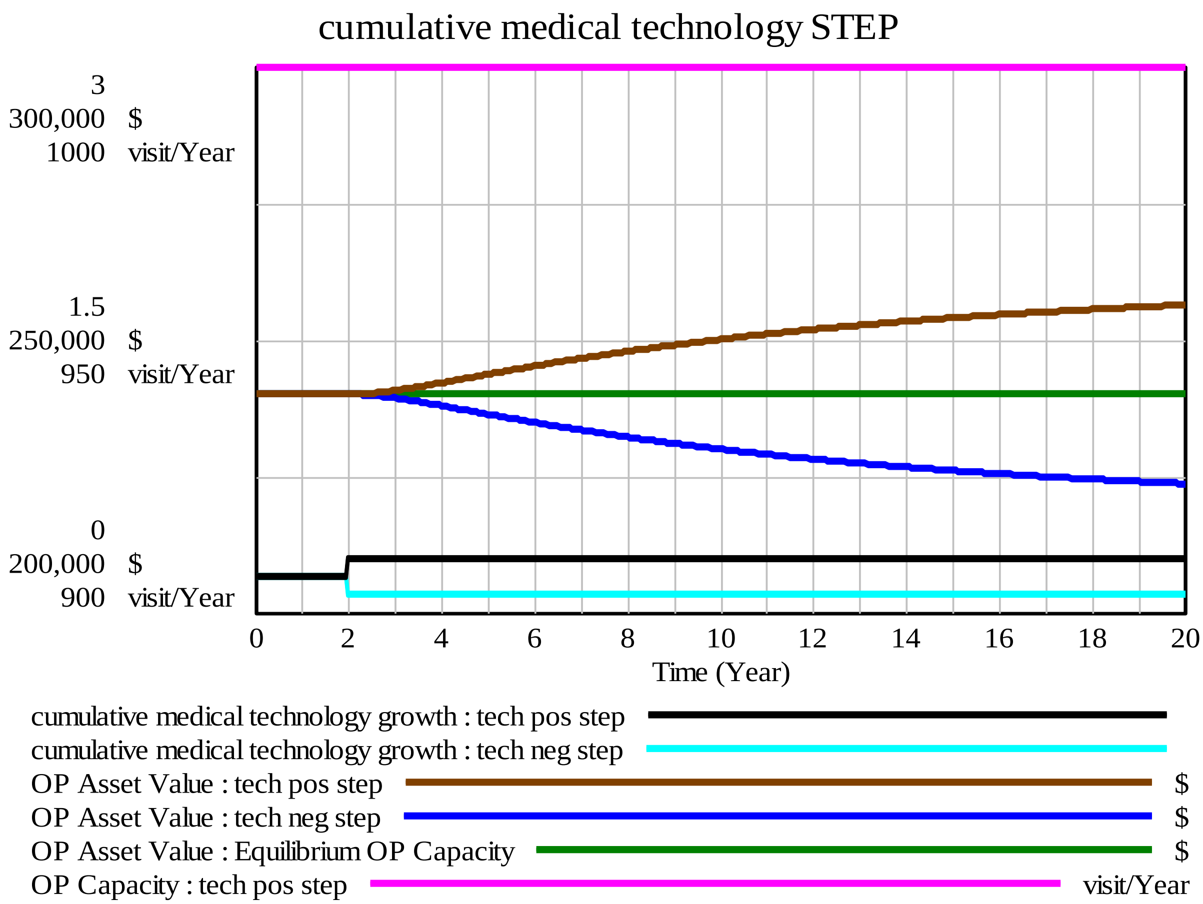

Figure 39: Effect of STEP in *cumulative medical technology growth* on *OP Asset Value* and *OP Capacity*

- *Results:*

Increase in *cumulative medical technology growth* → increase in *Technology Effect on Hospital Construction Cost* → increase in *adding OP asset value* → **increase in *OP Asset Value***. *OP Capacity* remains constant. Note that eighteen years is not enough for the system to stabilize after the shock, despite a 10% depreciation rate meaning that capacity should have a 10-year lifespan and thus be fully replaced with "upgraded" tech by approximately year 15, accounting for the technology diffusion time. This is due to the "mixing effect" in the stock.

- Test 2: *adding OP capacity* / *OP capacity retirement*

- *Expectations:*

This effect is simple: adding more capacity at a constant value will increase total asset value. A change in *adding OP capacity* will result in movement of *OP Asset Value* in the same direction. It will settle in a new equilibrium when *OP Capacity* = (*adding OP capacity* – *OP capacity retirement*) / *OP capacity depreciation rate*.

Because *OP capacity retirement* has the opposite effect of *adding OP capacity*, a change in the former will result in opposite direction movement in *OP Asset Value*.

- *Testing:*

(1) *adding OP capacity* = 100 + STEP(10, 2)

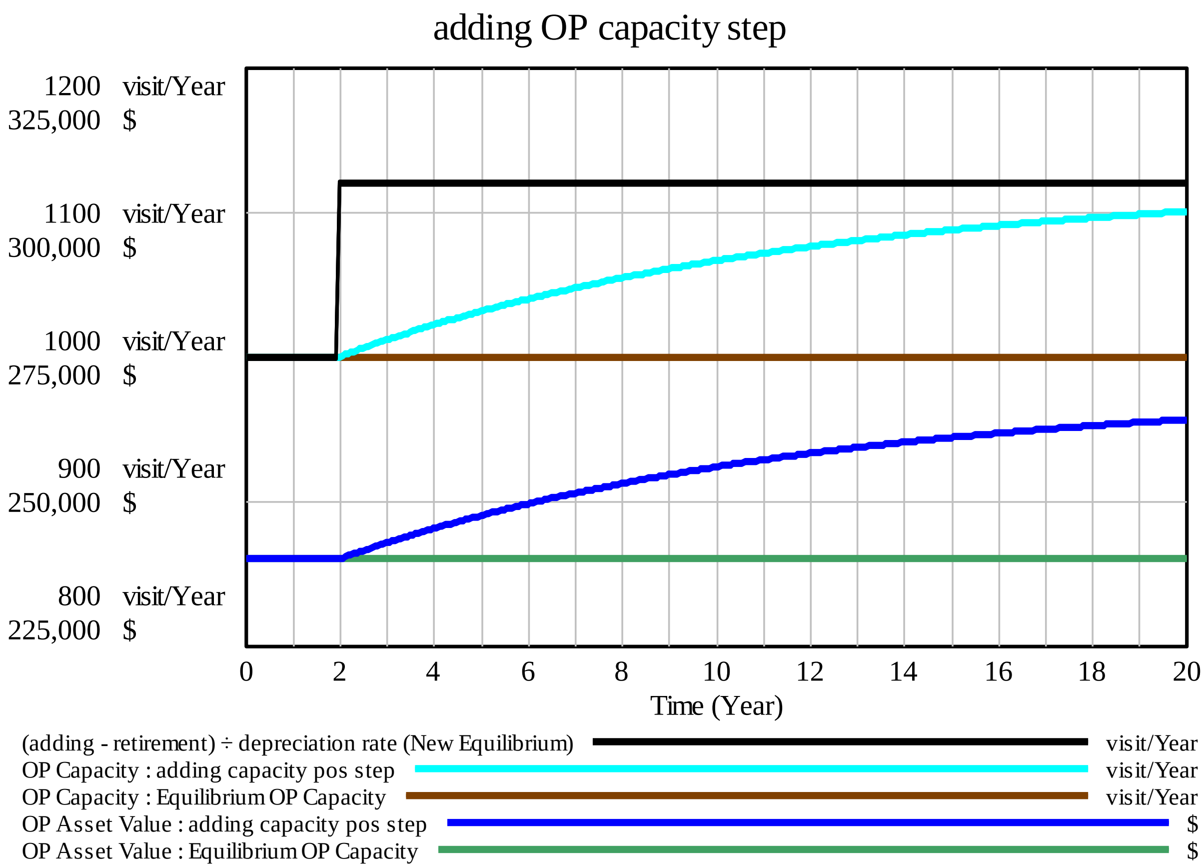

Figure 40: Effect of positive STEP in *adding OP capacity* on *OP Capacity* and *OP Asset Value*

(2) *OP capacity retirement* = 20 + STEP(2, 2)

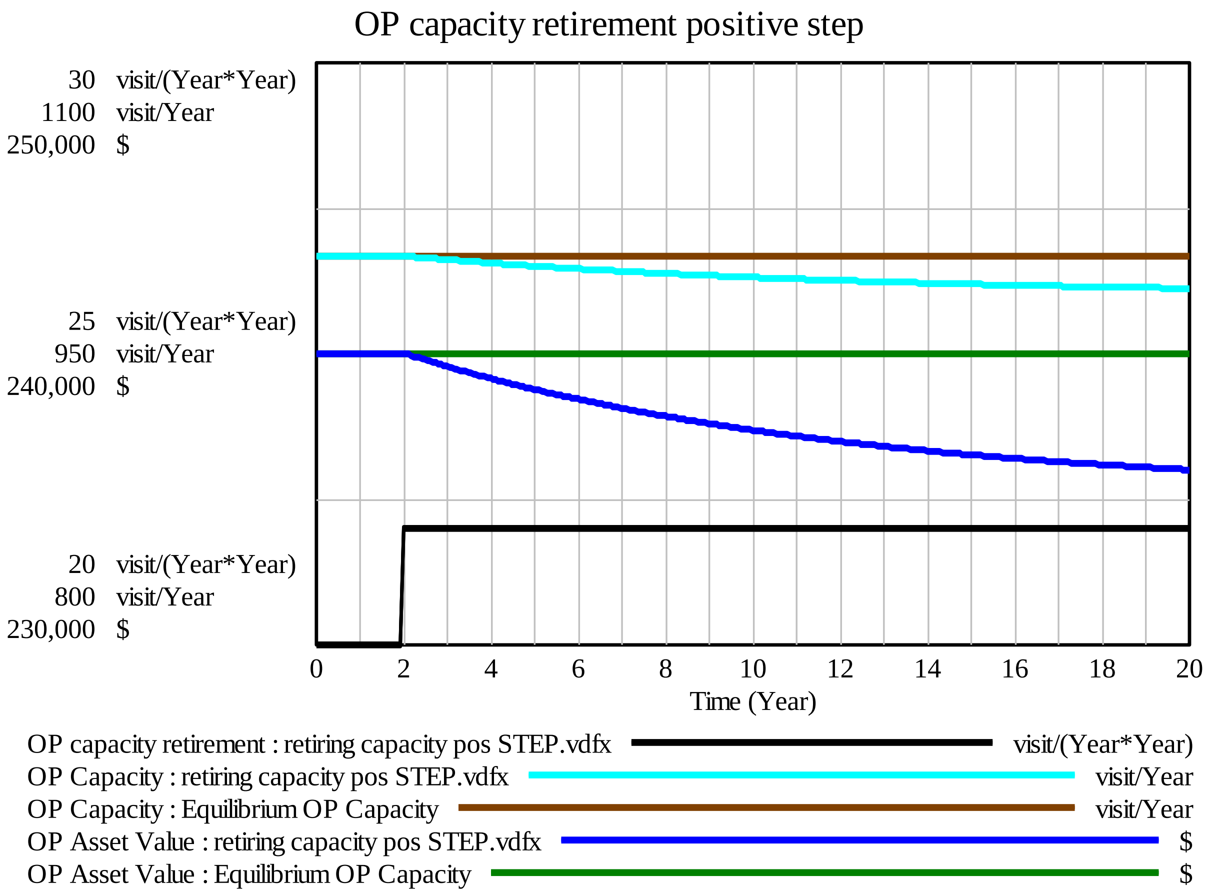

Figure 41: Effect of positive STEP in *OP capacity retirement* on *OP Capacity* and *OP Asset Value*

- *Results:*

increase in *adding OP capacity* → increase in *adding OP asset value* → **increase in *OP Asset Value***

increase in *OP capacity retirement* → increase in *OP depreciation charge* → **decrease in *OP Asset Value***

- Conclusion:

All expectations were confirmed – the sector operates according to its intended design.

- **Verification of other sectors:**
- ER ASSET VALUE: ☑
- IP ASSET VALUE: ☑
- **Recommendations and suggestions for further work:**

None

- **Module: Hospital Cost**
- **Purpose:**

The hospital cost module estimates average per visit operating costs for the outpatient and emergency venues and the average per day cost for inpatient visits.

- **Uses:**
- HOSPITAL COSTS
- **Diagram:**

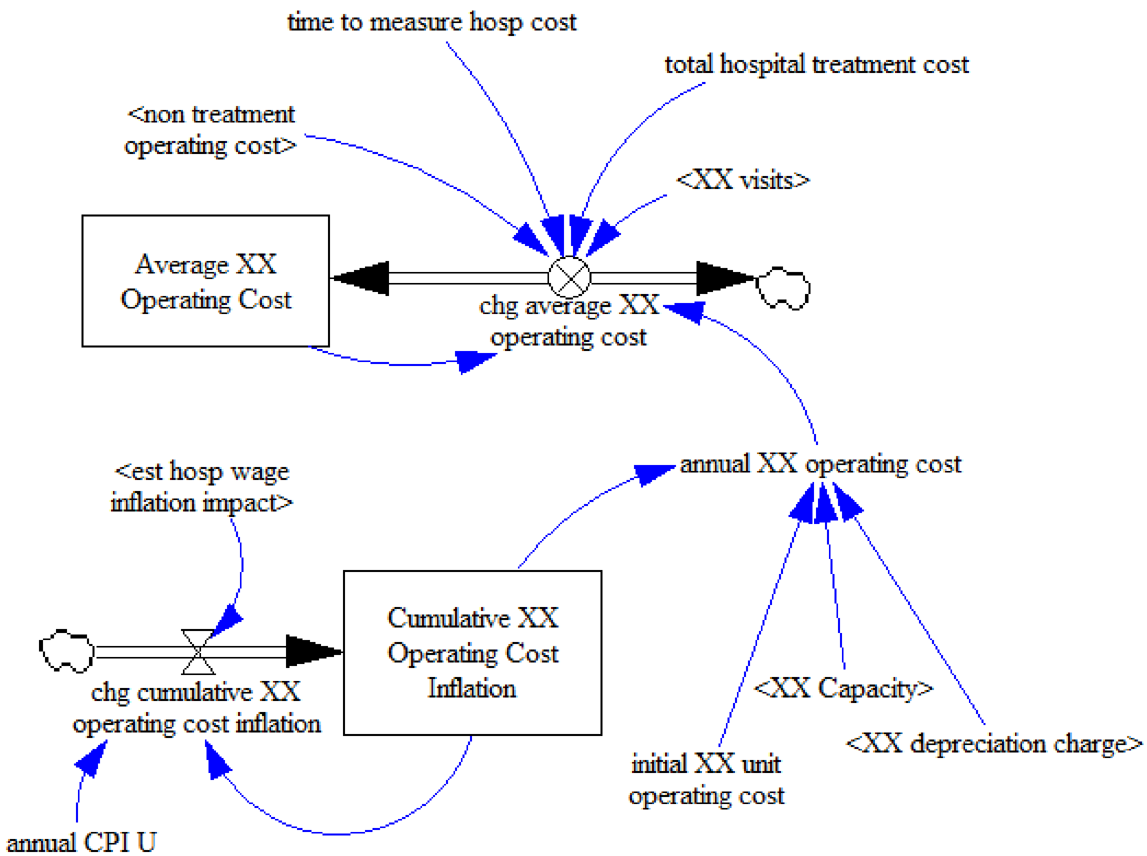

Figure 42: Diagram of venue cost structure

- **Summary:**

This sector is mostly computational, with similar calculations for ER, OP, IP, and non-treatment operating costs. Cost changes due to general inflation and labor cost fluctuations are tracked through the *Cumulative XX Inflation Index* stock, while the specified initial venue operating cost provides an anchor. In the manner of balance-sheet accounting, long-term asset costs are accounted for through depreciation charges. Among other factors (see module guide for more detail), asset cost depends on medical technology level, with a higher relative value increasing average asset costs. All units of venue capacity incur the same costs, whether they are utilized or not. Non-treatment operating costs (e.g.

administrative overhead, facilities maintenance) are distributed among the emergency, outpatient, and inpatient venues proportional to each venue's share of total hospital costs. This division was perhaps more realistic in the era when nearly all outpatient procedures were done in hospitals, but we still judge it to be an reasonable abstraction at this level of aggregation.

- Notable variables:
- ***annual XX operating cost =***
  initial annual XX operating cost * *Cumulative XX Inflation Index* * *XX Capacity*
  + *XX depreciation charge*
- ***chg cumulative XX inflation index*** =
  Cumulative XX Operating Cost Inflation * (*annual CPI U* + *est hosp wage inflation impact*)
- ***est hosp wage inflation impact***
  - Estimated rate of real price change of hospital wages and salaries
  - Does not affect non-treatment operating cost
- **Inputs:**
- From other sectors:
- ***annual ER visits*** [ER VISIT RATE]: *chg average ER operating cost*
- ***annual IP bed days*** [IP VISIT RATE]: *chg average IP operating cost*
- ***annual OP visits*** [OP VISIT RATE]: *chg average OP operating cost*
- ***IP Capacity*** [IP CAPACITY]: *IP bed capacity*
- ***IP depreciation charge*** [IP ASSET VALUE]: *annual IP operating cost*
- ***ER Capacity*** [ER CAPACITY]: *annual ER operating cost*
- ***ER depreciation charge*** [ER ASSET VALUE]: *annual ER operating cost*
- ***OP Capacity*** [OP CAPACITY]: *annual OP operating cost*
- ***OP depreciation charge*** [OP ASSET VALUE]: *annual OP operating cost*
- Parameters & Exogenous Inputs:

Variable Name	**Value**			**Source**	**Notes**
	ER	**OP**	**IP**		
annual CPI hospital and related services	Data Input (opt.)				Vensim data-type variable. Used to calculate wage inflation.
annual CPI U	Data Input (opt.)				Vensim data-type variable. General inflation.

bed day per year			365	N/A	Used to convert between IP beds and IP bed-days.
initial annual XX (unit/per bed) operating cost	150	350	210000		This variable multiplied by the corresponding *initial XX inflation index* should equal the actual value in the simulation start year.
initial annual non treatment operating cost	2,000,000,000 = 2 x 10^9				see above
initial XX inflation index	1	1	1		see note for *initial annual XX unit operating cost*
initial non treatment inflation index	1				see above
time hosp cost delay	0.5				Delay in wage inflation being reflected in costs[13]
time to measure hosp cost	1				
wage fract hosp operating cost	0.3				Fraction of non-depreciation costs used for medical staff wages and salaries.

last updated 12/9/20

- **In Isolation (Example venue: IP Cost)**
- For equilibrium:
- *Average (ER/OP/IP) Operating Cost* [Initial] = *annual XX operating cost + annual XX operating cost / total hospital treatment cost * non treatment operating cost* / *annual XX visits*
    - IP venue uses *annual IP bed days* rather than visits
- *Average Non Treatment Operating Cost* [Initial] = *non treatment operating cost*
- *annual CPI U* = 0

13 There is no analogous delay in *annual CPI U*. It is unclear why wage inflation is treated differently.

- Test 1: *annual CPI U*, *est hosp wage inflation impact*, and *IP depreciation charge*

To verify that *annual IP operating cost* behaves correctly with regards to inflation and depreciation influences, the following staggered input changes were tested in a single run. All values are fictional.

- *annual CPI U* = STEP (0.1, 2) – STEP (0.1, 10)
- *est hosp wage inflation impact* = STEP (0.2, 11) – STEP (0.2, 15)
- *IP depreciation charge* = 500,000 + RAMP (100,000, 18, 20) – RAMP (200,000, 20, 22)

For this run, the normal impact of *annual CPI U* on *est hosp wage inflation impact* was removed to allow separate testing.

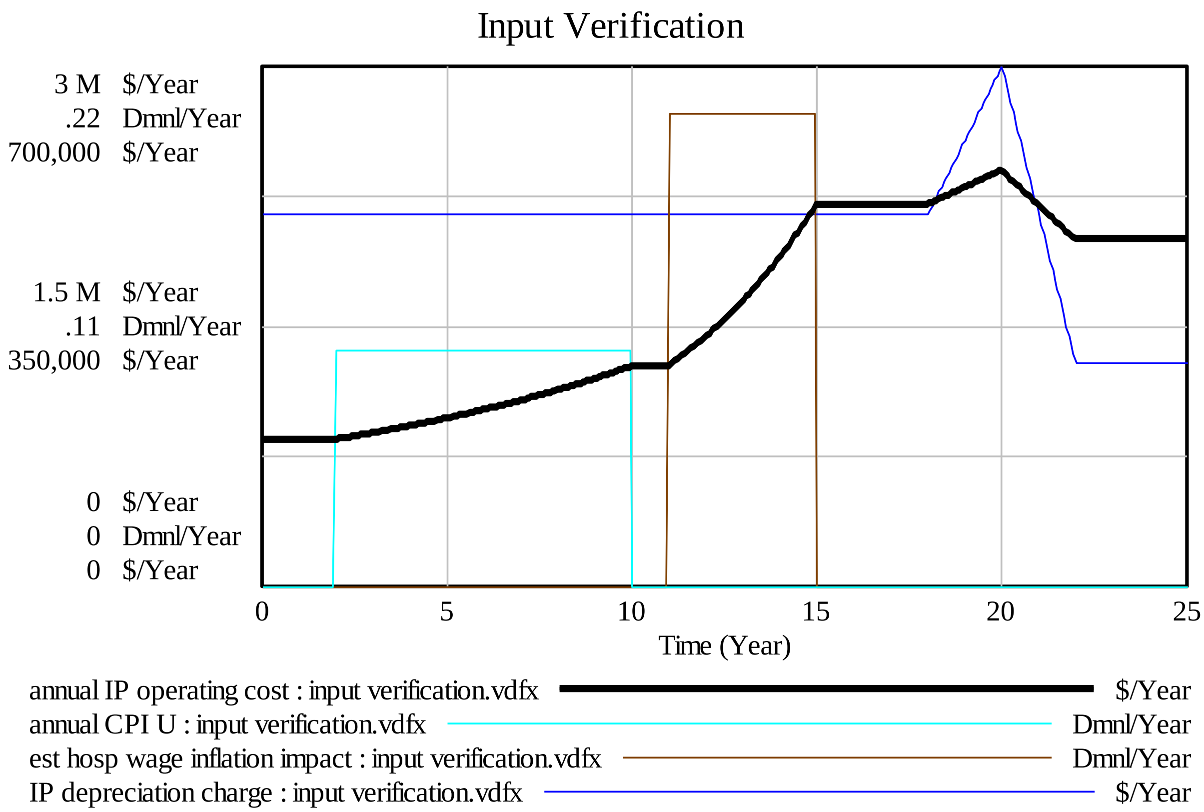

Figure 43: Effect of changes in *annual CPI U*, *est. hosp wage inflation impact*, and *IP depreciation charge* on *annual IP operating cost*

As the results in Figure 43 demonstrate, non-zero values of either *annual CPI U* or *est. hosp wage inflation impact* cause exponential growth, as they should. When both are zero, changes in *annual IP operating cost* mirror the changes (or lack thereof) in *IP depreciation charge*.

- Test 2: *IP Capacity*
- *Expectations:*

When capacity increases, the overall operating cost will increase. Additionally, because the venue will now account for a larger share of *total hospital treatment cost,* it will take on a larger share of *non treatment operating cost*. Because the number of bed days and visits remains constant, the per day cost will also be higher. If capacity decreases, both annual and per day costs will decrease.

- *Testing:*

IP bed capacity[14] = 100 + STEP (±20, 2)

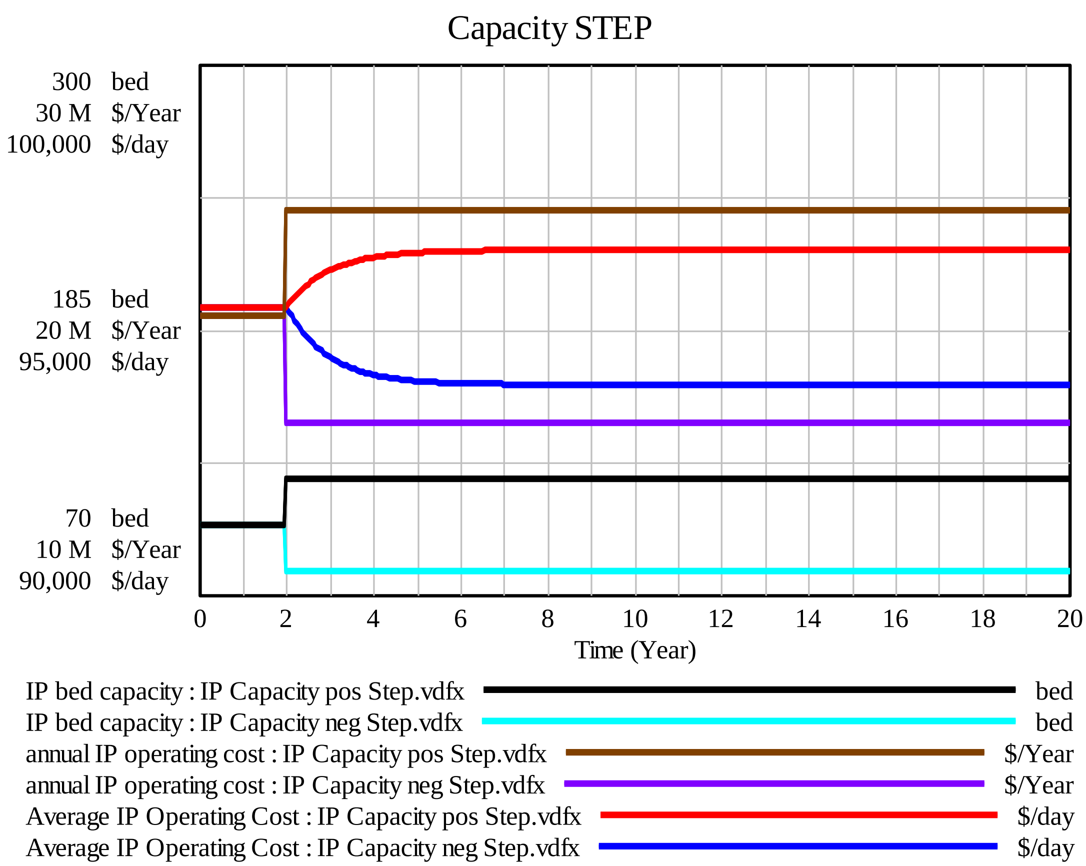

Figure 44: Effect of step changes in *IP bed capacity* on *annual IP operating cost* and *Average IP Operating Cost*

- *Results:*

14 *IP bed capacity = IP Capacity* / 365

As expected, a change in *IP bed capacity* causes movement of both *annual IP operating cost* and *Average IP Operating Cost* in the same direction. The adjustment in the former is immediate, while the latter variable follows an asymptotic adjustment path consistent with measurement delay.

- Test 3: *annual IP bed days*
- *Expectations:*

The variable *annual IP bed days* is the product of annual IP visits and average length of stay. As long as capacity remains constant, annual operating costs will remain constant regardless of changes in utilized bed days. However, if *annual IP bed days* increases (or decreases), the ability to spread the total cost over more (fewer) patients will decrease (increase) *Average IP Operating Cost*.

- *Testing:*

annual IP bed days = 20,000 + STEP (±2,000, 2)

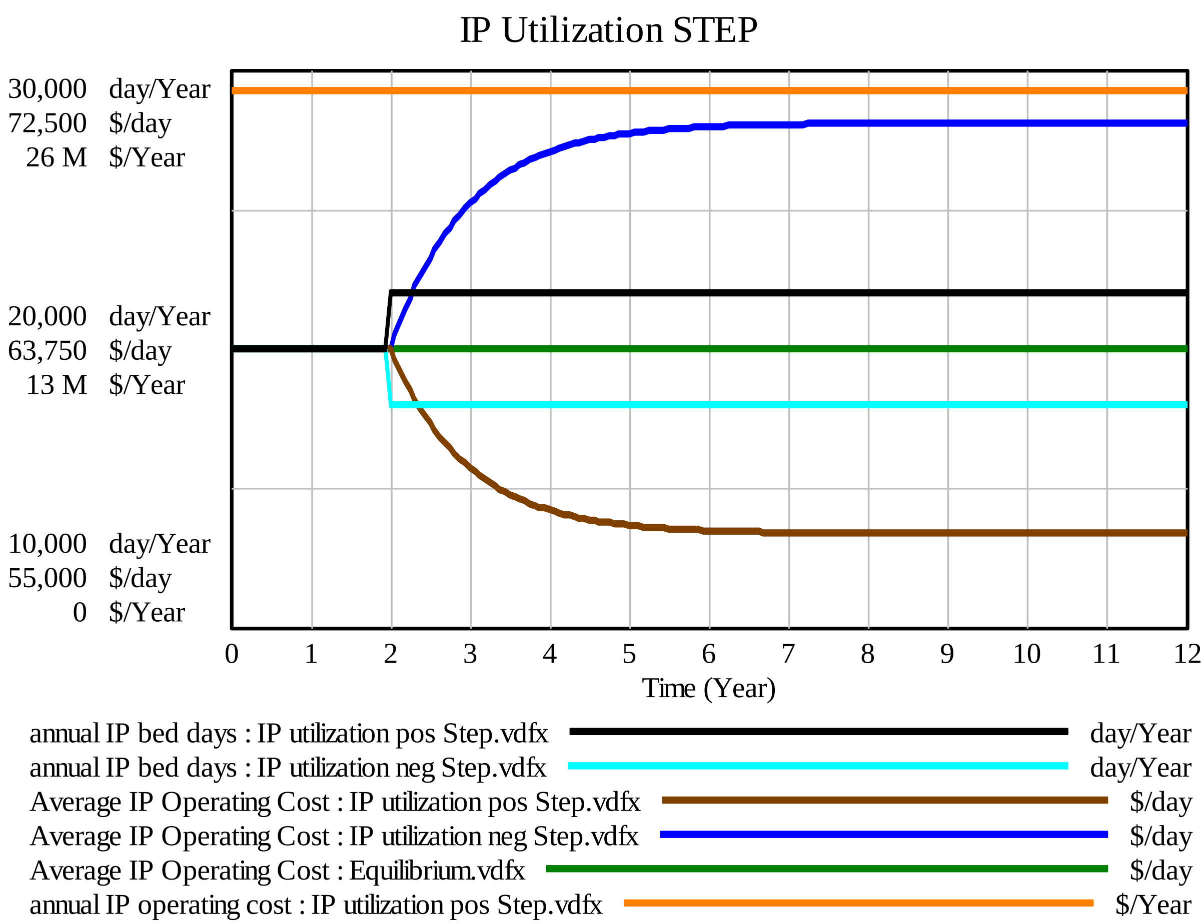

Figure 45: Effect of step changes in *annual IP bed days* on *Average IP Operating Cost* and *annual IP operating cost*

- *Results:*

As anticipated, *Average IP Operating Cost* is inversely related to *annual IP bed days*, although there is a measurement delay. *Annual IP operating cost* is constant.

- Conclusion:

All expectations were confirmed – this sector operates according to its intended design.

- **Verification of other venues:**
- ER Cost: ☑
- OP Cost: ☑
- **Recommendations and suggestions for further work:**

None

- **Module: PO Price**
- **Purpose:**

As the name implies, the PO Price module tracks physician office visit price. Because of the diversity in payment setups (insurance reimbursement, full or partial out-of-pocket), not to mention the variation among regions and even individual physicians, the price stock here denotes the national average in the most basic sense: total spent on physician visits divided by the number of annual visits. Thus, it incorporates payments made by both insurers and individuals.

- **Uses:**
- PO PRICE
- **Diagram:**

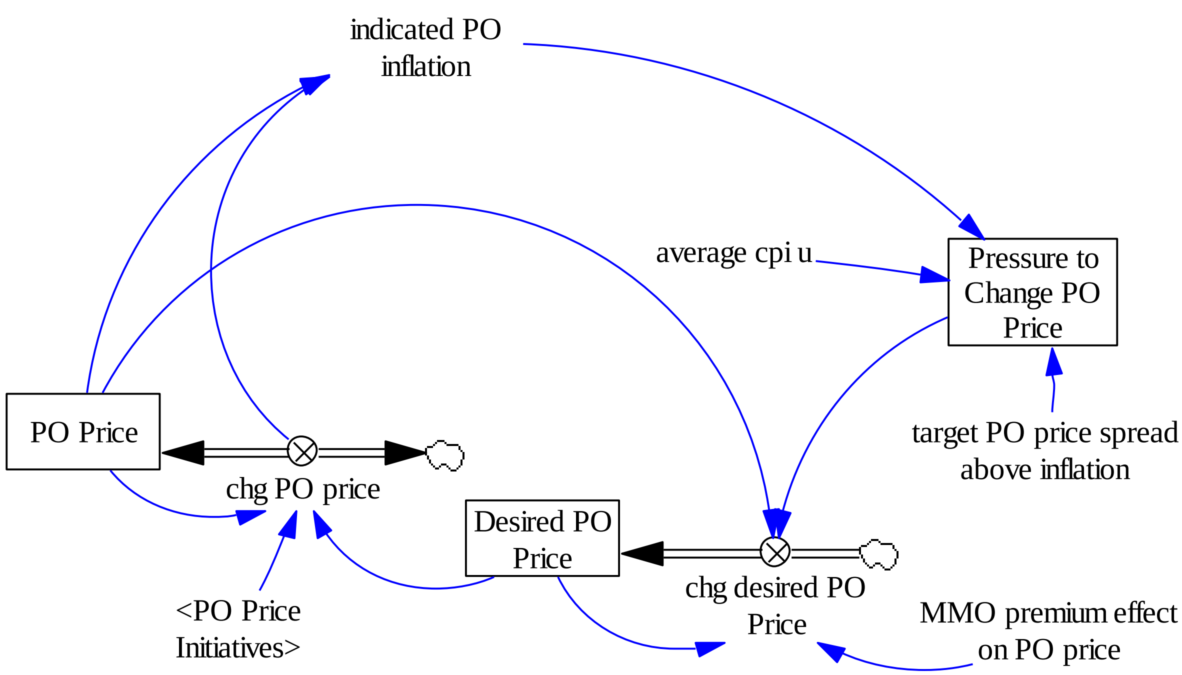

Figure 46: Diagram of PO Price structure

- **Summary:**

This structure can be divided into two sub-structures: the physicians' desired price and the actual average price paid, accounting for the downward price pressure exerted by insurers. This setup allows representation of disparate incentives for MCOs and providers.

Particularly given the level of aggregation, *Desired Price* necessarily represents a theoretical or unstated value that accounts for the markup physicians would like to receive for their services. The billed price is perhaps similar in concept, though there should be no expectation that the magnitude of the sticker markup is a reflection of the desired value as tracked by the model. Physicians are assumed to desire reimbursement that increases slightly faster than general inflation. If, for instance, the percentage increase in *PO Price* over a period (*indicated PO inflation*) is less than the sum of *average cpi u* and *target PO price spread above inflation*, *Pressure to Change PO Price* will grow. The trend in MMO premiums also influences desired price – if premiums are rising, *Desired PO Price* will rise as well, and the reverse.

Desired PO Price is the integral of the following flow:

chg desired PO price = (*PO Price* * (1 + *Pressure to Change PO Price* + *MMO premium trend effect on PO price*) - *Desired PO Price*) / *time to change desired PO price*

- ***Pressure to Change PO Price –*** Physicians would like their incomes to grow in real terms; most also consider themselves above-average practitioners and thus deserving of higher-than-average compensation. *Pressure to Change PO Price* models this desire. If PO price is increasing at a rate equal to general inflation plus *target PO price spread above inflation*, *Pressure to Change PO Price* tends towards zero. If PO price inflation falls below this desired rate, price pressure increases, in time producing a proportional increase in *Desired PO Price* and *PO Price*. *Pressure to Change PO Price* can take negative values, under the assumption that physicians do not want to increase prices so quickly as to scare away patients and insurers.
- ***MMO premium trend effect on PO price –*** Higher medical malpractice insurance premiums cut into the net revenue received by providers. They are assumed to respond to premium hikes by increasing their desired price. Similarly, declining premiums engender a lower desired price. The relationship between the inflation-adjusted premium trend and the desired price is specified by the graphical (aka lookup) function shown in Figure 22, modified by a constant *tune MMO premium trend effect on PO price*. This relationship specifies that providers are assumed to pass on a greater share of cost increases than they do savings.
    - Uses first-degree SMOOTH of lookup function
    - Because the immediate rather than cumulative trend is used, it is possible for the model to run in equilibrium despite a sustained non-zero trend. See Test 1: *MMO premium trend effect on price* and **Error! Reference source not found.**.

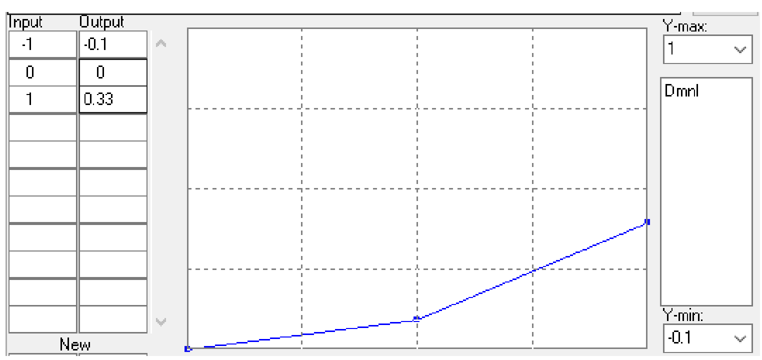

Figure 47: MMO premium effect on price f lookup function

Insurance initiatives may reduce the actual amount the hospital receives. *XX Price* is altered through the following bi-flow:

chg XX Price = ((*Desired PO Price* - *weight on XX price initiative* * *XX Price Initiatives* * *XX Price initiative effectiveness*) - *XX Price*) / *time to change XX price*

- ***PO Price Initiatives –*** MCO efforts to reduce required reimbursement cost. Because co-pays/co-insurance are included in the modeled price, the PO *Price Initiatives* variable does not include schemes which simply shift payment responsibility without changing total cost.
- ***PO Price initiative effectiveness*** – This parameter is currently static, unlike in the hospital cost sectors where increasing utilization improves effectiveness as a reflection of stronger initiative enforcement. This should be updated to match the hospital sectors (See Recommendations).
- **Inputs:**
- From Other Sectors:
- ***PO Price Initiatives*** [PO PRICE INITIATIVES]
- ***MMO premium trend effect on price*** [MMO PREMIUMS]
- Parameters & Exogenous Inputs:

Variable	Value / Restrictions	Source	Notes
annual CPI U	Data Input (opt.)		*average cpi u* is a 1^{st} degree SMOOTH of *annual CPI U*
nm PO Price initiative effectiveness	non-negative	Calibration	
nm target PO price spread above inflation			Generally assumed to be positive in practice, but there is no mathematical reason it cannot be zero or negative.
time to average cpi u	positive		See note for *annual CPI U*.
time to build PO price pressure	positive		
time to change desired PO price	positive		
time to change PO price	positive		
tune MMO premium trend effect on PO price	non-negative		
weight on PO price initiative	non-negative		

last updated 12/9/20

- **In Isolation:**
- Initial values for equilibrium:

- *Desired PO Price* [Initial] = *PO Price* * (1 + *Pressure to Change PO Price* + *MMO premium trend effect on PO price*)
- *PO Price* [Initial] = *PO Price Initiatives* * *weight on PO price initiative* * *PO price initiative effectiveness* / (*average cpi u* + *target PO price spread above inflation* + *MMO premium trend effect on PO price*)
- Test 1: *MMO premium trend effect on price*
- Expectations*:*

MMO premiums are an expense and thus accounted for in the desired price. When premiums increase, physicians will increase their desired price to compensate. With fixed MCO initiatives, this will also produce a delayed change in *PO Price* of the same direction and magnitude. Thus, a change in *MMO premium trend effect on price* should produce movement in the same direction in both *Desired PO Price* and *PO Price.* Because the input is the trend in premiums, not the value, a one-time positive pulse reflects a permanently higher premium price, which should be reflected in a permanently higher *PO Price*. A step decrease in premium trend, on the other hand, should be reflected in a steadily declining *PO Price*.

- *Testing:*

MMO premium effect on price = 0.05 + STEP (± 0.2, 2)

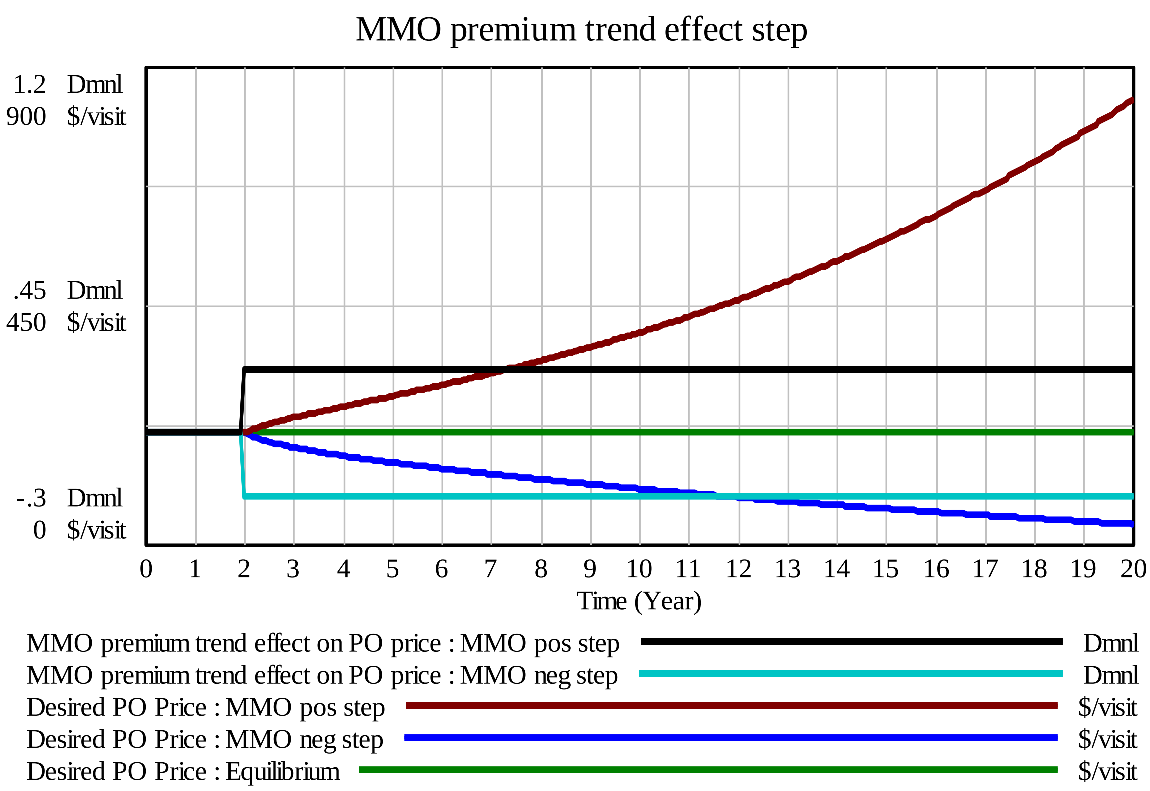

Figure 48: Effect of step change in *MMO premium trend effect on price* on *Desired PO Price*. *PO Price* is not shown but follows a similar trajectory.

- *Results:*

Both *Desired PO Price* and *PO Price* react to a change in *MMO premium effect on price* with movement in the same direction of the latter and each other, as expected. However, this test exposes a number of worrying behaviors. First, before time 2, the sector is in equilibrium despite a non-zero MMO premium trend. In other words, MMO premiums were continually increasing, yet *PO Price* can remain constant perpetually. This happens because *Pressure to Change PO Price* is not cumulative. Additionally, *PO Price* and *Desired Price* can become negative as long as *PO Price Initiatives* are positive. Granted, in the full model price initiatives would decline as *PO Price* trended towards zero, so it would likely never take negative values but could still reach zero. This is certainly not representative of real-world physician behavior.

- Test 2: *PO Price Initiatives*
- *Expectations:*

PO Price Initiatives aim to decrease physician visit price. Thus, *PO Price Initiatives* and *PO Price* should move in opposite directions. The likely effect on *Desired PO Price* is quite a bit less certain – perhaps physicians will increase their billed price in an attempt to maintain their previous income, or maybe they will become accustomed to lower prices over time and decrease their desired price. Or perhaps a combination of the two. In the current model structure, only the latter is represented. A step change in price initiatives should lead to asymptotic changes in *PO Price*, but the actual result is different.

- *Testing[15]:*

OP Price Initiatives = 10 + STEP(+/-10, 2)

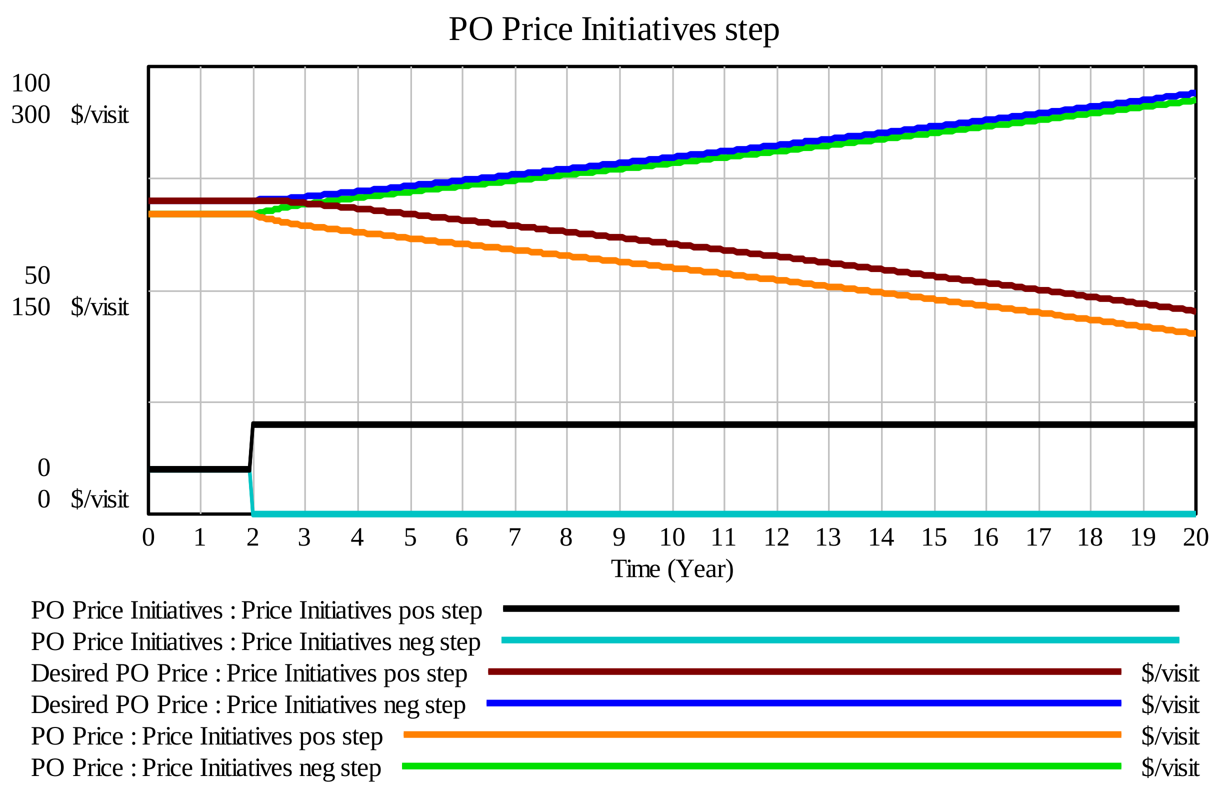

Figure 49: Effect of step changes in *PO Price Initiatives* on *Desired PO Price* and *PO Price*

- *Results:*

A decrease in *PO Price Initiatives* causes a sustained exponential decrease in both *PO Price* and *Desired PO Price*. Given that *target PO price spread above inflation* is zero, this is slightly concerning, but at least it seems plausible that physician prices might spiral if insurers reduce cost control efforts. More concerning is what happens in the other direction: a one-time increase in *PO Price Initiative* produces a

15 Converted from Level to Auxiliary type variable

sustained exponential decrease in *PO Price* and *Desired PO Price*. This behavior is extremely implausible on an aggregate scale.

- Conclusion:

There are a number of scenarios where input changes produce outcomes that are at odds with common sense and realistic behavior. More work is needed on this sector.

- **Recommendations and suggestions for further work:**
- There are a few thorny dimensional inconsistencies in this sector. Due to the other changes that need to be made, it may be worthwhile to wait on fixing units. (3)
- Unlike in the hospital price structures, demand has no effect on either initiative effectiveness or desired price. The link between demand and initiative effectiveness should be added. (1)
- The link between demand and desired price deserves further investigation. In particular, some previous research has found that physicians *increase* prices when demand falls in order to maintain a desired income level (Ratanawijistrasin, 1993). Such a finding suggests that increasing demand should reduce the desired price spread above inflation. The direction and magnitude of such an effect may depend on type of insurance (traditional fee-for-service vs PPO, for instance).
- Testing should be conducted to better examine alternate formulations for *MMO premium effect on price*. As it currently stands, the effect is based off the total aggregate (nationwide) premiums payed, adjusted for inflation. Perhaps it would be advisable to include adjustments for changes to total visits, for instance, to reflect the wider base over which premium costs can be spread. Other possibilities can surely be devised as well.
- To correct the problems noted in the above testing, I suggest severing the negative feedback loop between *Pressure to Change PO Price* and its flow. This would make the stock cumulative and solve a number of problems – notably the runaway response to a one-time step increase in inputs. To ensure that the path of *PO Price* didn't always return exactly to its original trajectory, there could be a separate "fading pressure" outflow.
- One possibility: (3)
    - *chg desired PO price* = (*PO Price* * (1 + *Pressure to Change PO Price*) - *Desired PO Price*) / *time to change desired PO price*
    - *Pressure to Change PO Price* = INTEG (*building PO price pressure*); Initial = 0
    - *building PO price pressure* = - (*indicated PO inflation* - *average cpi u* - *target PO price spread above inflation* - *MMO premium trend effect on PO price*) / *time to build PO price pressure*

- **Module: Hospital Price**
- **Purpose:**

The Hospital Price module tracks price for the three hospital venues: emergency department (ER), outpatient (OP), and inpatient (IP). Because of the extremely wide range of possible services delivered, diversity in payment setups and price variations among hospitals, the price stock here denotes the national average in the most basic sense: total spent in the given venue divided by the number of annual venue visits (or annual bed days, in the case of the IP venue). Thus, it includes payments made by both insurers and individuals.

- **Uses:**

HOSPITAL PRICE: Although organized in a single sector, the three venues have separate but identical structures with a few shared inputs.

- **Diagram:**

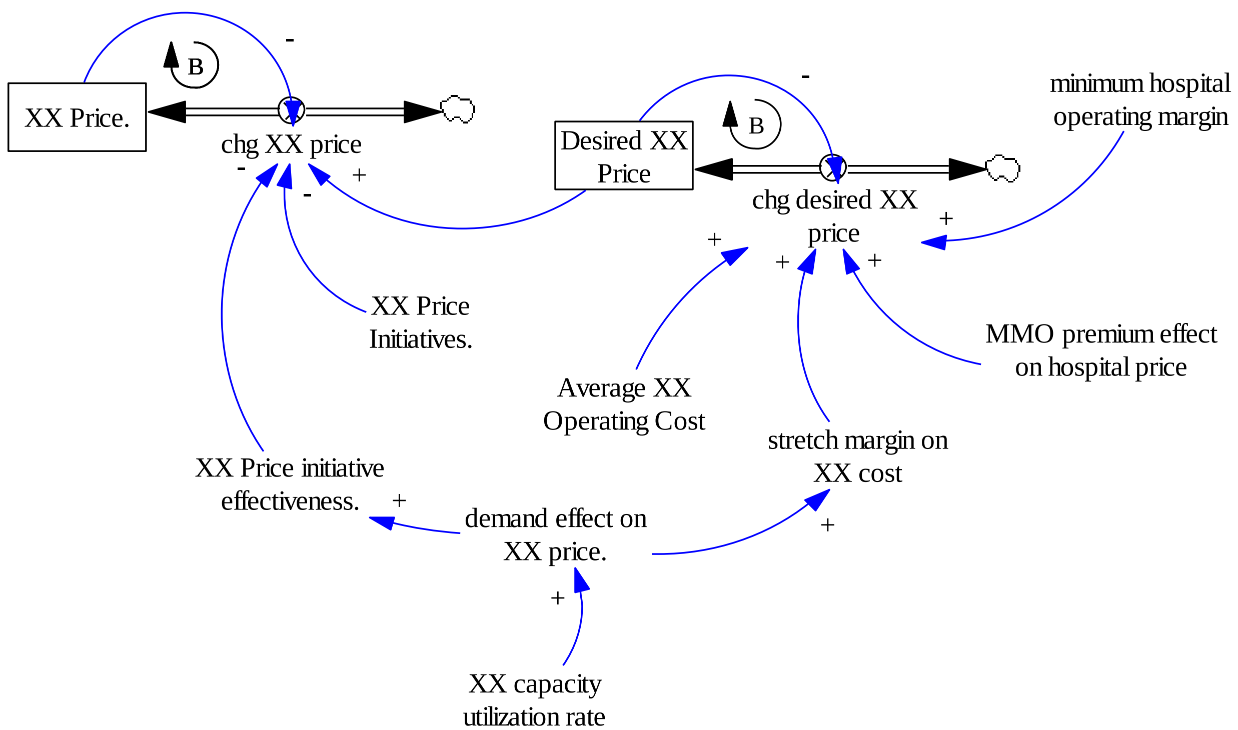

Figure 50: Diagram of XX Price structure

- **Summary:**

As with the PO PRICE sector which it resembles, this module's structure can be divided into two sub-structures: the providers' desired price and the actual average price paid, accounting for the downward price pressure exerted by insurers. This setup allows the model to represent the price tug of war between providers and payers. Elements of both are affected by the level of demand.

Particularly given the level of aggregation, *Desired Price* necessarily represents a theoretical or unstated value that accounts for the markup providers would like to receive for their services. The billed price is perhaps similar in concept, though there should be no expectation that the magnitude of the sticker markup is a reflection of the desired value as tracked by the model. Unlike for the physician price, the desired price in the hospital venues is anchored on the calculated costs for the respective sectors. Cost is multiplied by the total desired margin – composed of constant and demand-sensitive elements – plus the malpractice premium impact. Because the *Desired XX Price* has a semi-exogenous anchor, *chg desired XX price* must be modified by the cumulative (not instantaneous) MMO premium trend.

Desired XX Price is the integral of the following flow:

chg desired XX price = (*Average XX Operating Cost* * (1 + *minimum hospital operating margin* + *stretch margin on XX cost* + *MMO premium effect on hospital price*) – *Desired XX Price*) / *time to change desired XX price*

- ***Average (ER/OP/IP) Operating Cost*** – Operating cost serves as the primary anchor for *Desired XX Price*.
- ***minimum hospital operating margin –*** This is a fixed value representing the minimum margin the hospital must reach to continue providing care.
  - shared by all three hospital venues
- ***stretch margin on (ER/OP/IP) cost*** – Unlike the constant minimum margin, stretch margin is inversely proportional to demand: the more demand, the more leverage hospitals have to raise prices, for example. This is in line with standard supply-demand theory and interviews with hospital administrators, but runs contrary to some empirical findings regarding physician price-setting behavior. See sector recommendations.
  - *stretch margin on XX cost = nm stretch margin on XX cost * XX capacity utilization rate / desired average XX utilization rate*
- ***Cumul*[ative] *MMO Premium Effect on Price –*** Higher medical malpractice insurance premiums cut into the net revenue received by providers. They are assumed to respond by increasing their desired price. Similarly, declining premiums engender a lower desired price. The relationship between the real (inflation-adjusted) premium trend and price trend effect is specified by the lookup function shown in Figure 22. This relationship specifies that providers are assumed to pass on a greater share of cost increases than they do savings. Unlike the malpractice premium effect on visit rate or physician price, which depends on the smoothed trend (a flow), the *MMO premium effect on hospital price* depends on the cumulative trend effect (the corresponding stock). There are no adjustments for changes in number of providers or visits, though such changes could be tested in the future.

- Shared by all three hospital venues.
- Trend flow uses first-degree SMOOTH of lookup function.

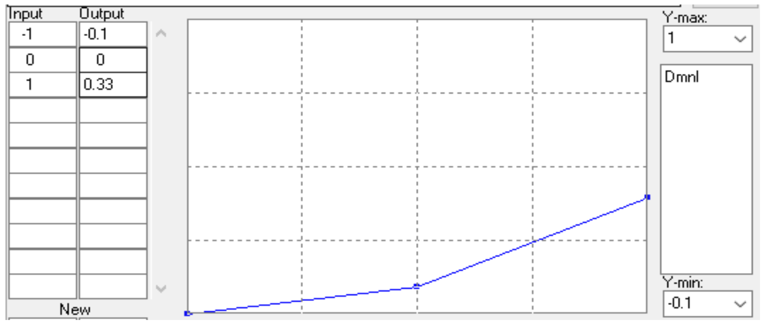

Figure 51: MMO premium effect on price f lookup function

Insurance initiatives may reduce the actual amount the hospital receives. *XX Price* is altered through the following bi-flow:

chg XX Price = ((*Desired XX Price* - *weight on XX price initiative* * *XX Price Initiatives* * *XX Price initiative effectiveness*) - *XX Price*) / *time to change XX price*

- ***(ER/OP/IP) Price Initiatives –*** MCO efforts to reduce required reimbursement cost. Because co-pays/co-insurance are included in the modeled price, the *Price Initiatives* variable does not include schemes which simply shift payment responsibility without changing total cost.
- ***(ER/OP/IP) Price initiative effectiveness*** – In contrast to the various visit initiative effectiveness variables present in the model, hospital price initiative effectiveness is dynamic. Normal effectiveness is modified by the ratio of current to desired venue utilization rate. When utilization increases, insurers are assumed to enforce coverage restrictions more strenuously. This is modeled as an increase in price initiative effectiveness, which in turn will put downward pressure on price. The effect also works in reverse.
- **Inputs:**
- From other sectors:
- ***Average XX Operating Cost*** [HOSPITAL COSTS]
- ***ER/OP capacity utilization rate / IP occupancy rate*** [XX CAPACITY]
- ***Cumul MMO Premium Effect on Price*** [MMO PREMIUMS]
- ***XX Price Initiatives*** [XX PRICE INITIATIVES]
- Parameters & Exogenous Inputs:

Variable	**Value / Restrictions**		**Source**	**Notes**
desired (ER/OP) utilization rate / desired IP occupancy rate	**ER**	0.476…		1 / (1 + *desired XX capacity reserve*)
	OP	0.476…		
	IP	0.588…		
minimum hospital operating margin	0.2			Shared.
nm XX Price initiative effectiveness	non-negative		Calibration	
nm stretch margin on XX cost	non-negative			
time to change desired XX price	positive			
time to change XX price	positive			
tune MMO premium effect on hospital price	non-negative			Shared.

weight on XX price initiative non-negative

last updated 11/29/20

- **In Isolation (Example Venue: OP Price):**
- Initial values for equilibrium:
- *Desired OP Price* [Initial] = *Average OP Operating Cost* * (1 + *minimum hospital operating margin* + *stretch margin on OP cost* + *MMO premium effect on hospital price*)
- *OP Price* [Initial] = *Desired OP Price - weight on OP price initiative* * *OP Price Initiatives* * *OP Price initiative effectiveness*
- Test 1: *Average OP Operating Cost*
- *Expectations:*

Price is ultimately based off the cost of providing care. A change in *Average OP Operating Cost* should produce movement in the <u>same</u> direction in both *Desired OP Price* and, with a delay, in *OP Price.*

- *Testing:*[16]

Average OP Operating Cost = 500 + STEP(± 50, 2)

16 Variable converted from level to auxiliary type.

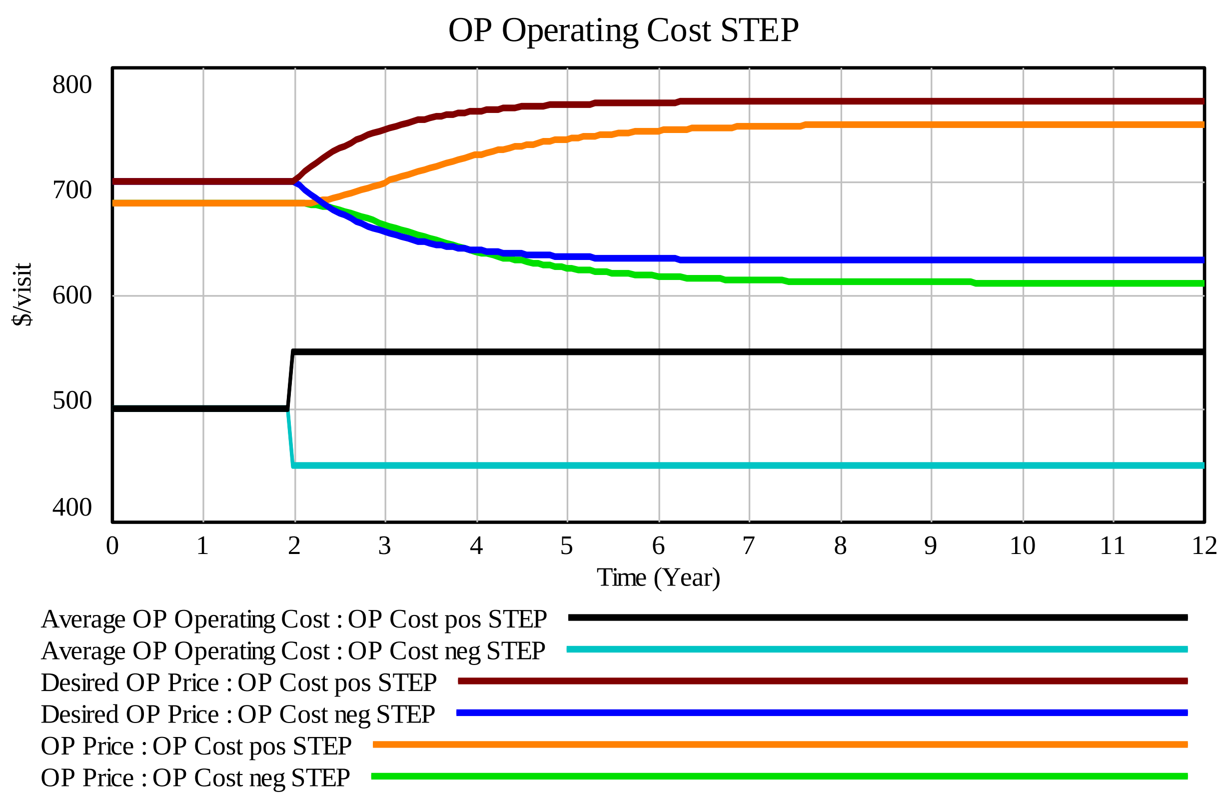

Figure 52: Effect of STEP in *Average OP Operating Cost* on *Desired OP Price* and *OP Price*

- *Results:*

As expected, positive and negative step inputs in *Average OP Operating Cost* caused asymptotic growth or decline, respectively, in both *Desired OP Price* and *OP Price*, with the latter adjusting more slowly.

- Test 2: *Cumul MMO Premium Effect on Price*
- *Expectations:*

MMO premiums are an expense and thus accounted for in the desired price. *Cumul MMO Premium Effect on Price* reflects the price level of premiums, so a change in the variable should produce movement in the same direction in both *Desired OP Price* and, because *OP Price Initiatives* is fixed, in *OP Price* as well.

- *Testing:*

Cumul MMO Premium Effect on Price = STEP (± 0.2, 2)

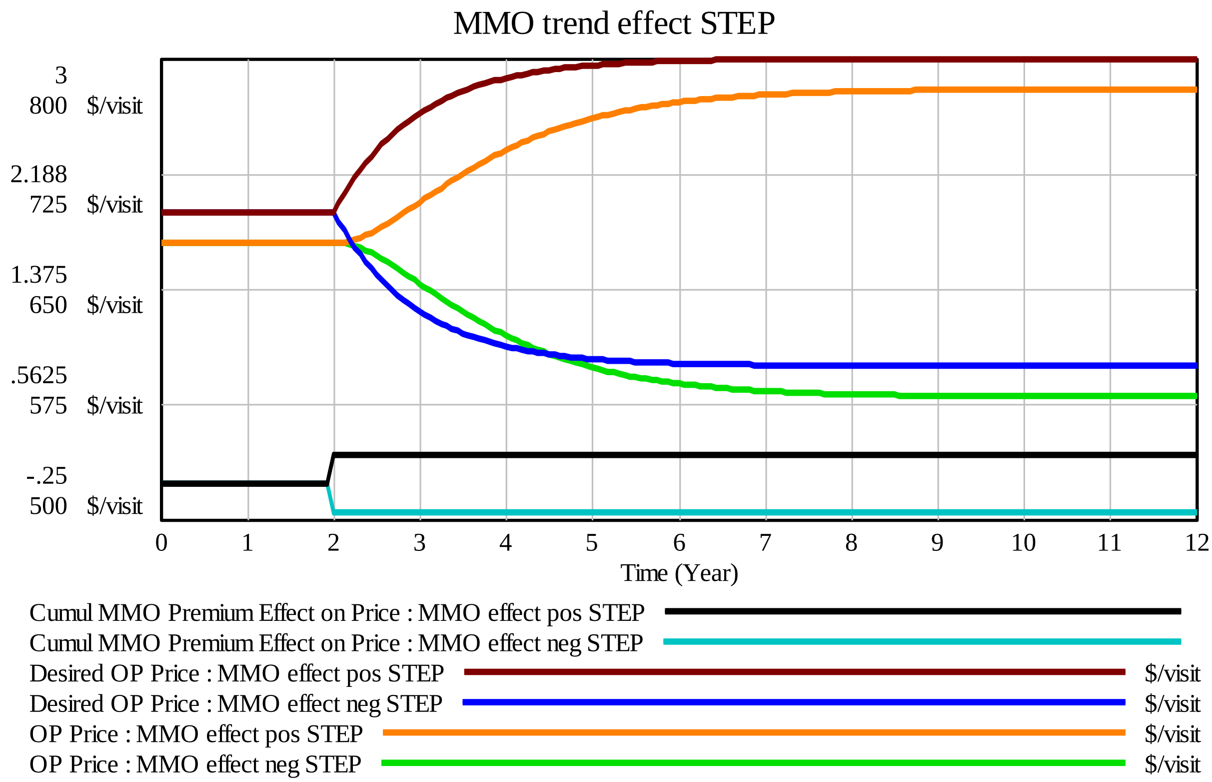

Figure 53: Effect of step change in *Cumul MMO Premium Effect on Price* on *Desired OP Price* and *OP Price*

- *Results:*

Both *Desired OP Price* and *OP Price* react to a change in *MMO premium effect on price* with asymptotic movement in the same direction, as expected.

- Test 3: *OP Price Initiatives*
- *Expectations:*

OP Price Initiatives aim to decrease outpatient visit price. Thus, *OP Price Initiatives* and *OP Price* should move in opposite directions. *Desired OP Price* is unaffected by initiative changes.

- *Testing:*[17]

OP Price Initiatives = 100 + STEP(+/-10, 2)

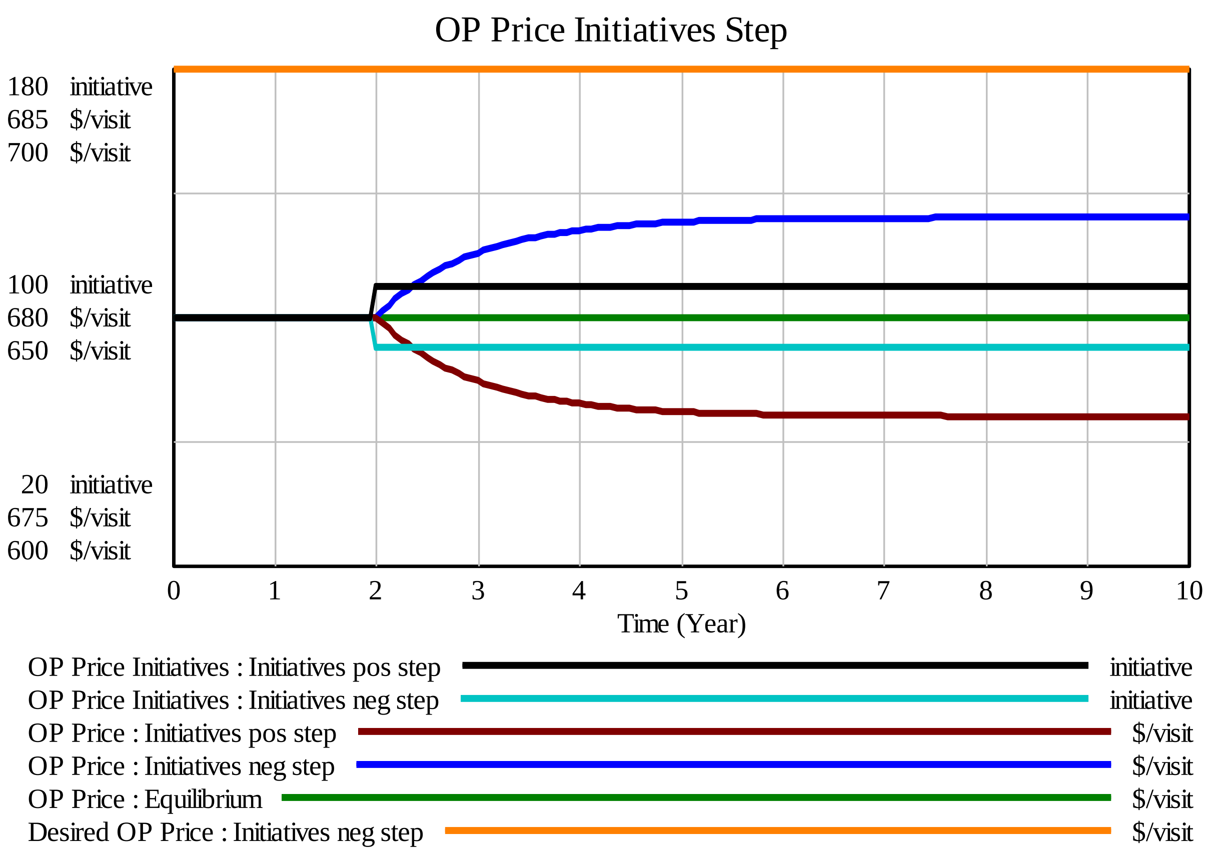

Figure 54: Effect of step changes in *OP Price Initiatives* on *Desired OP Price*, *OP Price*, and *chg OP price*

- *Results:*

An increase in *OP Visit Initiatives* causes a decline in *OP Price*, and a decrease in the former produces an increase in the latter. The adjustment path is asymptotic. As predicted, there is no effect on *Desired OP Price*.

17 Variable converted from Level to Auxiliary.

- Test 4: *OP capacity utilization rate*
- *Expectations:*

An increase in demand will increase hospitals' perceived ability to charge more, and vice versa, in line with traditional supply-demand theory and with interviews with hospital administrators (the demand effect). Thus, a change in *OP capacity utilization rate* will produce movement in the same direction of *Desired OP Price*. With a delay, this will be transmitted as a proportional change in *OP Price.* However, changes in utilization also affect the initiative effectiveness parameter, ultimately causing movement of *OP Price* in the opposite direction (the enforcement effect). Because there is no delay in the enforcement effect, *OP Price* will initially move opposite to the change in *OP capacity utilization rate*. Over time, the demand effect may come to dominate the change in *OP Price* and reverse its direction of movement. The net effect on *OP Price* is indeterminate, as it depends on the value of other variables and parameters.

- *Testing:*

OP capacity utilization rate = 0.5 + STEP(±0.1, 2)

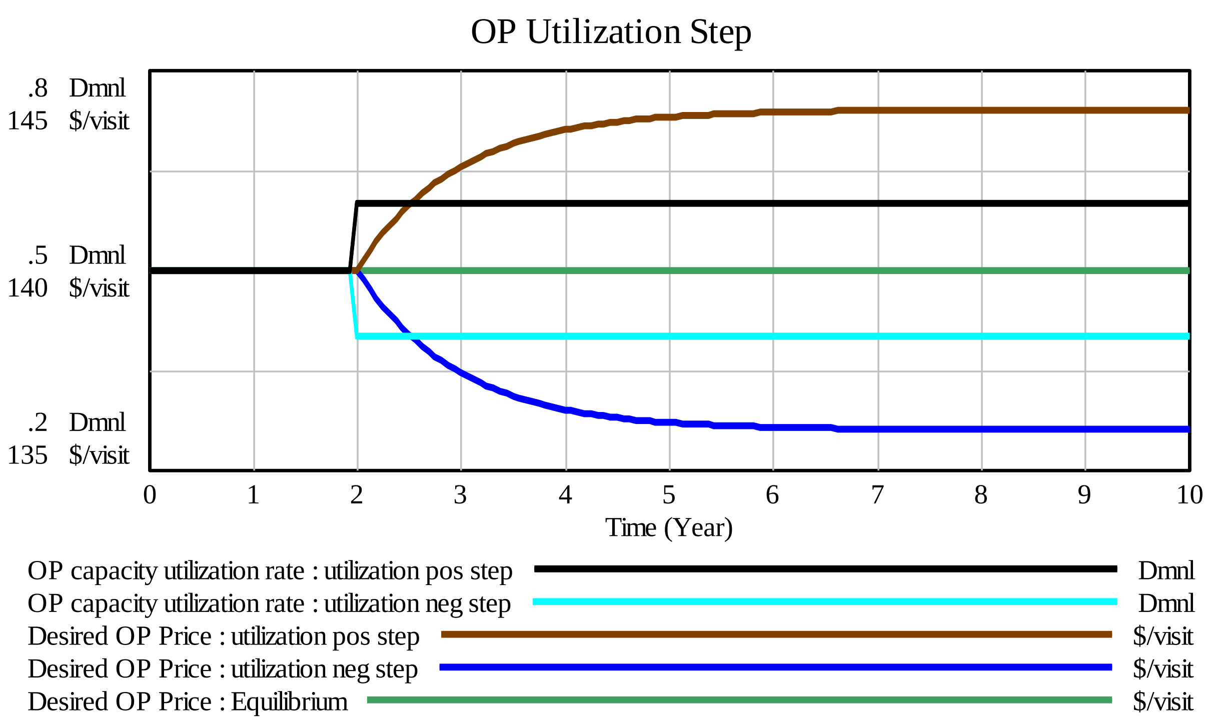

Figure 55: Effect of step changes in *OP capacity utilization rate* on *Desired OP Price*

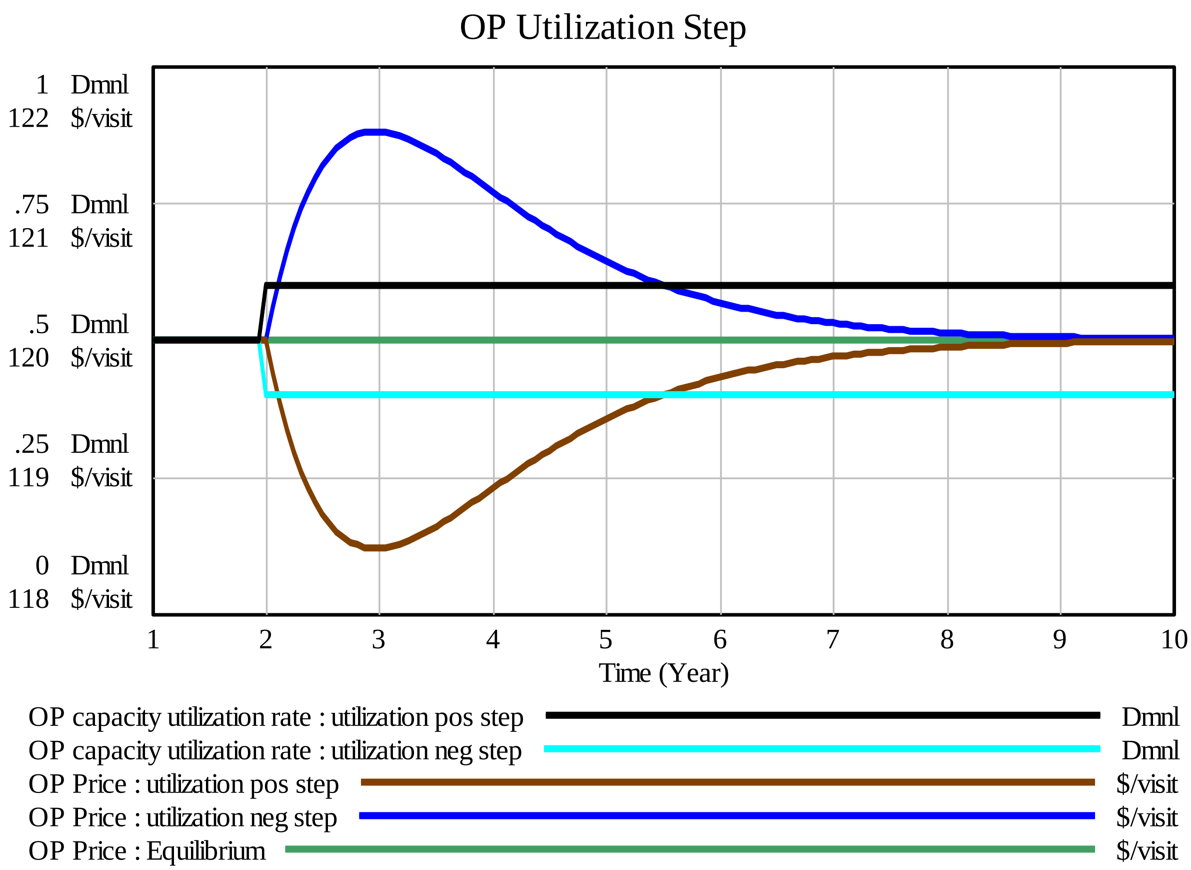

Figure 56: Effect of step changes in *OP capacity utilization rate* on *OP Price*

- *Results:*

Because the *Desired OP Price* is only affected by the "demand effect," it moves monotonically in the same direction as utilization, as demonstrated in Figure 55. Conversely, *OP Price* first moves in the opposite direction from the change in utilization (the "enforcement effect"), but the "demand effect" eventually comes to dominate and the price change reverses direction. In the pair of runs shown in Figure 56, by the time a new equilibrium is reached, the cumulative effects of the enforcement and demand effects are almost equal, returning *OP Price* to its original value. However, depending on the value of other variables, most notably *Average OP Operating Cost, OP Price Initiatives, weight on OP price initiative,* and *MMO premium effect on hospital price*, the relative strength of the two effects can vary greatly. As a result, a positive step change in *OP capacity utilization rate* can result in a new equilibrium where *OP Price* variously increases, returns to the original value, or decreases.

- Conclusion:

All expectations were confirmed – the sector operates according to its intended design.

- **Verification of other venues:**
- ER PRICE: ☑
- OP PRICE: ☑
- **Recommendations and suggestions for further work:**
- Some previous research has found that physicians *increase* prices when demand falls in order to maintain a desired income level (Ratanawijistrasin, 1993). This works because third parties (insurers) bear most of the cost. Such a finding suggests that perhaps the direction of demand influence on *stretch margin* should be reversed. More investigation is likely warranted. The direction and magnitude of such an effect may depend on type of insurance (traditional fee-for-service vs PPO, for instance).

- **Module: Price Initiatives**
- Purpose:

Managed Care Organizations (MCOs) would like to decrease the average price they reimburse for a health care visit. They employ a number of tactics in pursuit of this goal, including step therapy – requiring use of a generic drug before authorizing a patented medicine – excluding high-priced physicians from coverage networks, implementing a capitation payment scheme instead of fee-for-service. The Price Initiatives sectors track such initiatives by venue: physician office (PO), emergency department (ER), outpatient (OP), and inpatient (IP) settings.

- **Uses:**
- PO PRICE INITIATIVE
- ER PRICE INITIATIVE
- OP PRICE INITIATIVE
- IP PRICE INITIATIVE
- **Diagram:**

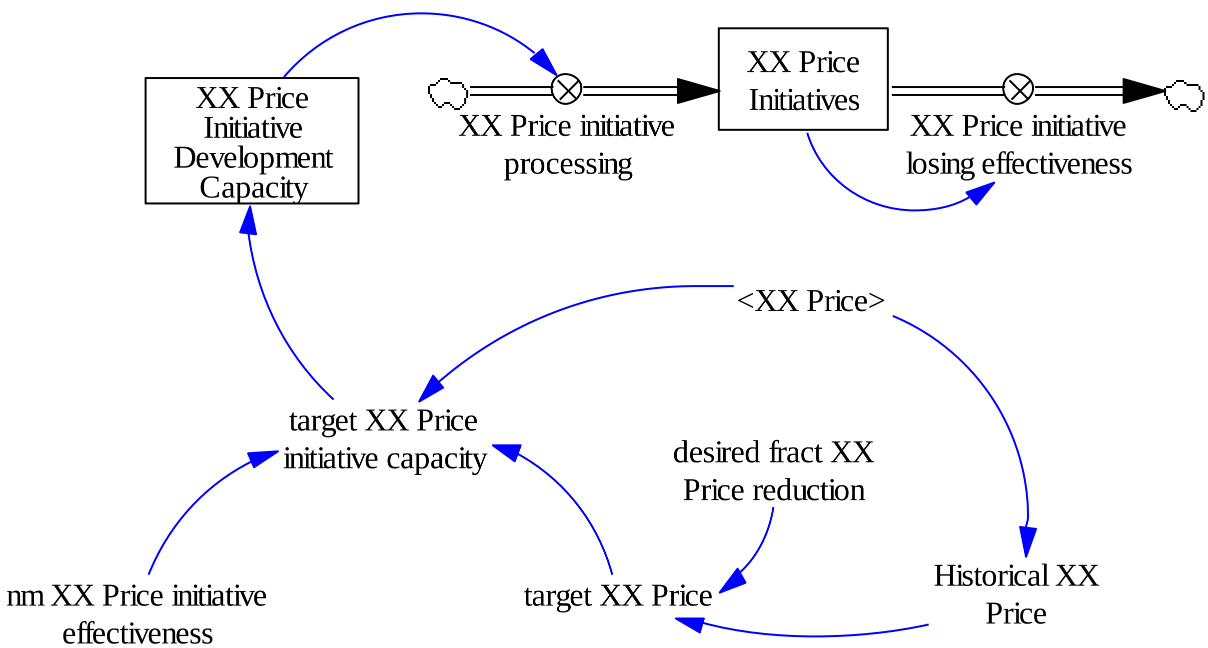

Figure 57: Diagram of *XX Price Initiatives* structure

- Summary:

MCOs determines a target price based on a fixed percentage reduction of an exponential smooth of historical prices, then adjust their initiative development capacity to meet that target. The model simulates initiative development as reactionary rather than proactive; insurers allocate resources to develop initiatives when increasing medical prices result in higher-than-anticipated payouts. However, no development capacity is allotted to replace initiatives which are “losing effectiveness”, meaning that initiatives rarely accomplish their full targeted price reduction. Development capacity takes time to adjust, and initiatives take time to be implemented. Initiatives also lose their effectiveness after a period of time, representing, among other possibilities, patients or providers finding work-arounds or the insurer terminating an initiative due to unpopularity or a large administrative burden.

- **Decision Points:**
- ***target XX Price –*** Medical care organizations are assumed to target price levels are based off the historical price level.
    - Price initiatives create a reinforcing feedback loop where success in limiting *XX Price* leads to a further fall in *target XX Price*. However, the structure also creates an additional balancing loop that restrains this effect. In most cases, these feedback loops should be of minor importance.
- ***target XX price initiative capacity –*** Implementing initiatives requires organizational resources, represented by the *XX Initiative Development Capacity*. Target capacity is determined by the gap between the target and actual prices. Target capacity is translated into actual capacity over time, as MCOs adjust the amount of resources directed towards initiatives. It is important to note that target capacity does not take into account existing initiatives and the capacity that will be needed to replace expiring programs. This is intended to model the reactive nature of these initiatives: if an initiative is successful and reimbursement outlays decline, the loss of financial urgency will tend to cause the insurer to lose focus on sustaining the initiative, even if it is responsible for the improvement.
    - *target XX price initiative capacity* cannot be negative (MAX function). A negative initiative capacity would represent insurers making efforts to increase the price of care. Because insurers pay the majority of this cost, such a scenario is unlikely.
    - *target XX price initiative capacity* uses the normal initiative effectiveness, not the demand-influenced actual effectiveness. There are two justifications for this decision. First, initiative effectiveness is forecasted based on actuarial analysis which is unlikely to be significantly affected by temporary shifts in ongoing initiative effectiveness. Secondly, this formulation avoids a case where MCOs would sabotage themselves in a manner unlikely in the real world. As explained in detail under the Hospital Price section, initiative effectiveness is positively linked to utilization; it is presumed that high demand will stretch MCO budgets, prompting the insurers to enforce existing restrictions more stringently. Despite the increase in initiative effectiveness, total MCO outlays would likely remain high due to above-average utilization. In such a scenario, the organizations would still focus on cost-cutting, making a drop in price initiatives illogical. However, tying the target initiative capacity to the actual effectiveness would cause the former to decrease when the latter increased. Using the normal effectiveness instead avoids this situation. A more realistic formulation might base initiative development and deployment on MCO margins.

- ***XX price initiative processing* & *XX price initiative losing effectiveness***
    - *XX price initiative processing = XX Price Initiative Development Capacity / time to develop XX price initiative*
    - The simplifying assumption is made that initiatives do not take resources to administer once they have been developed; if development capacity instantly dropped to zero, initiatives would still remain in effect for their normal lifespan.
- **Sector Inputs:**
- Endogenous Inputs:
- ***XX Price*** [XX PRICE]: *target XX initiative capacity* & *Historical XX Price*
    - *Historical XX Price* uses a 1st-order exponential delay function.
- **Parameters & Exogenous Inputs:**

Variable Name	**Value / Restrictions**	**Source**	**Notes**
desired fract XX price reduction		Calibration	Positive values result in reductions
nm XX price initiative effectiveness [from XX PRICE]	non-negative		
XX price initiative life	positive		
time to change XX price initiative development capacity			
time to develop XX price initiative			
MCO accounting horizon			Controls delay time for *Historical XX Price*

last updated 12/9/20

- **In Isolation (Example Sector: ER Price Initiatives):**
- For equilibrium:
- *ER Price Initiatives* [Initial] = *ER Price* * *ER price initiative effectiveness* * *ER price initiative life* /

(*time to develop ER price initiative* * *desired fract ER price reduction*)

- *ER Price Initiative Development Capacity* [Initial] = *target ER price initiative capacity*
- Test 1: *ER Price*
- *Expectations:*

Because initiatives are modeled as having an additive impact on price but insurers are assumed to target percentage decreases, an increase in price will require stronger initiatives, and vice versa. In other words, *ER Price Initiatives* will move in the same direction as the change in *ER Price*. However, because the target price is calculated based on a lagged price variable, the adjustment path will not be perfectly smooth. After a positive step increase in *ER Price*, for instance, *target ER price initiative capacity* will lose part of its initial gain once *Historical ER Price* catches up to *ER Price*.

- *Testing*[18]*:*

ER Price = 200 + STEP(±20, 2)

18 Converted from Level to Auxiliary

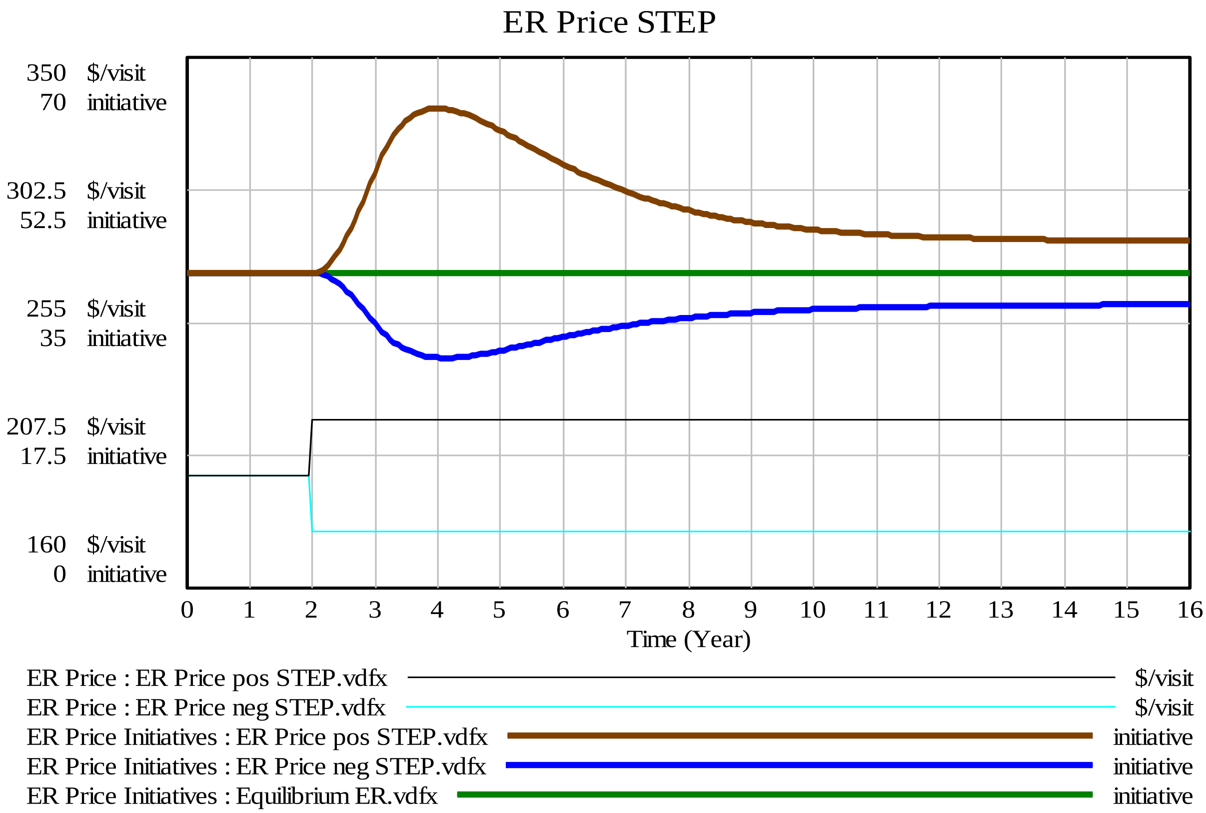

Figure 58: Effect of positive and negative STEP in *ER Price* on *ER Price Initiatives*

- *Result:*

Increase in *ER Price* → increase in *ER Price Initiative Development Capacity* **→ increase in *ER Price Initiatives***. Adjustment path depends on relative delay sizes; positive and negative changes may produce asymmetrical paths. Nevertheless, once a new equilibrium is reached, the respective differences from the original equilibrium are symmetrical (see Figure 58).

- Conclusion:

All expectations were confirmed – the sector operates according to its intended design.

- **Verification of other sectors:**

PO Price Initiatives: ☑

OP Price Initiatives: ☑

IP Price Initiatives: ☑

- **Recommendations and suggestions for further work:**

- Duplicate Consumer Response structure for all venues and integrate into Price Initiatives structure (3).

- Consider linking MCO margins to desired initiatives (5).

- **Module: Hospital Revenue**
- **Purpose:**

The Hospital Revenue sector produces national aggregate values for hospital costs and revenue.

- **Uses:**
- HOSPITAL REVENUE
- **Diagram:**

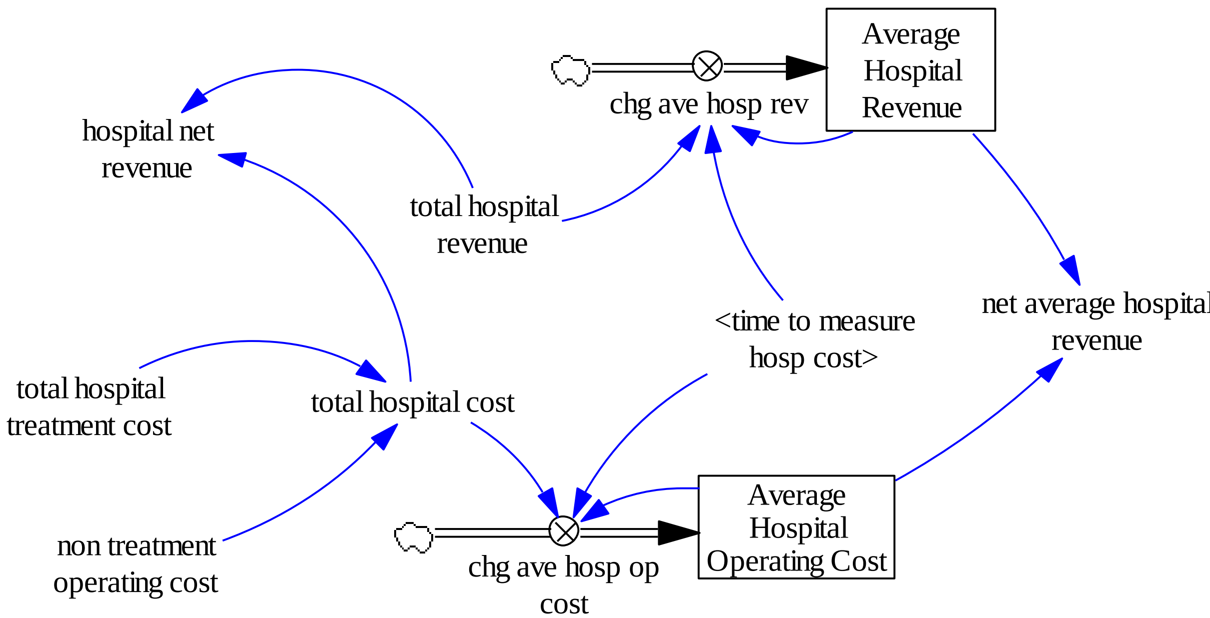

Figure 59: Diagram of the Hospital Revenue sector.

- **Summary:**

This sector is almost purely computational, with no decision or behavior modeling. All costs are summed to produce *total hospital cost*, all income sources contribute to *total hospital revenue*, and the difference is *hospital net revenue*. Related to these are *Average Hospital Operating Cost*, *Average Hospital Revenue*, and *net average hospital revenue*, respectively, which correspond to the delayed "measured" values. All these values represent totals, not per visit or per bed day figures.

- **From other sectors:**
- ***annual emergency operating cost*** [HOSPITAL COSTS]: *total hospital treatment costs*
- ***annual ER visits*** [ER VISIT RATE]: *total hospital revenue*
- ***annual inpatient operating cost*** [HOSPITAL COSTS]: *total hospital treatment costs*
- ***annual IP bed days*** [IP VISIT RATE]: *total hospital revenue*

- ***annual OP visits*** [OP VISIT RATE]: *total hospital revenue*
- ***annual outpatient operating cost*** [HOSPITAL COSTS]: *total hospital treatment costs*
- ***Cumulative Non Treatment Cost Inflation*** [HOSPITAL COSTS]: *total hospital treatment costs*
- ***ER Price*** [HOSPITAL PRICE]: *total hospital revenue*
- ***initial annual non treatment operating cost*** [HOSPITAL COSTS]: *total hospital treatment costs*
    - Constant
- ***IP Price*** [HOSPITAL PRICE]: *total hospital revenue*
- ***OP Price*** [HOSPITAL PRICE]: *total hospital revenue*

- **Notable calculation variables:**
- ***total hospital treatment cost*** = *emergency operating cost* + *outpatient operating cost* + *inpatient operating cost*
- ***non treatment operating cost*** = *annual non treatment operating cost* * *Expected Non Treatment Cost Inflation Effect*
- ***total hospital cost*** = *total hospital treatment cost* + non treatment operating cost
- ***total hospital revenue*** = *annual OP visits* * *OP Price* + *annual ER visits* * *ER Price* + *annual IP bed days* * *IP Price*
- ***hospital net revenue*** = *total hospital revenue* – *total hospital cost*

- **Parameters & Exogenous Inputs:**

Variable Name	Value / Restrictions	Source	Notes
time to measure hosp cost	positive		Also used in HOSPITAL COSTS sector.

last updated: 11/10/20

- **For equilibrium:**
- *Average Hospital Revenue = total hospital revenue*
- *Average Hospital Operating Cost = total hospital cost*

- **Module: Physicians**
- **Purpose:**

The physicians module tracks the number of practicing physicians.

- **Uses:**
- PHYSICIANS
- **Diagram:**

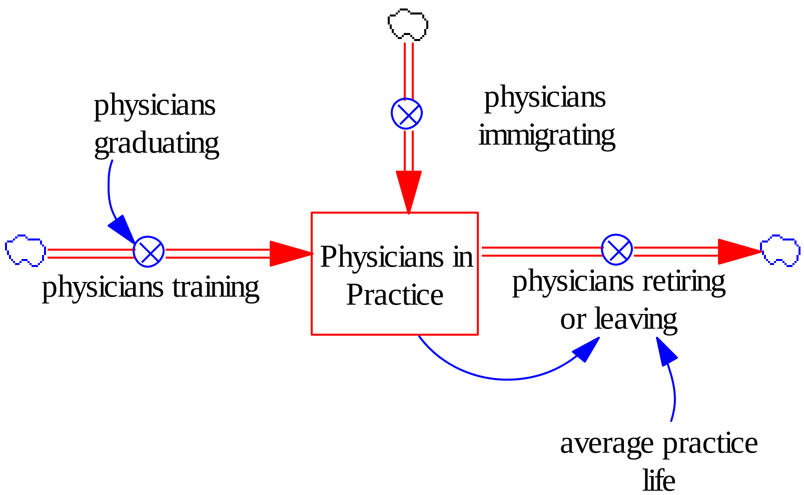

Figure 60: Diagram of the Physicians sector

- **Summary:**

There is one stock – *Physicians in Practice*. Physicians can enter either by graduating from medical school or by immigrating. As the name of the stock implies, both these inflows only include those individuals who go into practice – the model does not include people with medical degrees who are not practicing. The single outflow accounts for all physicians leaving active practice. All flows in this sector are fully exogenous.

- **Sector Inputs:**
- From other sectors:

None

- Parameters & Exogenous inputs:

Variable Name	Value / Restrictions	Source	Notes
average practice life	positive		

physicians graduating	Data-type input (optional)	Effectively an inflow to *Physicians in Practice* with a delay time of 1
physicians immigrating	Data-type input (optional)	Inflow to *Physicians in Practice*

- **In Isolation**
- For Equilibrium:
- *physicians graduating* = *Physicians in Practice* / *average practice life* - *immigrating physicians in practice*
- **Recommendations and suggestions for further work:**
- Physician flows (both entering and leaving) could be linked to physician price or another measure of financial success. (6)

- **Module: Medical Technology**
- **Purpose:**

Technology is one of the most important dynamic influences on health diagnosis, care delivery and outcomes. This sector tracks "Medical Technology Solutions," both pharmacological and non-pharmacological in nature. While the value of *Medical Technology Solutions* is not meaningful in and of itself, the cumulative trend can be tracked to create an index of technological progress.

- **Uses:**
- MEDICAL TECHNOLOGY
- **Diagram:**

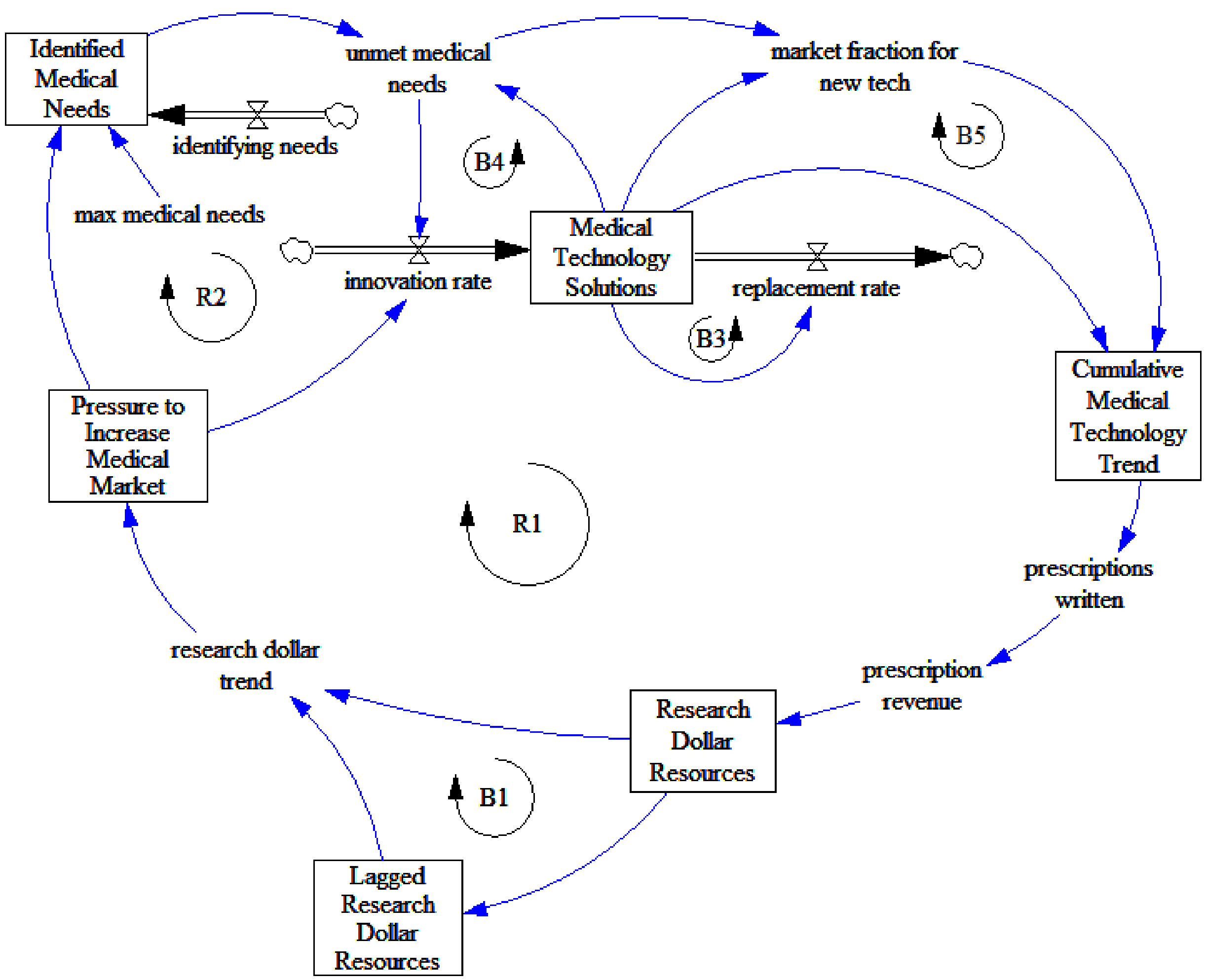

Figure 61: Simplified diagram of the Medical Technology sector, with selected feedback loops labeled

- **Summary:**

At its core, the medical technology sector is driven by the trend in prescription revenue (here, prescriptions refer to doctor's orders, whether for pharmaceuticals or other tests or procedures). Moreover, because the number of prescriptions written is proportional to *Medical Technology Solutions,* a pair of feedback loops is created within the sector (**B1** & **R1**).[19] The labels **B1** and **R1** actually represent three loops each, but the aggregate effect can be captured by thinking of a reinforcing loop and a delayed balancing loop. More prescriptions produce more industry revenue, some of which is re-invested in research and development. As industry revenue grows, more players join and there is a greater reward for innovation, speeding up the rate of new discoveries and development. It is worth emphasizing that industry size has **no** effect on innovation rate – only the trend matters. To illustrate the difference, consider that a one-time step increase in revenue will initially produce in increases in both revenue value and trend, but will eventually settle into a new equilibrium where the amount of revenue remains elevated but the trend returns to zero. In this scenario, both the innovation rate and the level of technology would return to their original values – the latter because the stock of technology depreciates over time (**B3**).

In the model, there are three categories of medical needs: "unidentified", "unmet" but identified, and those both identified and addressed by medical technology solutions. The more identified unmet needs, the faster the innovation rate (**B4**). This represents the declining efficiency of innovation as "low hanging fruit" becomes progressively rarer, an effect documented in the real world (McConaghie, 2018). The pool of unmet needs can be replenished by identifying new needs (**R2**), a process whose rate is affected by the industry revenue growth trend in a similar manner to the innovation rate. The sum of all medical needs (identified and not) is modeled as finite via the *max medical needs* parameter.

As the medical market becomes more saturated, the average new technology is assumed to target a more specialized market and thus have a smaller impact on aggregate medical decisions (**B5**). Market saturation is determined by the ratio of medical technology solutions to unmet medical needs. The latter is chosen over *max medical needs* to represent the new market opportunities produced by needs identification.

- Decision points:
- ***trend in medical technology solutions*** – As the name implies, this variable calculates the proportional change in *Medical Technology Solutions*. However, the value is modified by the *market fraction affected by new tech*. The flow into *Cumulative Medical Technology Trend* is the 1st order delay of *trend in medical technology solutions*, with a delay time equal to the parameter *med tech diffusion time*.

---

19 **R1** and **B1** are identical except that **B1** "detours" through *Lagged Research Dollar Resources*. Because the link between *Research Dollar Resources* and *Lagged Research Dollar Resources* is negative, the loop polarity is reversed. Loops **R2** and **B5** also have corresponding loops of opposite polarity that are unlabeled in Figure 61.

- ***prescriptions written*** – The total number of prescriptions written is the product of two factors: medical visits and prescriptions per visit. Relative technology level is assumed to affect both; however, the effect on visit rate is handled by the respective visit rate sectors. The relationship of technology to *prescriptions written* thus represents the effect on prescriptions per visit. New technology expands the options physicians have when ordering tests or procedures or prescribing medicines, which is assumed to create a positive relationship between technology and prescriptions per visit. Each visit type has an associated normal scripts per visit parameter.
- ***Research Dollar Resources –*** The money directed at research and development of new technologies or treatments, expressed in real dollars. The targeted *fraction of revenue to research* is constant, but there is an adjustment time (*time to chg research fract*) in the event of a change in income. In other words, *Research Dollar Resources* is a smoothed function of *prescription revenue*.
- ***Pressure to Increase Medical Market*** – When the medical technology industry is experiencing revenue growth, there is fiercer competition and a greater incentive to “win” through innovation. If industry revenue is declining, *Pressure to Increase Medical Market*, which is the ratio of *Research Dollar Resources* to *Lagged Research Dollar Resources*, impacts both the *time to innovate* and *time to identify needs*.
- ***identification of needs*** – This flow into *Identified Medical Needs* represents the identification of new medical conditions and the development of tests to identify disease. The concept encompasses the identification of distinct new conditions as well as advances in knowledge about known conditions that expand the understanding of potentially valuable treatment avenues.
- ***unmet medical needs –*** Medical needs that have been recognized but are not (fully) treated by current technology.
    - *unmet medical needs = Identified Medical Needs – Medical Technology Solutions*
- **Sector Inputs:**
- From other sectors:
- ***annual PO Visits*** [PO Visit Rate]: *prescriptions written*
- ***annual ER Visits*** [ER Visit Rate]: *prescriptions written*
- ***annual OP Visits*** [OP Visit Rate]: *prescriptions written*
- ***annual IP Visits*** [IP Visit Rate]: *prescriptions written*
- Parameters & Exogenous inputs:

Variable Name	**Value**	**Source**	**Notes**
fraction of revenue to research	0.052	Calibration	

max medical needs		Calibration	Theoretical value.
med tech diffusion time			
medical solution life			
min needs id time	10		
nm market fraction		Calibration	
nm time to identify needs			
nm scripts per ER visit	2		
nm scripts per IP visit	4		
nm scripts per OP visit	3		
nm scripts per PO visit	1		
nm time to innovate		Calibration	
script inflation rate function	Data input		
time to chg research fract		Calibration	research fract = fraction of revenues to research
time to feel pressure			time to feel competitive market pressure to innovate
time to lag value of research dollars			

last updated 12/7/20

- **In Isolation:**
- Initial values for equilibrium:
- *Fraction Market Affected by Adopted Medical Technology* [Initial] = *fraction market affected by new medical technology*
- *Identified Medical Needs* [Initial] = *max medical needs*
- *Lagged Research Dollar Resources* [Initial] = *Research Dollar Resources*
- *Medical Technology Solutions* [Initial] = *medical solution life* * *max medical needs* / (*medical solution life* + *nm time to innovate*)
- *Pressure to Increase Medical Market* [Initial] = 1
- *Research Dollar Resources* [Initial] = *fraction of revenue to research* * *prescription revenue*

- *script inflation rate* = 0

Note: Because initial *Identified Medical Needs* = *max medical needs*, *identification of needs* = 0 and the needs identification loops (**R2** and its unlabeled balancing counterpart) are inactive. Unfortunately, there is no other way to put the sector in equilibrium.

All endogenous inputs into this sector modify *prescriptions written*; therefore, demonstrating that changes in one input produce the desired results is sufficient to verify all inputs. Thus, verification will only be demonstrated for the *annual PO visits* input. For Tests 1-4, the equation is as follows:

annual PO visits = 1000 + STEP(500, 2)[20]

Due to the complexity of this sector, validation will begin with the least complex core structure and other elements will be added on in steps. After each addition, the results will be compared with expectations. Figure 62 displays the structural components, while Figure 63 lists the components used in each run. The results of negative step changes are not shown, but in all cases they run roughly symmetrical to positive step changes.

- Test 1: No major feedback loops

For the first test, the only feedback loop is the depreciation effect (**B3**). This means that the cumulative technology trend has no effect on the number of prescriptions written and *unmet medical needs* is a constant, in turn isolating the behavior of *research dollar trend*. The run is labeled "No Major Feedback" in Figure 64 and is cyan in color.

- *Expectations:*

When the number of physician visits increase, more prescriptions will be written and medical technology revenue will also rise, though with a delay. A positive revenue trend creates greater market pressure and speeds up innovation, but as *Lagged Research Dollar Resources* catches back up to *Research Dollar Resources*, *Pressure to Increase Medical Market* will trend back towards 1. Without the major feedback loops, *prescription revenue* will remain constant after the initial step, so the *research dollar trend* should peak soon after the step time and then return to zero. Because depreciation is proportional to the stock value, *Medical Technology Solutions* should decay to its original value.

- *Results:*

The model results for the "No Feedback Run" confirm expectations. The path closely follows the shape of a right-skewed bell curve, exhibiting S-shaped growth until it peaks around year 20, after which it slowly declines until it settles at the original equilibrium value.

20 For convenience, all visit numbers have been reduced by a factor of a million.

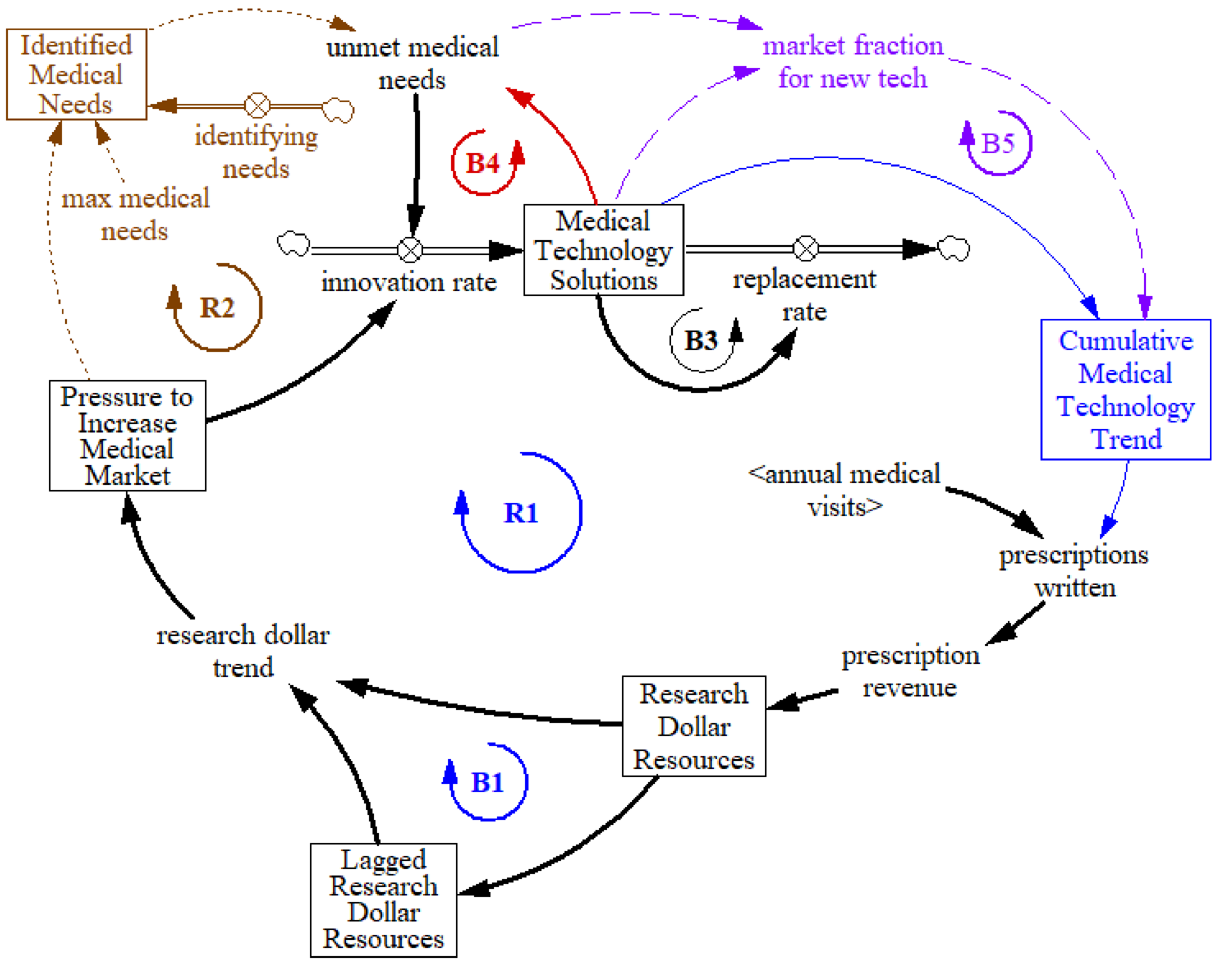

Figure 62: Simplified diagram showing testing progression

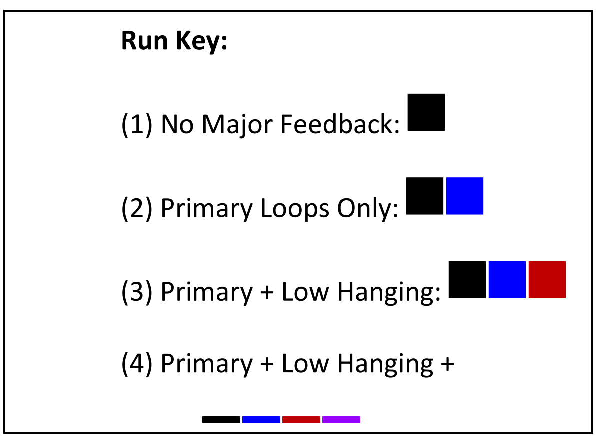

Figure 63: Testing run key

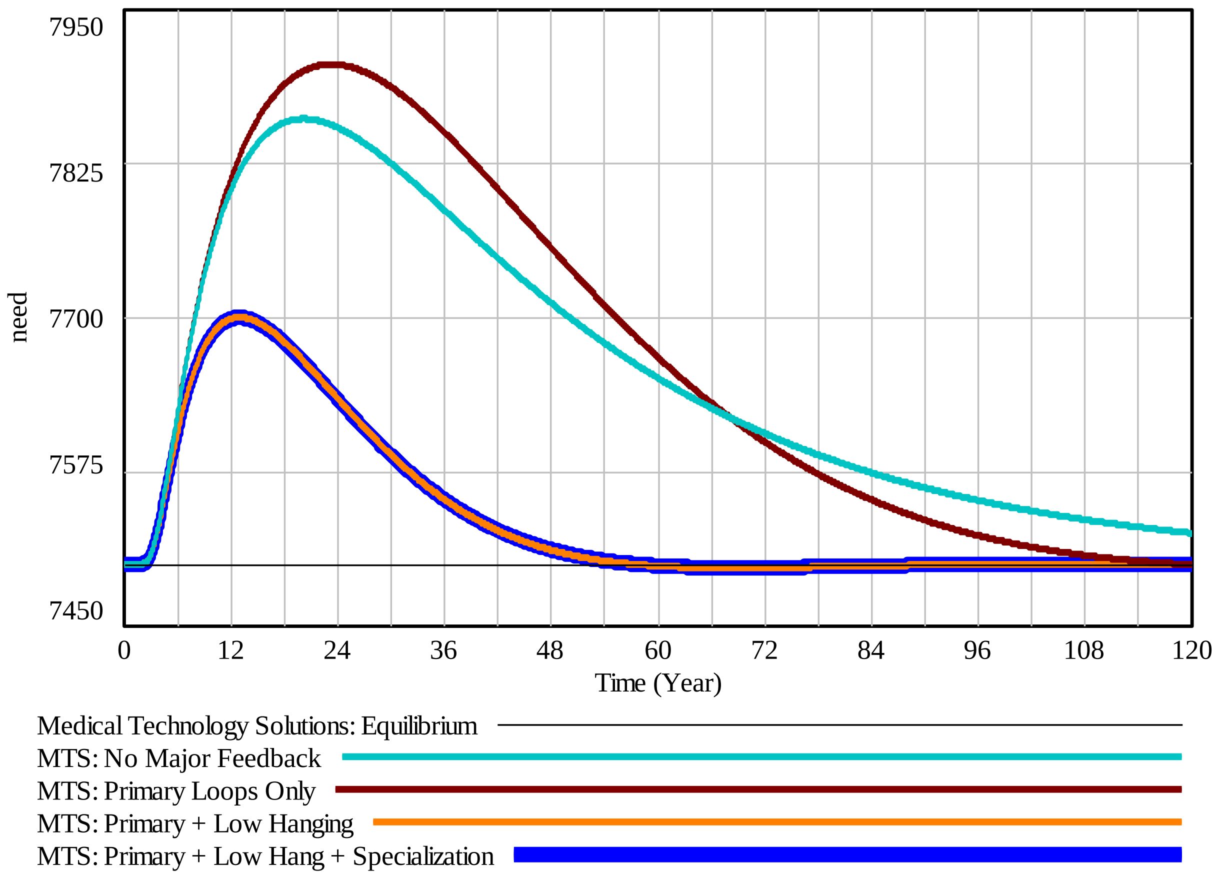

Figure 64: Graph of *Medical Technology Solutions,* runs 1 - 4

- Test 2: Primary Loops Only

In Test 2, the connection between *Cumulative Medical Technology Trend* has been reestablished, activating **R1** and **B1** loops (these labels technically represent three loops each, but the effect can be reasonably approximated as a reinforcing loop and a delayed balancing loop). In Figure 63 and Figure 64 this run is labeled "Primary Loops Only" and is colored brown.

- *Expectations:*

Due to the activation of the reinforcing feedback loop, *Medical Technology Solutions* should increase more than in Test 1. However, as *Lagged Research Dollar Resources* catches up to *Research Dollar Resources,* the new loops will virtually cancel each other out, resulting in temporary dominance of depreciation loop **B3**. Therefore, *MTS*[21] will once again return to its original equilibrium position.

- *Results:*

---

21 For the remainder of this module, *Medical Technology Solutions* and *MTS* will be used interchangeably.

As shown in Figure 64, *Medical Technology Solutions* indeed reaches a higher maximum in Run 2 ("Primary Loops Only") compared to Run 1 ("No Major Feedback"), and both eventually return to their original value, although Run 2 experiences mild damped oscillation. Note that Run 2 declines more rapidly; this is due to the new feedback loops accelerating the downward trend.

- Test 3: Adding Diminishing Returns

In this test, *unmet medical needs* is no longer a constant, although *Identified Medical Needs* is. This means that *unmet medical needs* decreases as *MTS* increases, activating loop **B4**. Thus, innovation becomes less efficient the larger *Medical Technology Solutions* is, representing a diminishing returns or "low hanging fruit" effect. This test run is labeled "Primary plus Low Hanging" and is orange in color.

- *Expectations:*

Because *innovation rate* is inversely proportional to unmet needs, this addition should curtail the growth in *MTS* compared to Run 2 ("Primary Loops Only"). As before, it should return to its original equilibrium value over time.

- *Results:*

As expected, the introduction of loop **B4** limits growth in *Medical Technology Solutions* quite severely compared to Run 2. As before, *MTS* returns to its original value via damped oscillation.

- Test 4: Adding Specialization

In this run, *market fraction affected by new tech* is no longer constant; instead, it decreases as *MTS* increases. As explained in the Summary section, this simulates the narrowed impact of average new innovation as the market becomes more saturated. Run 4 is labeled "Primary plus Low Hang plus Specialization" and is represented by a thick blue line in Figure 64.

- *Expectations:*

With *market fraction affected by new tech* free to adjust, an increase in *MTS* will cause a smaller increase in *trend in MTS* than in previous runs. This will dampen the effect of the **R1** feedback loop. Thus, *MTS* should peak lower in Run 4 than in Run 3 (Primary + Low Hanging Fruit).

- *Results:*

At the scale of Figure 64, the trajectories of Runs 3 and 4 are indistinguishable, but Run 4 in fact peaks slightly lower than Run 3; because of this, Run 4 also experiences slightly larger amplitude dampened oscillation.

- Test 5: Ramp and Exponential Inputs

To confirm that an exponential increase in *annual PO visits* is needed to keep *MTS* from returning to its original equilibrium value, the same active structure as in Test 4 was run twice more: once with a sustained ramp increase and once with an exponential increase in *annual PO visits*.

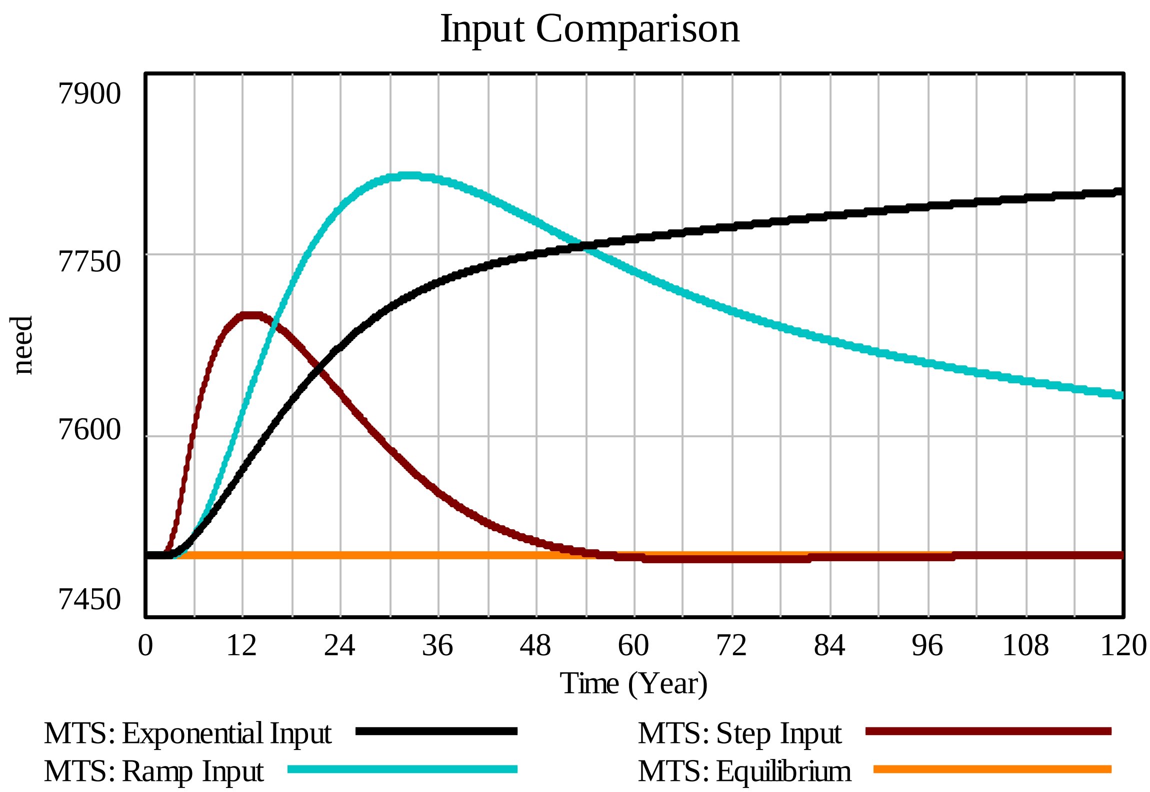

Figure 65: Comparison of input pattern effect on *Medical Technology Solutions*

- *Results:*

As shown in Figure 65, a constant ramp increase in *annual PO visits* is not sufficient to avoid decline in *MTS*. It takes a very long time (over 1000 years), but eventually it returns to the original equilibrium. An exponential input results in a monotonically increasing trend in *MTS*, but *MTS* nevertheless settles into a new equilibrium far below the value of *Identified Medical Needs*, which in these runs was 10,000. This is an important finding: in this model, constant exponential growth in *prescriptions written* causes *Medical Technology Solutions* to settle into an equilibrium where *unmet medical needs* is non-zero.

What happens when there is a **negative** ramp input? Figure 66 shows the results. *MTS* will decline as long as *prescriptions written* is positive and there is a sustained constant negative input change. As soon as the input levels out, however, *MTS* returns to the equilibrium value (see brown line). The exception is if *prescriptions written* reaches zero and stays there. Because this results in no prescription revenue, *Research Dollar Resources* (and consequently, *research dollar trend*) will also go to zero. With no innovation inflow, *MTS* will decay to zero (blue line).

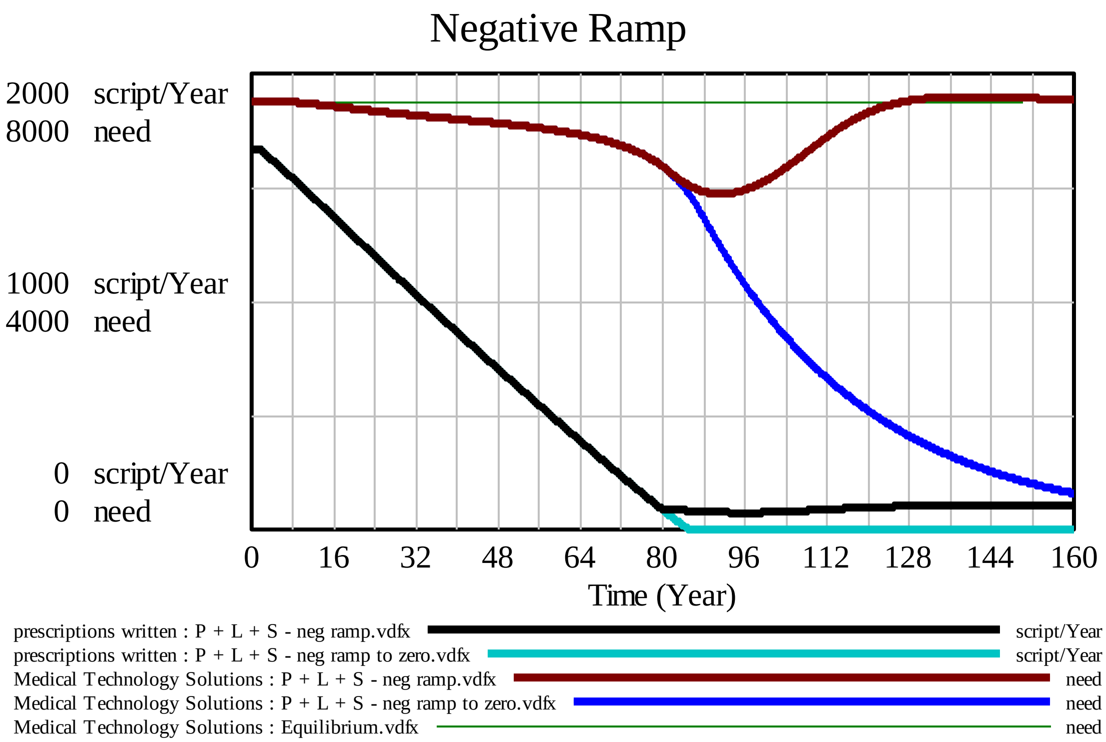

Figure 66: Effect of negative ramp input on *Medical Technology Solutions*

- Conclusion:

All expectations were confirmed – this sector operates according to its intended design with the very important caveat that the influential Needs Identification feedback loop cannot be active in an equilibrium scenario.

- **Recommendations and suggestions for further work:**

As mentioned above, it is not possible for the needs identification loop to be active while in an equilibrium-based policy testing mode; *Identified Medical Needs* must equal *max medical needs* for equilibrium behavior to be maintained. Clearly, this is not ideal, as this loop is an important contributor to the overall behavior of the sector. There are two general alternatives to address this issue. First, to redesign the sector in such a way that all loops can be active while maintaining equilibrium. The other option would be to choose not to initialize the model in equilibrium for policy testing, but rather to produce a base run that can be compared to policy-testing runs. This is not ideal either, as equilibrium initialization improves the ease of tracking policy effects. In any case, it is recommended that future users of this model seriously consider following one of these paths.

Other suggestions and research questions:

- Should absolute market size (rather than solely the trend) have an impact on innovation rate?
- Consider making *needs id rate* dependent on stock of *unmet medical needs.*
- Make *unidentified medical needs* an infinite source?

- Should the research fraction of revenues be variable?
- Jim Thompson originally envisioned separating pharmaceutical development into a complementary module. This could be a possible avenue for future expansion.(9)

- **Module: MMO Premiums**
- **Purpose:**

Tracks medical malpractice premiums by modeling the basic financial structure of medical malpractice insurers or organizations (MMO). When the model was constructed, malpractice premiums had been growing rapidly for several years and were thus a significant focus of efforts to forecast (and reduce) medical cost growth. This explains the detail devoted to this sector.

- **Uses:**
- MALPRACTICE PREMIUMS
- **Diagram:**

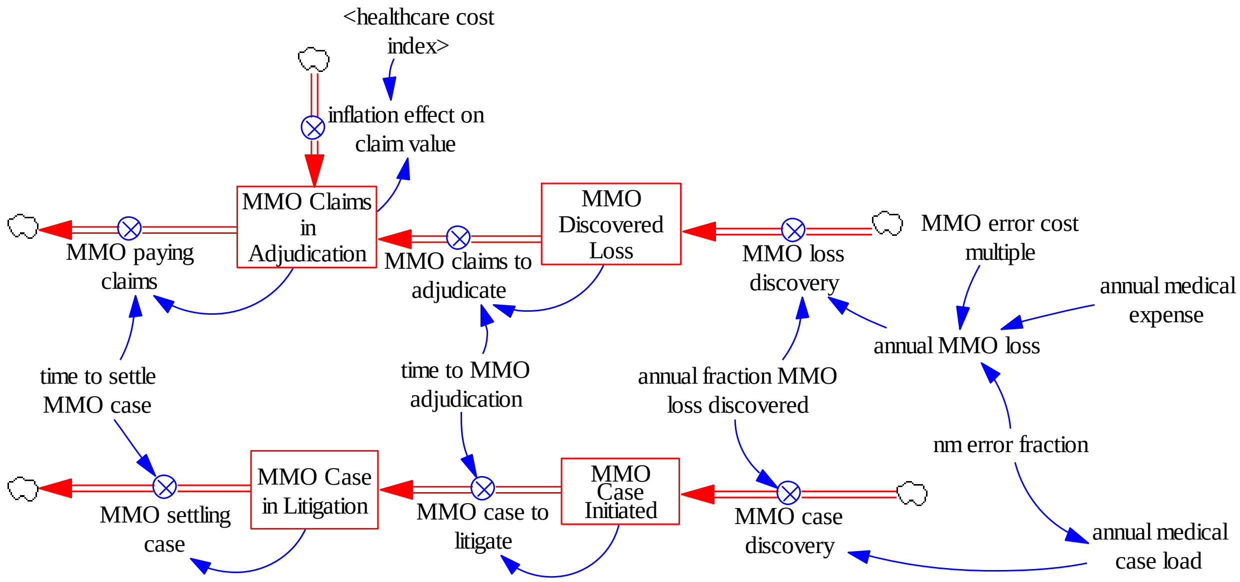

Figure 67: Diagram of part 1 of the MMO Premium module

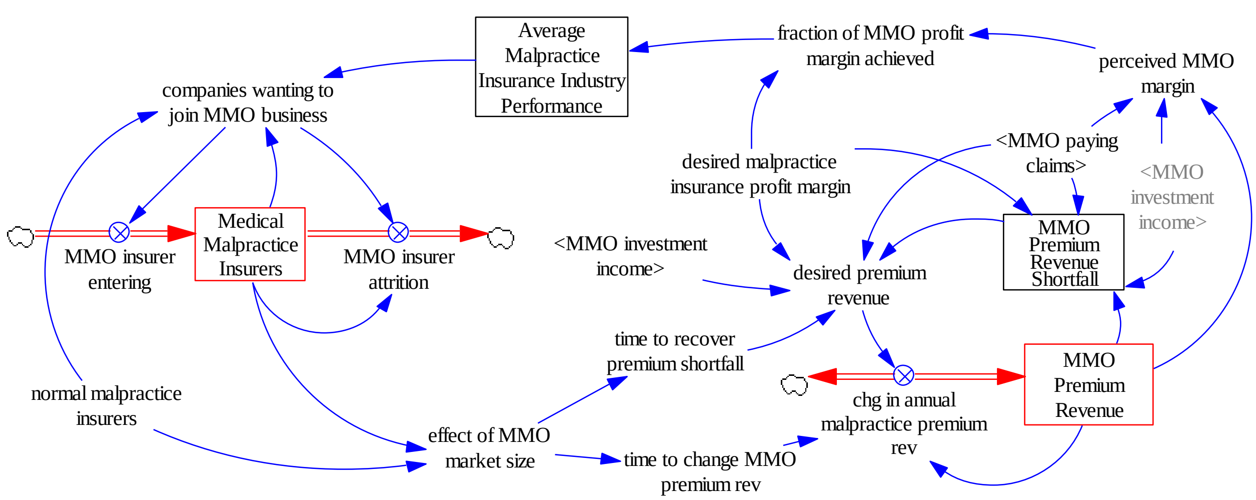

Figure 68: Diagram of part 2 of the MMO Premium module

- **Summary:**

In the model, malpractice claims are determined by the product of annual medical spending, the normal error fraction, and the error cost multiple. Because the model does not represent unsuccessful claims, the *nm error fraction* is the fraction of medical visits which result in <u>successful</u> malpractice suits.[22] *MMO error cost multiple* is the estimated ratio of the average claim value to the original visit cost. In other words, for every dollar's worth of negligent care, "*MMO error cost multiple"* dollars are claimed. Claim value is also modified by *healthcare cost index*, a measure of aggregate medical cost inflation, as measured by the aggregate*.* Furthermore, claims take time to be processed, adjudicated, and settled. The number of malpractice claims is also tracked (bottom chain in Figure 15), but only for the purpose of calculating the average claim value; for the purposes of MMO premium setting, only total claim value matters.

Malpractice insurers are assumed to set premium rates at a level which covers claim payments as well as a desired profit margin. Administrative costs are abstracted in claim payouts. Insurers also maintain an actuary reserve of invested assets which not only serves a cushion against a down period but also generates a return used to help fund operations. Because premiums cannot be changed instantaneously to account for shifts in claim payments, it is possible to have an imbalance between costs and income. Though claim payments can be covered by the actuary reserve, MMOs are assumed to attempt to recoup any cumulative shortfall by increasing future premiums. Conversely (despite the variable name), excess income reduces future premiums.

This sector includes a basic structure tracking the number of medical malpractice insurers. When MMO profits exceed targets, the industry becomes attractive and more players join. If profits are subpar, the opposite happens. Larger numbers of insurers increase the time required to adjust premiums and extends the desired time to recoup past revenue shortfalls. Smaller numbers do the opposite. When costs experience a sustained and premium revenue shortfalls appear, a decrease in *Medical Malpractice Insurers* allows premiums to adjust more quickly, narrowing the shortfall. When costs are decreasing, the increase in MMO numbers results in a slight larger profit margin as premiums take longer to fall.

- Decision Points:

---

22 Though this may seem like a major omission, especially given the relatively small percentage of malpractice claims settled in favor of the plaintiff, it is simply a calibration decision and does not change model behavior when compared to a structure where a fixed percentage of claims were dismissed. Modeling claim success rate endogenously would add considerable complexity in return for questionable gain.

- ***inflation effect on claim value –*** The purpose of this inflow to *MMO Claims in Adjudication* is unclear. It is equal to the product of that stock and *healthcare cost index*, the latter being the model's non-cumulative measure of aggregate healthcare cost inflation. However, the *annual medical expense* off which claim value is calculated already adjusts for this cost inflation. There are two possible purposes I can think of:
    - **1.** It is intended to model the growth of malpractice claim value *above* that of general medical cost inflation.
    - **2**. It simulates inflation during the delay between claim filing and payout.
- ***Average Malpractice Industry Performance*** – The smoothed ratio of the actual MMO profit margin to the desired margin.
- ***companies wanting to join MMO business –*** If the industry is performing well, more players want to join. Conversely, if it is doing poorly, some existing companies look to exit the market. The "desired" number of firms in the MMO market is the initial number of insurers (*normal malpractice insurers*) multiplied by the output of the lookup function *Malpractice Insurance Industry Performance f*, shown in graphical form in Figure 69. The input to the lookup function is *Average Malpractice Industry Performance*. *Companies wanting to join MMO business* takes the desired number and subtracts the current number. Thus, a positive value of this variable denotes an aggregate inflow of insurers, while a negative value signals an outflow.
    - The inflow and outflow to *Medical Malpractice Insurers*, *MMO insurer entering* and *MMO insurer attrition*, respectively, are controlled by IF THEN ELSE statements, and both cannot be active simultaneously.
    - As shown in Figure 69, the slope above one is much shallower than the slope below. This means that insurer numbers are much more sensitive to small decreases in aggregate industry performance than they are to small increases.

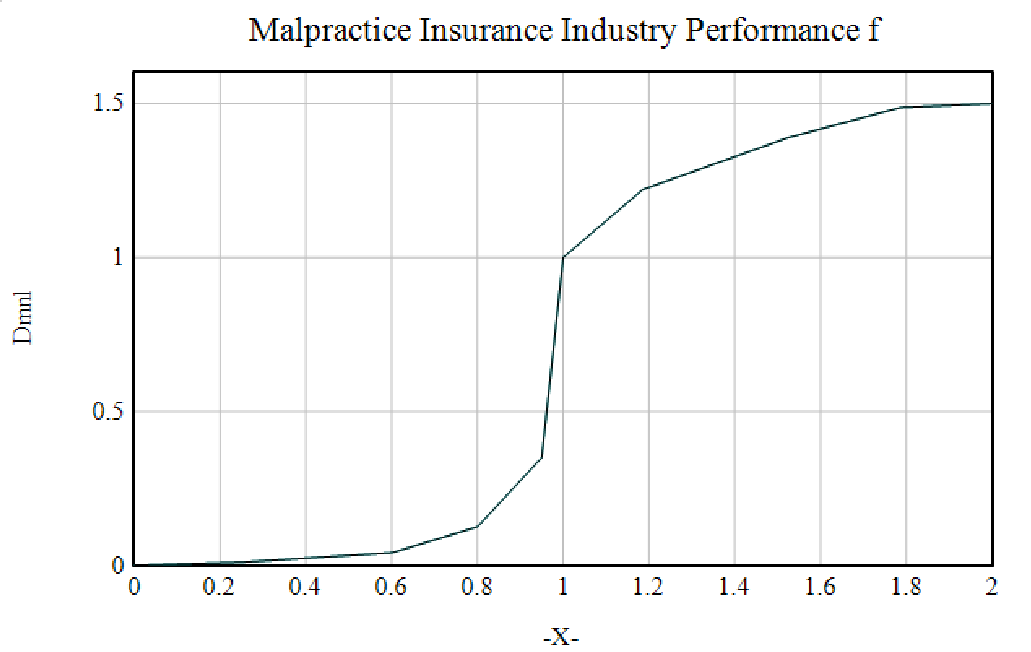

Figure 69: lookup function *Malpractice Insurance Industry Performance f*

- ***effect of MMO market size*** – The ratio of current to initial *Medical Malpractice Insurers*.
- ***time to recover premium shortfall –*** Insurers would like to recover a (1 / *time to recover premium shortfall*) fraction of *MMO Premium Revenue Shortfall* each year. This would generate exponential decay if there were no other influences. *Time to recover premium shortfall* is inversely proportional to *effect of MMO market size*. The reasoning for this relationship has been lost to time.
- ***time to change MMO premium rev –*** Insurer count is positively correlated to the adjustment time for *MMO premium revenue*. The relationship is determined by the *effect of market size f* lookup function shown in Figure 70. The input is *effect of MMO market size* and *time to change MMO premium rev* is the output.
    - There is a separately specified *min time to change MMO prem rev*

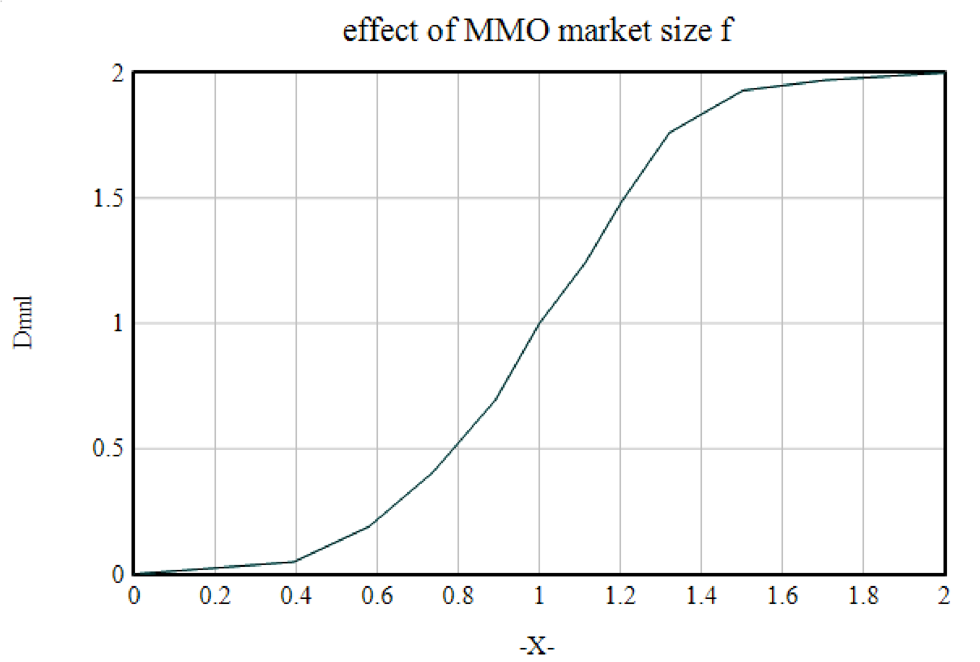

Figure 70: lookup function *effect of MMO market size f*

- **Inputs:**
- From other sectors:
- ***annual ER visits*** [PO VISIT RATE] }
- ***annual IP visits*** [PO VISIT RATE]
- ***annual OP visits*** [PO VISIT RATE]
- ***annual PO visits*** [PO VISIT RATE]
- ***ER Price*** [ER PRICE] **:** *annual medical expense*
- ***IP Price*** [IP PRICE]
- ***OP Price*** [OP PRICE]
- ***PO Price*** [PO PRICE]
- ***healthcare cost index*** [HEALTH CARE COST INDEX]: *inflation effect on claim value*
- ***MMO investment income*** [MALPRACTICE EQUITY]: *desired premium revenue* & *MMO Premium Revenue Shortfall* & *perceived MMO margin*

- Parameters & Exogenous inputs:

Variable Name	Value	Source	Notes
annual CPI U	Optional data input		Used in *MMO premium trend effect on price*
annual fraction MMO loss discovered	1	Calibration	Real-world meaning unclear (fails parameter verification test).
desired malpractice insurance profit margin	0.2		
min time to change MMO premium rev	0.5		
MMO error cost multiple	1000	JPT estimate	Ratio of claim value to original visit cost.
nm error fraction	8.5 * 10^(-6)		Fraction of care delivery resulting in a successful malpractice claim.
nm time to change MMO premium rev	2		
nm time to recover MMO premium rev shortfall	2		rev = revenue.
normal malpractice insurers	200		
potential malpractice case per visit	1		Multiplied by error fraction and visit totals to produce number of malpractice cases.
switch on malpractice effect	0 OR 1		0 = no malpractice effect
time to average MMO profit	2		Used in determining average industry performance.
time to enter MMO market	3		for insurers joining
time to exit MMO market	10		for insurers exiting

time to MMO adjudication	1	Average time to flow from *MMO Discovered Loss* to *MMO Claims in Adjudication.*
time to perceive MMO margin	10	Used in determining average industry performance.
time to perceive MMO premium trend effect on price	1	
time to perceive MMO premium trend effect on utilization	2	
time to settle MMO case	2	Average time to leave *MMO Claims in Adjudication* stock.

last updated 12/7/20

- **In Isolation:**
- For equilibrium:
- *Average Malpractice Insurance Industry Performance* [Initial] = *fraction of MMO profit margin achieved* = 1
- *healthcare cost index* = 0
- *Medical Malpractice Insurers* [Initial] = *normal malpractice insurers*
- *MMO Case in Litigation = annual fraction MMO loss discovered * annual medical case load * time to settle MMO case*
- *MMO Case Initiated = annual fraction MMO loss discovered * annual medical case load * time to MMO adjudication*
- *MMO Claims in Adjudication* [Initial] = *annual fraction MMO loss discovered * annual MMO loss * time to settle MMO case*
- *MMO Discovered Loss* [Initial] = *annual fraction MMO loss discovered * annual MMO loss * time to MMO adjudication*
- *MMO Premium Revenue* [Initial] = (1 + *desired malpractice insurance profit margin*) * *MMO paying claims – MMO investment income*
- *MMO Premium Revenue Shortfall* [Initial] = 0
- Test 1: *annual medical expense* step

Expectations: annual medical expense and *MMO Premium Revenue* will move in the same direction. Changes in *annual medical expense* represent changes in visit rates or prices. When this value increases, MMO claims will also increase, which, after a delay, will increase MMO payouts to claimants. Faced with rising costs, insurers must augment their income by raising premiums. Because there will be short-term losses, there may be a decrease in numbers of MMOs. In the "fixed MMI" runs, changes in the number of malpractice insurers have no effect on *time to recover premium shortfall* and *time to change MMO premium rev.*

- *Testing:*

annual medical expense = 500,000 + STEP(±100,000, 2)

- *Results:*

We will begin with the positive step in *annual medical expense*. Once the change propagates through to *MMO paying claims*, the combination of *MMO investment income* (which is fixed in these runs) and *MMO Premium Revenue* is insufficient to meet expenses, so the latter must increase. By the time premium revenue is sufficient to cover immediate expenses, a debt has accumulated in *MMO Premium Revenue Shortfall* (see Figure 47). As such, premiums continue to rise for a bit, then decline to their new equilibrium via damped oscillation as the shortfall is reduced to zero. The opposite process happens when *annual medical expense* declines.

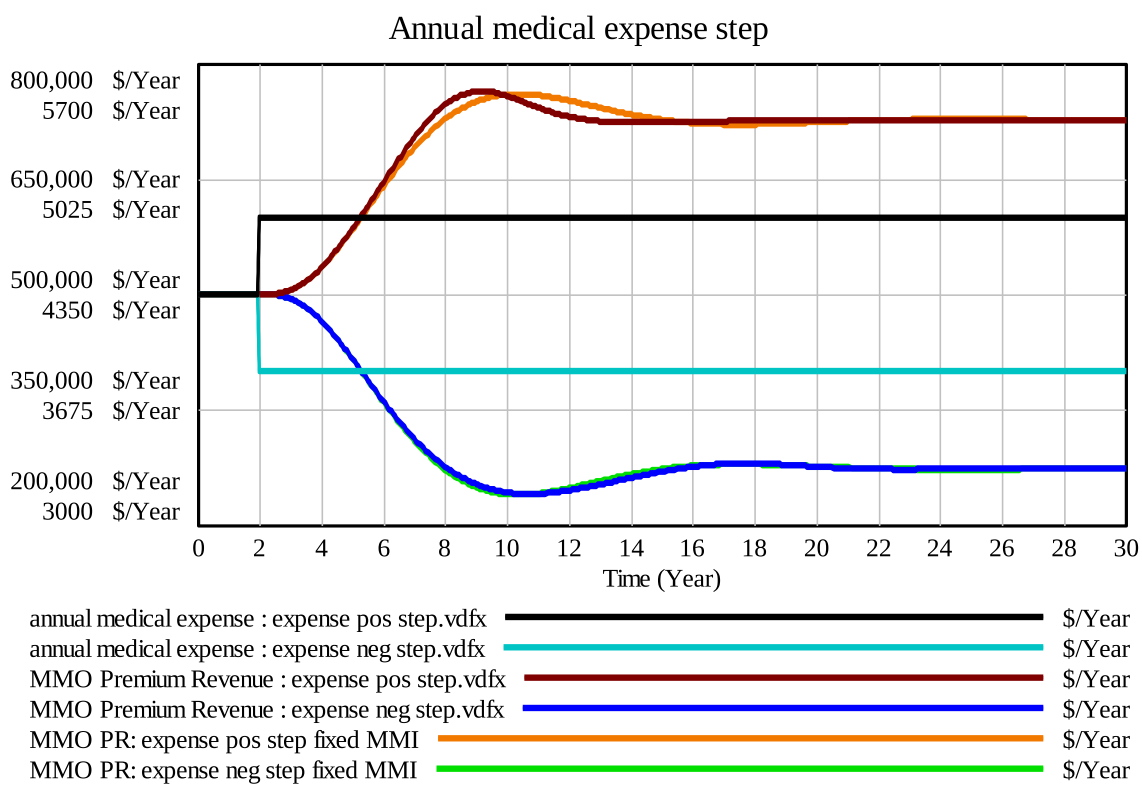

Figure 71: Effect of step changes in *annual medical expense* on *MMO Premium Revenue*

When claim costs increase, insurers initially cannot meet their targeted profit margins. As actors judge the industry to be less profitable, some insurers exit the market (see Figure 48). This reduces the premium adjustment time and also decreases *time to recover premium shortfall*; the aggregate effect is that insurers can increase premiums more rapidly than in the “fixed MMI run,” where these variables are constant. This results in a smaller peak shortfall and a quicker recovery, evident in Figure 71 and Figure 47.

In response to a fall in claims costs, insurers initially extract higher-than-normal profits, attracting more companies to the market. This increases premium adjustment time and lengthens the shortfall recovery (in this case, actually the surplus payback) horizon, leading to a slightly lower trough in *MMO Premium Revenue Shortfall* and slightly more pronounced oscillation in the variable MMI run. The difference between the variable and fixed MMI runs is much more noticeable with the positive step. This is due to the variable slope of the *effect of MMO market size f* lookup function used to determine *time to change MMO premium rev* (see Figure 70). Firms are modeled as being most sensitive to poor industry performance.

Also interesting to note is that the number of malpractice insurers drops just as low in the negative step run as in the positive step run, though it happens later in the simulation. The reason is that the industry performance calculations do not consider the *MMO Premium Revenue Shortfall.* When insurers are using their accumulated surplus to lower premiums, they are not meeting the desired margins, so companies want to exit the industry.

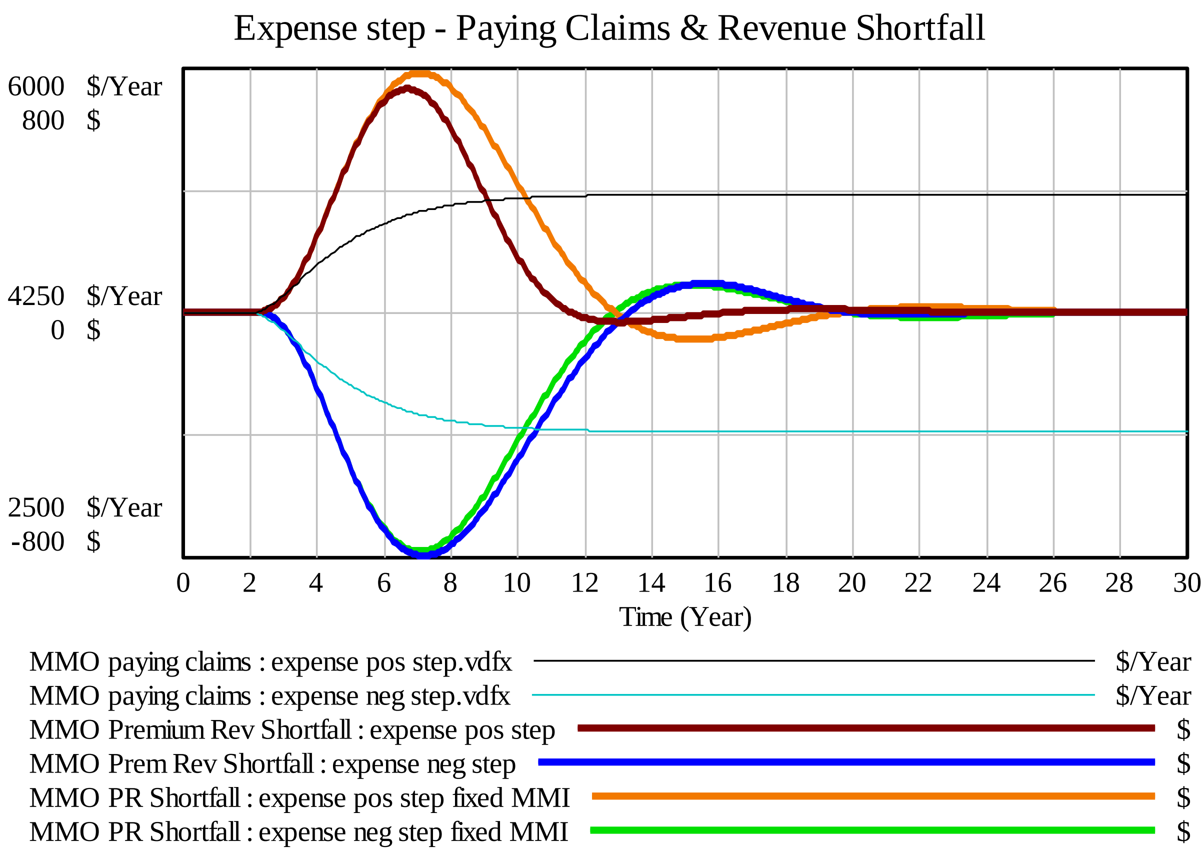

Figure 72: Effect of step changes in annual medical expense on MMO paying claims and MMO Premium Revenue Shortfall

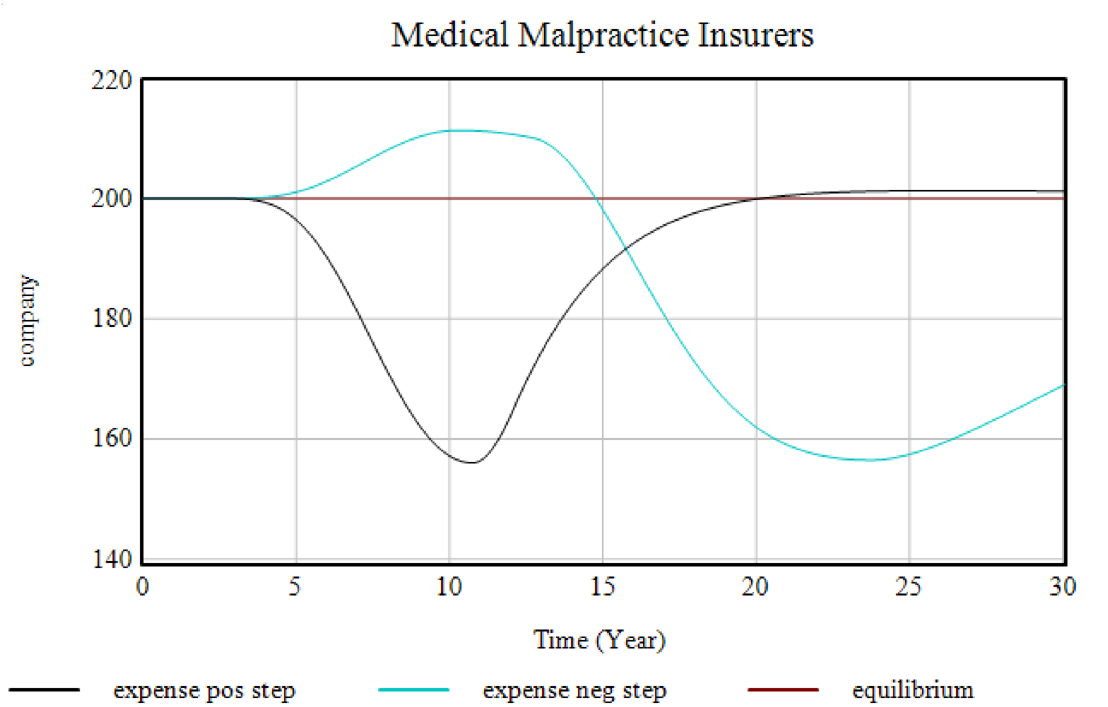

Figure 73: Effect of step changes in *annual medical expenses* on *Medical Malpractice Insurers*

- Test 2: *annual medical expense ramp*

This test demonstrates the potential for the sector to exhibit steady state error when faced with a sustained increasing input, whether linear or exponential.

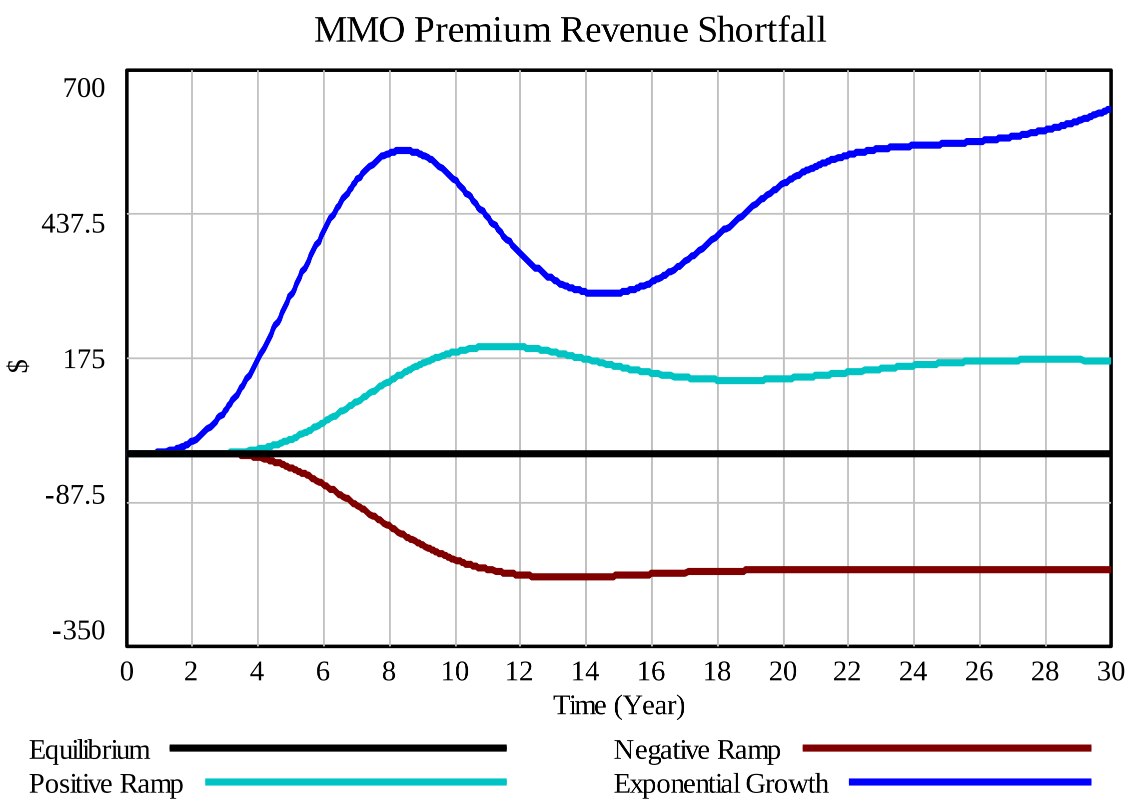

Figure 74: *MMO Premium Revenue Shortfall* under various input types

Figure 74 shows the *MMO Premium Revenue Shortfall* (not the *MMO Premium Revenue*) in response to ramp and exponential changes in *annual medical expense*. With both positive and negative ramp inputs, the shortfall settles into a non-zero equilibrium. Because the shortfall is the gap between actual and desired premium revenue, this is steady state error.

- Test 3: *healthcare cost index*

Expectations: Like *annual medical expense*, healthcare cost index affects claims payouts. The important difference is that *healthcare cost index* modifies the *inflation effect on claim value* flow into *MMO Claims in Adjudication*. This stock-flow pair forms a reinforcing loop which competes with the *MMO paying claims – MMO Claims in Adjudication* balancing loop. If *healthcare cost index* is less than 1 / *time to settle MMO case* (including if it is negative), the balancing loop will dominate and growth will be asymptotic. If greater than that value, growth will be exponential.

Testing:

healthcare cost index = STEP(0.1, 2) + STEP(0.1, 12)

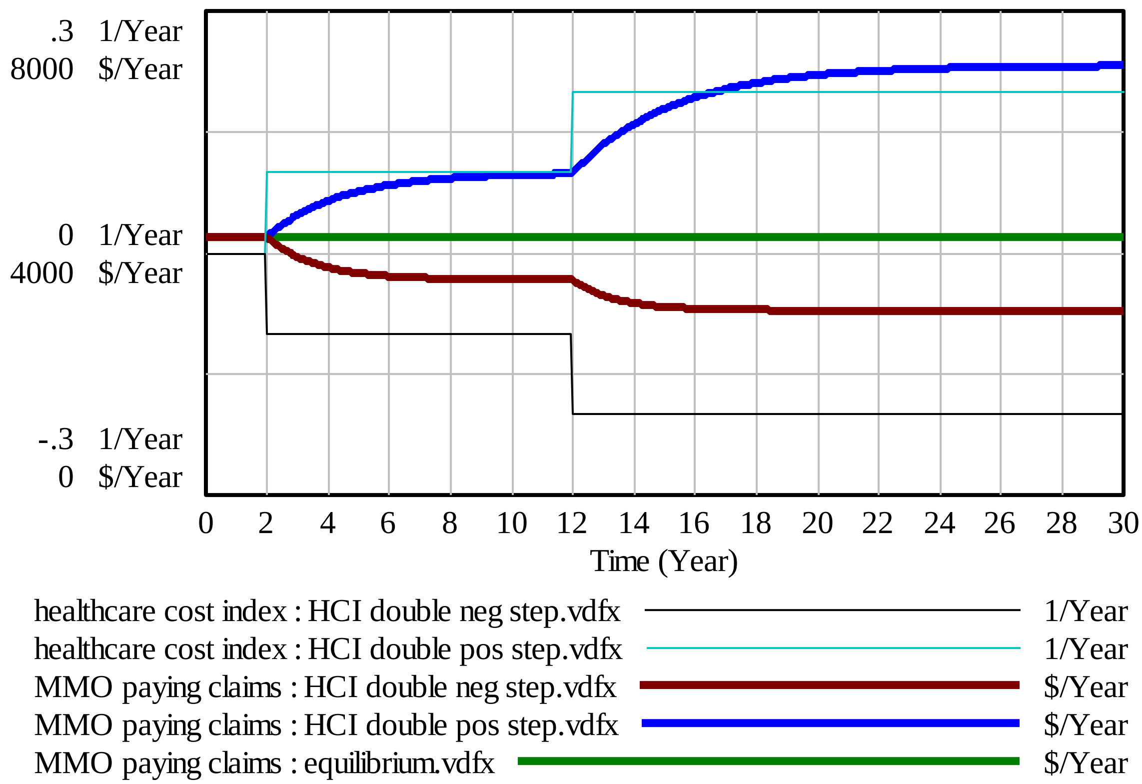

Figure 75: Effect of double step changes in *healthcare cost index* on *MMO paying claims*

Results:

Healthcare cost index is the averaged trend in aggregate healthcare costs, with a value of 0.1 representing a 10% yearly increasing trend. However, a step increase in the index from 0 to 0.1 causes a nearly 25% jump in claims costs, while an increase in the index from 0.1 to 0.2 (10% to 20% annual growth), there is an increase of over 30%, for a cumulative increase of over 65%. The corresponding values for step decreases in the cost index are 16%, 15%, and 29%. The discrepancy between the change in index and the change in claim value is due to the reinforcing loop between *Inflation effect on claim value* and *MMO Claims in Adjudication*.

- Conclusion:

The sector fulfills its main objectives, but there are a few areas which need some revision.

- **Recommendations and suggestions for further work:**

- *MMO premium revenue trend* is currently *chg MMO premium revenue / MMO Premium Revenue*. Consider replacing the denominator with the initial value of *MMO Premium Revenue*. Currently, a change in MMO premiums from 2% to 1% of physician costs has the same effect on PO price as a change from 10% to 5%. Making the denominator constant would mean that the trend is based off absolute rather than relative changes. The true effect is likely somewhere between the two extremes, so this is a modeler's judgement call. (2)

- Address the possibility for steady-state error when *annual medical expense* is growing exponentially. (4)
- *MMO premium trend effect on utilization* and *MMO premium trend effect on price*, along with their accessory variables, may be better suited in the utilization and price sectors, respectively. (1)
- Even though profit margins influence the number of malpractice insurers, there are no actual profits in the model: all excess income is used to decrease future premiums. Whether this is an issue likely depends on the purpose of the modeling project and the importance of the malpractice sector.
- Accumulated shortfall not factoring into industry performance calculations causes some questionable behavior. When insurers are using their accumulated surplus to lower premiums, they are not meeting the desired margins, so companies want to exit the industry. On the other hand, when revenue is greater than claim cost plus desired premiums, companies want to join, even though the "extra" revenue is being used to pay down a cumulative shortfall. This merits investigations.
- Examine real-world malpractice claim behavior to see if there is justification for the separate *inflation effect on claim value*.

- **Module: MMO Equity**
- **Purpose:**

The MMO Equity tracks the value of assets in the MMO Actuary Reserve and the income derived from those assets.

- **Uses:**
- MMO EQUITY
- **Diagram:**

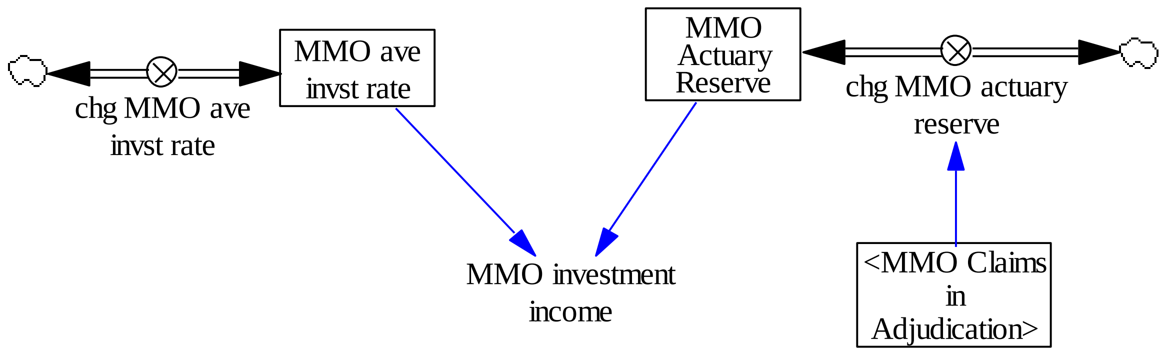

Figure 76: Diagram of the basic structure of the MMO Equity module.

- **Summary:**

Like other types of insurers, malpractice insurers must maintain a reserve in case of claim costs exceeding premium income over a certain period of time. Though they can make up the loss by raising future premiums, they need an immediate source for paying the claims. In many places, governments require malpractice insurers to keep a certain fraction of annual costs in a reserve. In the model, the target value of the actuary reserve is one year's worth of claims value. A notable simplification is that the money going in (or out) of the actuary reserve does not have to come from (or go) anywhere; *MMO Actuary Reserve* simply adjusts over time to equal *MMO Claims in Adjudication*.

Though the interest rate is set as a constant for equilibrium-based runs, it can be set up to be driven using historical data or another type of input..

- **Model Inputs:**
- From other sectors:
- ***MMO Claims in Adjudication*** [MMO PREMIUM]: *indicated change in MMO actuary reserve*
- Parameters & Exogenous inputs:

Variable Name	Value	Source	Notes

ave hist MMO invst rate	0.06	Calibration	The sector is currently structured such that this parameter provides the constant investment rate.
time to return to ave MMO invst rate	2.5		Currently unused. Intended to smooth transition between data input and constant when making future predictions (i.e. no further data available)
time to adjust MMO actuary reserve	2		
Last Updated 12/7/20			

- **In Isolation:**
- For equilibrium:
- *MMO Actuary Reserve = MMO Claims in Adjudication*
- *MMO ave invst rate = ave hist MMO invst rate*
- Conclusion:

This sector fulfills its intended purpose adequately, but there are important improvements that can be made.

- **Recommendations and suggestions for further work:**
- Consider linking changes in the actuary reserve to the rest of the MMO budget in the MMO PREMIUM module. Currently, an increase in claim costs will "magically" increase *MMO Actuary Reserve* (and thus investment income) at the same time as the MMOs are losing money. (3)

- **Module: MCO Premium**

Placeholder.