Modeling the future of the Canadian Cardiac Surgery Workforce using System Dynamics

INTRODUCTION

Concerns over the sustainability of the health care system in Canada have emphasized the need to ensure adequate health human resources (HHR) are available to support the system. Advance planning of HHR training is vital to ensuring there are sufficient providers to meet the needs of the population in the future. Although succession and workforce planning are important in many sectors, characteristics of the health care sector render it even more critical, particularly among highly specialized professions, as the specific knowledge and skills required limit the availability of alternative providers and increase the training requirements. With education programs requiring more than 10 years and barriers inhibiting the entry of international medical graduates (IMGs), the system cannot respond quickly to changing provider requirements. Recovery from provider shortages is slow and painful, resulting in lengthy wait times and/or inadequate care. Yet an over-supply of providers is also undesirable from the perspective of both unemployed providers and broader society, as the lengthy training process is significantly subsidized by the government. To avoid these situations, government, academic and professional bodies are turning to HHR planning models.

Determining HHR requirements in the future is non-trivial and the resulting predictions can be fickle, as noted in a recent editorial (Canadian Medical Association Journal, 2004), and no ideal method or model has yet been developed. In the past, many HHR planning models relied upon provider-to-population ratios, projecting the number of providers needed based on population projections (Al-Jarallah, et al., 2010). Yet this assumes that the ideal provider-to-population ratio can be determined, and in its simplest form, neglects the effect population demography may have

on provider requirements, hence this approach is largely considered inadequate and more sophisticated models are needed.

This paper presents a system dynamics (SD) model developed to simulate the workforce within a single specialty at a national level. SD is a continuous time modeling approach which simulates the flow of cohorts through various stages over time. The model is intended as a tool to give health care providers, students and external stakeholders insights into the effect time, population demographics, enrolment and productivity decisions have on the system. To do this, it includes both the demand and supply components; the former is determined based on the demographic composition of the population, while the latter incorporates both currently practicing providers and those in training, as well as the current and anticipated productivity of each. This model does not provide the optimal enrolment level, or provider population size; rather it provides a tool by which numerous "what-if" scenarios can be explored and long-term effects understood.

The impetus for this research was growing concern among senior cardiac surgeons as they observed a connection between declining specialty enrolment rates and a scarcity of full-time employment positions for new graduates. The current saturation of the cardiac surgery market and lack of job opportunities appears to be deterring medical students from pursuing the specialty. Although this may appear to be an ideal supply-demand response, the 10 to 12 year training process in this specialty means that enrolment decisions made now ought to be made with a view of what the need and demand for surgeons will be in a decade. Currently, with no clear indication of what the employment environment will be when they complete their training, students are making specialty selections based on the present situation. This model is intended to be a tool by which this can be ameliorated by providing a means of demonstrating possible future

situations, enabling those in the system to make more informed decisions. Although this paper presents a case study of the cardiac surgeon workforce, the general method is applicable to other specialties with HHR planning concerns.

Cardiac Surgery Background

Cardiac surgeons perform a variety of procedures, however historically the dominant procedure has been coronary artery bypass grafts (CABG). In recent years technology improvements, such as drug-eluding stents, and the increased use of non-surgical techniques, such as percutaneous coronary interventions (PCI), have decreased the need for surgical procedures and cardiac surgeons by extension (Sibbald, 2005). Since 2002, the number of CABG procedures performed annually in Ontario has been decreasing, with a total decrease of 10.57% between 2002/2003 and 2007/2008 (Figure 1), while rates of other procedures performed by cardiac surgeons have been rising. The combined demand has remained quite consistent, yet has not been enough to prevent a surplus of surgeons from developing.

The need for CABG or other "non-CABG" surgical cardiac procedures vary by age and gender (Figure 2). Per-capita rates are higher among males, and are highest among those over the age of 65. For both genders, per-capita rates for CABG peak among those aged 65-74, while the rates for non-CABG procedures increase with age. Hence, as the "baby boomer" generation ages and the demographics of the Canadian population shifts toward an increasingly senior population, overall demand for surgical interventions may increase despite decreasing per-capita surgical rates.

At present, the need for cardiac surgery is met by just over 150 licensed, clinically active surgeons across Canada. Of these, 43% are age 50 or older (Figure 3). Surgeons enter practice

after completing residency training programs offered at Canadian universities. Cardiac surgery trainees are currently distributed among twelve universities, with eleven funded residency positions available annually. There are no funded IMG residency positions. The training program consists of six or seven stages, varying by province, one of which is an academic enrichment stage during which trainees may pursue a postgraduate degree requiring several years of study. Many surgeons then complete one or two years of fellowships prior to obtaining full-time employment. Hence, the training process typically requires at least 10 years.

Recent years have seen more surgeons entering the workforce than the number of available positions. The prospect of unemployment has resulted in declining enrolment in the specialty, leaving residency positions vacant and, correspondingly, calls to reduce residency positions (Sibbald, 2005). Such a response by students is not surprising given the significant time and financial investments involved with the educational process. However, the lengthy education process also means that the current situation may not be representative of the employment environment current trainees will experience upon completion, as the aging of both the general population and the current cardiac surgeon workforce may significantly affect the need for cardiac surgery and the workforce available to supply it.

THE MODEL

Key goals of this model were to demonstrate the effects providers' workload decisions and unemployed or surplus providers have on the system in the future. To capture these feedback loops and the dynamic nature of the system, the model was developed using system dynamics. Other methods that have been employed to develop HHR planning models, including stochastic (Martel and Price, 1981), dynamic (Rao, 1990), and linear (Lavieri and Puterman, 2009)

programming, and "spreadsheet" modeling(Starkiene et al., 2005), lacked this capability. SD has previously been used to analyze the need for nurses in Atlantic Canada(Med-Emerg, 2005), physicians in Canada (Basu and Gupta, 2005) and China (Song and Rathwell, 1993), and more recently, the need for nurses in Canada (Tomblin-Murphy et al., 2009). These models, founded on components similar to those in the model presented here, typically involve projections of two key populations, the providers and the general population. The relationship between these can be as simple as determining the number of providers needed to meet a target provider-per-capita ratio, as in the Chinese model, or relating the demand for care generated by the population to a productivity level of providers, either through the typical equivalency to a full-time provider, or average annual care provision, such as the annual number of patient visits per provider. Within these models, provider workload is typically assumed to remain constant over time.

The model presented here includes both the provider supply and population demand components, but is unique because it incorporates feedback loops which capture the effect provider shortages have on provider productivity and unemployed graduates have on program enrollment. Since provider's behaviour in the presence of unmet need is driven by several factors, particularly when newly graduated unemployed providers are present in the system, we have modeled two extreme points on the spectrum. At one extreme, we pose the "Financially Driven" model, in which providers will increase their productivity as much as possible to meet unmet need regardless of whether there are unemployed providers available. At the other extreme, we present the "Altruistic" model, within which providers only increase their productivity level to meet unmet need if there are no unemployed graduates in the system. As the true case likely falls between these two extremes, the impact of each model can be weighted for interim results. The amount by which providers alter their productivity level is based on an assumed relationship, as

is the effect unemployed graduates have on program enrollment. In both, the impact each influencing factor has on the associated value can be altered by changing the weighting value. The sensitivity of the outcomes to these weighting values is presented in the case study. The model developed is maintainable and users can re-execute the model to obtain updated projections as more data becomes available or as the situation changes.

Our goal was to develop a tool which can be used to explore the effect enrolment, provider workload, demand rates and population demographics have on the future need for and supply of medical providers in Canada within a specialty. The model does not address geographical distribution, but rather examines both supply and demand nationally.

MODEL STRUCTURE

The model is composed of five modules as depicted in Figure 4. The Demand Module projects the number of cases of different procedures arising from the population every year. The Student Population Module simulates trainees as they transition between residency stages over time from entry into the specialty through the fellowship stage. The Provider Population Module simulates surgeons as they age over time, from entry into practice until retirement or departure. The Clinical Productivity Module projects the total surgical capacity yielded by the provider population based on the average clinical productivity among surgeons. The Demand-Supply Gap is then obtained from the comparison between the total demand and capacity; with gap size then affecting provider productivity.

Demand Module The model determines the total demand, $D(t)$ given the input D_{ijk} for each procedure type, i, based on the per-capita surgical rates for each gender, j, in 5-year age cohorts, k and the projected Canadian population. The population projections, P, for each year, t, were

imported into the model using Statistics Canada's population forecasts, hence no aging flow is needed. The sum of all procedures required for all populations produce the total demand in any year, $D(t)$.

$$D(t) = \sum_i \sum_j \sum_k D_{ijk} * P_{jk}^t$$

Equation 1

Student Population Module The stages of the training program are modeled via eight stocks, one for each of seven residency years (R-1 to R-7), and one for Fellowship (denoted here as R-8). Students primarily enter the system through entry into the R-1 stock, however inflows into R-2 to R-5 capture mid-process entries which occur if students switch specialties. Similarly, student attritions prior to graduation were included via outflows from stages R-1 to R-6. Both the mid-process arrival and departure rates were modeled as constants, whereas the R-1 entry rate (I_1) is based on a feedback loop. After the initial, user-defined value,$I_1(0)$, this loop varies the R-1 entry in response to the presence of unemployed providers in the New Graduates stock, simulating how the presence of unemployed providers deters students from entering the training program. The strength of this effect is subject to the weighting factor, $0 \leq w^e \leq 1$. This was modeled under the assumption that students assess the prospects of the program based on the number of unemployed graduates, (U), compared to the number of training program positions (v):

$$I_1(t) = \begin{cases} v - w^e U(t), & U(t) \leq v/w^e \\ 0, & otherwise \end{cases}$$

Equation 2

Where,

$$U(t) = \begin{cases} G(t) - NPS(t), & G(t) > NPS(t) \\ 0, & G(t) \leq NPS(t) \end{cases}$$

Equation 3

And *G* represents the number of graduates in the "New Graduates" stock, and *NPS(t)* the net provider shortage at time *t*.

Among trainees completing each stage, the rate of outflow, $Opass$, from a given stage, n, between stages depends on the level of the stock, or the number of trainees in the stage, *R*, and the duration of each stage, *d*. Due to the differing training program durations, students may flow from R-6 to R-7 then to Fellowship or flow directly to Fellowship, depending on the probability of graduating after R-6, $pgrad$, hence R-6 has an additional outflow, $Oearlygrad$, that bypasses R-7.

$$Opass_n(t) = \begin{cases} \frac{R_n(t)}{d_n}, & n = 1, \dots 5, 7, 8 \\ (1 - pgrad) * \frac{R_n(t)}{d_n}, & n = 6 \end{cases}$$

Equation 4

$$Oearlygrad(t) = pgrad\left(\frac{R_6(t)}{d_6}\right)$$

Equation 5

After departing the Fellowship stage, students flow to the New Graduates stock. Outflow from this stock ($Ograd$) only occurs in response to a provider shortage (PS), as follows:

$$Ograd(t) = \begin{cases} 0, & PS(t) \leq 0 \\ G(t), & PS(t) > 0 \; and \; PS(t) \geq G(t) \\ PS(t), & PS(t) > 0 \; and \; PS(t) < G(t) \end{cases}$$

Equation 6

Provider Population Module The flow of providers through the system is modeled via seven age stocks, six representing 5-year age cohorts (35-39,. . ., 60-64), and last encompassing 2 years (age 65-66). Two outflows are included from each age stock, modeling those who continue in practice and flow to the next age stock, $Oage_a$, and those who cease clinical activity, $Oexit_a$. The annual exit rate for those ceasing clinical activity depends on the probability, $pexit_a$, the number of providers in the stock, S_a and the duration of the age stage, d_a.

$$Oexit_a(t) = pexit_a S_a(t)/d_a, \qquad a = 1, \dots, 7$$

Equation 7

Similar to the student flow, the transition rate from one age stock to the next depends on the stock level and the duration, less the proportion that exit

$$Oage_a(t) = (1 - pexit_a) S_a(t)/d_a, \qquad a = 1, \dots, 7$$

Equation 8

Clinical Productivity Module Projecting the number of procedures that could be completed by the provider population annually, this module contains one stock, the Clinical Productivity Level (CPL), representing the average annual per-surgeon case load. This assumes the annual caseload is independent of provider age. The level of the CPL stock varies in response to changes in the Demand-Supply Gap. This feedback loop incorporates two assumptions. First, productivity is bounded by maximum (CPL^U)and minimum levels(CPL^L). Second, that there is a limit to how much the CPL can change in one year. The strength of this feedback is controlled by the weighting factor, w^p. The inflow, $Icpl$, to the CPL stock is thus determined by the following algorithm:

$$Icpl(t) = \begin{cases} 0, & Gap(t) < 0 \\ c(t), & Gap(t) \geq 0 \; and \; CPL(t) + c(t) \leq CPL^U \\ CPL^U - CPL(t), & Gap(t) \geq 0 \; and \; CPL(t) + c(t) > CPL^U \end{cases}$$

Equation 9

Where,

$$c(t) = \frac{w^p Gap(t)}{\sum_a S_a(t)}$$

Equation 10

In the Altruistic Model, this only occurs when there are no unemployed providers in the system, or $NPS(t) > 0$. When $NPS(t) \leq 0, Icpl(t) = 0$.

In the Financial Model, the CPL does not decrease, whereas in the Altruistic Model, the outflow of the CPL stock, $Ocpl$, is calculated as follows:

$$Ocpl(t) = \begin{cases} 0, & Gap(t) \geq 0 \\ CPL(t) - CPL^L, & Gap(t) < 0 \; and \; CPL(t) + c(t) < CPL^L \\ c(t), & Gap(t) < 0 \; and \; CPL(t) + c(t) \geq CPL^L \end{cases}$$

Equation 11

Demand-Supply Gap The difference between the total annual clinical capacity and the demand yield the Demand-Supply Gap:

$$Gap(t) = D(t) - \sum_a CPL(t) * S_a(t)$$

Equation 12

Using the average CPL, the gap is converted to a provider head-count providing the overall provider shortage level (PS), which is used to determine the number of graduates hired (Equation 6):

$$PS(t) = \frac{Gap(t)}{CPL(t)}$$

Equation 13

The Net Provider Shortage, NPS, then reflects the shortage remaining after available graduates have been hired, calculated as the Provider Shortage less the number of new surgeons entering the provider pool:

$$NPS(t) = PS(t) - Ograd(t)$$

Equation 14

Hence, a negative NPS indicates an oversupply of providers, while a positive value indicates a shortage.

IMPLEMENTATION

This model was developed using Vensim Professional32 version 5.2a (Ventana Systems Inc., Harvard MA) and has been applied to the Canadian cardiac surgery workforce system. A time step of 0.125 years was used to simulate 2008 to 2030. The data used to populate the model, shown in Table 1, were obtained from Statistics Canada (population projections and Ontario census data), the Cardiac Care Network of Ontario (historic annual case completion rates), a survey of recent training program graduates (training program details), the Canadian Post-M.D. Education Registry (current resident enrolment) and a survey of the department heads of all cardiac centers in Canada (current provider statistics). This latter survey provided the ages of 137 of the 152 clinically active surgeons; the remaining surgeons were distributed proportionally among the age cohorts.

Where data was unavailable, expert opinion, obtained from members of the Canadian Society of Cardiac Surgeons (CSCS) executive, provided estimates and assumptions. Specifically, it was assumed that:

- the academic enrichment year occurs in stage R-4;
- there is one mid-process entry into the training system and one mid-process departure annually, which may occur in any of the appropriate stages with equal probability;
- one percent of the providers depart the system annually from each age cohort under the age of 55, after which departure rates increased with age;
- per-capita surgical rates in Ontario are representative of national rates.

These assumptions and the data presented provided the "base case", in addition to which several scenarios were simulated to ascertain the effect various factors have on the system. These included varying the population projections, the CPL upper limit, and the CABG demand rates, as shown in Table 2. Figures 5 and 6 present the scenario results in terms of three key outcomes measures, the Net Provider Shortage, the number of available, unemployed graduates, and the R-1 enrolment rate.

Sensitivity Analysis

In the base case, the value of both weight variables, w^e and w^p, were assumed to be 0.5. The sensitivity of the model outcomes to these values was assessed by varying their values to 0, 0.25, 0.75 and 1.0. The effects of these changes on the net provider shortage in the final year are shown in Figure 7. The Financial Model outcomes were more sensitive to the different weightings. The effect of changes to w^e has a greater impact on the outcomes in both models.

DISSEMINATION

The results of an early version of this model were presented at the 2008 Canadian Cardiovascular Congress (CCC) within the CSCS post-graduate course session. The audience, comprised of cardiac surgeons, fellows and residents, provided excellent feedback which led to further data collection and model refinements. The results of the final model were presented at the CCC the following year. The audience confirmed the results were reflective of the current situation and the future outcomes appear reasonable. Additionally, the presentation of the scenario results incited significant discussion among the audience, as the results indicate that the future cardiac surgery workforce situation is significantly affected by the decisions trainees and surgeons make now, and proved to be a useful tool for communicating these effects to everyone involved. The model results were published in the Annals of Thoracic Surgery to disseminate the results to a broader audience (Vanderby et al., 2010).

DISCUSSION

HHR modeling is neither a simple endeavor nor an exact science, and history has shown that incorrect projections can have significant repercussions. However, as the sustainability of the health care system comes under scrutiny HHR planning efforts are being viewed as increasingly important, despite their inherent uncertainty (Cesa and Larente, 2004). With an awareness of the importance and implications of research in this area, models are becoming increasingly complex and adopt a systems-wide perspective. This is in part a response to the realization that the system is dynamic and health provider requirements depend on more than just the demographics and size of the population. In particular, it cannot be assumed that provider utilization rates are ideal or that they will remain unchanged in the future. Among providers, it cannot be assumed that clinical productivity levels will remain constant. The inherent uncertainty, complexity and

interconnectedness of HHR workforce systems have led to the use of SD for the development of several HHR planning models. As demonstrated here, SD models also enable the rapid simulation of various "what-if" scenarios, which is highly beneficial given the numerous factors which may affect the system.

When applied to the Canadian cardiac surgery workforce, the model results indicate that future net shortages are likely to occur under the scenarios tested, however, both the magnitude of the shortage and the number of unemployed graduates in the system were greatly affected by the workload decision paradigm. Under the Financial Model, in which practicing surgeons maximize their workload regardless of whether unemployed surgeons exist in the system, by 2030 the results indicate a shortage of 50 surgeons in the base case, with a range of 31 to 66 in the scenarios tested. In contrast, the Altruistic Model, in which surgeons only increase their workload if there are no surplus surgeons available, the surgeon shortage is only 16 in the base case, ranging from 0 to 44 in the scenarios. The effect of surgeon's workload decisions on employment and entry rates is distinctly evident. In the Financial Model, the population of available graduates persists until 2010, peaking at 13 surgeons, in the base case, whereas this population essentially disappears by 2011 in the base case of the Altruistic Model. In response to this, the enrolment rate decreases steadily down to 1.4 students in 2017 before gradually recovering again in the Financial Model, while in the Altruistic Model it remains fairly consistent around at 7.5 students per year until increasing again in 2024. It is clear that the availability of these trainees as they graduate throughout the years has a substantial impact on the provider shortages that develop and surgeons' workload decisions greatly affect the future of the specialty.

This model proved to be a useful tool for projecting cardiac surgery workforce requirements and for communicating the results to a broad audience, including surgeons, students and administrators of medical schools and residency programs. Among surgeons, the results indicate the effect their decisions have on the system, but also indicates that the skills of the excess surgeons currently in the system will be needed in the future, hence those who are currently clinically active have a responsibility to determine how the skills of these surgeons will be maintained during the "famine" years to ensure they are available when needed in the "feast" years. For students, this model demonstrates that their enrolment decisions should not be made on the basis of the current employment situation, but should instead be made with a view of the expected employment situation in the future when they will be completing their training. This is pertinent to medical school and residency program decision-makers as well, as discussions surrounding the elimination of residency positions stemming from the current situation may have a significant effect on the future workforce. This model also provides an approach for HHR planning within other specialties, and demonstrates the importance of including the dynamics of provider workload in HHR models, as it is evident from these results that this has a substantial effect on the projected outcomes. The model also indicated data which is not currently available but would enable model refinements and may be beneficial for the specialty to collect in the future, such as the relationships between surgeon age and productivity. Additionally, as an excess supply of cardiac surgeons is a new phenomenon, multi-year trend analysis was not possible in the determination of the relationship between unemployed surgeons and entry rates. Hence, this was approximated from the current situation within the cardiac surgery workforce and could be reexamined if more data becomes available.

Limitations in this model include the assumption that procedures have similar time or workload requirements; while this was deemed appropriate in the cardiac surgery context it may not be applicable in other specialties. Procedure differences could be accommodated by applying weights to the total demand and surgical capacity and proportional allocation calculations. This model also assumes utilization is indicative of need, and while this is a common discussed limitation of HHR planning models, in relation to cardiac surgery this is likely a valid assumption, as it is unlikely patients undergo unnecessary cardiac surgery, and the lack of wait lists for surgery indicate current needs are being met (Alter et al., 2006). Additionally, the model does not include provider gender as the consensus among the cardiac surgeons to whom this was presented was that cardiac surgeon productivity is unaffected by gender, although this may not be the case among other specialties. If provider gender was deemed important, it could be incorporated without difficulty but would increase data requirements. Also, within this model excess surgeons remain in the system, implicitly assuming that the surgeons will remain in Canada. Among cardiac surgeons this is an accurate assumption as licensing requirements differ between Canada and the United States (the most common destination for expatriating physicians), hence it is difficult for Canadian-trained surgeons to emigrate. Finally, the model does not include the arrival of IMGs into the system, although this could be added with any affiliated licensing requirements.

CONCLUSIONS

In conclusion, we developed a national health provider planning model using system dynamics which captures the effect surgeons' workload decisions and student enrollment decisions have on the system. A key outcome of this model is the net excess or shortage of providers which is determined based on the average provider productivity level, which responds dynamically to

imbalances between the supply and demand for care, and the clinically active provider population. The model simulates the population of providers as they age over time and the flow of students through the specialty training process prior to their entry into the provider population, with enrolment rates affected by the presence of unemployed providers. Demand for care is determined based on historical per-capita utilization rates and the national population projections by age and gender. Two provider decision making paradigms are presented, in which providers are either financially driven or motivated by altruism. These two paradigms provide the extreme ends of the spectrum; in reality, provider's workload decisions likely fall somewhere in between.

The model is applied to the case of cardiac surgeons in Canada through the execution of numerous scenarios. The results of most scenarios indicate a short-term excess of surgeons after which a surgeon shortage develops. However, the number of excess surgeons and the projected shortages differ among scenarios and are notably affected by the decision making paradigm. This model proved to be an effective tool for communicating the workforce system and possible future scenarios to both surgeons and students, while also providing insights that are valuable to those making decisions regarding residency programs. With low data requirements and rapid execution time, this model can be maintained and updated to enable ongoing use as additional data and information become available in the future.

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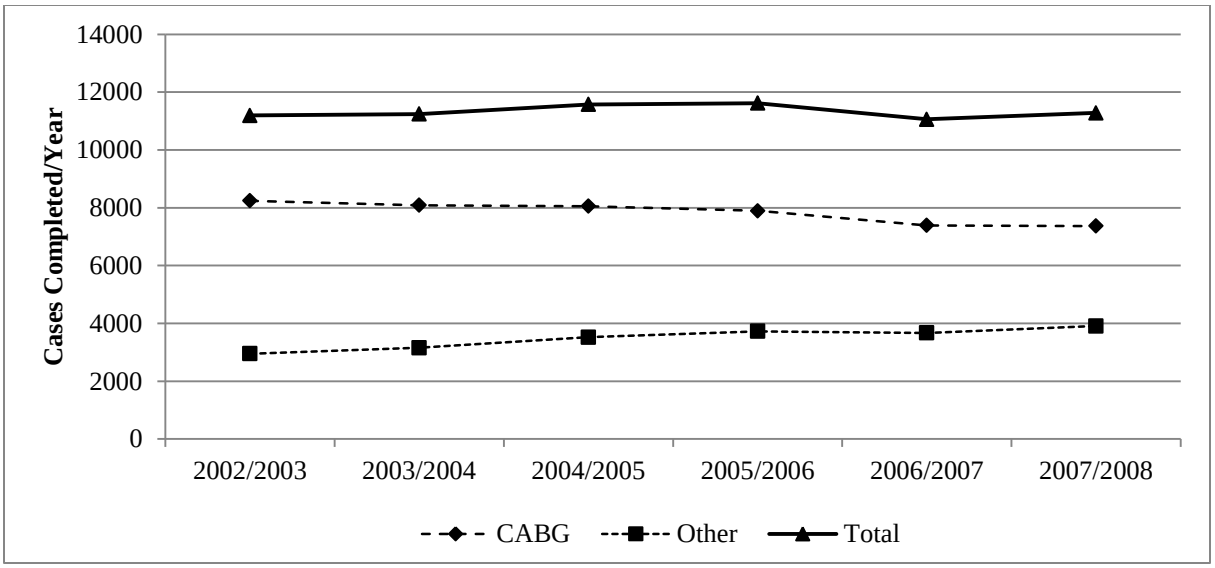

Figure 1: number of cardiac surgery procedures performed annually in Ontario (Source: Cardiac Care Network of Ontario)

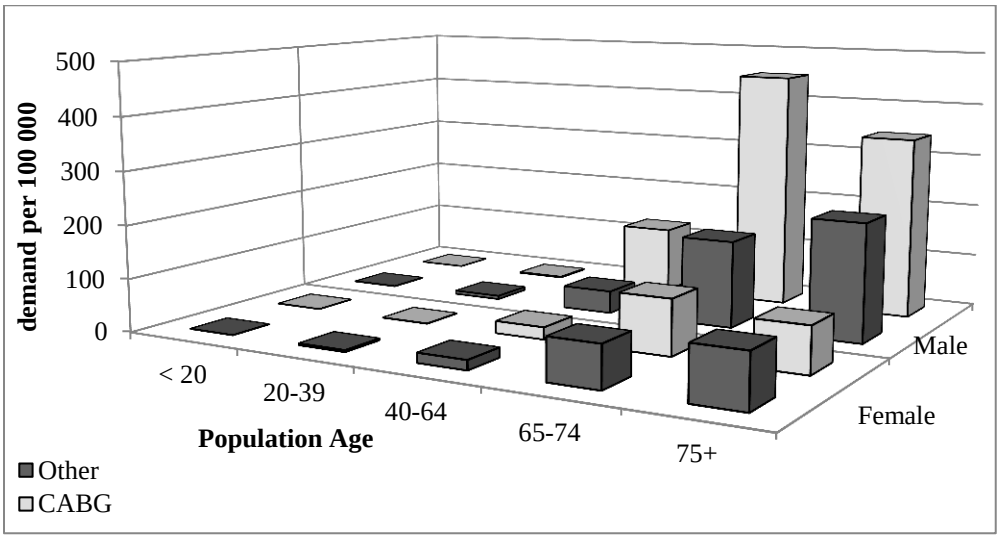

Figure 2: cardiac surgery demand rates by age and gender

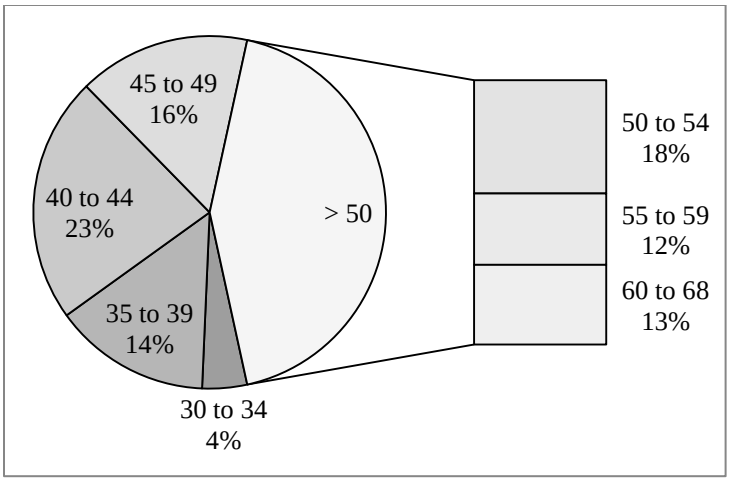

Figure 3: Age distribution of clinically active cardiac surgeons (Source: 2008 CSCS survey)

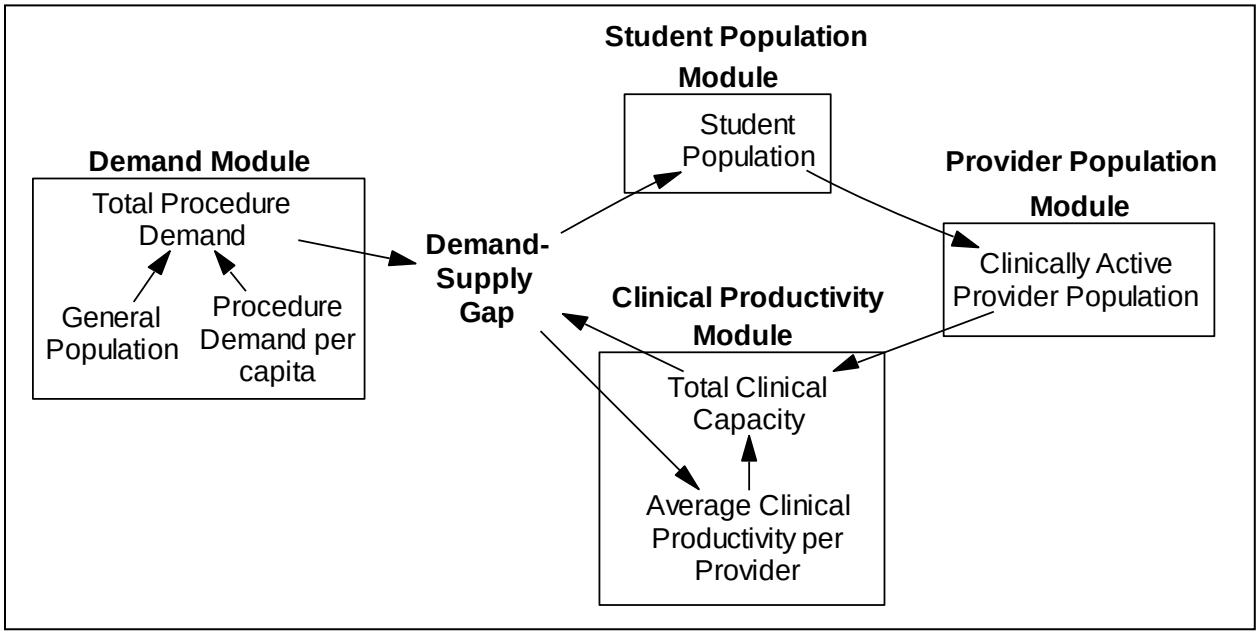

Figure 4: Influence diagram of the workforce planning model

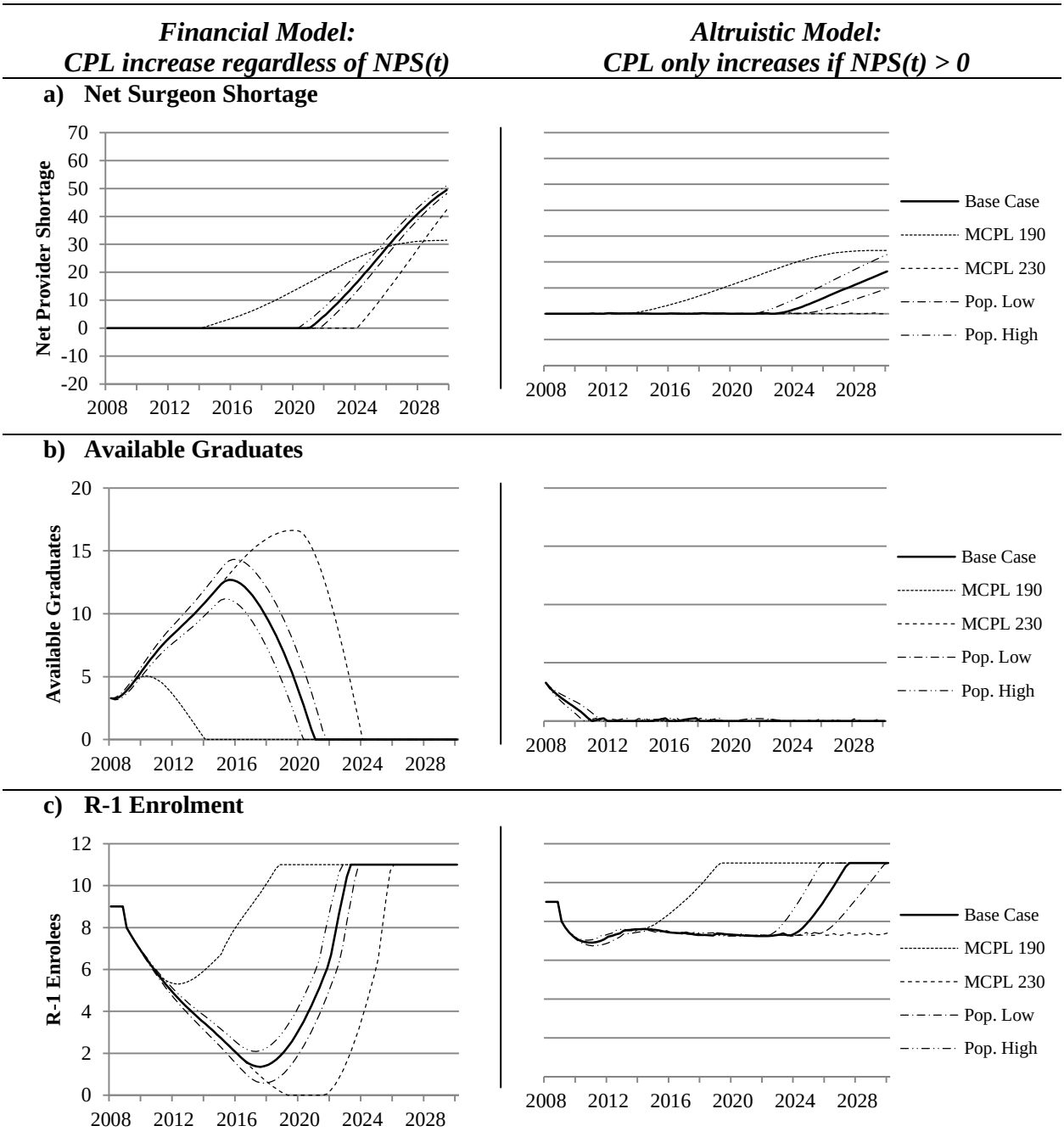

Figure 5: Cardiac surgery workforce model results for various scenarios relating to population and productivity on (a) the Net Surgeon Shortage, (b) the population of Available Graduates and (c) First Year Residency (R-1) Enrolment

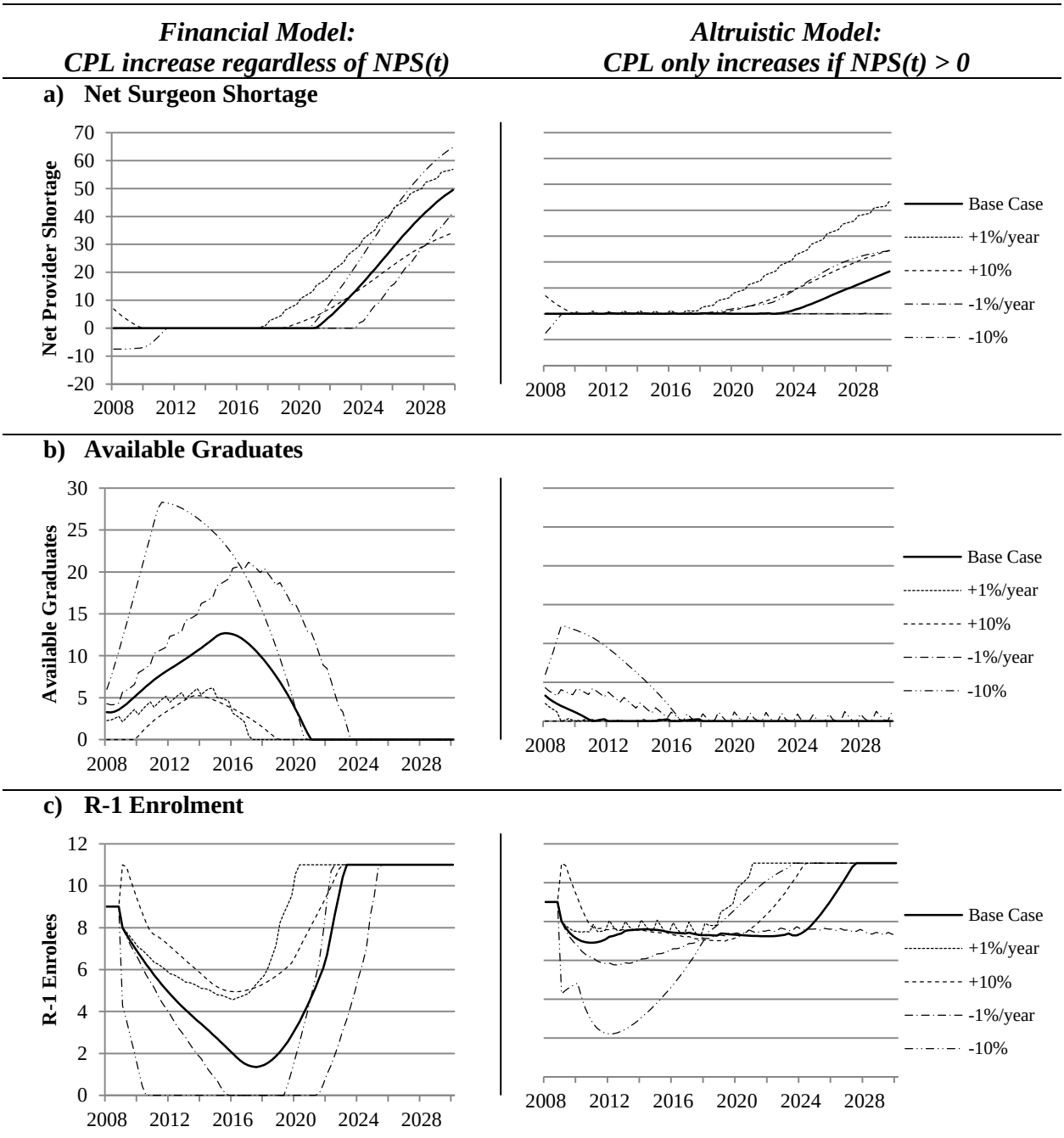

Figure 6: Cardiac surgery workforce model results for various scenarios relating to coronary artery bypass grafts (CABG) demand on (a) the Net Surgeon Shortage, (b) the population of Available Graduates and (c) First Year Residency (R-1) Enrolment

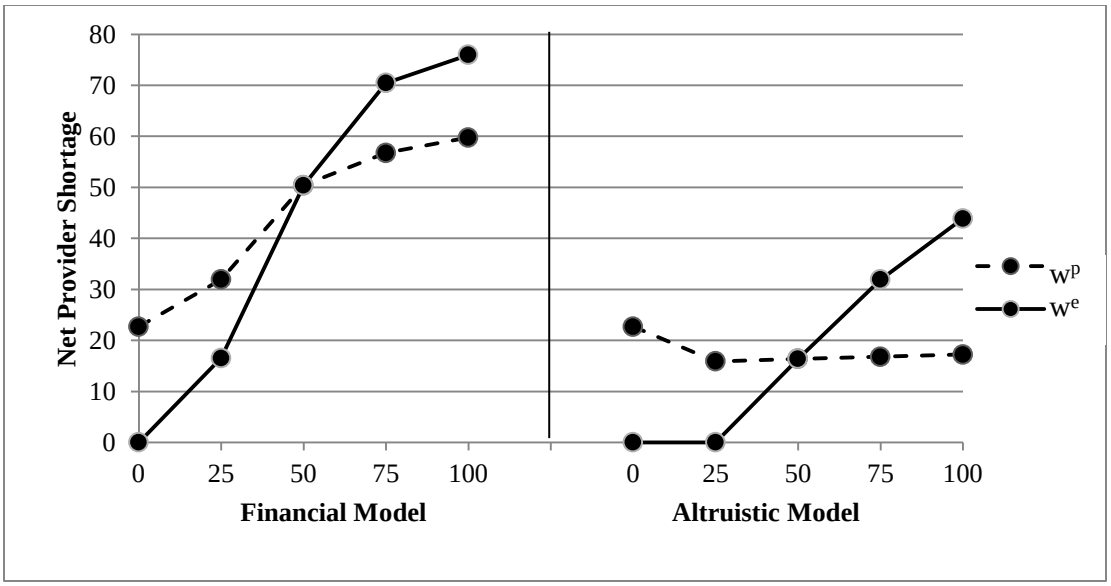

Figure 7: Sensitivity Analysis - Effect of enrolment and productivity weights (w^p and w^e) on Net Provider Shortage outcomes at end of the model time horizon (2030)

Table 1: Model Data Inputs

Data Element	Variable	Value
R-1 Enrolment (students/year)	$I_1(0)$	9
Residency positions (students/year)	v	11
Initial Student Population (students)		
R-1	$R_1(0)$	9
R-2	$R_2(0)$	7
R-3	$R_3(0)$	8
R-4	$R_4(0)$	10
R-5	$R_5(0)$	8
R-6	$R_6(0)$	9
R-7	$R_7(0)$	2
Fellowship	$R_8(0)$	11
R-6 graduation proportion (%)	$Pgrad$	0.8
Currently Unemployed (surgeons)	$G(0)$	6
Residency stage duration (years)		
R-1 – R-3, R-5 – R-7	d_n, $n=1\text{-}3,5\text{-}7$	1
R-4	d_4	2.114
Fellowship	d_8	2
Initial Surgeon Population (surgeons)		
35-39	$S_1(0)$	28.11
40-44	$S_2(0)$	34.36
45-49	$S_3(0)$	23.95
50-54	$S_4(0)$	28.11
55-59	$S_5(0)$	17.70
60-64	$S_6(0)$	16.66
65-66	$S_7(0)$	3.12
Surgeon Departures Rates (%)		
35-39	$Pexit_1$	0*
40-44	$Pexit_2$	0*
45-49	$Pexit_3$	0*
50-54	$Pexit_4$	0*
55-59	$Pexit_5$	0.10*
60-64	$Pexit_6$	0.65*
65-66	$Pexit_7$	1.00*
Initial CPL (cases/year)	$CPL(0)$	184
CPL Upper Limit (cases/year)	CPL^U	210*
CPL Lower Limit (cases/year)	CPL^L	$CPL(0)$
Weighting factor – enrollment	w^e	0.5
Weighting factor – productivity	w^p	0.5
Population Projections (Canada)	P_{jk}	Medium

*estimates provided by Canadian Society of Cardiac Surgeons executives

Table 2: Cardiac surgery workforce model scenario details

	Population Projection, P_{jk}	**Productivity Upper Limit (cases/year),** CPL^U	**CABG demand,** $D_{1jk}(t)$
Base Case	Medium	210	Constant
Scenarios	High, Low	190, 230	±10%, ±1% /year

CABG: coronary artery bypass grafts