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Simulation Model for the Analysis of Patient Pathways and Delivery of Medical Services for Coronary Heart Disease in the Swiss Population

Working Paper
Öffentliches Gesundheitsmanagement ÖGM

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Lucerne, September 2018

Content

Abstract

The Swiss health system is sound, but expensive and the discussion on how to curb rising costs without compromising quality of health care is controversial. This controversy pertains to the definition of an appropriate supply and to the design of adequate policy interventions. To address these issues, needs-based approaches are favored, but to date only few attempts have been made to adopt this approach. We propose and assess a simulation model as an instrument for a needs-based health care planning for an exemplary case. Our study is focused on coronary heart disease in Switzerland, following the patient pathway from the onset of symptoms to diagnostic and therapeutic interventions. We suggest that the proposed model is a valuable framework to explain empirical data and to test hypotheses with regard to potential overuse of diagnostic interventions. Moreover, it provides a generic cohort model structure to analyze a chronic disease in a population, where prognosis depends on age and time since first event (or the onset of the chronic disease). We identify relevant knowledge gaps and present suggestions for further model development.

1. Introduction

The Swiss health system is sound, but expensive (OECD 2011). Costs are rising, in the inpatient as well as the outpatient sector. The discussion on how to curb rising costs without compromising quality of health care is controversial. This controversy pertains to the definition of an appropriate supply and to the design of adequate policy interventions.

Health care policy interventions rely on the analysis of demand and utilization of health care services. For this analysis, three types of methodological approaches are distinguished: supply projections or trend models, demand-based approaches and needs-based approaches (SAMW n.d.). Demand-based approaches include the analysis of the utilization of medical services, while needs-based approaches include also changes with regard to prevalence and incidence of diseases and risk factors. However, needs-based models are deemed to be complex and challenging. For this reason, only few attempts have been made to date to adopt this approach.

The objective of this project is to provide an instrument for a needs-based analysis of the amount of medical services for an exemplary disease in the Swiss population. We argue that a system dynamics approach would be appropriate as it is per se dynamic and allows for an integration of different sources of information. The time dimension plays an important role in health care planning, due to e.g. demographic ageing, changes in incidence and prevalence of risk factors for a certain disease, changes in medical practice, as well as technological progress. Moreover, the supply side may also change over time, providing non-medical incentives for delivery and use of medical services.

For this purpose, we develop a dynamic simulation model to analyze the demand of medical services for coronary heart disease (CHD). The case of CHD has been chosen as an example, because cardio-vascular diseases are the leading causes of morbidity and mortality in Switzerland ((Federal Statistical Office n.d.), and because only a limited number of different medical specializations are involved in diagnosis and treatment of CHD. Moreover, empirical evidence suggests a potential overuse of medical services for diagnosis and treatment of CHD. A recent study by (Chmiel et al, 2015) found evidence of insufficient guideline adherence and a potential overuse of possibly harmful and inappropriate diagnostic interventions in non-emergency situations.

In this paper, we focus on the following research questions:

- What is an appropriate model structure to represent the patient pathway and the delivery of medical services for CHD?
- What are the most relevant knowledge gaps arising from this study that should be addressed when aiming at a needs-based health care approach for CHD?
- What is the potential of a system dynamics simulation model as an instrument for a needs-based health care approach?

Thus, in the broader context of the discussion of an appropriate medical supply, our project seeks to make two contributions. First, we want to assess the potential of the developed simulation model for a needs-based approach and second, we want to create the prerequisites for a future integration of supply and demand in a dynamic simulation model. Such a model could then contribute to a more focused and transparent discussion of appropriate medical supply.

In this paper, we present a first attempt for a dynamic, population-based model, which explains and integrates the available empirical data about diagnostic and therapeutic interventions for CHD in Switzerland. We discuss the validity of this simulation model and, based on this analysis, identify knowledge gaps, which should further be investigated. To date no policy studies have been undertaken. These studies would in particular pertain to the effect of primary and secondary prevention. We conclude with suggestions for further model development.

2. State of research

The potential overuse of medical services is reflected in a broad literature on supply-induced demand (see e.g. (Breyer, Zweifel, and Kifmann 2013; Cutler et al. 2013; Skinner 2011). This research relies largely on the analysis of geographical variations in health costs and health care utilization. An overview on unwarranted medical practice variation in the OECD countries is presented in (Corallo et al. 2014). Studies for Switzerland also suggest that supply-induced demand does exist to a certain extent. However, evidence found with regard to the relation between health care utilization and the densities of specialists and general practitioners is not entirely consistent (Busato et al 2012; Busato and Künzi, 2008; Busato et al, 2010; Camenzind, 2012; Crivelli et al, 2006; Reich et al, 2012). Moreover, criteria and numerical values for an appropriate supply with physicians for a specific region (Switzerland or a single Swiss canton) cannot be deducted.

The majority of studies aimed at assessing potential under- or overuse of health care services rely on statistical and econometric methods. From a methodological point of view, however, a complementary, more systemic perspective would be needed (Camenzind 2012). Such an approach should contribute to a more thorough understanding of the observed outcomes in health care, based on a number of cause-and-effect models. These models should take into account that the problem is dynamic and that the different components are mutually interconnected. As such, a feedback perspective, where causes and effects are linked endogenously, would be appropriate.

Furthermore, most studies do not adopt a dynamic perspective and therefore present evidence only for a specific point in time. However, due to changes with regard to technology, medical practice and also with regard to the supply of medical services, such as for example the number of heart catheter labs in Switzerland, dynamic studies over a larger period of time should be undertaken. To our knowledge, no such studies have been undertaken for the case of coronary heart disease.

It is acknowledged that health care planning should go beyond a utilization-based approach, which relies on the assumption that future utilization (or demand) will be equal to current utilization. Some models make assumptions about future changes in morbidity (for Switzerland see e.g. (Seematter-Bagnoud et al. 2008)). However, it would be preferable to move from utilization-based models to needs-based models, where future changes in health status and demand for health care would be considered endogenously. Moreover, these models would also offer the opportunity to consider medical practice variation along the treatment chain, including efforts in prevention. To date only few attempts have been made to implement needs-based models for health care planning.

System dynamics simulation models have been used in the health sector to analyze the effect of health care strategies (Homer 2012; Homer and Hirsch 2006; Sterman 2006). They have also been applied to evaluate interventions at different levels to improve cardiovascular health (Hirsch et al. 2014). These include interventions at clinical level, behavioral support, changes in taxes and regulations, as well as health promotion and access.

To our knowledge, no dynamic population-based study has been undertaken to date to analyze the amount of medical services for diagnosis and treatment of CHD in the Swiss population. In particular, no such study is available to investigate the effect of potential overuse of specific diagnostic and/or therapeutic interventions.

3. Model overview

3.1. Model purpose

The purpose of the simulation model is to calculate the amount of medical services for diagnosis and treatment of CHD in the Swiss population. We focus on the demand side, starting from population data and health determinants in the Swiss population, such as smoking fractions or incidence of hypertension. To describe the pathway of patients, we refer to scientific literature as well as to empirical data. These empirical data, however, reflect current (or past) medical practice, and may also include potential oversupply. Therefore, the supply side cannot be excluded completely. For this reason, we undertake a number of sensitivity studies, and analyse the effect of medical practice variation.

3.2. Scope of the model

The geographical scope of the model is Switzerland, due to data availability. The time horizon of the model is 2000 – 2030. This allows for calibration against empirical data as well as for policy studies for the next decade. We refer to Swiss population data, including net migration as well as future population scenarios. Risk factors taken into consideration are gender, age, smoking and hypertension.

3.3. Patient pathways

The simulation model follows the stages from the onset of symptoms to diagnostic and therapeutic interventions, and finally to a stage with diagnosed CHD. Thus people without CHD may present with symptoms of CHD (lead symptom: chest pain), undergo diagnostic interventions and are potentially diagnosed with CHD. Figure 1 shows on a high level of abstraction how patient pathways are represented in the simulation model.

Patients presenting with chest pain symptoms undergo first anamnesis with a general practitioner, followed potentially by non-invasive and invasive diagnosis. In each diagnostic intervention, they may be diagnosed “negative”, “positive” or “uncertain”. Patients with negative diagnosis flow back to “population without CHD”. Patients diagnosed “uncertain” are referred to the next diagnostic intervention, either non-invasive or invasive, in particular coronary angiography. Patients with “positive” diagnosis are the new incident cases of CHD and receive treatment, either invasive (PCI or CABG)[1] or by medication only. Patients with acute myocardial infarction (acute MI) presenting at an emergency department are treated separately, and are added to the flow rate of new cases with CHD. Patients referred to treatment may also die in hospital. After treatment, patients either undergo secondary prevention, including rehabilitation, or they do not adhere to appropriate secondary prevention. Patients may have recurrent events, potentially with new cardiac events.

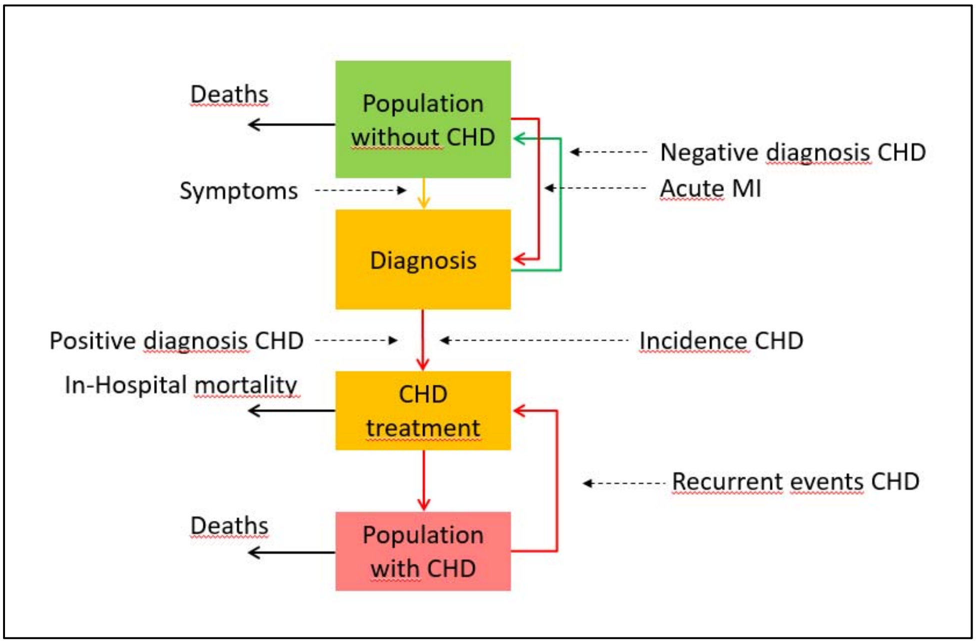

Figure 1: Patient pathway (simplified representation)

3.4. Key structures in the model

In the following three figures, we present and briefly explain the key structures in the model. The figures presented here refer to one single cohort. Each cohort has an identical structure, characterized by its creation time (year of birth), and gender. Here we show the model structure for the non-smoker population. The smoker population has the identical structure, but different parameter values. The scientific references with regard to parameters, functional relations, as well as to initial values and empirical data, are presented in the following section.

In Figure 2, we describe the onset of symptoms and following diagnosis (“diagnostic pathway”) together with the inflow of acute MI, presenting at an emergency department. Patients may present with chest pain, and undergo a first anamnesis with a physician. The chest pain rate depends on age, gender, smoking, and an exogenous variable, which describes an observed increase in hypertension. The “Factor New Onset Chest Pain Rate” has been introduced to adapt the available scientific evidence to the Swiss situation. Patients with chest pain symptoms may be diagnosed “negative”, flowing back to the population without CHD (“Population Non Smoker”), or “uncertain”, with referrals to the next diagnostic intervention. This intervention can be non-invasive,[2] or the patients may be referred directly to invasive diagnosis. After non-invasive diagnosis patients can be diagnosed negative, uncertain with referral to invasive diagnosis, positive with appropriate medication, or they can be diagnosed with stable angina pectoris (stable AP), which means that no acute coronary problem is present. These direct referrals to invasive diagnosis are often a matter of debate and are suspected to contribute to unnecessary diagnostic interventions (Chmiel et al. 2015).

[1] PCI: Percutaneous Coronary Intervention; CABG: Coronary Artery Bypass Grafting.
[2] NIIT: non-invasive ischemic testing.

From the rates of patients admitted to invasive diagnosis, we calculate the fractions of patients with positive diagnoses, who are referred to treatment (Figure 3). We include in-hospital mortality (30-days mortality) and calculate the number of new incident cases with CHD. These cases include the referrals to hospital as well as patients who have been diagnosed positive by a physician and receive medication only.

The flow of “New Cases CHD” triggers the creation of new cohorts with CHD. These cohorts are characterized by age (the age of their parent cohort) and by time of cardiac event. The latter is used to calculate the mortality rates of patients with CHD, which depend on the time since the first cardiac event. We distinguish between patients with surgical treatment[3] and treatment with medication only.

Figure 4 shows a part of the model structure for patients with CHD. These patients may undergo recurrent events, which are calculated as a fraction of the population with CHD. From these recurrent events, we calculate the fraction of patients with reinfarctions, who are referred to treatment. We take into consideration that in-hospital mortality for recurrent events is higher than for first events. Patients may adhere to secondary prevention with a certain loss rate of adherence. We do not take into account recurrent events of patients who receive medication only, because due to their age, they often do not receive surgical treatment. The model structure for patients with secondary prevention is identical with the one shown in this figure. However, this section of the model is not yet fully implemented. Here, we would like to include further knowledge about prognosis of patients with CHD, in particular taking into account the effect of adherence to secondary prevention.

[3] Here denoted as “revascularisation” (PCI, CABG).

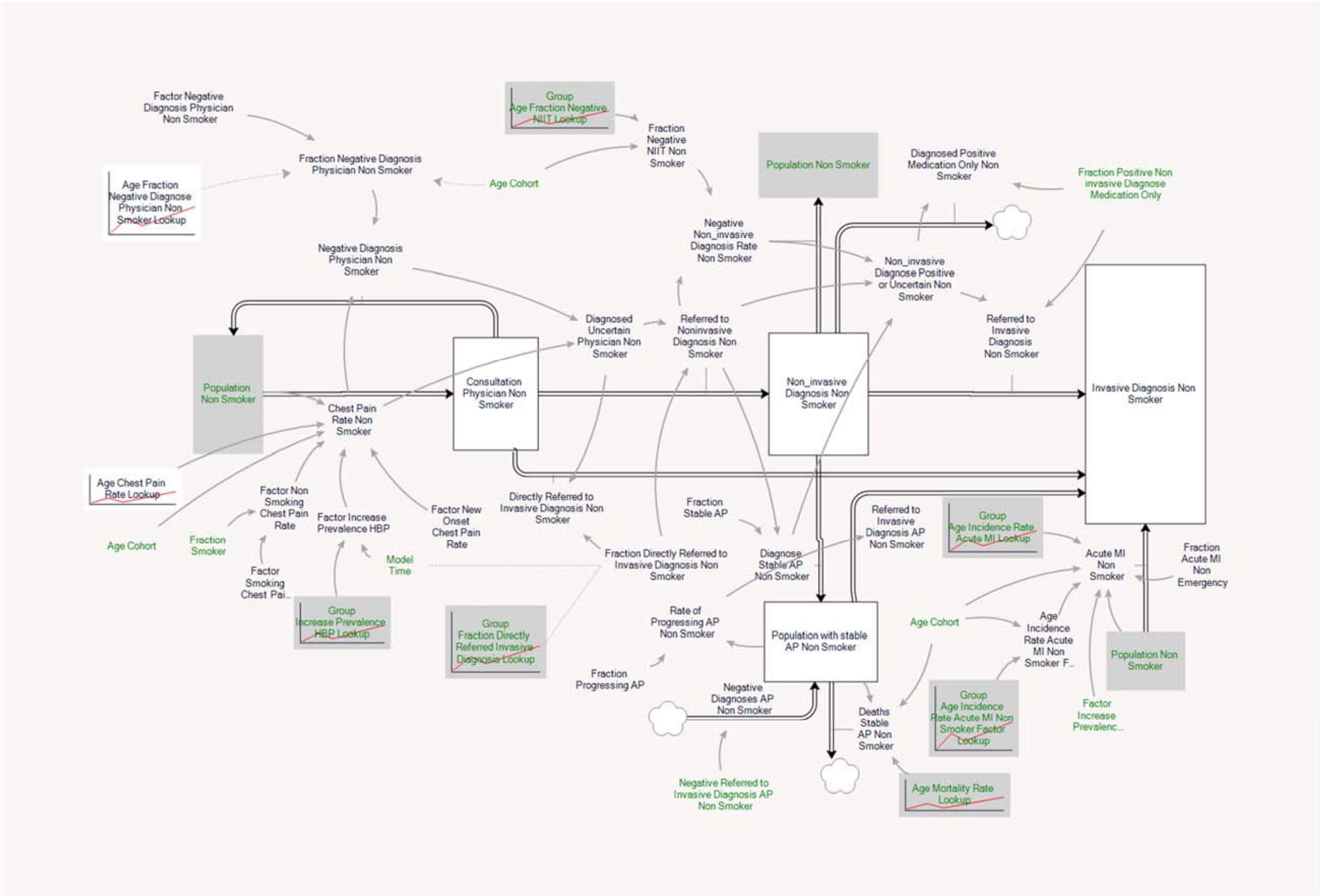

Figure 2: Patient pathway with onset of symptoms and diagnostic interventions.

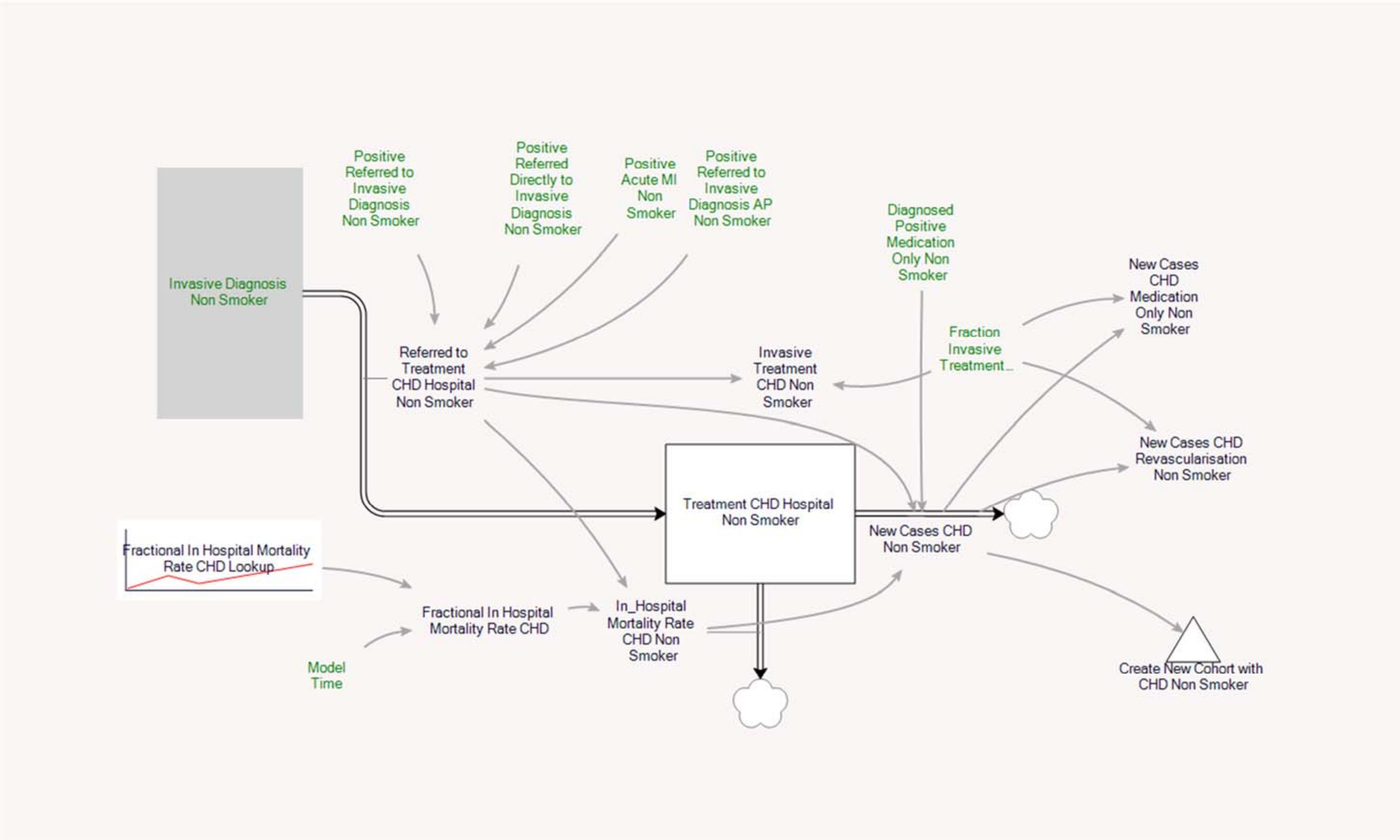

Figure 3: Treatment CHD and new (incident) cases with CHD.

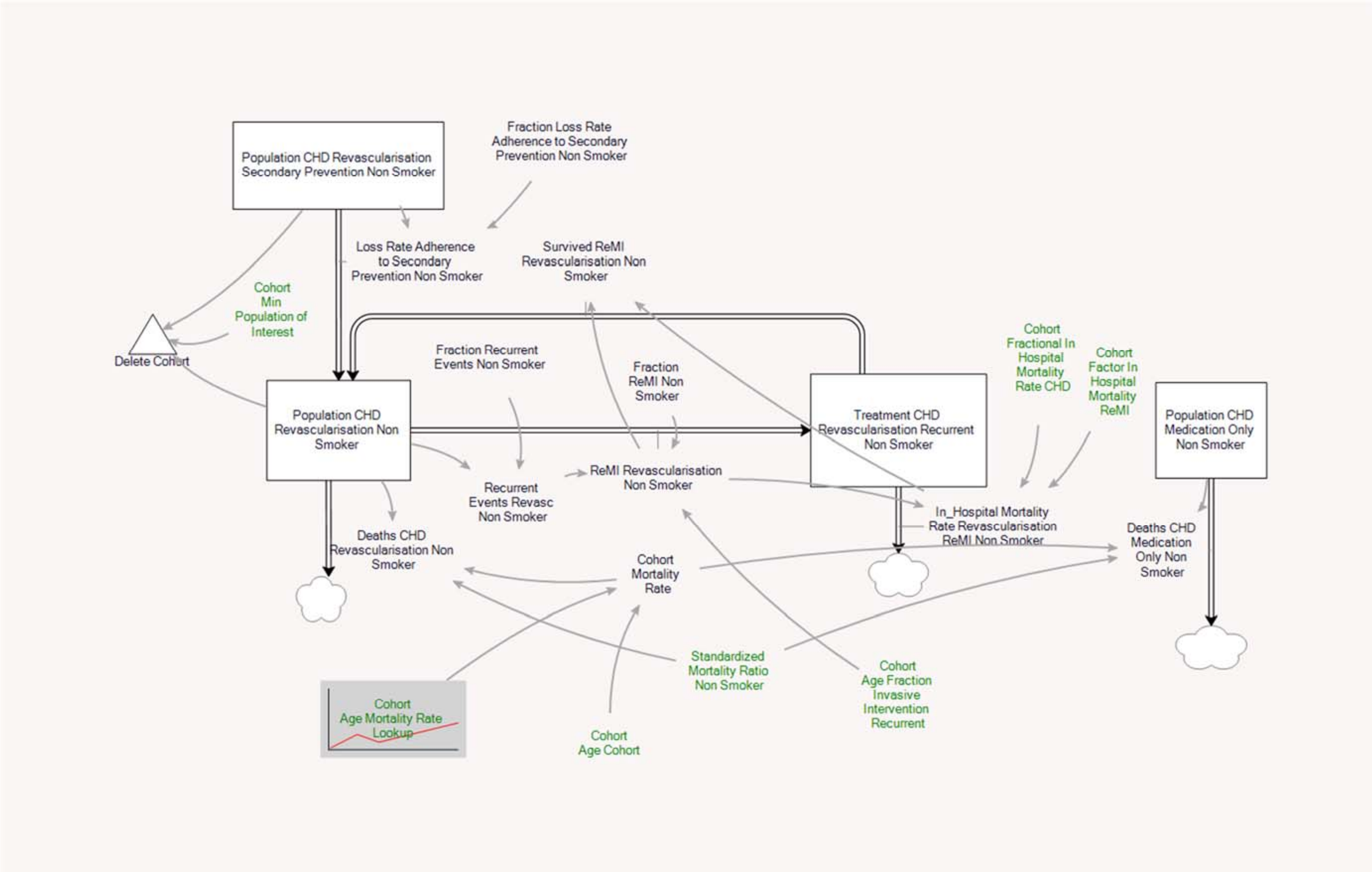

Figure 4: Recurrent events of patients with CHD.

3.5. Empirical evidence

In this section, we present the empirical evidence, on which we refer for the model simulation. A comprehensive parameter list together with the key references is included in the appendix (Table 3). In this table, we indicate, if these parameters are constant (independent of age and time), age-dependent, and/or time-dependent. Parameters with little scientific or empirical references are indicated, and will be included in the sensitivity analysis.

For the number of chest pain visits with a general practitioner we refer to (Frese et al. 2016; Ruigomez 2005) for the age distribution and to (Verdon et al. 2008) and to Obsan4 to adapt to the Swiss situation. Age-specific fractions of positive or negative diagnoses after coronary arteriography (CA) are derived from Helsana insurance data. We use different fractions for patients with or without preceding non-invasive diagnosis. For the fractions of negative diagnoses with a general practitioner we refer to the German SESAM 2 study (Frese et al. 2016). For the number of patients with acute MI presenting at an emergency department we refer to Obsan.5 However, information about the referring instance is often missing. For this reason, we include a fraction of patients with acute MI who do not present at an emergency department and include this parameter in the sensitivity analysis. Because data about acute MI do not distinguish between smoker and non-smoker, we include a factor, which takes into consideration the fractions between smokers and non-smokers, as well as the increased risk for acute MI for smokers. Here we refer to the AGLA risk score6, which is an adaptation of available international risk scores7 to the Swiss population.

With regard to treatment, we distinguish between surgical interventions (PCI, CABG) and medical (conservative) treatment, because the outcomes as well as the costs of both surgical interventions (PCI, CABG) are in the same order of magnitude (Fox et al. 2010), and secondary prevention is similar in both cases. Fractions of surgical versus conservative treatment are derived from the Swiss AMIS-Plus registry8 and from (Zellweger and Bopp 2016). These data also reflect a shift from conservative to surgical treatment, which took place in the early 2000. Data for in-hospital mortality (30-days mortality) are based on (Fox et al. 2010) and Obsan9 and reflect medical progress in the last decades.

For the number of recurrent events and the fractions of recurrent myocardial infarction (reMI) from these recurrent events, we refer to (Fox et al. 2010; Radovanovic et al. 2016). According to (Radovanovic et al. 2016) in-hospital mortality (30-day mortality) is higher than for first events. Moreover, clinical outcomes for smokers are substantially worse than for non-smokers (Zhang et al. 2015), which we take into account in the simulation model. After treatment, patients may undergo secondary prevention, including rehabilitation, or not adhere to appropriate secondary prevention. Total mortality rate for patients with CHD depends on age and on standardized mortality ratios, which depend on the time since the cardiac event (Smolina et al. 2012).

As mentioned above, we include age, gender, smoking and hypertension as risk factors. In the model, we distinguish between smoker and non-smoker populations, and take into account transitions between these populations. For the smoker/non-smoker population in Switzerland we refer to the Swiss health surveys 2002-2012 and in particular to (Notari et al. 2014). For the prevalence of hypertension in Switzerland we refer to (Zellweger et al. 2014) and to Obsan.10 No information is available about prevalence of CHD in Switzerland. Therefore, we refer to (Gößwald et al. 2013) for prevalence of CHD in the German population and to (Mozaffarian et al. 2015) for the prevalence of

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[4] Swiss Health Observatory: https://www.obsan.admin.ch/en/obsan
https://www.obsan.admin.ch//de/indikatoren/konsultationen-hausarzt-oder-allgemeinarztpraxen

[5] https://www.obsan.admin.ch/de/indikatoren/myokardinfarkt with additional data analysis M. Widmer (Obsan)

[6] https://www.agla.ch/risikoberechnung/agla-risikorechner

[7] For example: ESC risk score, Framingham risk score, PROCAM score.

[8] AMIS Plus - National Registry of Acute Myocardial Infarction in Switzerland (http://www.amis-plus.ch/) with additional data analysis D. Radovanovic

[9] Obsan Bulletin 2/2017: Qualität der stationären Leistungen unter der neuen Spitalfinanzierung: https://www.obsan.admin.ch/sites/default/files/publications/2017/obsan_bulletin_2017-02_d.pdf

[10] https://www.obsan.admin.ch/de/indikatoren/bluthochdruck

CHD in the United States. For the prevalence of stable angina pectoris (stable AP) we use the values presented in (Hemingway et al. 2006).

For the amount of medical services, we focus on the number of CA and invasive interventions, for which empirical data are available from (Zellweger and Bopp 2016) and (Balmer et al. 2005). Future studies should include medical services and costs along the entire patient pathway.

3.6. Generic model structure for modelling a chronic disease with Ventity

The simulation model is implemented using Ventity 1.2 (http://ventity.biz/). This is a novel, object-oriented, hierarchical software to describe complex dynamic problems. In particular, it is appropriate for modelling dynamic cohorts, where some effects vary with cohort age (e.g. rate of symptoms, mortality). For further information about cohort modelling with Ventity see (Fiddaman and Yeager 2017).

The fundamental structure of our simulation model is shown in Figure 5. Each cohort has the same structure. Every year a cohort is created and receives members through births. Over time, a number of processes take place, which include net migration (not shown in the diagram), all-cause mortality, onset of symptoms (chest pain rate), and eventually incidence of CHD and in-hospital mortality. Each cohort retains its creation time, from which the age of the cohort is calculated.

For those patients with incident CHD who survive ("Survivors CHD First Event"), a new cohort is created, called "Cohort with CHD". This means that for one specific age cohort several new cohorts with CHD may be created, for every year where we have a positive flow rate of survivors. These new cohorts receive the number of survivors and they inherit the characteristics of their parent cohort, in particular their age. The creation time of these cohorts corresponds to the time of the first event. For this reason, we may now refer to the age of these cohorts as well as to the time since event. This is particularly important, because prognosis depends on age as well as on time since event. In the "Cohort with CHD", we describe the follow-up with potential recurrent events. As mentioned, all-cause mortality with CHD depends now on age as well as on time since event. In the follow-up we distinguish between patients adhering to rehabilitation programs or not, including loss of adherence (not shown in the diagram).

We think that the model structure, which we developed here, has a generic structure. It can well be applied to other chronic diseases (e.g. cancer), where incidence depends on age (and other risk factors), and prognosis depends both on age and time since first event (or the onset of the chronic disease).

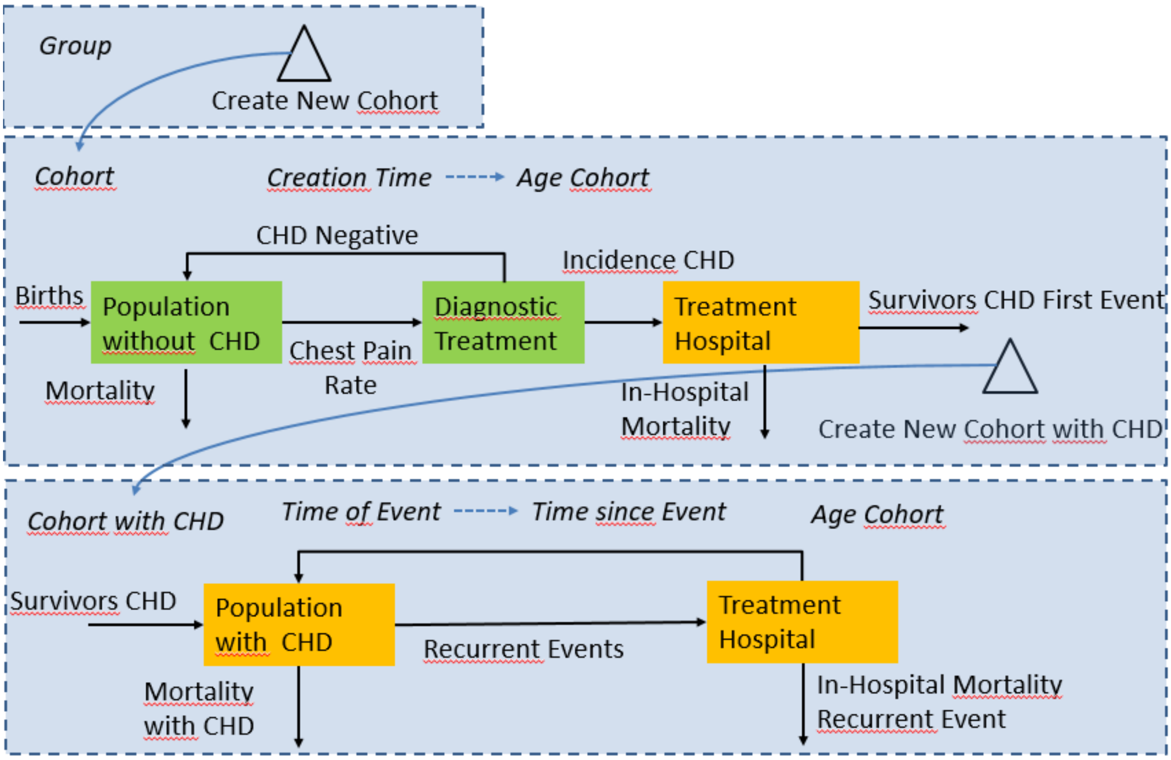

Figure 5: Fundamental structure of the CHD model.

4. Results

4.1. Incidence and prevalence

In this section, we present results of our simulation model for incidence and prevalence of CHD and compare our results with other studies, in particular with the Canadian study of CHD by (Blais and Rochette 2015). Following their definition, we calculate incidence of CHD as total number of newly diagnosed cases divided by the total number of people at risk (population aged 20 years and over minus prevalent cases). Blais and Rochette (2015) report for Canada for 2012/2013 a crude incidence of 6.9 per 1000. Our model shows a value of approximately 5.0 for the same period. For the prevalence of CHD, Blais and Rochette (2015) report a value of 9.4 per 100 in 2012/2013 (crude prevalence in the population aged over 20). Our simulation yields a value of approximately 6.6 per 100 for the same period. This difference of approximately 40% might be due to different values in risk factor prevalence. However, we could not yet verify this hypothesis.

4.2. Coronary angiographies and invasive treatment

For the amount of medical services, we focus on the number of CA and invasive interventions, for which empirical data are available for Switzerland. Time series data for invasive interventions in Switzerland from 2000 – 2014 are available in (Zellweger and Bopp 2016), as well as data for coronary angiographies from 2006 – 2014. Additional data about coronary angiographies in Switzerland are presented in Balmer et al. (2005).

Calibration of the simulation model against empirical data shows that historical data can be reproduced reasonably well, for what we think are the right reasons (Figure 6). However, the comparison of our simulation results with empirical data seems to indicate that the number of CA and of invasive interventions follow different trends. The number of CA significantly deviates from the figures, which we would expect according to the base case. In the base case we take into account changes with regard to risk factor prevalence as well as to medical progress (e.g. fraction of surgical versus conservative treatment, in-hospital mortality), but no explicit change with regard to referral practice and/or fractions of negative diagnoses.

This observation suggests that a change in referral practice, in particular an increase in direct referrals to CA should be investigated (Figure 7). To test this hypothesis, we assume an increase in direct referrals to CA of 50% between 2000 and 2015. The simulation demonstrates, that with this assumption the trend of CA can be better explained. However, with an increase of CA, the number of invasive treatments also increases. This is due to the fact, that we use constant fractions of positive/negative diagnoses after CA. Therefore, both variables increase. This observation points to two aspects, which should be taken into consideration. First, referral practice and fractions of positive/negative diagnoses are not independent of each other. Second, an increase in CA might cause an increase in invasive treatment, because there is a "grey" zone between diagnostic and therapeutic interventions. However, this practice might lead to potentially unnecessary interventions.

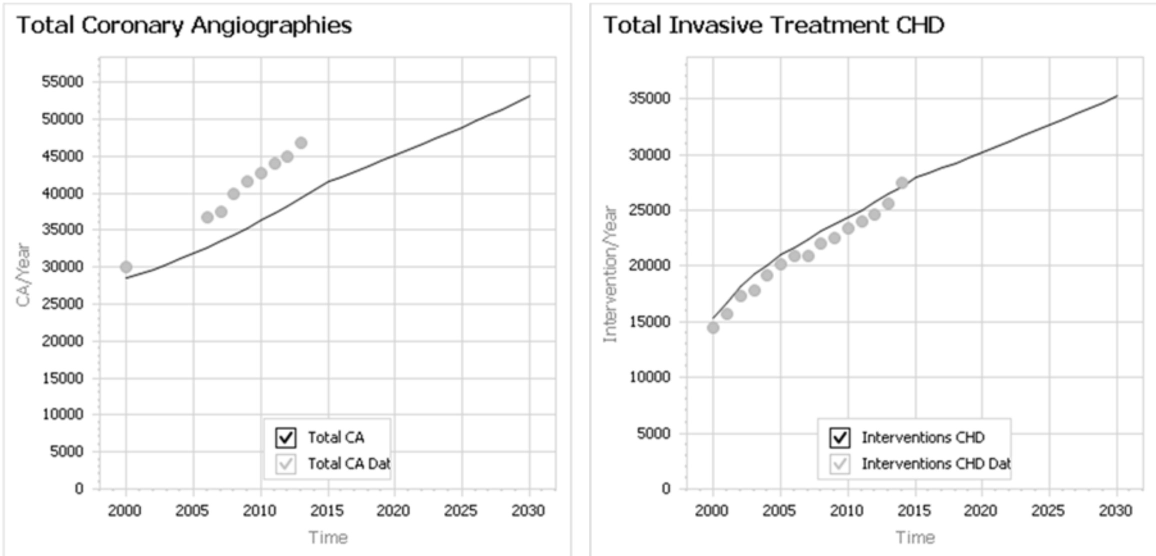

Figure 6: Coronary angiographies and invasive treatment (Base case)

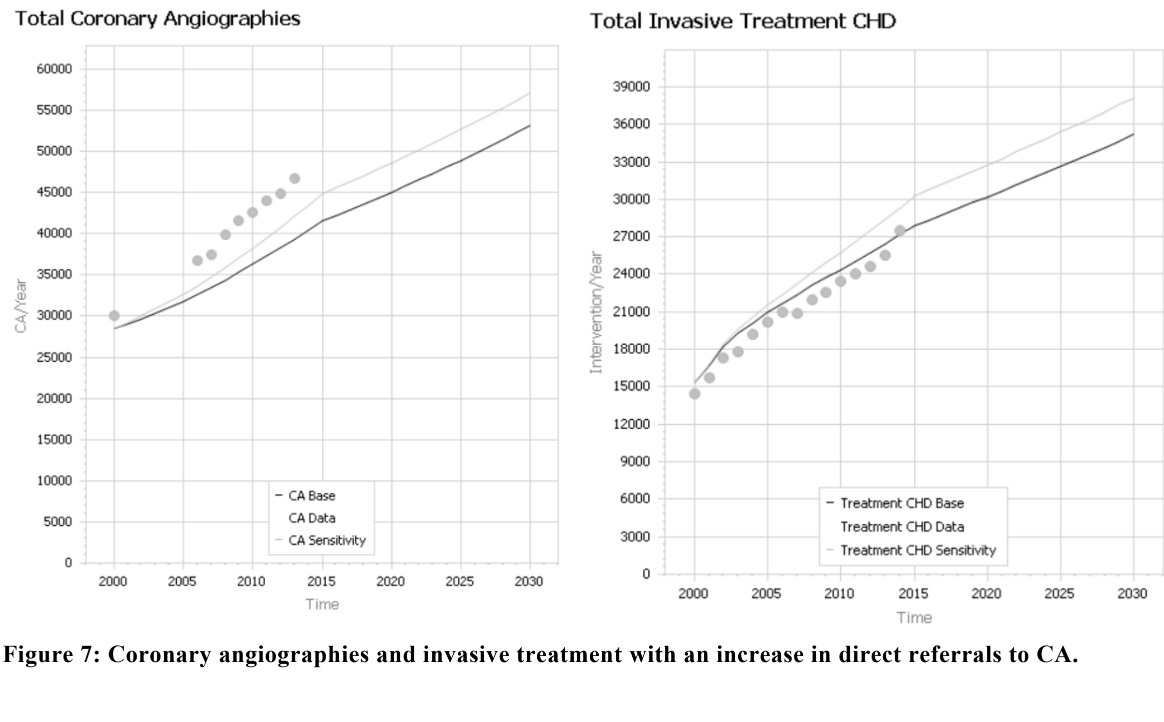

Figure 7: Coronary angiographies and invasive treatment with an increase in direct referrals to CA.

5. Model testing

Model testing consists of a calibration of the simulation model against empirical data and of a sensitivity analysis of model parameters. Model calibration and plausibility arguments have been presented in the previous section. Here, we show the results of a sensitivity analysis of those parameters, for which little empirical evidence is available (see also **Fehler! Verweisquelle konnte nicht gefunden werden.**). These parameters are varied in a range of +/- 20 percent, and the effect of this variation on the number of CA and of invasive interventions for 2015 is indicated (Table 1: Sensitivity analysis. We distinguish between variables with low, medium or high impact on the target variables (Table 2).

Parameter	Default value	Low value	High value	CA		Invasive intervention	
		-20%	+20%	Low	high	Low	high
				(%)	(%)	(%)	(%)
Factor Onset New Chest Pain Rate	1.6	1.28	1.92	- 11.9	+ 11.9	- 11.7	+ 11.7
Fraction Acute MI Non Emergency	0.3	0.24	0.36	+ 2.1	- 2.1	+ 2.2	- 2.2
Fraction referred directly to invasive diagnosis	0.4	0.32	0.48	- 3.1	+ 3.1	- 4.1	+ 4.1
Fraction recurrent event (of CHD population)	0.15	0.12	0.18	- 2.5	+ 2.0	- 3.0	+ 2.6
Fraction Negative CA Recurrent Events	0.1	0.08	0.12	- 0.2	+ 0.2	- 0	+ 0
Fraction Coro Total Recurrent Events	0.1	0.08	0.12	- 2.4	+ 2.4	- 0	+ 0

Table 1: Sensitivity analysis

Effect on target variables	Impact category	
0 – 2 %	low	
2 – 10 %	medium	
> 10%	high	

Table 2: Impact categories of model parameters

From this sensitivity analysis, we conclude that no single parameter has an effect on the target variables, which would undermine model consistency. One parameter has a high impact on the target variables. This is the “Factor Onset New Chest Pain Rate”, which has been introduced to adapt the available scientific evidence from other countries to the Swiss situation. Therefore, it is one of the primary parameters, which affects the amount of patients entering the “diagnostic” pathway and a key variable to calibrate the final model to empirical data. Three parameters have a medium impact. We argue that additional data inquiry should be undertaken, to limit the range of plausible values for these parameters. For the parameters with low impact, we suggest to rely on the default values used in the simulation model.

6. Discussion and outlook

Based on the work presented in the previous sections, we can now discuss our research questions as follows:

- What is an appropriate model structure as to represent the patient pathway and to calculate the delivery of medical services for CHD?

We conclude that the cohort model presented here is an appropriate approach to describe diagnosis and treatment of CHD at an aggregate level. We base this conclusion on the ability of the model to reproduce the historical data sufficiently well, for what we think are the right reasons. The model is detailed enough to account for the variation in risk prevalence and to the decision options along the patient pathway. However, the model section describing secondary prevention and recurrent events would benefit from substantial improvements. We would like to include further knowledge about prognosis of patients with CHD, in particular take into account the effect of adherence to secondary prevention explicitly.

Moreover, we think that the proposed model structure is applicable also to other chronic diseases in a population. It is possible to combine information about incidence, diagnosis and treatment, as well as follow-up and prognosis of the disease into one dynamic simulation model. The suggested cohort model approach takes into account in a natural way the effect of demographic ageing. Moreover, variations of medical practice over time (e.g. a change in diagnostic treatment and referral practice) can also be included in the model.

- What are the most relevant knowledge gaps arising from this study that should be addressed when aiming at a needs-based health care approach for CHD?

We identified a number of single parameters with substantial effect on the model results, where additional empirical knowledge should be provided. These include amongst other the number of visits with a general practitioner with chest pain symptoms, as well as more detailed information with regard to acute MI. In addition, as we showed with the example of an increase in direct referrals to invasive diagnosis, we emphasize the need to take into account changes in medical practice over time. However, additional data analysis is needed to provide appropriate empirical knowledge to address this issue.

- What is the potential of a system dynamics simulation model as an instrument for a needs-based health care approach?

We think that we could provide an additional approach to the established health care perspectives, which are mostly epidemiological, clinical or economic, while still relying on and incorporating the concepts and rationales broadly accepted in health care science. The model proposed here has the potential to test different hypotheses with regard to the delivery of medical services. We argue that the proposed model structure is a valuable framework to discuss existing data and trends with different experts and stakeholders, and to integrate different sources of knowledge.

However, additional work is needed to include policy studies with regard to primary and secondary prevention. In particular, it would be interesting to analyze the effect of improved prevention on the delivery of medical services and health costs over the entire patient pathway.

7. References

Balmer, Florian, Martin Rotter, Mario Togni, Dorothy Pfiffner, Andreas M. Zeiher, Willibald Maier, and Bernhard Meier. 2005. 'Percutaneous Coronary Interventions in Europe 2000'. *International Journal of Cardiology* 101 (3): 457–63. https://doi.org/10.1016/j.ijcard.2004.03.064.

Blais, C., and L. Rochette. 2015. 'Trends in Prevalence, Incidence and Mortality of Diagnosed and Silent Coronary Heart Disease in Quebec'. *Health Promotion* 35 (10). http://www.phac-aspc.gc.ca/publicat/hpcdp-pspmc/35-10/assets/pdf/ar-02-eng.pdf.

Breyer, Friedrich, Peter Zweifel, and Mathias Kifmann. 2013. *Gesundheitsökonomik*. 6th ed. Berlin Heidelberg: Springer Gabler.

Busato, A., P. Matter, B. Kunzi, and D. Goodman. 2012. 'Geographic Variation in the Cost of Ambulatory Care in Switzerland'. *Journal of Health Services Research & Policy* 17 (1): 18–23. https://doi.org/10.1258/jhsrp.2011.010056.

Busato, André, and Beat Künzi. 2008. 'Primary Care Physician Supply and Other Key Determinants of Health Care Utilisation: The Case of Switzerland'. *BMC Health Services Research* 8 (1): 1–8. https://doi.org/10.1186/1472-6963-8-8.

Busato, André, Pius Matter, Beat Künzi, and David C. Goodman. 2010. 'Supply Sensitive Services in Swiss Ambulatory Care: An Analysis of Basic Health Insurance Records for 2003-2007'. *BMC Health Services Research* 10 (1): 1–8. https://doi.org/10.1186/1472-6963-10-315.

Camenzind, Paul A. 2012. 'Explaining Regional Variations in Health Care Utilization between Swiss Cantons Using Panel Econometric Models'. *BMC Health Services Research* 12 (1): 62. https://doi.org/10.1186/1472-6963-12-62.

Chmiel, Corinne, Oliver Reich, Andri Signorell, Ryan Tandjung, Thomas Rosemann, and Oliver Senn. 2015. 'Appropriateness of Diagnostic Coronary Angiography as a Measure of Cardiac Ischemia Testing in Non-Emergency Patients-a Retrospective Cross-Sectional Analysis.' *PloS One* 10 (2). http://dx.plos.org/10.1371/journal.pone.0117172.

Corallo, Ashley N., Ruth Croxford, David C. Goodman, Elisabeth L. Bryan, Divya Srivastava, and Therese A. Stukel. 2014. 'A Systematic Review of Medical Practice Variation in OECD Countries'. *Health Policy* 114 (1): 5–14. https://doi.org/10.1016/j.healthpol.2013.08.002.

Crivelli, Luca, Massimo Filippini, and Ilaria Mosca. 2006. 'Federalism and Regional Health Care Expenditures: An Empirical Analysis for the Swiss Cantons'. *Health Economics* 15 (5): 535–41. https://doi.org/10.1002/hec.1072.

Cutler, David, Jonathan Skinner, Ariel Dora Stern, and David Wennberg. 2013. 'Physician Beliefs and Patient Preferences: A New Look at Regional Variation in Health Care Spending'. National Bureau of Economic Research. http://www.nber.org/papers/w19320.

Federal Statistical Office. n.d. 'Causes of Death in 2014'. Accessed 13 March 2017. https://www.bfs.admin.ch/bfs/de/home/statistiken/gesundheit.assetdetail.40503.html.

Fiddaman, Tom, and Larry Yeager. 2017. 'Dynamic Cohorts: A New Approach to Managing Detail'. In *Proceedings of the 35th International Conference of the System Dynamics Society and 60th Anniversary of System Dynamics Celebration Conference*. Cambridge, Massachusetts, USA. https://www.systemdynamics.org/assets/conferences/2017/proceed/papers/P1363.pdf.

Fox, K. A. A., K. F. Carruthers, D. R. Dunbar, C. Graham, J. R. Manning, H. De Raedt, I. Buysschaert, D. Lambrechts, and F. Van de Werf. 2010. 'Underestimated and Under-Recognized: The Late Consequences of Acute Coronary Syndrome (GRACE UK-Belgian Study)'. *European Heart Journal* 31 (22): 2755–64. https://doi.org/10.1093/eurheartj/ehq326.

Frese, Thomas, Jarmila Mahlmeister, Maximilian Heitzer, and Hagen Sandholzer. 2016. 'Chest Pain in General Practice: Frequency, Management, and Results of Encounter'. *Journal of Family Medicine and Primary Care* 5 (1): 61. https://doi.org/10.4103/2249-4863.184625.

Hemingway, Harry, Alison McCallum, Martin Shipley, Kristiina Manderbacka, Pekka Martikainen, and Ilmo Keskimäki. 2006. 'Incidence and Prognostic Implications of Stable Angina Pectoris Among Women and Men'. *JAMA* 295 (12): 1404–11. https://doi.org/10.1001/jama.295.12.1404.

Hirsch, Gary, Jack Homer, Justin Trogdon, Kristina Wile, and Diane Orenstein. 2014. 'Using Simulation to Compare 4 Categories of Intervention for Reducing Cardiovascular Disease Risks'. *American Journal of Public Health* 104 (7): 1187–1195.

Homer, Jack B. 2012. *Models That Matter: Selected Writings on System Dynamics 1985-2010*. Barrytown, N.Y: Grapeseed Press.

Homer, Jack B., and Gary B. Hirsch. 2006. 'System Dynamics Modeling for Public Health: Background and Opportunities'. *American Journal of Public Health* 96 (3): 452–58. https://doi.org/10.2105/AJPH.2005.062059.

OECD. 2011. 'OECD Reviews of Health Systems: Switzerland 2011'. *OECD Publishing*. http://dx.doi.org/10.1787/9789264120914-en.

Radovanovic, Dragana, Lea Maurer, Osmund Bertel, Fabienne Witassek, Philip Urban, Jean-Christophe Stauffer, Giovanni Pedrazzini, and Paul Erne. 2016. 'Treatment and Outcomes of Patients with Recurrent Myocardial Infarction: A Prospective Observational Cohort Study'. *Journal of Cardiology* 68 (6): 498–503. https://doi.org/10.1016/j.jjcc.2015.11.013.

Reich, O., C. Weins, C. Schusterschitz, and M. Thoni. 2012. 'Exploring the Disparities of Regional Health Care Expenditures in Switzerland: Some Empirical Evidence'. *Eur J Health Econ* 13 (April): 193–202. https://doi.org/10.1007/s10198-011-0299-x.

Ruigomez, A. 2005. 'Chest Pain in General Practice: Incidence, Comorbidity and Mortality'. *Family Practice* 23 (2): 167–74. https://doi.org/10.1093/fampra/cmi124.

SAMW. n.d. 'Steuerung Der Anzahl Und Der Verteilung von Ärztinnen Und Ärzten'. Accessed 6 December 2016. http://www.samw.ch/dam/jcr:0f4d6172-5329-4e87-ad07-bdef13af4e49/SAMW_Comms_AerzteZahl_16_D_fWeb-kl.pdf.

Seematter-Bagnoud, Laurence, Julien Junod, Hélène Jaccard Ruedin, Maik Roth, Claudia Foletti, and Brigitte Santos-Eggimann. 2008. 'Offre et Recours Aux Soins Médicaux Ambulatoire.Pdf'. http://www.google.ch/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0CCgQFjAB&url=http%3A%2F%2Fwww.obsan.admin.ch%2Fbfs%2Fobsan%2Fde%2Findex%2F02%2F02%2F01.html%3FpublicationID%3D3198&ei=lQGgU-3QPKXb0QXumo-DIDg&usg=AFQjCNEYIOYs3fGrX0wE3mdgja7DLbqB2w&bvm=bv.68911936,d.d2k.

Skinner, Jonathan. 2011. 'Causes and Consequences of Regional Variations in Health Care11This Chapter Was Written for the Handbook of Health Economics (Vol. 2). My Greatest Debt Is to John E. Wennberg for Introducing Me to the Study of Regional Variations. I Am Also Grateful to Handbook Authors Elliott Fisher, Joseph Newhouse, Douglas Staiger, Amitabh Chandra, and Especially Mark Pauly for Insightful Comments, and to the National Institute on Aging (PO1 AG19783) for Financial Support.' In *Handbook of Health Economics*, 2:45–93. Elsevier. https://doi.org/10.1016/B978-0-444-53592-4.00002-5.

Smolina, Kate, F. Lucy Wright, Mike Rayner, and Michael J. Goldacre. 2012. 'Long-Term Survival and Recurrence After Acute Myocardial Infarction in England, 2004 to 2010'. *Circulation: Cardiovascular Quality and Outcomes* 5 (4): 532–40. https://doi.org/10.1161/CIRCOUTCOMES.111.964700.

Sterman, John D. 2006. 'Learning from Evidence in a Complex World'. *American Journal of Public Health* 96 (3): 505–514.

Verdon, Francois, Lilli Herzig, Bernard Burnand, Thomas Bischoff, Alain Pecoud, Michel Junod, N. Muhlemann, B. Favrat, and others. 2008. 'Chest Pain in Daily Practice: Occurrence, Causes and Management'. *Swiss Medical Weekly* 138 (23/24): 340.

Wieser, S, I Rüthemann, Boni De, K Eichler, M Pletscher, D Radovanovic, T Ulle, and H Auerbach. 2012. 'Cost of Acute Coronary Syndrome in Switzerland in 2008'. *Swiss Medical Weekly*, August. https://doi.org/10.4414/smw.2012.13655.

Zellweger, Ueli, and Matthias Bopp. 2016. 'Zahlen Und Daten Über Herz-Kreislauf-Krankheiten in Der Schweiz'. https://www.swissheart.ch/fileadmin/user_upload/Bilder_Inhalt/5.0_Ueber_uns/5.1_Aufgaben_u_Aktivitaeten/HerzStatistik.pdf.

Zhang, Yao-Jun, Javaid Iqbal, David van Klaveren, Carlos M. Campos, David R. Holmes, Arie Pieter Kappetein, Marie-Claude Morice, et al. 2015. 'Smoking Is Associated With Adverse Clinical Outcomes in Patients Undergoing Revascularization With PCI or CABG: The SYNTAX Trial at 5-Year Follow-Up'. *Journal of the American College of Cardiology* 65 (11): 1107–15. https://doi.org/10.1016/j.jacc.2015.01.014.

8. Appendix

Influence factors and parameters	Constant	Distinction smoker/non-smoker	Age-dependent	Time-dependent	Depending on time of event	Sensitivity analysis	Key references
Population			x	x			BFS
Mortality Rate			x	x			BFS
Smoking			x	x			Notari et al 2014
Hypertension			x	x			Obsan
Chest pain rate			x	x			Ruigomenez 2005; Frese et al 2016, Verdon et al 2008
Acute MI		x	x	x			Obsan
Fraction Acute MI Non Emergency	x					x	Obsan
Fraction negative diagnosis physician			x				Frese et al 2016
Fraction referred directly to invasive diagnosis	x					x	
Fraction negative non-invasive diagnosis	x	x				x	
Fraction Positive non-invasive diagnosis medication only			x				AMIS Plus
Fraction negative invasive diagnosis (CA)			x				Helsana
Fraction negative referred directly to invasive diagnosis (CA)			x				Helsana
Fraction invasive vs. conservative treatment CHD			x	x			AMIS Plus; Zellweger, Bopp 2016
In-hospital mortality				x			Schmidt et al Obsan
Fraction recurrent event (of CHD population)	x	x				x	
Fraction ReMI (of recurrent events)	x	x					Fox et al 2010 ; Zhang et al 2015 ; AMIS Plus
Fraction Coro Total Recurrent Events	x					x	
Adherence to secondary prevention	x						Helsana
Mortality rate of CHD patients			x		x		Smolina et al 2012
In-hospital mortality of CHD patients	x	x					Obsan; Zhang et al 2015

Table 3: Parameter list