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Cost Sensitivity Simulators for Health Care: AI Readiness Issues, Some Contributions for Economic Model

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ABSTRACT

It is timely to discuss issues such as reliability and validity for the rapid deployment of AI technologies, given the explosion of data elements and the creation of huge health data hubs (e.g., EU Health Data Space) before speeding up tools and methods. This paper provides a brief history and main contributions with the European Society of Operational Research, useful for the decision tool called cost sensitivity simulators. This type of decision tool comes from experimental research on the interference of economics and health care choices, especially in the diagnostic and treatment space. The original contingent valuation methodology was a reversed conjoint algorithm, with economic cognitive cues and not only clinical cues (cues were selected with the Lens psychological model, not with traditional marketing methods used to identify attributes). Such valuation methods are now included in the category of Discrete Choice Experiments and are powerful methods in the Preference Research community. This paper is a selection of issues discussed at ORAHS and EWG-MCDA working groups. It compares consistency measures from psychologists and axiomatic systems from mathematical economists, and recent developments of axioms with a triad approach, for use in simulations and possible aggregation of choice models in meso or macro-economic models.

Keywords: *Decision Tools; Cost Sensitivity Simulation; Discrete Choice Experiments; Preference Research; Choice Models.*

1. Introduction

This paper aims to discuss how some recent developments in AI technologies can enhance cost-sharing research developments, especially for the cost sensitivity simulators proposed under the academic enterprise EndepUSresearch, created for the development of decision tools for health care financing [1]. It is timely to discuss the rapid development of AI technologies since the explosion of data elements and the creation of huge health data hubs, such as the EU Health Data Space, speed up the need for reliable tools and methods.

This paper provides a brief history and main contributions at some working groups of the European Society of Operational Research and its international conferences, useful for cost sensitivity simulators. The relationship started in Vienna in 2016, first with the European Working Group on Multi-Criteria Decision Analysis (EWG-MCDA). Then, it was also with the health service research working group called ORAHS: two main communications for the decision tool were given in Oslo in 2018 [2] on consistency issues, and one in June 2025, on health systems in the ORAHS stream of the EURO Leeds conference, with an overview of approaches and design theories [3]; this may lead to innovative ways for implementation in health systems, within the global Universal Health Care (UHC) agenda, concerning the topic of how deployment of recent AI systems can impact the business method. A lecture was also given at the EWG-MCDA meeting at West Attica University in Athens, in April 2024, on how deployment of recent AI systems can impact this business method and system.

The main reason to establish such a relationship with the EURO academic society (in addition to membership at ISPOR, specialized in Pharmacoeconomics and Outcomes Research) has been to discuss comparable reliable metrics for the simulation tools and links with optimization methods for health care budgeting, medical and economic systems. The European scientific society specializes in Operational Research and is dominated by computer engineers; however, a community of economists and financial officers in charge of public budgeting also has strong interactions with the society, especially in sessions related to operational research in health systems. Recent AI technologies and the use of big data also lead to major developments in new methodologies, such as automatization of algorithms; the most relevant one for the decision tools concerns the use of recent OR methods for automated pricing. The EURO conference provided recent studies, also discussed during the visits to MIT, on automatization of pricing processes for global businesses. For instance, the Levi' study [4], with the use of neural network transformers, presented how this approach can modify demand forecasting and aggregated models for profit maximization, instantly across many countries.

The tradition of operational research varies according to countries and industrial sectors. Some health systems, such as the NHS in the UK, have created internal operational research departments. In France, the Ministry of Finance has led the use of such methods inside the public administration (e.g., Rationalization des Choix Budgétaires (RCB)); however, this global budgeting approach is dominated by politics and ideology, and the government is under pressure to close budgets under political pressures. Rationalization processes, as proposed by operational research units, may not meet the demands of political groups and interest groups; however, they can still be useful for adjustment of welfare contracts and optimization of some economic systems (e.g., in Finland, use of financial optimizers such as Detech optimizer, presented at EURO, Aalto, 2022 [5]).

2. Brief History of the Decision Tool Called Cost Sensitivity Simulator

This first section describes a brief history of how the algorithm on reversed conjoint leads to the development of prototypical and technological improvements for simulators, called cost simulators. Originally, this tool partly came from a spin-off of two EU projects, especially the last one, entitled ENDEP/Biomed project (Huttin and Endepresearch group, IOS Press/SAGE book, 2003) [6]; an academic enterprise had been created in Cambridge, Massachusetts, USA, in the field of health care technologies and medical economics. Statistical results and additional experiments were performed in North America, first presented at Brunswik Society meetings, specialized in judgment studies (Minneapolis, 2004; Toronto, 2005 [7]); this society had a chapter on clinical judgment analysis, led by Prof. Wigton from Nebraska University. As this type of analysis was used for the experimental designs of the "reversed conjoint" experiment on physicians, it was the right audience; regular presentations were also given at ISPOR Pharmacoeconomics and Outcomes Research Society, and Prof. Huttin was invited to several task forces or interest groups, especially to contribute to best practice reports. The most relevant one was the task force on conjoint design and Discrete Choice Experiments (D.C.E.); however, ISPOR represents the industry, and regulators or government officials who attend the conferences provide information on ongoing reforms and regulatory changes in interactions with industry players. With current AI technologies and their roles in data analytics, EURO Society events are useful for collaboration with computer engineers for implementation of decision tools.

Unmet Critical Patient Needs and Psychological Cues for Cost Simulators

The conjoint design experimental research originally used a psychological model, especially the conceptual framework of the Lens model [8, 9]; it was used to identify the main criteria (or cues, in psychological terminology) to detect interference of economics with care decisions, especially at critical decision points in medical decision-making processes. It is particularly useful for the identification of unmet critical needs of patients: psychological cues detect various barriers, especially financial constraints or pressures coming from patients' or physicians' economics, as well as product economics; such studies can prevent decision shifts leading to lack of adherence and compliance with treatments. In the translational medicine space, the cost simulator has been identified as a useful cost index or economic marker for critical decision points at prognostic and diagnostic stages. Advances in phenotyping methods and NGS, for instance, reduce the scope of misdiagnosis (e.g., in multiple sclerosis and cardiovascular diseases); economic markers could be useful for rapid adjustment in payment plans (Huttin and Liebman [10], BioIT, 2023).

In the type of psychological models used in the physicians' cost sensitivity studies, consistency of judgments within a health system is measured with what is called "Rs" in the mathematical formulae from Tucker [11,12]. However, such consistency tests are usually not performed and are missing from studies on economic topics and choice models in health care. So, this paper mainly highlights which advances in some EURO working groups met between 2016 and 2025 may be of use for cost sensitivity simulators and decision tools based on reversed conjoint algorithms and discrete choice experiments (D.C.E.) for physicians' choice models (including possibly additional techniques, e.g., AHP, for evaluation in various delivery systems and additional criteria for infrastructures and communications).

To identify verbal information on costs, focus groups of physicians and patients have been used to explore, in conversations about care between providers and patients, how socio-economic narratives could lead to decision shifts in diagnostic and treatment choices. Economic narratives, and not only clinical narratives, have then been incorporated in clinical vignettes, administered with experimental or quasi-experimental plan designs, to physicians in different health systems; the studies had reliable metrics with enough statistical power. The expansion of unstructured data in the latest AI technologies could lead to economical ways to implement such methods and use cost sensitivity simulators at points of care where economic interference leads to severe increases in budget, decreases in patient outcomes, and reduced resource allocation.

Psychological models remain important in health care, especially in medical decision-making. Prof. Huttin continues to contribute to the Brunswik Society newsletter (www.brunswik.org) [7], where this approach to cognitive systems is discussed. However, interactions with the operational research community have encouraged the exploration of other approaches. Economists active in this field are often engineering economists, including those working in mechanism design. The mechanisms used to control systems differ from judgment-analysis approaches, such as those developed within the Brunswik Society. In particular, consistency measures used in psychology, such as the "Rs" measure, differ from mathematical axioms.

As computer scientists dominate the development of agent models, AI technologies, and architectures of big data, it is also important to understand the ways the different scientific fields are used for improving or optimizing medical or health systems. The EURO Society meetings have been useful for exploring new venues and epistemic issues in such interdisciplinary nexus of science, technology, and health policy [2,13,14].

3. Main Contributions from EURO Interactions for the Decision Tools in Healthcare

3.1. DECK Consortium and Tools Based on MCDA Algorithms

The DECK consortium idea originated in the research lab at University of Paris Dauphine under Prof. B. Roy's initiative; it was mainly a consortium formed under the EWG-MCDA working group to establish a platform with all algorithms available and their different developments. Prof. C. Huttin met the group in Paris and started to present a special application of conjoint models for testing cost sensitivity of professionals and patients under various financial restrictions. However, the consortium was not sustained; only a group of researchers, mainly based in Poznan University, took over to create another platform. In the future, a platform on these MCDA algorithms may be sustained by the EWG-MCDA group; preliminary inputs for cost sensitivity simulators could then be imported to their DECK Consortium.

3.2. Consistency Issues and Conjoint Models in Health Care

This contingent valuation methodology for the cost sensitivity simulator is a business method and system based on a reversed conjoint model with economic cognitive cues and not only clinical cues. It can lead to powerful instruments, not limited to the evaluation of product and service attributes [15]. Communications at EURO and IFORS societies led to discussions of specific issues and possible additional methodological improvements for the reliability and validity of the cost sensitivity simulator and its implementation in some health or medical systems.

A major technical issue for the cost sensitivity simulator is to make sure the data generated with the experimental study designs are consistent among the groups of professionals and patients. At EURO meetings, it was explored whether the axiomatic system used by mathematical economists could be useful in addition to the tests used in the original studies, mainly based on psychological cues in research experiments in Europe, then in Ontario (Canada, collaboration between Prof. Huttin and Prof. Gafni) and Boston (with the academic enterprise, ENDEPUSresearch, Inc., Mass., USA [15]). In addition to the original reversed conjoint design, a new study design was presented at AcademyHealth in 2011 in Seattle. It included a research design with IT innovation [16,17], with an application on diabetes (communications at Society for Medical Decision Making in Toronto in 2010, ISPOR in Baltimore, 2011, and Montreal, 2014).

However, consistency issues around such cost studies have not been discussed with psychologists. There are limited judgment studies on economics and clinical decision-making, and the meta-reviews [11,12] on judgment studies do not show studies on such topics, but only on clinical tasks in the medical field. Consistency issues for the cost sensitivity simulators have been covered with other approaches, close to the one discussed in EURO Society circles. The original study used best practices from market research companies and covered some main issues related to conjoint survey administration [18]. The project was conducted in partnership with SKIM Analytical, a market survey company (Sawtooth's licensee for Europe); this can directly relate to the discussions with some EWG-MCDA working groups.

The objective of consistency tests is to address whether economic information measured with cost cognitive cues is consistent within and between samples of physicians in different national health systems. The cost cognitive cues are psychological cues (from the Lens model or its revisions); therefore, tests derived from the mathematical Tucker formulae could be a useful approach. Judgment studies in clinical systems usually use such formulae, and the consistency measure called "Rs" is the consistency of judges' responses to multi-cues for clinical tasks (physicians, trainees or experienced physicians, nurses) between physicians in each ecological system.

If the ecological system, as in the original cost studies, is limited to the point of physical care in a physician practice, it could be well controlled with this approach. However, with the open boundaries due to different modes of delivery, especially with fast digitalization of the system (mHealth or eHealth), consistency issues are also dependent on software developers in charge of data generation and their migration, and social or medical devices. Experimental designs of such cost studies will be useful for national policymakers only if they reach the validation stage in the different modes of delivery.

Such cost studies remain also important inside healthcare organizations, on limited samples or scales (e.g., for drug review committees for guiding their decisions). They can also be useful for other applications in healthcare, such as listing committees for revision of formularies (Ontario study) or for subcommittees in charge of approval of emerging technologies (Thailand, since ICIUM 2004, Chiang Mai).

However, as "Rs" consistency indices are usually lacking in judgment studies on economics and medical decision-making, an approach with axioms, such as the one developed by mathematical economists, may apply to "reversed conjoint models". This was discussed at the ORAHS meeting in 2018.

Further development may rely on methods developed within this EURO Society in Europe or the INFORMS Society in the USA, where data analytics is a major field. The next section highlights which advances, discussed in working groups since 2016, may be of use for cost sensitivity simulators and decision tools (with the original reversed conjoint algorithm, within a broader category known as Discrete Choice Experiments).

3.3. Discussion on Consistency and Transitivity with Mathematical Axiomatic Systems

Recent developments of axiomatic systems by economists, especially from Trento and Budapest universities, have been presented at the EWG-MCDA meetings, especially during the period 2019-2022. They bring important scientific discussion to combining the series of axioms for consistency and transitivity. This research stream on axiomatic systems is led by mathematical economists attending the working groups within EURO Society.

The axiom system presented at Trento University [19] originally included six axioms, called P1 to P6. This research team has discussed the conditions to obtain consistency and transitivity in pairwise comparisons from multicriteria methods. Table 1 provides a list of this comprehensive set of axioms for inconsistency and which axioms were relevant for the physicians' cost study, using a reversed conjoint algorithm. The Trento research team demonstrated that if the first five properties for consistency indices are satisfied, transitivity cannot be verified (or it cannot reach transitivity). Then, the working group explored how to combine consistency and transitivity and the conditions that may allow both consistency and transitivity, namely if the property P5 on continuity is excluded. The argument would be that for small changes, a system can verify at the same time the set of axioms for consistency and transitivity. This development on the axioms is worth considering for applications in economic and medical systems. Several properties of axiomatic systems were used in the physicians' reversed conjoint study. Table 1 provides the first three axioms applied in the cost sensitivity studies; other axioms were not used in the studies.

Table 1. Properties of Axiomatic Systems for Conjoint Estimations Used in the Reversed Conjoint Physicians' Study

Property	Application in the study
P1: Test the degree of inconsistency of preferences	Yes, but only within a country.
P2: Test the stability	Yes, stability across clinical vignettes in each country.
P3: Test the monotonicity and intensity	Intensity of responses varies among health systems; issues of interstate or federal levels in the design of reimbursement systems.
P4: Test of monotonicity	N.A.
P5: Test of continuity	N.A.
P6: Invariance of preferences	N.A.

Source: [2] (following ORAHS, Oslo, 2018).

3.4. New Axioms for the Axiomatic Systems of MCDA Methods

Another development on axiomatic systems concerns the use of two additional axioms; they were presented at the Budapest working group meeting in 2021 [20], and some ideas were then explored in Prof. Huttin's communication at the same meeting. However, this development is more useful for the inclusion of choice modeling (using DCEs) into the economic model than for the reliability of the reversed conjoint algorithm, with cost cues and/or economic variables. This recent axiomatic development may be relevant for some discrete choice experiments in economic models for health or medical systems. It may be useful for consistency indices in multicriteria methods using a triad approach. This approach was used in physicians' discrete choice experiments, especially in the experimental study by Huttin and Hausman [21], which includes a choice set of three alternatives on diabetic drugs, with two alternatives on types of pharmacotherapies (alternatives 1 and 2) and a third alternative of no drug.

The series of discrete choice models, with this triad approach, has been considered for an economic model on medical markets during Prof. Huttin CC's visits to Prof. J. Hausman at MIT. The recent specification tests proposed by Hahn, Hausman, and Lustig [22] were also coded for the simulated economic (supply/demand) model of this medical market. The computation of this specification test also uses a triad approach; it allows checking whether removing one alternative among the three in the choice set of three alternatives (A, B, C) would not have any effect on the choice between the two remaining alternatives.

Therefore, recent research on inconsistency indices in pairwise comparisons with a triad approach may be useful for further development of the choice models and decision tools and is worth exploring. However, a comprehensive series of choice sets will still be needed to complement the first drug choice set of the diabetic study by Huttin and Hausman.

The next section presents a summary of the axiomatic development discussed during the EURO working group meetings. The research community of operational research has many contributions on consistency and inconsistency indices, especially for pairwise comparisons; the discussion in this section of the paper is limited to the domain of triads, namely, pairwise comparison matrices with only three alternatives. Csato et al.'s extension of the economic axiomatic system on pairwise comparisons for triads may contribute to the decision tools for medical markets. So, it is important to understand the ideas behind the two new axioms, called Axioms 7 and 8 [20,23]:

Axiom 7: Homogeneous Treatment of Alternatives (HTA)

"According to homogeneous treatment of alternatives, if the first and the second alternatives are equally important on their own and compared to a third alternative, then the inconsistency of the results in the triad should not be influenced by the relative importance of the new alternative."

Axiom 8: Scale Invariance (SI)

"Scale invariance implies that inconsistency is independent of the mathematical representation of the preferences."

With these two new axioms, the author introduces the notion of relative importance between each alternative; for instance, "moderately more important" is coded by numbers such as 2, 3, 4.

(1) On optimization of indices, see, for instance, [24], Optimal consistent approximation of a preference matrix in decision making.

(2) On dynamic consistency and intertemporal choices, see, for instance, [25], for some empirical evidence on dynamic inconsistency.

The new scale axiom implication is illustrated by an example used for the choice set of the physician choice model between three alternatives. In the study by Huttin and Hausman [21], physicians had the choice between three alternatives listed as A, B, and C. The main choice for the physician was to decide whether to have a patient on pharmacotherapy (A, B) or no drug therapy (C); if these axioms apply, it would mean that when we introduce the option C (the third option) not to prescribe any drugs, we would need to check whether the choice between drug therapy A or drug therapy B would be impacted. In addition to the econometric test used for the choice experiment [22], Casto's team proposes to consider the relative importance between alternatives.

It can be illustrated by the diabetes choice model from Huttin and Hausman [21]. At the time of this study, there was an additional controversy on strategies between the two professions, clinicians and pharmacists: either having patients on preventive strategies with lifestyle change (physicians for some cases) versus a more secure strategy (often preferred by pharmacists) to have patients on drugs anyway (one oral agent such as Metformin).

The three alternatives of the drug choice set were:

- **Alternative A:** oral agent only
- **Alternative B:** combined therapy with insulin and an oral agent (including combined drugs)
- **Alternative C:** no drug

According to the recent axiom proposed by Casto et al. on scale invariance, it could be useful, then, to compare different triads, for instance, Triad T1 and Triad T2 of choice sets with three alternatives (Alt A, B, C), where the relative importance between the alternatives is different in T1 and T2.

In Triad T1

In a first triad, the relative importance between the three choices is the following:

A compared to C: A is "3 times" better than C (no drug)

B compared to C; B is "2 times" better than C (no drug)

$$\begin{array}{cc} \begin{matrix} \text{Alt A} & \text{B} & \text{C} \end{matrix} & \\ \begin{bmatrix} 1 & 1 & 3 \\ 1 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{bmatrix} & \begin{matrix} \text{Alt A} \\ \text{Alt B} \\ \text{Alt C} \end{matrix} \end{array}$$

In Triad T2

In the second triad, the relative importance is higher between the three choices:

A is judged 6 times better than C (no drug)

B is judged 4 times better than C

$$\begin{array}{cc} \begin{matrix} \text{Alt A} & \text{B} & \text{C} \end{matrix} & \\ \begin{bmatrix} 1 & 1 & 6 \\ 1 & 1 & 4 \\ 1/6 & 1/4 & 1 \end{bmatrix} & \begin{matrix} \text{Alt A} \\ \text{Alt B} \\ \text{Alt C} \end{matrix} \end{array}$$

If Alternatives A and B are equally important, there would be no change in preferences with the comparison with C.

For instance, to be on an oral agent only versus on an oral agent and an additional drug, there would be no difference if it is two times better or four times better than no drug. However, this is mainly to illustrate the reasoning of the axioms on the existing choice sets; it may be more relevant to explore the relevance of such axiomatic development according to levels of clinical risks in some disease stages; for instance, moderately severe, severe, very severe cases or low-, medium-, and high-risk cases within subgroups of the population. Moreover, in remote monitoring cases, this may be interesting for modifications of thresholds of targeted populations monitored, with critical performance points (90%, 80%, 70%), to check for lack of stability.

Conclusions

Cost Simulators and Optimization: Can Such Decision Tools Be Used for Optimization of Economic Systems?

The next milestone in this research line, if the previous steps can be sorted out in different contexts of research experiments, will be to consider how such simulation can be useful as a calibration method for the economic model and for better adjustment of the medical/health system with the economic system. The 2022 EURO conference in Helsinki introduced participatory modeling, especially with Prof. Hämäläinen's behavioral OR research stream [26]. The translation of participatory modeling for the application would need to combine the perspectives of diverse groups of economists, especially health economists, macroeconomists, and behavioral economists.

Economic evaluation for helping decision-makers in the choice of health and medical technologies followed the various methodological approaches of project evaluation, since Little and Mirrlees' early contributions in 1990 [27]; then, it was expanded by health economists in various ways under pharmacoeconomic evaluation techniques, the main ones are Cost of Illness studies and Burden of Disease [28], especially relevant for links with the cost sensitivity simulators, or other techniques of Cost-Benefit analysis, Cost-Effectiveness studies, Benefit-Risk ratios, and Incremental Cost-Effectiveness Ratios (ICERs). These tools are useful and implemented in various health systems; they structure a rule-based system and provide quantitative estimates for thresholds for different diseases and disease stages. Health Technology Assessment Agencies (HTAs), especially in regulated systems such as Europe, use these rules and may reach consensus through the network of HTAs at the European level. In more liberal systems such as the US system, there is no national HTA agency, but the Institute of Medicine (IOM) also refers to such thresholds to guide decisions for approval and reimbursement of medical and pharmaceutical technologies (e.g., use of QALYs).

However, the main source of conflicts inside the economic community is with macroeconomists, who cannot just follow the rule-based system for comparing technologies, even with criteria addressing equity and not only effectiveness or efficacy versus cost. For better welfare contract adjustments, some radical solutions have been suggested, not only by Big Tech firms. Medical markets have complex use of multiple algorithms from the supply and demand sides [29]. The idea of using random generators for pricing medical markets is an approach for rapid adjustment of markets, with the help of recent machine learning technologies and powerful results of studies with random generators in other markets, such as the financial markets.

Further research is needed to explore how the latest AI technologies can assist academic research experiments for policy-aiding tools for health, and especially in financing mechanisms. Researchers now apply them to experimental studies supporting economic models for medical decision-making, using HB estimators and random price generators. The study on physicians using a reversed conjoint model also remains a useful application for understanding the effects of economics on critical decision points in medical practices and inside the deployment of AI-based systems in healthcare.

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