THE SUSTAINABILITY OF THE LOMBARDIA HEALTH SYSTEM

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SUMMARY AND CONCLUSIONS

SUMMARY

THE RESEARCH AND ITS SCOPE

This research analyzes the epidemiological, demographic, economic and financial variation in the Lombardia Health System in the period 1997-2009, and it proposes a theoretical framework to assess its short-term effects and its long-term sustainability to the year 2050.

The epidemiological and economical metrics developed in the macro model focus in particular on the effects of demographic, economic and financial variation on specific hospital care epidemiological variables such as complexity, severity, hospitalization rate, average length of stay, quality, saturation and the number of acute care hospital beds.

The main challenge has been to develop a mathematical and statistical model to assess the short and long term conditions of static and dynamic equilibrium of a health system in general, and under which additional conditions can it re-equilibrate following a temporary exogenously caused disequilibrium to achieve a sustainable equilibrium.

Successively, the metrics of the model have been experimentally applied to the Lombardia Health System in the period 1997-2009, in order to assess both the short term effects and the long term sustainability thereof, and the resulting associations statistically tested with SAS 9.1.

All data sets derive from Regione Lombardia Servizio Epidemiologico e Informativo, Ministero del Tesoro e delle Finanze, ISTAT, Banca d'Italia, International Monetary Fund and OECD

The validity of the macro model at a micro level (single payor or provider) has not been tested.

We remark the fact that the approach undertaken in this work is somehow opposite to that of traditional public health economic studies, in particular OECD studies, since the latter focus on the economic effects of epidemiological and demographic variation, whereas we focus here on the epidemiological effects of exogenous demographic, economic and financial variation *per se*.

One additional postulate is worth mentioning: the author of this research considers the equity of a health system to be a fundamental value for its equilibrium and sustainability. The lack of health equity opens the door to epidemiological and, in the long term, demographic and economic discontinuities. As a lemma, in this research: *i*) demographic variation has always been considered exogenous, i.e. no form of control over demographic growth or immigration/migration has been taken into consideration; *ii*) economic resources are pooled and allocated equally on risk adjusted capitarian basis regardless of differences in individual or sub-group wealth.

THE STARTING POINT

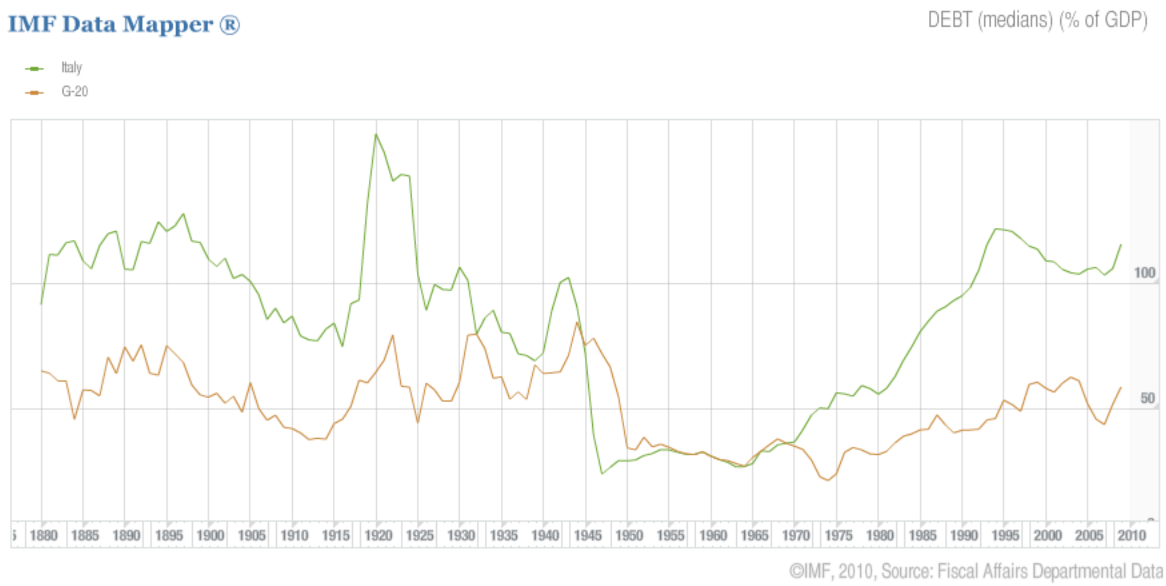
We began our research by looking at the broader picture of the fundamental Italian and Lombardia public finance economic and financial variables within the European context, before analyzing their epidemiological effects on the public health and health system, in particular that of Lombardia, and attempt an assessment, within the theoretical framework proposed, of whether such system is sustainable in the long-term.

Since the '70s, Italy has been characterized by a growing public Debt as percent of the Gross Domestic Product, with a growing gap with respect to advanced G-20 economies (Exhibit 1).

In the early ‘90s, such ratio has surpassed that of World War II, though still lower than that of World War I, with only a mild reduction in the late ‘90s and early 2000, as an effect of the Eurozone Debt and Deficit Convergence Criteria.

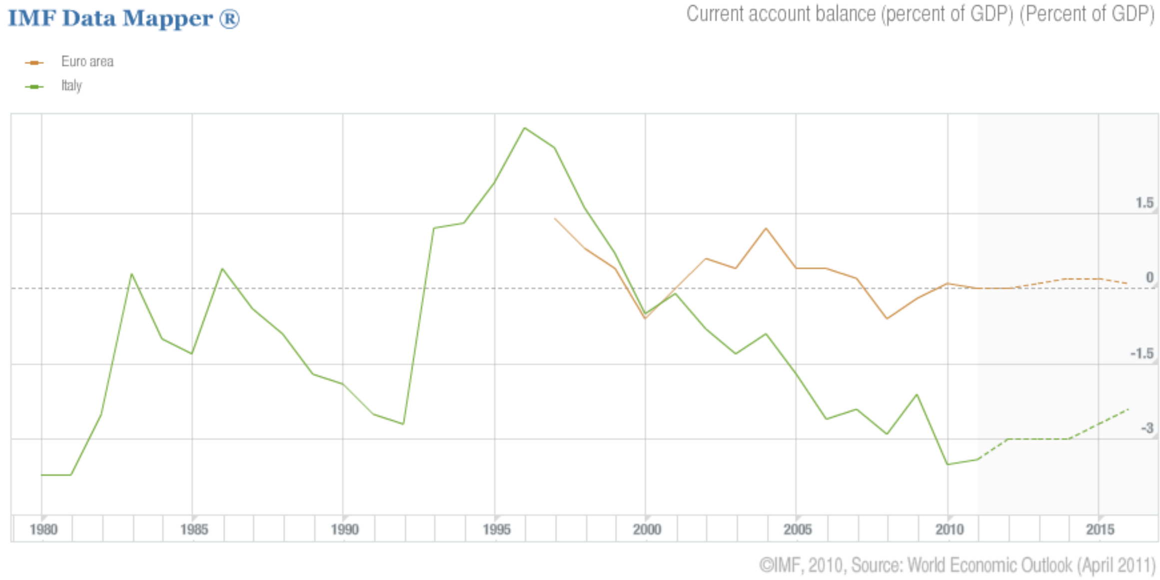
The world financial crisis of 2008 introduced an only temporary discontinuity, since, as can be evinced from Exhibit 1, the trend re-emerges in the year 2010, with an even steeper growth rate.

Exhibit 1: Debt as percent of GDP – Italy/G-20



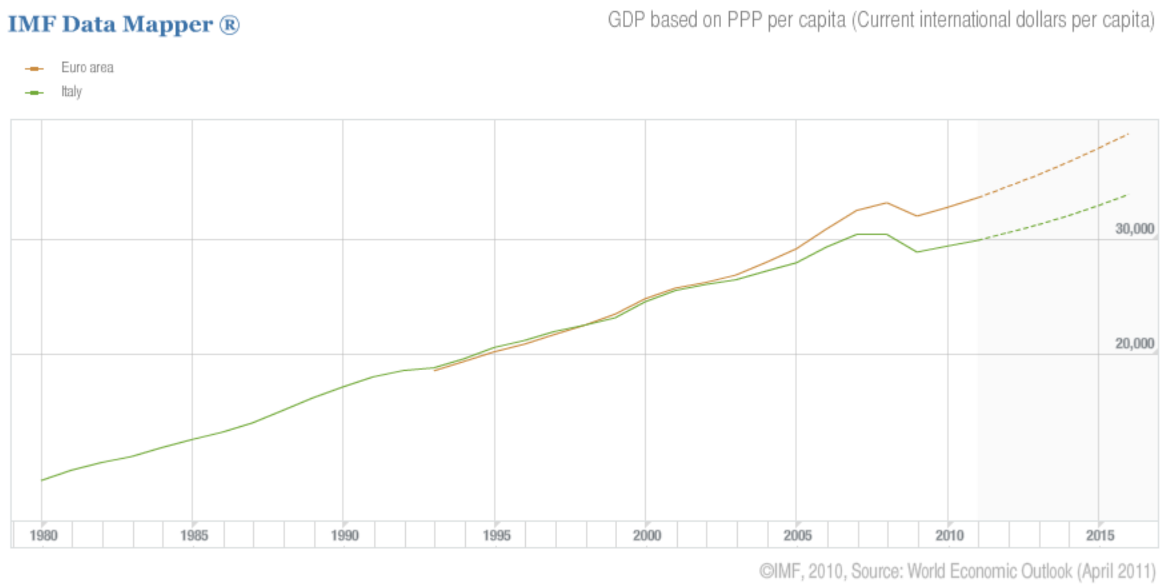
The introduction of the Euro in the year 2000, a stronger currency with respect to the former de-valuable Italian Lira, has progressively eroded the competitiveness of the Italian industrial system amongst the countries in the Euro area, and progressively worsened the balance between imports and exports (Exhibit 2).

Exhibit 2: Current account balance as percent of GDP – Italy/Euro Area



In the same period, fuelled by an exponentially growing public Debt (Exhibit 1), Italian *per capita* Gross Domestic Product has been growing steadily together with other Euro Zone economies, slowing down proportionally just after ca. 2005 (Exhibit 3).

Exhibit 3: GDP *per capita* – Italy/Euro Area



Since, from a budgetary point of view, Public Health and health Expenditure in Italy is financed through national pooling and capitarian redistribution of direct and indirect taxation, which, on its own turn, depends on *per capita* annual income which, ultimately, depends on the value of the goods and services produced by the economy, its growth should, at least in principle, follow that of *per capita* Gross Domestic Product.

Nevertheless, as far as Health Care is concerned, in Italy and Lombardia in the period 1997-2009 nominal Public Health Expenditure has been growing at an even faster rate than the national nominal Gross Domestic Product (Exhibit 4) while, on the contrary, nominal Public Hospital Financing has been growing at a slower rate in the same period.

Specifically, in 1997, Lombardia implemented a health reform with Legge Regionale 11 luglio 1997, n.31: “Norme per il riordino del servizio sanitario nazionale e sua integrazione con l’attività dei servizi sociali” following the national Decreto Legislativo 30 dicembre 1992, n.502:”Riordino della disciplina in materia sanitaria”. The essentials of the reform were: i) the abolition of the retrospective cost based payment system and the introduction of a prospective iso-resource complexity based reimbursement system, ii) the introduction of public health system accreditation rules equal for public and private providers and iii) competition between public and private providers. The main purposes of the reform were to reduce the waste of resources, to increase the value per euro of care and to reduce the growth of the health bill. (Exhibit 4)

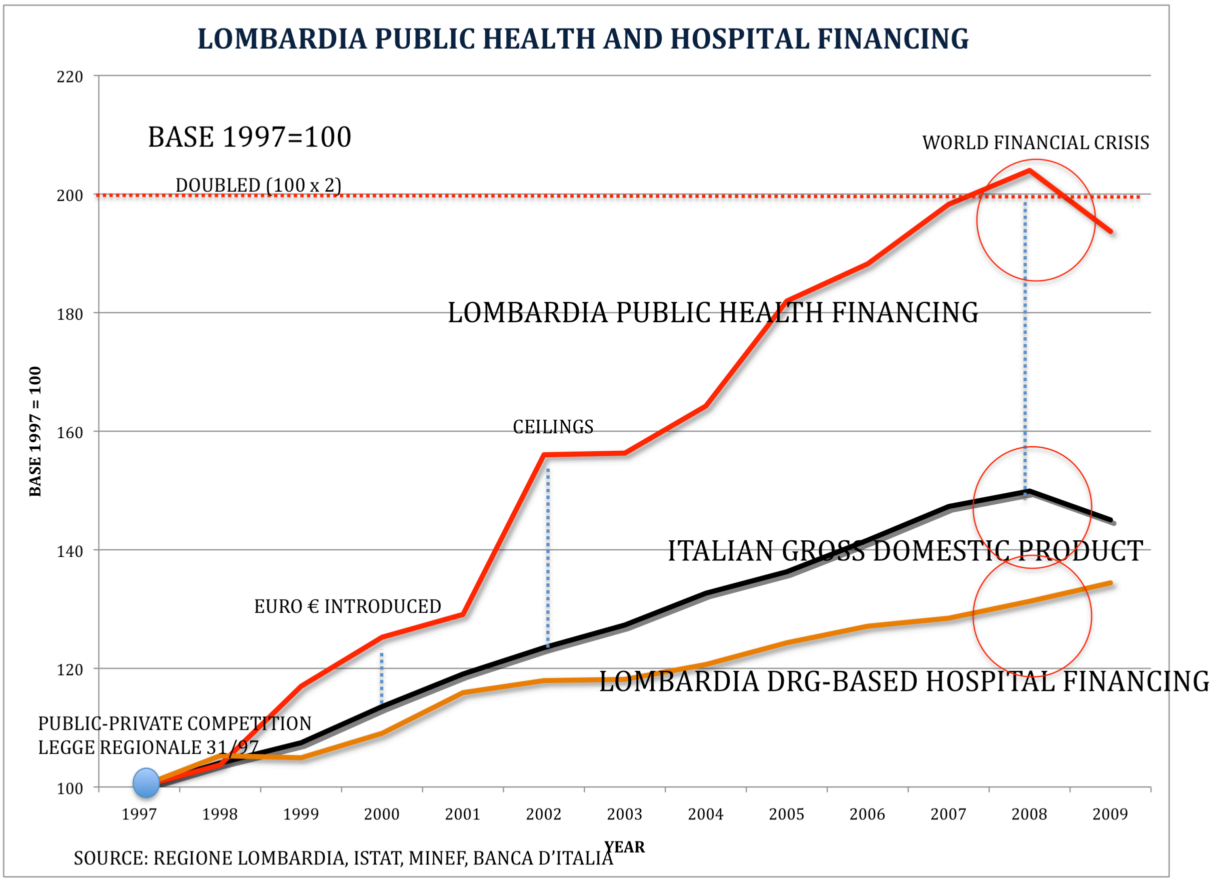
However some of the premises of the health reform have been left unattended.

Immediately after the reform, health expenditure has been growing not only steadily, but faster and faster.

Consequently, beginning in 2002-2003, a progressive system of budgetary caps on health expenditure (“ceilings”) has been introduced, with the purpose of financially curbing the exponential growth of health care costs. (Exhibit 4)

In 2009, following the world economic crisis of 2008, a sharp decrease marked both the growth rate of the Italian nominal Gross Domestic Product and that of Public Health Expenditure with, as we shall see, mixed epidemiological effects on the Lombardia Hospital System.

Exhibit 4: Lombardia Public Health and Hospital Financing



From this scenario two questions arise:

1. is this trend sustainable in Lombardia in the long-term, in this study to the years 2025 and 2050?

2. which are the epidemiological effects on the Lombardia Hospital System in the short and in the long term?

ECONOMIC AND FINANCIAL SUSTAINABILITY

In order to assess the sustainability of the Lombardia Hospital System, we developed a Sustainability Function, where epidemiological, demographic, economic and financial variables related to public health in general and to hospitals specifically are jointly related and analyzed in the period 1997-2009, and whose results are summarized in Exhibit 5.

Exhibit 5: The Sustainability Function in Lombardia in 1997-2009

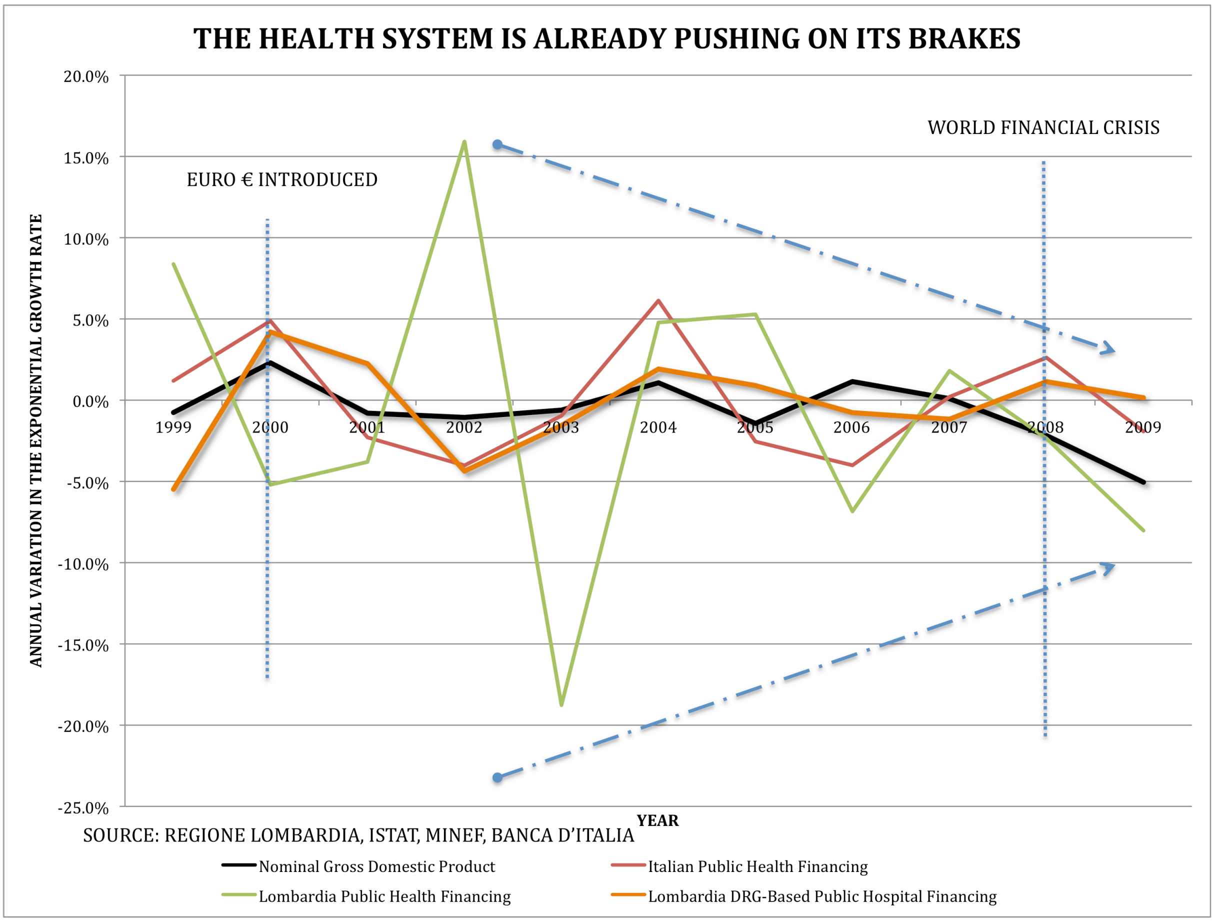
		1997	2009	GROWTH AS A FUNCTION OF TIME		GROWTH AS A FUNCTION OF EQUILIBRIUM		
SUSTAINABILITY FUNCTION	PERIOD	0	12	PEARSON CORRELATION COEFFICIENT	EXPONENTIAL GROWTH RATE - LINEAR REGRESSION	PEARSON CORRELATION COEFFICIENT	SLOPE - LINEAR REGRESSION	INTERCEPT - LINEAR REGRESSION
EQUILIBRIUM - PRO CAPITE WEALTH	**Y/Π**	**18,430**	**25,211**	**0.97**	**2.9%**	1.00	1.00	0.00
Intensity	v	2,603	3,526	0.96	2.3%	0.88	0.71	0.85
Average Complexity	w	0.94	1.15	0.91	1.9%	0.96	0.67	-6.61
Average DRG-Based Public Hospital Expenditure per Inpatient Case	**x_1**	**2,452**	**4,060**	**0.99**	**4.2%**	**0.97**	**1.38**	-5.77
Average Length of Stay - Inpatient Cases	x_2	8.90	9.16	0.15	0.1%	-0.07	-0.02	2.31
Average Public Hospital Expenditure per Inpatient Day-of-Stay	**x_3**	**275**	**443**	**0.97**	**4.1%**	**0.98**	**1.39**	-8.08
Hospitalization Rate (per 100)	h	0.17	0.12	-0.98	-2.7%	-0.95	-0.88	6.91
Lombardia Population Coefficient	x_d	0.16	0.16	0.99	0.3%	0.97	0.11	-2.90
Italian Public Health Spending Coefficient	x_a	0.05	0.07	0.98	2.3%	0.96	0.76	-10.38
Lombardia Public Health Spending Coefficient	x_b	0.15	0.15	0.33	0.4%	0.42	0.15	-3.43
Lombardia DRG-Based Public Hospital Spending Coefficient	**x_c**	**0.50**	**0.35**	**-0.94**	**-3.8%**	**-0.97**	**-1.30**	12.08
Lombardia DRG-Based Public Hospital Inpatient Spending Coefficient	x_{c-1}	0.87	0.86	-0.02	0.0%	-0.10	-0.01	-0.03
Lombardia DRG-Based Public Hospital Inpatient Spending Propensity	φ	0.00	0.00	-0.84	-1.1%	-0.91	-0.40	-1.75
EQUILIBRIUM - PRO CAPITE WEALTH	SE	18,430	25,211	0.97	2.9%	1.00	1.00	0.00

SOURCE: REGIONE LOMBARDIA, MINEF, TREASURY, ISTAT, BANCA D'ITALIA

Per capita nominal Gross Domestic Product (*Per capita* Wealth in Exhibit 5) has been growing at an average exponential growth rate of 2.9%, whereas Public Hospital Expenditure per Inpatient Case and per Day-of-Stay have been growing respectively at a significant exponential rate of 4.2% (1.45 times faster than the nominal Gross Domestic Product) and 4.1% (1.41 times faster than the nominal Gross Domestic Product).

In the same period, Regione Lombardia has been pushing on its brakes spending proportionally less and less on hospitals (-3.8%) (Exhibit 4) and progressively, possibly on a learning curve basis, stabilizing the oscillations of the yearly variation in the growth rate (Exhibit 6).

Exhibit 6: The health system is already pushing on its brakes



If doubts may legitimately arise in the first place as to the long-term economic and financial sustainability of a system whose expenses grow faster than the production of wealth - the combined effects of a growing-faster-than-GDP public hospital expenditure both per inpatient case and per day of stay, with a growing-slower-than-GDP share of the public health budget spent on hospital acute care, lead us directly to the next question: which are and will be the epidemiological effects on the Lombardia hospital system?

EPIDEMIOLOGICAL SUSTAINABILITY

In order to assess the epidemiological effects on the Lombardia Hospital System of the evolution of the demographic, economic and financial variables in the period 1997-2009, and its sustainability in the long term (2050), we developed two additional functions, with the purpose of relating the demographic, economic and financial variables of the Sustainability Function to the epidemiological variables of intensity, complexity, severity, hospitalization rate and quality: the Epidemiological Function and the Financial Function.

The idea at the basis of our work has been to assess the conditions under which the Epidemiological, Financial and Sustainability Functions are in short-term static and dynamic equilibrium or disequilibrium, if and how do these Functions re-equilibrate and under which additional conditions such equilibrium is maintained and is sustainable in the long term.

The final findings for the Epidemiological Function are summarized in Exhibit 7.

Exhibit 7: Epidemiological and Financial Function in Regione Lombardia in 1997-2009

		1997	2009	GROWTH AS A FUNCTION OF TIME		2050
	PERIOD	0	12	PEARSON CORRELATION COEFFICIENT	EXPONENTIAL GROWTH RATE - LINEAR REGRESSION	41
EPIDEMIOLOGICAL FUNCTION						
Italian Population	Π	56,904,379	60,340,328	0.96	0.5%	75,546,338
Lombardia Population		8,922,371	9,826,141	0.98	0.9%	14,079,036
Total Inpatient Cases		1,480,957	1,190,423	-0.95	-1.9%	554,713
Total Complexity		1,395,061	1,370,534	0.05	0.0%	1,388,726
Total Inpatient Days		13,180,517	10,909,155	-0.86	-1.8%	5,287,090
Lombardia Population Coefficient	xd	0.16	0.16	0.99	0.3%	0.19
Average Intensity	v	2,603	3,526	0.96	2.3%	9,171
Average Complexity	**w**	**0.9420**	**1.1513**	**0.91**	**1.9%**	**2.5035**
Average DRG-Based Public Hospital Expenditure per Inpatient Case	x_1	2,452	4,060	0.99	4.2%	22,959
Average Length of Stay - Inpatient Cases	x2	8.90	9.16	0.15	0.1%	9.53
Average Public Hospital Expenditure per Inpatient Day-of-Stay	x_3	275	443	0.97	4.1%	2,409
Inpatient Hospitalization Rate (per 100)	**h**	**17%**	**12%**	**-0.98**	**-2.7%**	**4%**
Lombardia DRG-Based Public Hospital Inpatient Epidemiological Function	H_e	3,631	4,833	0.98	2.4%	12,736
FINANCIAL FUNCTION						
Nominal Gross Domestic Product	Y	1,048,766	1,521,262	0.98	3.5%	6,321,415
Italian Public Health Financing		57,014	110,588	0.99	5.8%	1,199,345
Lombardia Public Health Financing		8,286	16,050	0.97	6.2%	201,396
Lombardia DRG-Based Public Hospital Financing		4,175	5,612	0.99	2.4%	14,825
Lombardia DRG-Based Public Hospital Inpatient Financing		3,631	4,833	0.98	2.4%	12,736
Italian Public Health Spending Coefficient	**xa**	**5%**	**7%**	**0.98**	**2.3%**	**19%**
Lombardia Public Health Spending Coefficient	x_b	15%	15%	0.33	0.4%	17%
Lombardia DRG-Based Public Hospital Spending Coefficient	**xc**	**50%**	**35%**	**-0.94**	**-3.8%**	**7%**
Lombardia DRG-Based Public Hospital Inpatient Spending Coefficient	x_{c-1}	87%	86%	-0.02	0.0%	86%
Lombardia DRG-Based Public Hospital Inpatient Spending Propensity	φ	0.35%	0.32%	-0.84	-1.1%	0.20%
Lombardia DRG-Based Public Hospital Inpatient Financial Function	H_f	3,631	4,833	0.98	2.4%	12,736

SOURCE: REGIONE LOMBARDIA, MINEF, TREASURY, ISTAT, BANCA D'ITALIA

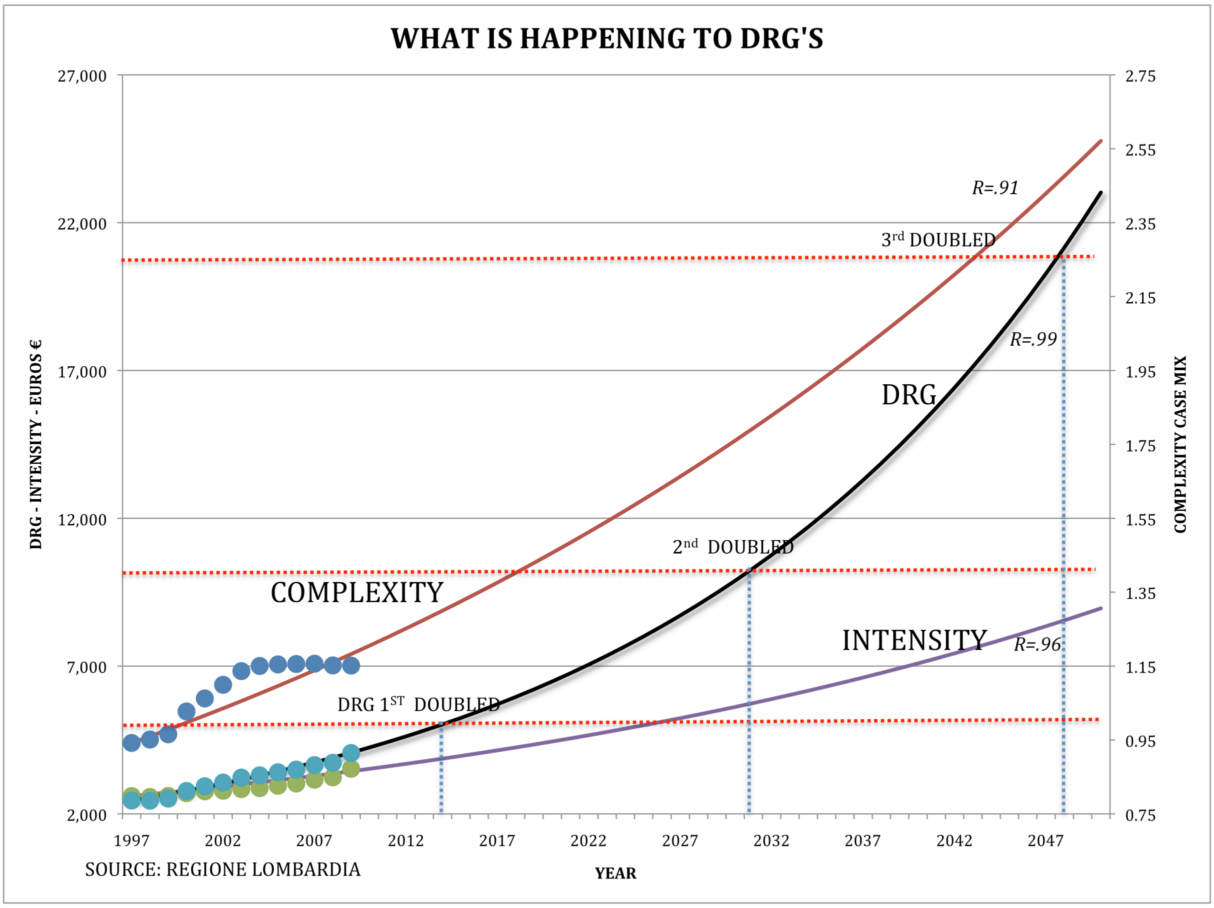
The table highlights the fact that the hospital system is characterized, from an epidemiological point of view, by a growing intensity (+2.3%) and complexity (+1.9%) of the acute care inpatient cases in the period 1997-2009, and on the other by a reduction in total inpatient days (-1.8%) and total inpatient cases (-1.9%).

This shift towards inpatient acuteness of care is not, however, matched by a willingness to spend proportionally more public money on hospitals, as highlighted by the Financial Function, where in fact the hospital inpatient spending propensity has decreased in the same period at a rate of -1.1%.

The evolution of these variables in the long-term (2050) is best summarized in graphic form.

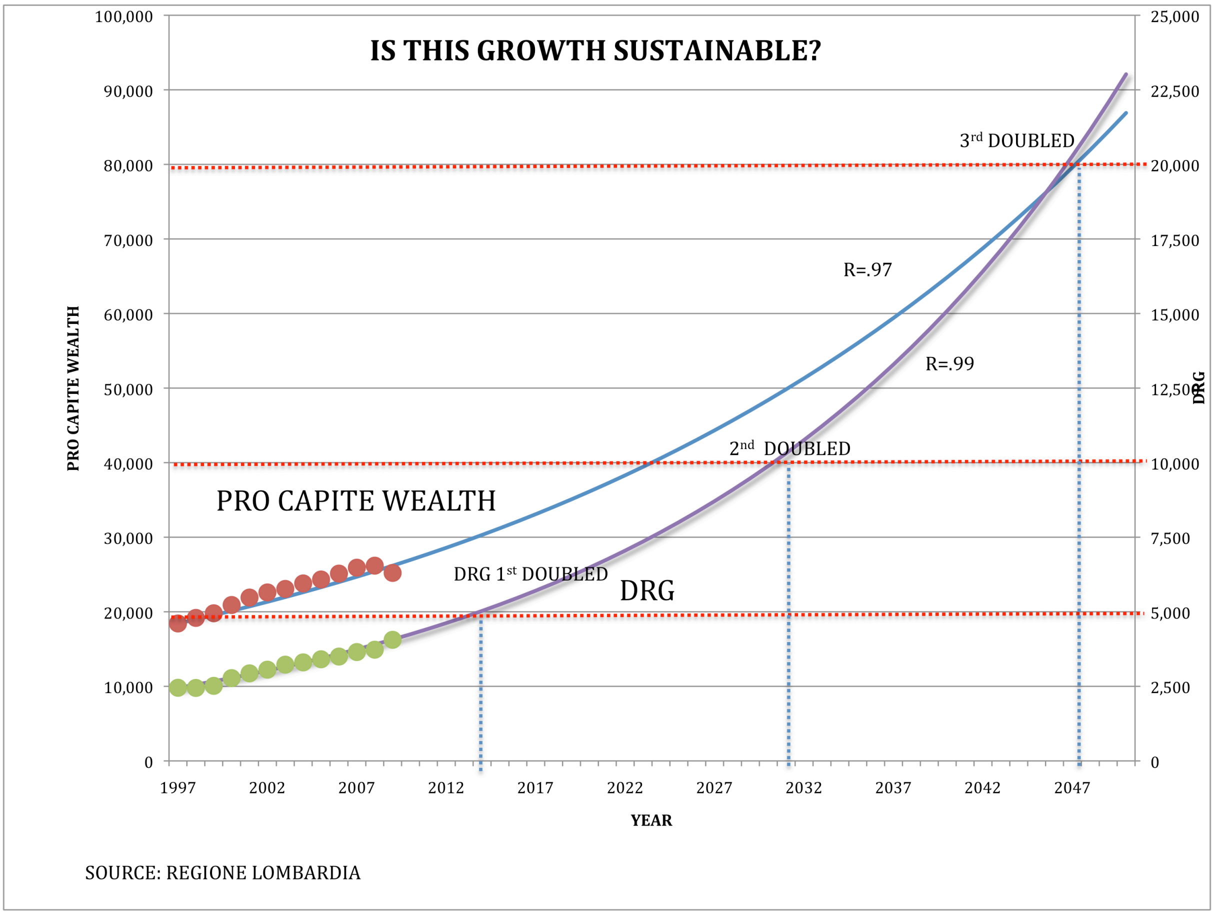
Exhibit 8 highlights the fact that, whereas in the period 1997-2009, the growth of acute cases complexity has somehow slowed down, the growth in intensity has continued relentlessly to grow, with the combined effect of increasing the average value of the prospective based reimbursement tariff per case presently in use in Lombardia (3M-Iso Resource Diagnoses Related Groups-DRGs) by 4.2% (Exhibit 7), which is higher than the growth of the National Goss Domestic Product (+3.5%), and which, at this exponential growth rate, will have doubled the first time sometime around the year 2015.

Exhibit 8: What is happening to DRGs?



In addition, the growth rate of the DRGs (+4.2%) is higher than that of *per capita* wealth (+2.9%) as highlighted by the sustainability function, rising further concerns about its long-term sustainability (Exhibit 9).

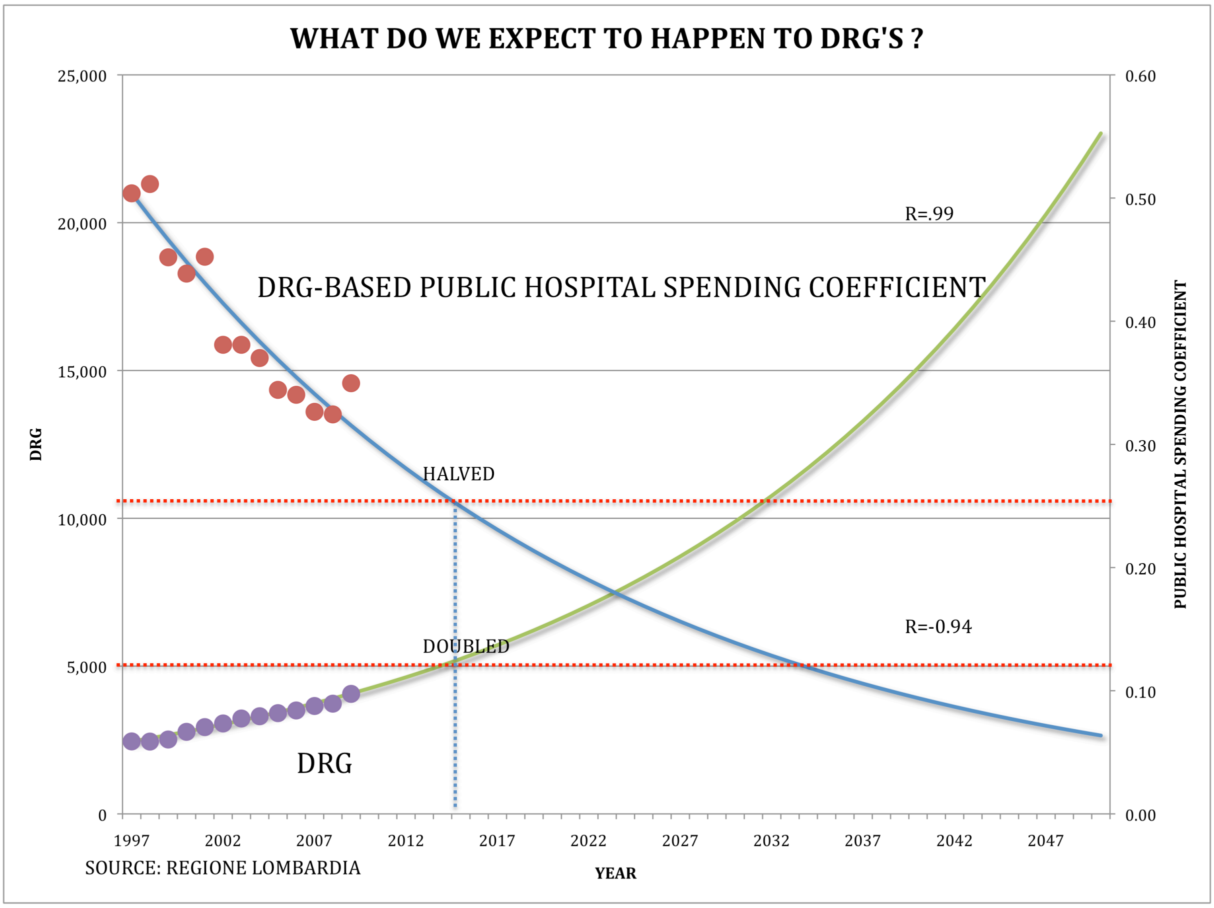
Exhibit 9: Is this growth sustainable?



This concern about long term sustainability is fortified by the reduction in *per capita* wealth which has followed the world financial crisis of 2008, as highlighted in graphic form in Exhibit 9.

The combined analysis of the long-term trend of the Epidemiological and Financial Function clarifies the present opposite trend between a reduction in the propensity to spend in hospitals and an increase in the reimbursement of acute care cases (Exhibit 10).

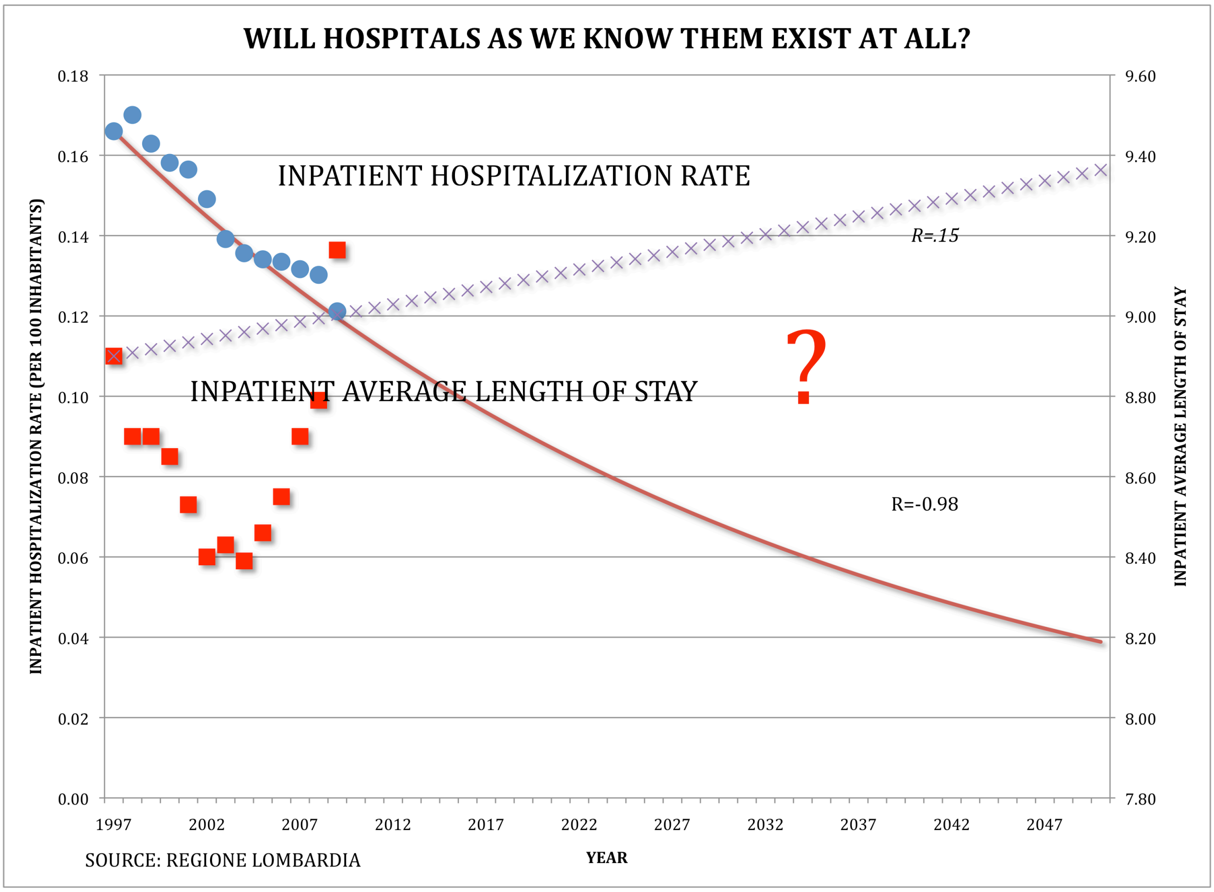
Exhibit 10: What do we expect to happen to DRGs?



The combined analysis of the epidemiological effects of demographic, economic and financial variation in the period 1997-2009, and the assessment of the sustainability of the Lombardia Hospital System to the year 2050, rises the additional question whether will hospitals as we know them exist at all in the future.

Exhibit 11 shows two epidemiological trends, the hospitalization rate, from which the number of hospital beds can be derived, and the average length of stay of acute care cases.

Exhibit 11: Will Hospitals as we know them exist at all?



Whereas the hospitalization rate has been steadily decreasing, the average length of stay does not have a clear trend.

In synthesis, the Lombardia Health System is heading toward proportionally less resources to the hospital system which, on the contrary, is facing increasing complexity and intensity.

The planning of hospital beds faces the conflicting trends of a reduction in the number of inpatient days without a clear decrease in the average length of stay.

LONG TERM SUSTAINABILITY AND QUALITY

The theoretical model developed incorporates also a conceptual framework for the analysis of the effects of demographic, economic, financial and epidemiological variation on the quality of the health system in terms of its effectiveness and efficiency.

The basic assumption is that quality is both a cause and an effect of the equilibrium and sustainability of a health system.

In other words, a health system where quality is not pursued is not sustainable in the long term, and the pursuit of quality, both in terms of effectiveness and efficiency, will guarantee sustainability.

This introduces the iterative nature of quality, equilibrium and sustainability.

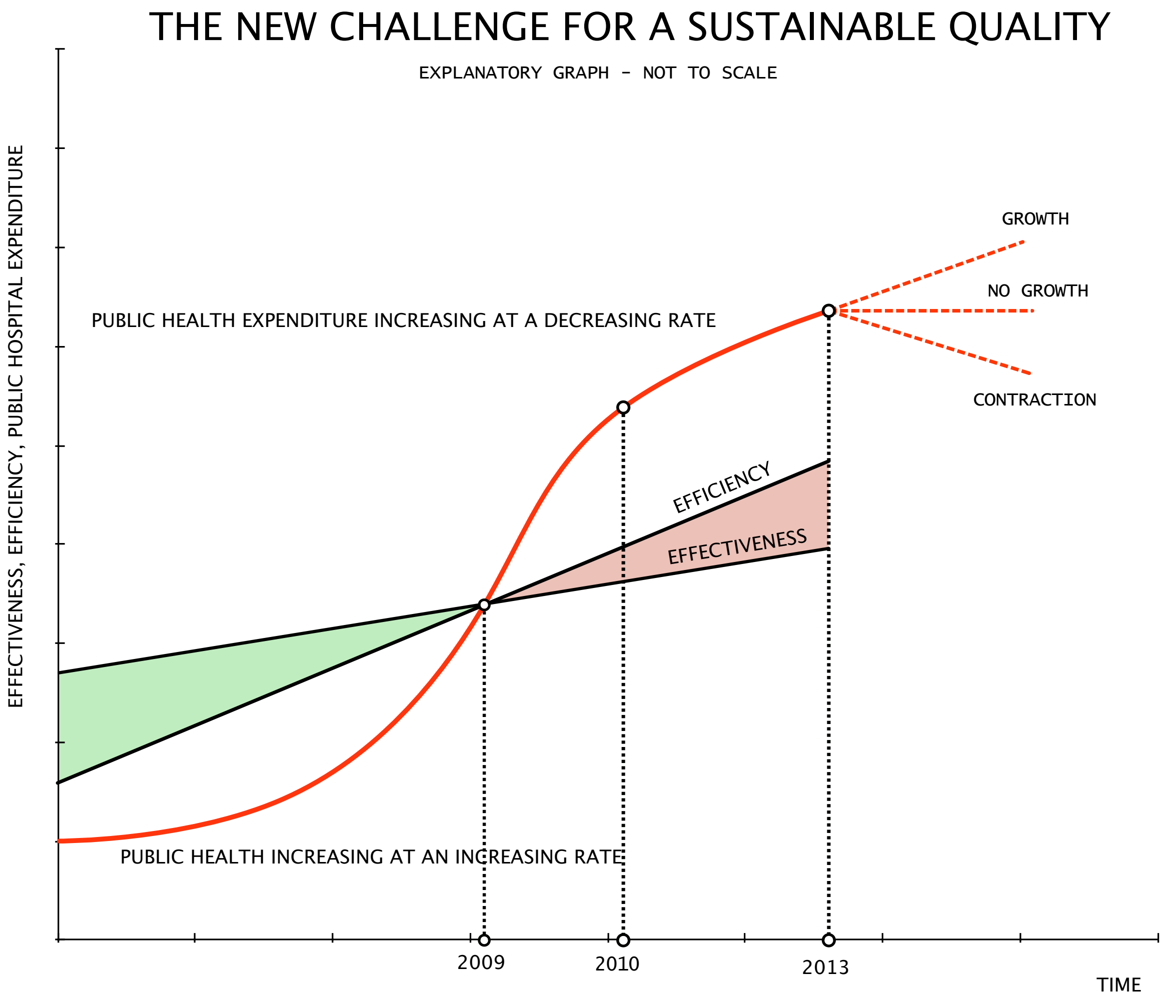
The model, however closely linked and based on the basic postulates and findings of the Equilibrium and Sustainability Model, and for this treason included in this research, will not be applied empirically for two reasons:
1. a quantitative and synthetic measure of the effectiveness of the Lombardia hospital system in terms of outcomes utilizable in the epidemiological function has not been achieved yet, even if public health researchers of the CRISP (Centro di Ricerca Interuniversitario per i Servizi di Pubblica Utilità) have already determined, for other independent purposes, the fundamental parameters.
2. the analytical tools required for its comprehension require an advanced training in the mathematics of Bayesian and Nash Equilibria in Games Theory, which, from a strictly methodological point of view, is beyond the scope of this work.

The Quality Theoretical Model is summarized in graphic form in Exhibit 12 (Explanatory Graph – Not to Scale).

The reduction in the growth rate of public health expenditure in 2009, following the world financial crisis of 2008, will imply a growing focus on efficiency in the assessment of the quality of care, while a growing public expenditure in the period 1997-2008 has allowed a higher focus on effectiveness with respect to efficiency, as has been the case in Lombardia.

In the model, in the long term a growing effectiveness of care is attainable by a health system only under the condition, hence the Bayesian postulate, that the budgeted goals of efficiency are attained as well.

Exhibit 12



WHAT IS HAPPENING IN THE ITALIAN AND LOMBARDIA HEALTH SYSTEM IN 2011 AS WE PUBLISH THIS RESEARCH ?

This research began in 2008 just when the World Financial Crisis suggested the quite simple question: what is going to happen to publicly financed health systems and what epidemiological effects shall this crisis produce?

The principal functions were, albeit still in experimental form, defined by the beginning of 2009, and immediately thereafter the excessive growth of public health expenditure, with respect to the evolution of the underlying epidemiological, demographic and financial variables, was assessed. There followed the consideration that such growth was not sustainable, and that at least some financial intervention was necessary, with a consequent prediction, afforded by the metric of the model, on its effect on the epidemiological variables.

In this respect, the datasets successively released in the years 2009, 2010 and 2011 by Regione Lombardia Servizio Epidemiologico e Informativo, Ministero del Tesoro e delle Finanze, ISTAT, Banca d'Italia, International Monetary Fund and OECD relative to the years 2007, 2008, 2009 and, lately, 2010, have been both treated as bases for a refinement of the fundamental functions, and as evidence of the predictive value of the model itself.

Coherently, as further evidence, we hereafter reproduce the latest Documento di Economia e Finanza 2011 – Programma Nazionale di Riforma of the Italian Ministero del Tesoro e delle Finanze, in particular the section dedicated to public health expenditure.

From a static point of view, Exhibit 13 and 14 show that the reduction of Italian public health expenditure, in particular the reduction of personnel, is amongst the main goals of the reform.

Exhibit 13: Documento di Economia e Finanza 2011 – Programma Nazionale di Riforma

SOURCE: MINISTERO DELL’ECONOMIA E DELLE FINANZE

IT		Descrizione delle misure								Classificazione delle misure		
		Misura	Riferimenti normativi	Descrizione della misura	Stato di implentazione	Stato di avanzamento	Data di inizio	Data fine	Impatto sul bilancio pubblico	Bottleneck	Europe 2020 target	Anual Growth Survey actions
16	Contenimento della spesa pubblica	Misure per il contenimento della spesa pubblica sanitaria.	Intesa Stato - Regioni del 3 dicembre 2009, nonché art. 9, co. 16 e art. 11 co. 5 del D.L. 78/2010	Si rafforza la *governance* nel settore sanitario e in particolare si prevede una manovra nel settore sanitario pari a 1.018 milioni di euro per l'anno 2011 e 1.732 milioni di euro a decorrere dall'anno 2012 per effetto di misure di contenimento della spesa per il personale e della spesa farmaceutica.	Iniziato	Operativo	2010		Nel periodo 2009-2013 la spesa sanitaria raggiungerà un tasso di crescita annuale del 2,9%. Nel periodo 2005-2009 il tasso di crescita annuo è stato del 3,6%. Il finanziamento statale al SSN è pari a: 103.461 mln di euro nel 2009, 105.565 nel 2010 e 106.800 nel 2011.	**Bottleneck n. 1** Consolidamento fiscale e debito pubblico		Consolidamento fiscale
17	Contenimento della spesa pubblica	Riforma della legge di bilancio	A. L. 196/2009 B. AC 3921-B C. Delega art.30 L. 196/09	A. Nuova normativa del bilancio pubblico con tempi e contenuti più certi; contenimento della spesa pubblica; B. Modifiche alla L. 31 dicembre 2009, n. 196, conseguenti alle nuove regole adottate dall'Unione Europea in materia di coordinamento delle politiche economiche degli Stati Membri; C. Tracciabilità della spesa in conto capitale e monitoraggio delle opere pubbliche.	A. Approvata B. Approvata C. Implementazione in corso	Operativo	A. 2010 B. 2011 C. 2010	C. II Trim. 2012	Per la predisposione della Banca dati unitaria (art. 13) sono stati stanziati 10 mln di euro per il 2010, 11 mln di euro per il 2011 e 5 mln di euro a decorrere dal 2012.	**Bottleneck n. 1** Consolidamento fiscale e debito pubblico		Consolidamento fiscale
18	Mercato dei prodotti, concorrenza e efficienza amministrativa	Concorrenza e apertura dei mercati	D.lgs. 59/2010 - attuazione della Direttiva Servizi	Con il D.lgs. 26 marzo 2010, n. 59, é stata recepita nel nostro ordinamento la Direttiva 2006/123/CE. Con esso sono state effettuate precise scelte volte a favorire la semplificazione e la libera concorrenza nel mercato dei servizi.	Pubblicato in G.U	Operativo			Senza oneri aggiuntivi	**Bottleneck n. 3** Mercato dei Prodotti - Concorrenza ed efficienza amministrativa	Tasso di occupazione	Liberare le potenzialità del mercato unico
19	Mercato dei prodotti, concorrenza e efficienza amministrativa	Concorrenza e apertura dei mercati	Regolamento n. 713/2009 che istituisce un’Agenzia per la cooperazione fra i regolatori nazionali dell’energia, Direttive 2009/72/CE e 2009/73/CE in materia di energia elettrica e gas naturale, e i Regolamenti n. 714/2009 e n. 715/2009 in materia di accesso alla infrastrutture di trasmissione/trasporto.	Al fine di garantire la sicurezza degli approvvigionamenti del sistema gas e l'equilibrio tra domanda e offerta sul mercato nazionale nonchè della qualità e del livello di manutenzione delle reti, il MISE emana una serie di atti di indirizzo. In particolare, con decreto da adottare entro 18 mesi dall'entrata in vigore dal decreto di recepimento sarà individuata una procedura trasparente e non discriminatoria per la realizzazione di nuova capacità di produzione elettrica.	D.lgs. approvato dal CdM del 3 marzo 2011 (esame preliminare)	Operativo			Senza oneri aggiuntivi	**Bottleneck n. 3** Mercato dei Prodotti - Concorrenza ed efficienza amministrativa	Tasso di occupazione	Liberare le potenzialità del mercato unico
20	Mercato dei prodotti, concorrenza e efficienza amministrativa	Regime fiscale estero	D.L. 78/2010	Riduzione oneri amministrativi; applicazione del regime fiscale estero per imprese della UE.	Iniziato	Operativo	2010			**Bottleneck n. 3** Mercato dei Prodotti - Concorrenza ed efficienza amministrativa	Tasso di occupazione	Liberare le potenzialità del mercato unico
21	Mercato dei prodotti, concorrenza e efficienza	Zone a 'Burocrazia Zero'	D.L. 78/2010	Istituzione di aree con vincoli amministrativi ridotti nel Mezzogiorno.	Iniziato	Operativo	2010		Senza oneri aggiuntivi	**Bottleneck n. 5** Ridurre le disparità regionali	Tasso di occupazione	Liberare le potenzialità del mercato unico

Exhibit 14: Documento di Economia e Finanza 2011 – Programma Nazionale di Riforma

TABLE 2.10: EFFECTS OF DECREE-LAW 78/2010 CONVERTED INTO LAW 122/2010, FOR THE MAIN SECTORS AFFECTED- (in € mn including induced effects)

	2010	2011	2012	2013
Title I				
CHAPTER I - REDUCTION OF SPHERE AND COST OF GENERAL GOVT.	45	1,423	2,058	2,708
10% reduction of expenditures that can be reconfigured	0	1,400	2,050	2,700
Other	45	23	8	8
CHAPTER II - REDUCTION OF POLITICAL & ADMINISTRATIVE COSTS	181	-53	-51	39
Proceeds from the shutdown of entities	150	0	0	0
Other	31	-53	-51	39
CHAPTER III	-436	8,836	14,224	15,693
Containment of expenditure on public-sector work force	-81	1,696	2,683	3,286
Personnel turnover: central government economic bodies	*0*	*8*	*65*	*230*
Reduction in financing of National Healthcare Service for personnel	*0*	*418*	*1,132*	*1.132*
Contractual holiday pay and freeze on wage adjustment	*0*	*4*	*597*	*597*
Freeze on automatic wage increases for 2011-2013 three-year period	*0*	*98*	*172*	*264*
Freeze on automatic wage increases for 2010-2011-2012 - Schools	*0*	*320*	*640*	*960*
Reduction of expenditures on personnel having contracts with expiration date	*0*	*100*	*100*	*100*
Armed forces and police	*0*	*770*	*0*	*0*
Other measures	*-81*	*-22*	*-23*	*4*
Containment of expenditure on healthcare, assistance and pensions	-355	1,390	3,591	4,457
Plan to control disability claims	*0*	*80*	*160*	*220*
Reduction of expenditure on pharmaceuticals and healthcare cards	*-250*	*580*	*580*	*580*
Revision of requirements for qualifying for an ordinary retirement pension and an early retirement pension	*0*	*360*	*2,610*	*3.650*
Severance pay	*-100*	*390*	*240*	*0*
Other measures	*-5*	*-20*	*1*	*7*

SOURCE: MINISTERO DELL’ECONOMIA E DELLE FINANZE

From a dynamic point of view, Exhibit 15 highlights the fact that the Italian Ministry of Finance is intervening in allowing public health expenditure to grow only at a definite percent of the nominal Gross Domestic Product (circa 7.2%) (Exhibit 16), which, in other words, means that it cannot grow faster than the national wealth, as predicted by the Sustainability Function of the model.

Exhibit 15: Documento di Economia e Finanza 2011 – Programma Nazionale di Riforma

TABELLA II.2-1 CONTO ECONOMICO DELLE AMMINISTRAZIONI PUBBLICHE (VALORI IN MILIONI)

	2010*	2011	2012	2013	2014
SPESE					
Redditi da lavoro dipendente	171.905	171.090	170.693	170.840	172.191
Consumi intermedi	137.009	137.425	138.857	142.366	147.081
Prestazioni sociali	298.199	306.200	313.630	324.940	336.540
Pensioni	236.931	244.630	252.100	260.790	270.740
Altre prestazioni sociali	61.268	61.570	61.530	64.150	65.800
Altre uscite correnti	62.349	62.392	60.622	61.029	61.416
Totale spese correnti netto interessi	**669.462**	**677.107**	**683.802**	**699.175**	**717.228**
Interessi passivi	70.152	76.087	84.023	91.313	97.605
Totale spese correnti	**739.614**	**753.194**	**767.825**	**790.488**	**814.833**
di cui: Spesa sanitaria	*113.457*	*114.836*	*117.391*	*122.102*	*126.512*
Totale spese in conto capitale	**53.899**	**48.691**	**45.217**	**46.037**	**45.956**
Investimenti fissi lordi	31.879	31.230	27.014	27.816	28.192
Contributi in c/capitale	20.442	17.826	16.058	16.109	16.104
Altri trasferimenti	1.578	-365	2.145	2.112	1.660
Totale spese netto interessi	**723.361**	**725.798**	**729.019**	**745.212**	**763.184**
Totale spese finali	**793.513**	**801.885**	**813.042**	**836.525**	**860.789**
ENTRATE					
Tributarie	445.416	457.066	476.544	492.008	507.935
Imposte dirette	225.494	230.221	242.320	250.379	257.940
Imposte indirette	216.530	226.272	233.645	241.043	249.401
Imposte in c/capitale	3.392	573	579	586	594
Contributi sociali	214.508	219.820	225.447	230.813	237.360
Contributi sociali effettivi	210.460	215.701	221.267	226.574	233.060
Contributi sociali figurativi	4.048	4.119	4.180	4.239	4.300
Altre entrate correnti	58.583	58.472	60.513	61.948	63.536
Totale entrate correnti	**715.115**	**734.785**	**761.925**	**784.183**	**808.237**
Entrate in conto capitale non tributarie	3.795	4.608	5.678	5.998	6.069
Totale entrate finali	**722.302**	**739.966**	**768.182**	**790.767**	**814.900**
Pressione fiscale	*42,6*	*42,5*	*42,7*	*42,6*	*42,5*
Saldo primario	**-1.059**	**14.168**	**39.163**	**45.555**	**51.716**
Saldo di parte corrente	**-24.499**	**-18.409**	**-5.900**	**-6.305**	**-6.596**
Indebitamento netto	**-71.211**	**-61.919**	**-44.860**	**-45.758**	**-45.889**
PIL nominale	**1.548.816**	**1.593.314**	**1.642.432**	**1.696.995**	**1.755.013**

*Dati 2010 provvisori: fonte ISTAT

Exhibit 16: Author's elaboration on Documento di Economia e Finanza 2011 – Programma Nazionale di Riforma

	2010	2011	2012	2013	2014
PUBLIC HEALTH EXPENDITURE	113,457	114,836	117,391	122,102	126,512
NOMINAL GROSS DOMESTIC PRODUCT	1,548,816	1,593,314	1,642,432	1,696,995	1,755,013
PUBLIC HEALTH EXPENDITURE AS PERCENT OF nGDP	**7.33%**	**7.21%**	**7.15%**	**7.20%**	**7.21%**
SOURCE: MINISTERO DELL'ECONOMIA E DELLE FINANZE					

However, if savings are to be made, the underlying epidemiological effects (increase in complexity, invariance in the acute inpatient cases length of stay, increase in intensity) have not been addressed yet, which introduces the bi-faced question if such savings are sustainable or if their epidemiological effects are acceptable.

In this regard, the Epidemiological Function, analyzed in its simultaneous equilibrium with the Financial Function, offers a viable tool for the prediction of the epidemiological effects of the nationally planned health budget interventions necessary to re-equilibrate the public health accounts.

CONCLUSIONS

The *cœteris paribus* trend of growth of the Lombardia Hospital System epidemiological, demographic, economic and financial variables analyzed in this research in the period 1997-2009 is not sustainable in the long-term, for the purpose of this research to the year 2050.

Even if in the period 2002-2009 some financial and epidemiological adjustment has indeed been attempted (as highlighted by the Financial Function), in particular with yearly activity budgetary financial constraints and compulsory transfers from acute to ambulatory care (as highlighted by the Epidemiological Function), by means of which short-term financial equilibrium has temporarily been maintained, this same adjustment does not guarantee long-term epidemiological, demographic, economic and financial sustainability (as highlighted by the Sustainability Function).

The Italian Ministero dell'Economia e delle Finanze is indeed intervening in curbing the growth rate of public health expenditure by fixing it at a definite percent of the national gross domestic product (circa 7.2%). Most of the savings are based on the reduction of personnel.

Since health funds are pooled and equally allocated on a risk adjusted capitarian basis, the same savings will be required on the part of Lombardia.

However, if savings are to be made, the underlying epidemiological trends (increase in complexity, invariance in the acute inpatient cases length of stay, increase in intensity), as highlighted by the Epidemiological Function, have to be addressed as well, which introduces the bi-faced question if such savings are sustainable or if their epidemiological effects are acceptable.

If there is an almost general consensus among both health operators and regulators in Italy and Lombardia that both effectiveness and efficiency are the main drivers of the long term sustainability of a health system, it appears from the first applications of the model presented here that the Italian and Lombardia Hospital System is still governed by a tendency to manage the short term effects of rising medical, labor and variable costs in general, than by a much more challenging direct intervention into the epidemiological and operational parameters governing the health system in the long term.

Certainly, an excellent clinical effectiveness has been achieved, even if, in order to be sustainable in the long term, increases in clinical quality must be proportional to the reduction in the economic waste of financial resources, both in the form of excess costs of the public providers and excess profits in the private ones.

Once again, the authors of this paper argue that there can be no health without equity, no equity without quality, and no quality without sustainability.

Contents

SUMMARY 2
THE RESEARCH AND ITS SCOPE 2
THE STARTING POINT 3
ECONOMIC AND FINANCIAL SUSTAINABILITY 7
EPIDEMIOLOGICAL SUSTAINABILITY 9
LONG TERM SUSTAINABILITY AND QUALITY 14
CONCLUSIONS 21
THE LIMITS OF GROWTH 40
GROWTH, EQUILIBRIUM AND SUSTAINABILITY 42
The Association Between Quality and Epidemiological, Demographic, Economic and Financial Variables in Public Health Literature 42
Demographic, Epidemiological, Economic and Financial Sustainability 45
THE SPACE AND TIME OF A HEALTH SYSTEM 46
The Space of a Health System 46
Time in a Health System 47
Equilibrium in a Health System 47
The Space and Time Continuum 48
METHODOLOGY 48
Circularity and Regression 48
Circularity and *Continuum* 49
The Principle of Computational Equivalence 50
Exponential *versus* Logistic Growth 50
Debt *51*
Public Health Expenditure *52*
Efficiency, Effectiveness and Composite Quality 53
Intrinsic and Extrinsic Quality 54
The Universal Coverage Postulate 55
The Theory of Quality, Equilibrium and Sustainability 55
SUSTAINABLE HEALTH QUALITY AND RESTRICTED NASH EQUILIBRIUM WITH A REDISTRIBUTION AGREEMENT 57
INTRINSIC QUALITY 59
Intrinsic Effectiveness (q) 59
Intrinsic Efficiency (L) 62
Note *63*
Intrinsic Composite Quality (Q) 63
The Intrinsic Composite Quality Function (ICQF) 64
EXTRINSIC QUALITY 65

Extrinsic Effectiveness (q) 65
Extrinsic Efficiency (L) 66
The Extrinsic Composite Quality Function (ECQF) 67

COMPOSITE QUALITY OPTIMIZATION 67

THE EPIDEMIOLOGICAL FUNCTION (EF) 70
Epidemiological Variables 71
Quality Variables 72
Demographic Variables 73
Transformation Variables 73
The X_1 Hyper-Plane Vector In A Prospective Payment Health Financing System 73
The X_1 Hyper-Plane Vector In A *Per Diem* Health Financing System 74
Example 74
Application 75
Conclusions 77

THE FINANCIAL FUNCTION (FF) 77
Financial Variables 78
The Capitation Unified Allocation System xb 78
The Health Spending Propensity φ And The Relative Propensity Φ 80
Example 80
Application 1 81
Constant Health Spending Propensity 82
Application 2 83
Conclusions 84

THE EFFICIENCY ADJUSTED FINANCIAL FUNCTION (EAFF) 85
NOTE 85
Conclusions 85

THE ECONOMIC FUNCTION (ECF) 86
The Economic Variables 86
The Case Mix Adjusted Cost Per Admission *v* (CMAA) 87
Example 1 88
Example 2 89
Example 3 89
The Indifference Coefficient (A) Between Public and Private Provision of Health Care 89
Example 4 90
Application 91
Conclusions 91

THE EFFICIENCY FUNCTION (L) 92
Example 92
Conclusions 93

GENERAL EQUILIBRIUM (GE) 94
Static Equilibrium (SE) 94
Application 95
Conclusions 96
Dynamic Equilibrium (DE) 96
Application 98
Conclusions 99
Dynamic Disequilibrium (DD) 100
Static Initial Disequilibrium 100
Example 101
Application 101

Dynamic Disequilibrium 101
Example 1 .... *102*
Example 2 .... *103*
Application *103*
Conclusions *104*
Dynamic Re-Equilibrium (DR) 105
Example *106*
Application *106*
Conclusions *107*
General Equilibrium (GE) 107
Application *108*
Conclusions *109*

GENERAL SUSTAINABLE EQUILIBRIUM (GSE) 110
The Sustainability Function (SF) 110
Application *111*
Conclusions *112*
General Sustainable Equilibrium (GSE) 113
Application *114*
Conclusions *116*

EXTRINSIC QUALITY IN GENERAL SUSTAINABLE EQUILIBRIUM 117
The Isoquantum Quality Function (IQF) 117
Example *118*
Application *119*
The Extrinsic Composite Quality Function (ECQF) in General Sustainable Equilibrium 119
Lemma 1 .... *120*
Lemma 2 .... *120*
Lemma 3 .... *121*
Conclusions *122*
The General Definition of the Epidemiological Function (EF) 122
Example 1 .... *123*

THE THEORETICAL QUALITY DISTRIBUTION (TQD) 125
Example *126*
Conclusions *128*

THE ACTUAL COMPOSITE QUALITY DISTRIBUTION 128
Example *128*
Conclusions *129*

THE QUALITY VECTOR MODEL 130
The Displacementof the Health System From Optimum Composite Quality 130
Example 1 .... *132*
The Relative Velocity ω of the Health System Towards Optimum Composite Quality 133
Example 2 .... *133*
Conclusions *134*

TOTAL COMPOSITE QUALITY 135
Application *136*

THE VECTORS X1 AND X3 IN TERMS OF TOTAL COMPOSITE QUALITY 136
Application *137*
Conclusions *138*

THE AVERAGE LENGTH OF STAY (ALOS) X2 138

THE ROLE OF THE ALOS X2 IN A PROSPECTIVE AND *PER DIEM* PAYMENT SYSTEM....139
PROVIDERS' MARGINAL UTILITY (MU)....140
PROVIDERS' ISOSTATIC (ISCU), ISODYNAMIC (IDCU) AND TOTAL CUMULATIVE UTILITY (TCU)....141
Example 1....143
Example 2....143
Example 3....144
Application....144
Conclusions....145
TOTAL PATIENT DAYS (D)....145
Application....147
THE DIMENSIONING OF HOSPITAL BEDS CAPACITY....147
HOSPITAL BEDS FINANCING....148
Application....149
Conclusions....151

Exhibits

Exhibit 1: Debt as percent of GDP – Italy/G-20 4
Exhibit 2: Current account balance as percent of GDP – Italy/Euro Area 4
Exhibit 3: GDP per capita – Italy/Euro Area 5
Exhibit 4: Lombardia Public Health and Hospital Financing 7
Exhibit 5: The Sustainability Function in Lombardia in 1997-2009 8
Exhibit 6: The health system is already pushing on its brakes 8
Exhibit 7: Epidemiological and Financial Function in Regione Lombardia in 1997-2009 10
Exhibit 8: What is happening to DRGs? 11
Exhibit 9: Is this growth sustainable? 12
Exhibit 10: What do we expect to happen to DRGs? 12
Exhibit 11: Will Hospitals as we know them exist at all? 13
Exhibit 12 16
Exhibit 13: Documento di Economia e Finanza 2011 – Programma Nazionale di Riforma 17
Exhibit 14: Documento di Economia e Finanza 2011 – Programma Nazionale di Riforma 18
Exhibit 15: Documento di Economia e Finanza 2011 – Programma Nazionale di Riforma 19
Exhibit 16: Author's elaboration on Documento di Economia e Finanza 2011 – Programma Nazionale di Riforma 21
Exhibit 17: Debt as % of GDP: Current and Projected 51
Exhibit 18: Total Debt and Deficit, Current 52
Exhibit 19: Italian Nominal Public Health Expenditure 1995-2013 53
Exhibit 20:Composite Quality Optimization 68
Exhibit 21: Lombardia Epidemiological Function (EF) 76
Exhibit 22: Lombardia Financial Function (FF) 81
Exhibit 23: Italy Financial Function (FF) 83
Exhibit 24: Lombardia Static Equilibrium (SE) 95
Exhibit 25: Lombardia Dynamic Equilibrium (DE) 98
Exhibit 26: Lombardia Dynamic Disequilibrium (DD) 104
Exhibit 27: Lombardia Dynamic Re-Equilibrium (DR) 106
Exhibit 28: Lombardia General Equilibrium (GE) 108
Exhibit 29: Lombardia Sustainability Function (SF) 112
Exhibit 30: Lombardia General Sustainable Equilibrium: LN(F(t)) 115
Exhibit 31: Lombardia General Sustainable Equilibrium: F[1] 115
Exhibit 32: Lombardia General Sustainable Equilibrium: Total Differential 116
Exhibit 33: Lombardia Isoquantum Quality Function (IQF) 119
Exhibit 34: Optimum Composite Quality in General Sustainable Equilibrium 122
Exhibit 35: (Lq) Coordinate System 126
Exhibit 36: Composite Quality Theoretical Distribution (TQD) 127
Exhibit 37:Plot of the Theoretical Quality Distribution (TQD) 127
Exhibit 38: Composite Quality Actual Distribution (AQD) 129
Exhibit 39: Plot of the Actual Composite Quality Distribution (R) 129
Exhibit 40: QUALITY VECTOR MODEL REFERENCE FRAME 131
Exhibit 41: Displacement of the Health System from Optimum Quality 132
Exhibit 42: Plot of the Displacement of the Health System from Optimum Quality 132
Exhibit 43: Relative Velocity in the QUALITY VECTOR MODEL 133
Exhibit 44: Lombardia Total Composite Quality 136
Exhibit 45: Lombardia Vectors x1 and x3 137

Exhibit 46: Plot of the Isostatic, Isodynamic and Total Cumulative Utility 143
Exhibit 47: Lombardia the Isostatic, Isodynamic and Total Cumulative Utility 145
Exhibit 48: Lombardia Total Patient Days (D) 147
Exhibit 49: Lombardia Hospital Beds Equivalent – All Hospitals 149
Exhibit 50: Lombardia Hospital Beds Equivalent – Private Hospitals 150
Exhibit 51: Lombardia Hospital Beds Equivalent – Public Hospitals 151

Equations

Equation 1: Health Quality in a Restricted Nash Equilibrium with a Redistribution Agreement 57
Equation 3: Intrinsic Effectiveness 60
Equation 2: Standard Weighted Intrinsic Effectiveness 60
Equation 4: Intrinsic Composite Quality Function (ICQF) 64
Equation 5: Elasticity of Q on q 64
Equation 6: Elasticity of Q on L 64
Equation 7: Composite Quality Function Gradient Vector 65
Equation 8: Composite Quality Function Taylor Second Order Linear Transformation 65
Equation 9: Extrinsic Effectiveness (q) 66
Equation 10: Extrinsic Composite Quality Function (ECQF) 67
Equation 11: Composite Quality Optimization 68
Equation 12: Epidemiological Function (EF) 70
Equation 13: X1 Vector In A Prospective Payment System 73
Equation 14: X1 Vector In A Per Diem Payment System 74
Equation 15: Financial Function (FF) 77
Equation 16: General Definition of the Financial Function (FF) 79
Equation 17: Health Spending Propensity 80
Equation 18: Constant Health Spending Propensity 83
Equation 19: Efficiency Adjusted Financial Function (EAFF) 85
Equation 20: Economic Function (ECF) 86
Equation 21: Beta of Losses and 87
Equation 22: Case Mix Adjusted Cost Per Admission (CMAA) 87
Equation 23: Indifference Coefficient (A) 90
Equation 24: Efficiency Function (L) 92
Equation 25: Static Equilibrium (SE) 95
Equation 26: Condition of Dynamic Equilibrium (DE) 97
Equation 27: Cumulative Dynamic Equilibrium (DE) 98
Equation 28: Condition of Static Initial Disequilibrium 100
Equation 29: Static Initial Disequilibrium-Debt 101
Equation 30: Condition of Dynamic Disequilibrium (DD) 101
Equation 31: Dynamic Disequilibrium-Debt 102
Equation 32: Cumulative Dynamic Disequilibrium 102
Equation 33: Condition of Dynamic Re-Equilibrium (DR) 105
Equation 34: Dynamic Re-Equilibrium-Debt 105
Equation 35: Condition of General Equilibrium 108
Equation 36: Sustainability Function (SF) 111
Equation 37: Total Differential of Sustainability Function (SF) 114
Equation 38: Condition of General Sustainable Equilibrium (GSE) 114
Equation 40: Extrinsic Effectiveness q in Terms of the SF 117
Equation 41: Isoquantum Quality Function (IQF) in GSE 119
Equation 42: Theoretical Composite Quality Distribution (TCQD) 126
Equation 43: Vector R0 in the QUALITY VECTOR MODEL 130
Equation 44: Displacement R0 in the QUALITY VECTOR MODEL 131
Equation 45: Maximum Displacement R0 in the QUALITY VECTOR MODEL 131
Equation 46:Relative Velocity in the QUALITY VECTOR MODEL 133
Equation 47: Total Composite Quality 136

Equation 48: Total Number of Hospital Patients 138
Equation 49: Total Number of Patient Days 138
Equation 50: Average Length of Stay (ALOS) 138
Equation 51: Average Length of Stay in Terms of Complexity and Severity 139
Equation 52: Total Number of Patient Days in Terms of the Intensity of Care and the per diem Reimbursement 139
Equation 53: Vector x3 in Terms of the Financial Function FF and Total Composite Quality TCQ 139
Equation 54: Vector x3 in terms of Vector x1 and the ALOS x2 139
Equation 55: Condition of Indifference between a Prospective and a per diem Reimbursement Payment System 140
Equation 56: Marginal Utility in a per diem Payment System 141
Equation 57: Marginal Utility in a Prospective Payment System 141
Equation 58: Isostatic Cumulative Utility (ISCU) 141
Equation 59: Isodynamic Cumulative Utility (IDCU) 142
Equation 60: Total Cumulative Utility (TCU) 142
Equation 61: Total Patient Days (D) in Terms of Total Composite Quality 146
Equation 62: Number of Hospital Beds Equivalent in General Sustainable Equilibrium 148
Equation 63: Hospital Beds Financing in a per diem Payment System 148
Equation 64: Hospital Beds Financing in a Prospective Payment System 149

Definitions

Definition 1: Demographic Variation — 49
Definition 2: Principle Of Computational Equivalence — 50
Definition 3: Exponential Versus Logistic Growth — 50
Definition 4: Universal Coverage Postulate — 55
Definition 5: Restricted Nash Equilibrium with a Redistribution Agreement — 57
Definition 6: Intrinsic Effectiveness (q) — 59
Definition 7: Proxy Effectiveness Indicators — 61
Definition 8: Intrinsic Efficiency (L) — 62
Definition 9: Composite Quality (Q) — 63
Definition 10: Intrinsic Composite Quality Function (ICQF) — 64
Definition 11: Composite Quality Optimization — 67
Definition 12: Epidemiological Function (EF) — 70
Definition 13: Financial Function (FF) — 77
Definition 14: Constant Health Spending Propensity — 82
Definition 15: Efficiency Adjusted Financial Function (EAFF) — 85
Definition 16: Economic Function (EcF) — 86
Definition 17: Efficiency Function (L) — 92
Definition 18: Static Equilibrium (SE) — 94
Definition 19: Dynamic Equilibrium (DE) — 96
Definition 20: Dynamic Disequilibrium (DD) — 100
Definition 21: Dynamic Re-Equilibrium (DR) — 105
Definition 22: General Equilibrium (GE) — 107
Definition 23: Sustainability Function (SF) In Terms Of The Wealth Of The System — 110
Definition 24: Sustainability Function (SF) In Terms Of The Nominal Gross Domestic Product (nGDP) — 111
Definition 25: General Sustainable Equilibrium (GSE) — 113
Definition 26: Condition Of General Sustainable Equilibrium (GSE) — 114
Definition 28: Isoquantum Quality Function (IQF) — 117
Definition 29: QUALITY VECTOR MODEL — 130
Definition 30: Marginal Utility in a Per Diem Payment System — 140
Definition 31: Marginal Utility in a DRG-based Payment System — 141
Definition 32: Isostatic Cumulative Utility (ISCU) — 141
Definition 33: Isodynamic Cumulative Utility (IDCU) — 142
Definition 34: Total Cumulative Utility (TCU) — 142
Definition 35: Hospital Bed Equivalent (HBE) — 148

Glossary

GREEK LETTERS FOLLOW ROMAN ALPHABETICAL ORDER

0^{th} = the optimum composite quality (Q) point with Lq coordinates (1,1)

A = indifference coefficient from the inefficiency (L) point of view between a for-profit and not-for-profit health care provider

AQD = actual composite quality distribution in the QUALITY VECTOR MODEL

B = the losses or excess profits of the ith-provider determined in the interval $B \geq 0$

Cact = Total Actual Costs – The Total Actual Cost of health care for the patient population that is associated with a group of providers

Cstd = Total Standard Costs – The Total Standard Cost of health care for the patient population that is associated with a group of providers. The Cstd includes a reasonable return on capital for the investor[a]

CAGR = compound annual growth rate (also i), where if *r* is the exponential growth rate, $i = e^{r} - 1$

Dem = demographic variables in general

diag = a measure of the diagnoses per patient[1], defined in the interval (diag≥1)[b]. For example in Lombardia the ICDM classification of diseases is in use, and the 3M HCFA Grouper transduces the ICDM codes into DRGs[2]

D = total number of inpatient days

Dem = demographic variables in general

Epi = epidemiological variables in general

E* = the *per capita* wealth of a nation

Eco = economic variables in general

EAFF = Efficiency Adjusted Financial Function. The relationship between the financial and the efficiency variables

EcF = Economic Function. The relationship between costs and the financial variables

ECQF = Extrinsic composite quality function is the value of the composite quality function when the health system is in General Sustainable Equilibrium

EF = Epidemiological Function. The relationship between the epidemiological variables

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[a] the definition of a health investment risk premium β is not analyzed in this paper.
[b] in Italy the diagnoses per patient increased from 2.0 in 1998 to 2.4 in 2008 (EXP= 0.0180) [Ministero della Salute 2010].

EXP = exponential growth rate (also r)

Extrinsic effectiveness and efficiency = the effectiveness and efficiency of the health system in a condition of General Sustainable Equilibrium

ε = the elasticity of Q on q and L

Fin = financial variables in general

FF = Financial Function. The relationship among the financial variables

φ = the percentage of the national Nominal Gross Domestic Product Y* dedicated to a particular health care sub-sub-system, defined in the interval ($0 \leq \varphi \leq 1$). In the application to Lombardia φ corresponds to the percentage of the Lombardia health care expenditure allocated to hospital care

G = is the maximum value of *g*(q,L)

GE = General Equilibrium

GSE = General Sustainable Equilibrium

h = the cumulative health care utilization rate per 100[c] members of the population, defined in the interval ($0 \leq h \leq 1$). In the case of hospital care, *h* is the number of admissions in percent of the resident population[d]

H_e = the Epidemiological Function (see EF)

H_f = the Efficiency Adjusted Financial Function (see EAFF)

H = public health care financing and expenditure in general

HBE = Hospital Bed Equivalent is the number of hospital beds necessary for a certain number of inpatient days at a predetermined saturation σ

i = compound annual growth rate (CAGR)

ISCU = Isostatic Cumulative Utility of the j-th provider in terms of the increase in case reimbursement from x1,1 to x1,2 when the Average Length of Stay x2 is unchanged

IDCU = The Isodynamic Cumulative Utility (IDCU) of the ith-provider in reducing x2 when x1 is unchanged, determined by the integral defined in the interval ($1 \leq x2 \leq ul$[e])

Intrinsic effectiveness and efficiency = the effectiveness and efficiency of the health system regardless of the General Sustainable Equilibrium

L = a measure of the inefficiency, or waste, in the utilization of the financial resources available, defined in the interval ($1 < L \leq 2$). The meaning of L is analyzed in detail in the chapter dedicated to Efficiency (L)

L* = the extrinsic inefficiency, or waste, of the health system in a condition of General Sustainable Equilibrium

L_{act} = the actual inefficiency of the health system

L_{std} = the standard or acceptable inefficiency of the health system

m = the intra-hospital mortality rate per 100 patients, defined in the interval ($0 \leq m < 1$).

---

[c] *h* is often defined *per* 10,000. Here we utilized the percent notation.
[d] Waiting lists affect effectiveness q.
[e] upper limit of ALOS

MU = marginal utility of the j-th provider in reducing the average length of stay in a prospective payment system and in increasing the average length of stay in a *per diem* payment system

ω = the relative velocity of the health system towards optimum effectiveness and efficiency

p and *i* = prevalence and incidence. Prevalence and Incidence are defined and accounted for in the EF according to the following definition:

$$i = \text{incidence}=\frac{\text{number of new cases of disease in the population in a definite period }(\Delta\Pi_M)}{\text{total number of healthy people at the beginning of the period}(\Pi-\Pi_{M_i})}$$

$$p = \text{prevalence}=\frac{\text{number of ill people in a definite period }(\Pi_{M_f})}{\text{population in a definite period}(\Pi)}$$

(Manzoli, Villari, Boccia. Epidemiologia. 2008:19-26, op. cit.)

$$u\text{=capacity utilization rate=}\frac{\text{number of ill people who utilize hospital services in a definite period }(\Pi_h)}{\text{number of ill people in a definite period }(\Pi_{M_f})}$$

h = hospitalization rate=up

$$\Pi = \Pi_{M_f} + (\Pi - \Pi_{M_f})$$

$$\Pi_{M_f} = \Pi_h + (\Pi_{M_f} - \Pi_h)$$

$$i = \frac{\Delta\Pi_M}{\Pi - \Pi_{M_i}}$$

$$p = \frac{\Pi_{M_i} + i\left(\Pi - \Pi_{M_i}\right)}{\Pi} = \frac{\Pi_{M_i} + \Delta\Pi_M}{\Pi} = \frac{\Pi_{M_f}}{\Pi}$$

$$h = up = \frac{\Pi_h}{\Pi_{M_f}} \cdot \frac{\Pi_{M_f}}{\Pi} = \frac{\Pi_h}{\Pi}$$

$$\Pi_h = up\Pi = h\Pi$$

P = total number of inpatient cases. Day hospital and day surgery cases are considered inpatients, whereas ambulatory and surgical ambulatory cases are considered outpatients

P_m = the number of deceased patients, where P_m+P_v=P, and $P=hx_d{}^*\Pi^*$. In fact:

$$\frac{h\Pi - P_m}{1-m} = \frac{P_v + P_m - P_m}{1-m} = \frac{P_v}{1-m} = h\Pi$$

Π^* = the demographic population (Π>0*)*

q = a measure of the effectiveness of the health system[f], defined in the interval (0<q≤1). The value and meaning of *q* when the health system is in a condition of General Equilibrium and General Sustainable Equilibrium is analyzed in detail in the Isoquantum Extrinsic Quality Function (IEQF) and the QUALITY VECTOR MODEL

Q = composite quality function, which is a function of both effectiveness and efficiency defined as *f*(q,L)

---

[f] The quality of the health outcomes will be analyzed in the chapter on the standardized weighted extrinsic quality parameter q.

q^* = the extrinsic effectiveness of the health system. $q=q_{std}=q^*$ only in a condition of General Sustainable Equilibrium

q_{act} = the actual effectiveness of a health system

q_{std} = the standard effectiveness of a health system. In the Theory of the Quality, Equilibrium and Sustainability of a Health System standard effectiveness corresponds to the desired effectiveness

QVM = Quality Vector Model

r = exponential growth rate (also EXP)

R = the actual composite quality point with coordinates (L_{act} ,q_{act})

s = a measure of the severity of the disease, defined in the interval (s>0). APR iso-severity DRGs utilize *s* in addition to *w* to determine the absorption of resources. In the case study of Lombardia, where an iso-resource and not an iso-severity prospective payment system is in use, *s* will be assumed equal to 1

σ = the saturation of the hospital beds

ther = a measure of the therapies per patient, defined in the interval (ther≥1)[g]. For example in Lombardia the ICDM classification of diseases is in use, and the 3M HCFA Grouper transduces the ICDM codes into DRGs

TCU = The Total Cumulative Utility (TCU) of the ith-provider in reducing x2 when x1,1 has been increased to x1,2

TQD = theoretical quality distribution in the QUALITY VECTOR MODEL

v = a measure of the intensity of resources required per unit of intensity of care *ws,* defined in the interval (*v*>0). In the DRG system the variable *v* is the Case Mix Adjusted Cost Per Admission (CMAA), a measure of a hospital's average cost per admission, adjusted for complexity, equal to a hospital's total reported costs divided by its total reported admissions divided by the hospital's CMI. *v* is an economic variable which is utilized in the epidemiological function H_e in order to transform the results in terms of resources utilized and render it comparable with the financial function H_f. The variable *v* will be analyzed in detail in the Economic Function

w =*f*(*d,t*) = Case Weight or Relative Case Weight – A Exhibit assigned to each DRG code which represents the expected resource utilization for that patient group compared to the average resource utilization for all patients. *w* can either determine complexity in iso-resource DRGs or any other convenient measure of intensity of care

x1 = represents a measure of all the resources absorbed per single patient, inpatient and outpatient

x2 = is the average length of stay (ALOS) of inpatients, defined in the interval x2≥1

x3 = is the *per diem* reimbursement, defined in the interval x3≥0

x_a = the percentage of Y* dedicated to health care, defined in the interval (0≤a≤1)

x_b = the Capitation Unified Allocation System (CUAS), defined as a percentage of x_aY^* dedicated to a particular health care sub-system, defined in the interval

[g] In Italy the therapies per patient increased from 1.6 in 1998 to 2.5 in 2008 (EXP=0.0450) [Ministero della Salute 2010].

($0 \leq xb \leq 1$). In the case study of Lombardia, x_b represents the percentage of national health resources allocated to Lombardia. A federal system would increase x_b

x_c = the percentage of $x_a x_b Y^*$ dedicated to a particular health care sub-sub-system, defined in the interval ($0 \leq xc \leq 1$). In the case study of Lombardia, x_c represents the percentage of Lombardia health resources allocated to hospitals

x_d = the proportion of the demographic population of a specific sub-system ($0 \leq x_d \leq 1$), for example the population of Lombardia

Y = the wealth of the system, defined in the interval: ($Y^* > 0$). The most common measure is the nominal gross domestic product of a nation (nGDP)

γi = the share of the national Nominal Gross Domestic Product Y generated by the sub-system i

ξ = a constant which accounts for particular conditions which justify a different reimbursement, defined in the interval $\xi > 0$

Peface

John Maynard Keynes introduces his brilliant exposition, The General Theory of Employment, Interest and Money[3] in the following terms:

> ‘This book is chiefly addressed to my fellow economists. I hope it will be intelligible to others. But its main purpose is to deal with difficult questions of theory, and only in the second place with the applications of this theory to practice. Thus I cannot achieve my object of persuading economists to re-examine critically certain of their basic assumptions except by a highly abstract argument and also much controversy’

Apart from substituting “Employment, Interest and Money” with “Quality, Equilibrium and Sustainability” and “economists” with “public health epidemiologists”, there is no better way to describe the aim of this paper.

This paper proposes a theoretical approach (a “theory”) of the mechanisms which determine the behavior of a health system in its pursuit of optimum quality while maintaining an economic and financial sustainable equilibrium.
The analysis has been applied to the Lombardia Health System in the period 1997-2008.
For practical purposes, a QUALITY VECTOR MODEL is suggested for those who are interested in monitoring quality within the conceptual framework proposed. The last part of the paper deals with some applications to some typical health planning problems.

Intoduction

Lombardia is the second largest region of Italy and economically the most developed producing about 25% of the GDP, with 9.5 million inhabitants on a surface of 25.000 square Km.

The Italian Health System is financed almost entirely by general taxation; the providers of health care are public and private, the latter both for- and not-for-profit.

In Lombardia a deep reform of the health system was started in 1997.

This research project started in 2009, as an ecological study of the epidemiological effects of such a reform in the period 1997-2008.

In particular the effects of the introduction of a DGR-based prospective payment system on the distribution and evolution of the quality of health services were considered.

Multiple, multivariate and time trend regressions of epidemiological data and quality proxies were analyzed and tested, yielding a patchwork of significant though apparently fragmented if not contradictory correlations.

In the meantime, during the end of 2009 and the beginning of 2010, as the global and, in particular, the European financial crisis got progressively worse, it became evident that a discontinuity was emerging in the period under scrutiny.

Some proxy indicators of health quality, and even some epidemiological data, such as the average complexity of diagnoses and therapies, appeared to be significantly affected by some unknown effects on the health system produced by the crisis. It appeared as if the health system, unable to waive its obligation to fulfill the health requirements of the population, was undergoing some kind of self adjustment in order to safeguard its equilibrium and comply with the terms of the different scenario surrounding it.

The concept that started to emerge was that the quality of a health system, both in terms of its effectiveness and efficiency, was linked by some kind of relationship to its epidemiological, demographic, economic and financial equilibrium and, in the long term, to the sustainability of such equilibrium.

Sustainability is in fact, and specifically the sustainability of a health system, not only a technical question, but an ethical, social and economic question as well, pertaining the values[4] a nation holds.

With the present research we intend to propose a theory of how a health system adjusts to exogenous variation in its pursuit of quality in terms of optimum effectiveness and efficiency.

In more detail:

- how is equilibrium affected by the effectiveness an efficiency of the health system?
- is optimum quality, in the end, sustainable in the long term? And if it is so, under which conditions?
- how does a health system behave in its micro and macro adjustment towards optimum quality in relation to the continuous exogenous variation of the financial and demographic limits and the continuous exogenous variation of the epidemiological and economic variables thereof ?

In other words, if, how and in which measure can a health system readjust endogenously, in order to limit the effects of exogenous intervention and eventual negative feedback, and how can quality be achieved endogenously without sacrificing the values of universal equality and accessibility to health care in the presence of limited resources?

We argue that the quality of a health system is sustainable if pursued through direct interventions to improve its efficiency and effectiveness and not by indirect intervention, i.e. simply by limiting the exogenous financial resources available and let the *internal markets* seek adjustment.

The present paper proposes a theory underlying the direction, nature and magnitude of such direct interventions.

Last, but not least, as far as the reader is concerned, we apologize for the innumerable repetitions and, not unlikely, contradictions, which he will have to possibly endure.

PART I
GROWTH

THE LIMITS OF GROWTH

The idea of sustainable growth has been preceded by the idea of the existence of a forthcoming limit to such growth.

In 1972 the Club of Rome in Geneva commissioned a study by the Massachusetts Institute of Technology (MIT)[5], with the purpose of assessing if limits to human development existed at all and, if they did exist, what would their impact in the long term be. The MIT concluded that only through endogenous controlled growth could the effects of exponential growth be limited and a state of global equilibrium be achieved and maintained throughout the year 2050.

In 1976 the Nobel Prize physicist Dennis Gabor published the research "Beyond the age of waste"[6], again commissioned by the Club of Rome in Geneva, where he revealed that, in order to secure sustainable growth. the exponential waste of resources had to be endogenously controlled through advancements in technology, in order not to set in motion exogenous feedback mechanisms which would severely hinder human development.

Other researchers in different branches of science have followed.

In the year 2000 the Georgetown University historian J.R. McNeill and senator P. Kennedy challenged the stability of twentieth century scientific, economic and ecological evolution[7].

In 2001, the Lucasian Professor of Physics at Cambridge University and Nobel Laureate Sir Stephen Hawking has questioned the predictability of the outcomes of human development, arguing that the effects of exponential biological growth will reach levels of unprecedented complexity[8].

In 2002 the Harvard University biologist Edward O. Wilson rose the issue of sustainability in its broader possible meaning, i.e. the future sustainability of life on the planet in face of the ongoing ecological plight[9].

As far as health is concerned, biomedical scientists and epidemiologists have concentrated mostly on the human health consequences of an aging population[10,11], of the depletion of ecosystems[12], on the consequent strengthening of health systems[13], on the right to health[14], on attaining universal coverage[15], on access to care[16], on the global interactions[17] in the quality of care[18] and on maximizing global synergies[19].

Circa thirty-five years later the most severe world crisis since WWII has reawakened long forgotten fears about the actual sustainability of unlimited growth[20].

Since mid-2007 the world has been going through a period of extreme financial and economic turmoil. The financial sector's problems have impacted all areas of economic activity, and the outlook for the next several years is extremely uncertain and precarious[21]. Several health care systems have been affected and are not exempt from future risks.

Health care provision which has been characterized, on one hand, by a unrelenting growth of costs and, on the other, by the necessity to secure health coverage to the whole population, has been hit by the crisis just as other areas of economic activity, but, since the right to health care is a constitutional and fundamental right in all the advanced countries of the world, health systems may not adjust to financial crises in strict economic terms, simply by reducing quality driven costs or by treating ill people less.

Consequently the authors of this paper argue that, in the long term, there can be no health without equity, no equity without quality, and no quality without sustainability[22].

GROWTH, EQUILIBRIUM AND SUSTAINABILITY

The Association Between Quality and Epidemiological, Demographic, Economic and Financial Variables in Public Health Literature

Public health researchers have explored some associations between epidemiological, demographic, economic and financial[23] variables in an effort to reassess the correct relationship between the utilization of resources and the quality of the outcomes[24].

These studies have highlighted often controversial findings as to the nature and direction of these associations.

In synthesis the debate now essentially rests on the question whether more resources are needed to improve the quality of health care or if resources are being actually wasted and outcomes could rather be improved through a more appropriate coordination among health providers[25] and an improved health technology assessment (HTA).

We argue that all these analyses contribute to a deeper understanding of the relationships among *ad hoc* specific variables, but incur in the limit that they lose sight of the more general equilibrium of the system, whose own independent behavior risks to render such improvements not feasible and, in certain cases, confound some associations[26].

To put it in the way of Heisenberg's Uncertainty Principle, these studies analyze in detail the position of the relationship, but not its velocity and acceleration.

The Dartmouth Institute for Health Policy and Clinical Practice has an ongoing project, which has been gathering data for the last twenty years on the epidemiological quality of care related to health technology and spending. In particular, the association between hospital utilization, prevalence of severe chronic illness and Medicare *per capita* spending has been analyzed[27]. Their research has shown that mortality is higher in regions where the intensity of care in managing chronic illness is higher[28], and accordingly propose to render the system more efficient with the introduction of preference sensitive care against the present supply sensitive care. This theory is not exempt from criticism, in particular by the American Heart Association, for whom, on the contrary, teaching hospitals that use more resources caring for patients hospitalized for heart failure have lower mortality rates[29].

The growth of health care costs and their association with clinical outcomes has been studied by Fisher, Bynum and Skinner[30] and Sutherland[31], who highlighted a lack of correlation.

Elliott, Fisher, Wennberg, Stukel and Gottlieb[32], analyzing variations in the longitudinal efficiency of academic medical centres, revealed that increased intensity of care does not appear to be associated with higher outcome quality or to result in better survival.

The specific technical utilization of DRGs is not our task here to analyze. The issue is being so much debated, and its consequences so relevant to social equilibrium, that the Massachusetts Attorney General published in 2010 a Report for the Annual Hearing on the Examination of Health Care Costs and Cost Drivers[33] of which we report a full transcription[h]:

"*Our findings show that the current system of health care payment is not value-based – that is, wide disparities in prices are not explained by differences in quality, complexity of services, or other characteristics that justify a different price. These findings have powerful implications for ongoing policy discussions about ways to contain health care costs, reform payment methodologies, and control health insurance premiums. If we accept that our health care system can be improved by better aligning payment incentives and controlling cost growth, then we must begin to shift how we purchase health care to align payments with "value," measured by those factors the health care market should justly reward, such as better quality.*

Prices paid for health care services reflect market leverage. As a greater portion of the commercial health care dollar shifts, for reasons other than quality or complexity, to those systems with higher payment rates and leverage, costs to the overall system will increase and hospitals with lower payment rates and leverage will continue to be disadvantaged. If left unchecked, there is a risk that these systemic disparities will, over time, create a provider marketplace dominated by very expensive "haves" as the lower and more moderately priced "have nots" are forced to close or consolidate with higher paid systems.

The present health care market does not allow employers and consumers to make value- based purchasing decisions. The market currently lacks transparency in both price and quality information, and other tools that allow employers and consumers to

[h] underlined by the author

be prudent purchasers. We should expect employers and consumers to be seriously engaged in cost containment, and making the health care market more transparent is a critical step to enlist their participation.

These market dynamics and distortions must be addressed in any successful cost containment strategy. Payment reform, such as the global payment methodology recommended by the Special Commission on the Health Care Payment System, should result in system benefits such as better integration of care and better alignment of system incentives. In order for a shift to global payments to help control costs, it should be coupled with steps to address the dynamics and distortions of the current marketplace.

This report does not point to any simple solutions, and comprehensive and sustainable system improvements will require significant collective effort."

As far as Italy is concerned, sufficient understanding can be achieved with the comprehensive description by Manzoli et al.[34] and with the analysis of the impact of DRGs on quality and outcomes in Italy by Louis, Yuen, Braga et al.[35], who revealed a reduction in the average length of stay, a reduction in the number of ordinary admissions and an increase in severity with little or no change in mortality and readmission rates.

A comprehensive comparison between iso-severity and iso-resource DRGs has been proposed by Sedman, Bahl, Bunting et al.[36] who revealed that iso-severity DRGs better describe the correlation with resources absorption in pediatric patients.

Efficiency and value-based health care have been analyzed by Porter[37], who argues that the challenge is not to reduce expenditure but to increase value per dollar spent.

The use of clinical information to project health spending has been studies by Huang, Basu, O'Grady and Capretta[38], who proposed a projection model based on epidemiological data of chronic diseases to demonstrate that health spending is underestimated.

The long term implications of increased spending on health care, and its lack of long term sustainability, have been studied by Chernew, Hirth and Cutler[39], who analyzed relative growth rates and demonstrated the perverse effects of differential compound growth rates.

The financial consequences of demographic variables[40], in particular population growth, population aging and the consequent increase in dependency rates are being studied by the OECD (Organization for Economic Co-operation and Development) for their potential prospective disruptive effects on national accounts[41].

The problem of the short term and long term fiscal and economic sustainability of health care financing has been thoroughly analyzed by the European Observatory on Health Systems and Policies[42], the International Monetary Fund[43] and the Council of the European Union.

Demographic, Epidemiological, Economic and Financial Sustainability

Sustainability in its broader meaning has historically been an issue which has interested more biologists[44] and economists[45] than public health epidemiologists.

For the purpose of this study we define sustainability as:

- **epidemiological sustainability** as the ability of the health system to satisfy *effectively* the health needs of a population in the long term;
- **economic sustainability** as the ability of the health system to utilize *efficiently* the financial resources available to satisfy the health needs of a population in the long term;
- **financial sustainability** as the ability of a system to provide the financial resources necessary to a health system in the long term;
- **general sustainability** as the capability of a health system to adjust continuously to continuous variation without the necessity of re-equilibrating exogenous intervention;

This paper argues that the scope of a health system is to achieve simultaneously demographic, epidemiological, economic and financial sustainability at constant or improving quality.

When sustainability is simultaneous, we say that the health system is in equilibrium.

We define discrete equilibrium (for example annual equilibrium) a special condition, whereas continuous equilibrium is a general sustainable condition.

The milestone of this theory is that, in the future, financial resources will no longer be a variable dependent from independent epidemiological needs, but, on the contrary, financial resources will be an exogenous independent and limited variable, and it will be up to the efficiency and effectiveness of the health system to make do with the resources available.

THE SPACE AND TIME OF A HEALTH SYSTEM

The problem is that public health and clinical multiple health care choices and interactions occur at spatial, temporal and complexity scales beyond those that individuals are able to grasp, let alone address[46].

This research aims at analyzing how all the variables interacting in the same space and time[47] affect the health system as a whole.

The Space of a Health System

A health system *H* continuously interacts with the demographic system *D*, the epidemiological system *E*, the financial system *F* and the economic system *Ec*[i].

In terms of set mathematics, we define the health system *H* as the intersection among *D, E, F* and *Ec*.

The health system exists to perform a function which is the *effective* prevention and cure of the diseases of the population utilizing *efficiently* the financial resources available[48].

We assume that a change in any of the independent variables which define the health system will consequently affect the health system as a whole, therefore

$$H \equiv f(D, E, F, Ec)$$

where the macro variables *D, E, F* and *Ec* are each defined by sets of independent variables[j] which together determine *H*.

[i] Health law, which also affects the behaviour of the health system, defines the postulates which determine the general rules of universal coverage, equity, public and private provision, accreditation, waiting lists, public and private payment and clinical guidelines.

[j] The meaning of the independent variable will be defined in the chapter on the Fundamental Functions

Time in a Health System

Since the D_0, E_0, F_0 and Ec_0 systems evolve at a rate r with respect to time t, so does the health system H_0.

The identity

$$H \equiv f(H_0, r, t)$$

will be expressed as

$$H = \mathbf{H}e^{\mathbf{rt}} = \begin{pmatrix} D & E & F & Ec \end{pmatrix} \begin{pmatrix} e^{r_D t} \\ e^{r_E t} \\ e^{r_F t} \\ e^{r_{Ec} t} \end{pmatrix}$$

The spatial and temporal relationships among H_0, r and t need to be assessed in statistical terms.

In the Lombardia and Italian health systems, in the period following the health reform of 1995, such relationships are significant and exponential[k].

This study argues that the growth of a health system is exponential in nature[l], but that in the long term exogenous intervention occurs to limit such growth in terms of evolution towards logistic growth.

H is therefore defined by a reference frame accelerated respectively to time *t.*

Equilibrium in a Health System

The accelerated exponential nature of the system leads time projections of past statistically significant trends over extended periods of time to absurd predictions[m], since they do not take into account how mutual spatial relationships vary with time *t*.

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[k] see *infra*
[l] see *infra*
[m] see Applications to Lombardia health system 2008 – 2050 for an example

Hence the necessity to add to a fundamental theory of general equilibrium (GE), where only time *t* has been considered, a general theory of equilibrium (GSE), which we consider sustainable, where also variation in the spatial relationships $\frac{\partial H}{\partial r}$ when *Δt=1* have been considered.

The Space and Time Continuum

The *continuum* defines how the *D, E, F* and *Ec* variables, which define the health system *H,* evolve continuously[49] with respect to time Δ*t* and with respect to total differential variation $\frac{\partial H}{\partial r}$.

The theory will demonstrate that long term total differential variation is towards general equilibrium (GE) and, in particular, towards general sustainable equilibrium (GSE), since no other state of the health system is compatible with long term sustainability.

METHODOLOGY

Circularity and Regression

The essence of the Theory of Quality, Equilibrium and Sustainability is the definition of both the static-dynamic and the circular relationships[50] which describe the epidemiological, demographic, economic and financial behavior of the health system towards the several possible Nash Equilibria.

In other words, whereas General Equilibrium is achieved thru static-dynamic variation, General Sustainable Equilibrium is achieved thru infinite iterations among effectiveness, efficiency and the epidemiological, demographic, economic and financial variables.

Since time and repeated iterations are not trivial both to time trend regression and game theory, both have been taken into consideration in the definition of the dynamics of the fundamental and extended relationships towards equilibrium.

Circularity and *Continuum*

The main challenge has been incorporating in a Nash Equilibrium iterative model the effects of exogenous continuous variation, or, in mathematical terms, moving from a linear static model to an exponential dynamic model and finally to a *continuum*, which defines continuous endogenous adjustment to continuous exogenous variation.

In other words, equilibrium has been analyzed simultaneously both in terms of endogenous circular iterations and in terms of endogenous continuous spatial and temporal adjustment to exogenous variation.

The transition from the differential geometry of the Theory of Quality, Equilibrium and Sustainability to the QUALITY VECTOR MODEL has been achieved with the definition of a Euclidean reference system and quality vectors.

From the mathematical[51] and statistical[52,53] methodological point of view the present theory is divided into four parts:

- The first part utilizes linear functions and univariate time trend correlation to describe the intrinsic quality function, the epidemiological function, the financial function, the efficiency adjusted financial function, the economic function, the intrinsic quality function and the conditions of static macro equilibrium;
- The second part utilizes exponential functions and univariate time trend correlation to describe the conditions of dynamic equilibrium, dynamic disequilibrium, dynamic re-equilibrium and general equilibrium;
- The third part utilizes a multidimensional differential continuous hyper-plane to describe the conditions of general sustainable equilibrium and the extrinsic quality function;
- The fourth part utilizes a linear equations and Euclidean vectors to describe the QUALITY VECTOR MODEL.

Regression, correlation and significance statistical analyses have been assessed and tested utilizing SAS 9.1 software.

The exogenous variables will be indicated with an asterisk (*), where necessary for text comprehension.

In the Theory of Quality, Equilibrium and Sustainability and the QUALITY VECTOR MODEL demographic variation is always considered exogenous.

Definition 1: Demographic Variation

The Principle of Computational Equivalence

The description of equilibrium in this theory has been attempted on the basis of the Principle of Computational Equivalence proposed by Stephen Wolfram in *A new kind of science*[54], which states that:

"A system behavior that is not obviously simple can be thought of as corresponding to a computation of equivalent sophistication, where repeated simple interactions produce systems of incredible complexity"

Definition 2: Principle Of Computational Equivalence

In similar terms, A.J. Schofield defines such a possibility as: " *a classic example of the emergence, whereby new, simple principles arise from a complex interacting system.*"[55]

In fact a model that attempts to describe a health system must deal with millions and millions of non-standard daily interactions which are subject to high degrees of randomness and to the discretionary powers of all the players involved[56].

However, we argue that the rules underlying these single interactions are simple, and for this reason the author tried to utilize computational equations just as simple.

Exponential *versus* Logistic Growth

One of the main axioms of this theory is that the endogenous nature of growth of the epidemiological, demographic, financial and economic variables is exponential and neither linear nor logistic.

We assume that:

Endogenous exponential growth becomes logistic when exogenous presently unknown factors intervene to limit growth[57].

Definition 3: Exponential Versus Logistic Growth

This axiom implies that we assume the health system to be in sustainable equilibrium when its endogenous variation is in continuous equilibrium with the exogenous variation.

This study argues that the dynamics of demographic growth, public health expenditure growth and debt growth are the braking factors which will intervene to limit exponential growth.

Debt

The role of debt as a braking factor for the exponential growth of public expenditure has been studied by the economists Uri Dadush, Bennet Stancil, Vera Eidelman, Shimelse Ali, Paola Subacchi, Moisès Naìm and Sergey Aleksashenko of the Carnegie Endowment for International Piece[58].

The resistance, or momentum, of the system to the limiting effects of exponential growth can be seen in Exhibit 17: Debt as % of GDP: Current and Projected

In Italy and Greece, regardless of the ongoing financial crises and of the fact that they have among the highest public debts in the world, debt is still expected to rise at an exponential growth rate of 0.022 in the period 2009 – 2014.

This means that it will have doubled by the year 2040[n].

Exhibit 17: Debt as % of GDP: Current and Projected

Debt as % of GDP, Current (a) and Projected (p)	*2009-a*	*2011-p*	*2014-p*	$EXP_{2009\text{-}14}$[o]
Japan	218.6	231.9	245.6	0.023
Italy	115.1	123.5	128.5	0.022
Greece	113.4	126.8	--	--
Belgium	97.9	104.9	--	--
United States	84.8	97.7	108.2	0.049
France	77.4	86.6	92.6	0.036
United Kingdom	72.9	89.3	98.3	0.060
Germany	72.5	87.8	89.3	0.042
Ireland	64.5	87.9	--	--
Spain	55.2	66.9	--	--

Sources: European Commission, IMF, OECD, author's elaborations

[n] $dt = 31.51 = \frac{\ln 2}{0.022}$

[o] $EXP = \frac{\ln\left(\frac{D_{2014}}{D_{2009}}\right)}{\Delta t}$

The future effect of debt may be best appreciated in Exhibit 19: Total Debt and Deficit, Current, taking into account also the sheer amount of debt and the effect of deficit.

Exhibit 19: Total Debt and Deficit, Current

Total Debt and Deficit, Current	***Total debt (% GDP)***	***Total debt (€ m)***	***2009 deficit (% GDP)***
Italy	115.8	1,760,765	5.3
Greece	115.1	273,407	13.6
Belgium	96.7	326,606	6.0
France	77.6	1,489,025	7.5
Portugal	76.8	125,910	9.4
Germany	73.2	1,762,211	3.3
Malta	69.1	3,948	3.8
UK	68.1	1,067,819	11.5
Austria	66.5	184,105	3.4
Ireland	64	104,667	14.3
Netherlands	60.9	347,021	5.3
Cyprus	56.2	9,527	6.1
Spain	53.2	559,650	11.2
Finland	44	75,217	2.2
Slovenia	35.9	12,519	5.5
Slovakia	35.7	22,585	6.8
Luxembourg	14.5	5,464	0.7

SOURCE: Eurostat. All Exhibits for 2009

Public Health Expenditure

In Italy public health expenditure (Exhibit 21) has been rising steadily since the health reform of 1995 (EXP=0.06063; Pr>|t|<.0001)[p].

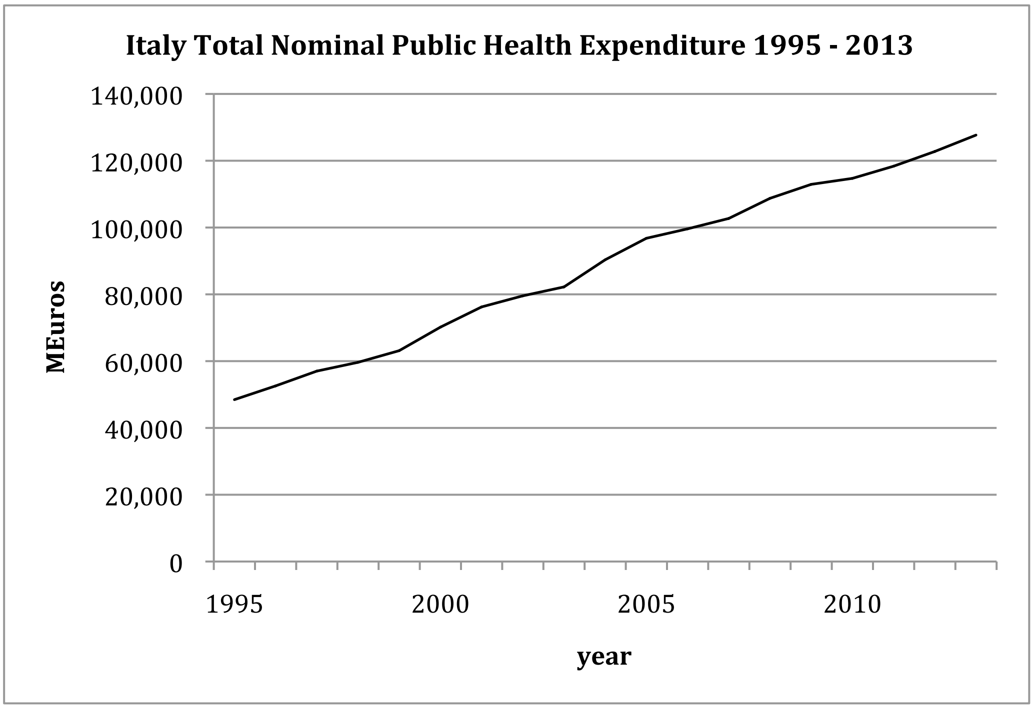
Several questions arise:

- Is this exponential growth sustainable?

[p] SAS 9.1

- Will this exponential growth eventually turn into a logistic growth?
- If so, when will this happen?
- And when it happens, which will the effect be on the epidemiological, economic and ultimately demographic variables of the health system?
- How and in which direction will the health system readjust?
- Can the health system disequilibria be re-equilibrated from outside?
- If and how will quality and universal coverage be affected?

Exhibit 21: Italian Nominal Public Health Expenditure 1995-2013



Source: ISTAT, MINEF

Efficiency, Effectiveness and Composite Quality

The Theory of Quality, Equilibrium and Sustainability analyzes three kinds of Quality:

- **Efficiency (L):** Efficiency (L) determines if the health system is efficient and capable of achieving and maintaining a condition of sustainable equilibrium at constant Effectiveness (q);
- **Effectiveness (q):** Effectiveness (q) determines if the health system is effective at constant Efficiency (L);
- **Composite Quality (Q):** Composite Quality (Q) determines the dynamic relationship between efficiency and effectiveness.

In other words, the theory analyzes simultaneously the effects on Effectiveness, Efficiency and Composite Quality of the changing conditions of Equilibrium of the exogenous and endogenous epidemiological, demographic, economic and financial variables.

Intrinsic and Extrinsic Quality

In the Theory of Quality, Equilibrium and Sustainability we introduce the concepts of Intrinsic and Extrinsic[59] Quality, in addition to the traditional concepts of Efficiency and Effectiveness.

- **Intrinsic Quality**: the Quality of the health system in terms of Effectiveness, Efficiency and Composite Quality when the health system is in condition of General Equilibrium, i.e., as we will see later, equilibrium is maintained through exogenous external intervention;
- **Extrinsic Quality**: the Quality of the health system in terms of Effectiveness, Efficiency and Composite Quality when the health system is in a condition of General Sustainable Equilibrium, i.e., as we will see later, equilibrium in maintained endogenously without the necessity of external intervention.

In other words, Intrinsic and Extrinsic Quality are a quantitative measures of Efficiency and Effectiveness, but they coincide only if the general conditions of General Sustainable Equilibrium are met.

Therefore we will define:

- **1.1 Intrinsic Effectiveness, 1.2 Intrinsic Efficiency and 1.3 Intrinsic Composite Quality**:
- **2.1 Extrinsic Effectiveness, 2.2 Extrinsic Efficiency and 2.3 Extrinsic Composite Quality.**

As we have discussed in the premises, this theory argues that quality is not a *per se* concept, but affects and is affected by the equilibrium of the health system

Hence the necessity in the present paper to analyze the general and general sustainable conditions of equilibrium of a health system before analyzing its sustainable quality.

The Theory of Quality, Equilibrium and Sustainability will demonstrate that, if the conditions of General Sustainable Equilibrium are met, Quality may be determined by Effectiveness and Efficiency alone, likewise the traditional approach to quality.

Therefore, in General Sustainable Equilibrium:

- **1.1 Effectiveness, 1.2 Efficiency**

The other side of the coin is that, according to the Theory of Quality, Equilibrium and Sustainability, the traditional definition of Effectiveness, Efficiency and Composite Quality is not sufficient to determine the quality of a health system if the system is not in a condition of General Sustainable Equilibrium.

The Universal Coverage Postulate

This theory is based on the postulate that the prerequisite of a health system is to attain universal coverage.

Definition 4: Universal Coverage Postulate

In this theory we accept as an *a priori* postulate that there cannot be equilibrium and sustainability if portions of the population do not have access to health care, or the poor have access to a lower quality of care[60].

The Theory of Quality, Equilibrium and Sustainability

In more detail, the Theory of Quality, Equilibrium and Sustainability is divided into five parts:

1. THE THEORY OF QUALITY

Where Effectiveness, Efficiency, Composite Quality, Intrinsic and Extrinsic Quality are defined in mathematical terms;

2. THE FUNDAMENTAL FUNCTIONS

Where the relationships linking the demographic, epidemiologic, economic and financial variables are made explicit in mathematical terms;

3. THE THEORY OF EQUILIBRIUM

Where the steps leading the health system to General Equilibrium are analyzed as:

- **static equilibrium (SE)**, where the epidemiological function H_e and the efficiency adjusted financial function H_f are in macro equilibrium in a static form;

- **dynamic equilibrium (DE)**, which incorporates time *t* as an independent variable, where the epidemiological function H_e and the efficiency adjusted financial function H_f are in macro equilibrium in a dynamic form;
- **dynamic disequilibrium (DD)**, which incorporates initial disequilibrium and dynamic disequilibrium, where the epidemiological function H_e and the efficiency adjusted financial function H_f are in macro disequilibrium in a dynamic form;
- **dynamic re-equilibrium (DR),** which incorporates the mechanics of exogenous re-equilibrium, where the epidemiological function H_e and the efficiency adjusted financial function H_f are in equilibrium in a dynamic form;
- GENERAL EQUILIBRIUM (GE), where system equilibrium incorporates time, initial static disequilibrium, dynamic disequilibrium and exogenous re-equilibrium, and the epidemiological function H_e and the efficiency adjusted financial function H_f are in equilibrium in a dynamic form.

4. THE THEORY OF SUSTAINABILITY

GENERAL SUSTAINABLE EQUILIBRIUM (GSE), where system equilibrium is achieved by continuous epidemiological endogenous temporal and spatial feedback;

5. THE QUALITY VECTOR MODEL, which defines the relative dynamic effects of variation in the efficiency and effectiveness of the health system when the health system is in a condition of General Sustainable Equilibrium;

6. OTHER APPLICATIONS OF THE THEORY OF QUALITY, EQUILIBRIUM AND SUSTAINABILITY, where the GSE and the QUALITY VECTOR MODEL are utilized to solve some practical health planning problems.

The general categories applied to define the variables and the functions utilized enable the theory to be applied on a macro level to different health systems and to different aspects of the same system, and on a micro level to single operators within the system.

Part II
The Theory Of Quality

SUSTAINABLE HEALTH QUALITY AND RESTRICTED NASH EQUILIBRIUM WITH A REDISTRIBUTION AGREEMENT

This paper argues that sustainable effectiveness and efficiency need to be assessed in a condition of Restricted Nash Equilibrium with a Redistribution Agreement[61].

Definition 5: Restricted Nash Equilibrium with a Redistribution Agreement

In detail:

1. Nash Equilibrium, defined in general as: "A pair of actions, one for you and one for me, is jointly sustainable if your action is your best response to mine and mine is my best response to yours", because if the purchaser of the health services asks the providers for higher effectiveness, this usually means for them higher costs and higher capital investments and, subsequently, higher losses or lower profits. If, on the other hand, the purchaser asks for higher efficiency, this will usually turn out for the providers to signify lower prices and, once again, higher losses or lower profits. For these reasons, health quality has been expressed in the form:

$$\text{composite quality} = \text{effectiveness} \times \text{efficiency}$$

Equation 1: Health Quality in a Restricted Nash Equilibrium with a Redistribution Agreement

where maximum quality requires maximum effectiveness and maximum efficiency and in the Theory of Quality, the Fundamental Functions, in General Equilibrium, in General Sustainable Equilibrium and in the QUALITY VECTOR MODEL, a reduction in effectiveness or efficiency will always comport a reduction in the financing of the provider[q];

2. <u>With a Redistribution Agreement</u>, because health markets do not behave like perfect markets, both because inefficient players do not usually go bankrupt and because the safeguard of the public good usually has a political priority over economic restrictions. For this reason exogenous intervention to re-equilibrate the health system has been analyzed by the Theory of General Equilibrium;

3. <u>Restricted</u>, because continuous exogenous variation changes the settings of the payoff matrix and determines a continuously varying exogenous restriction on the endogenous rational actions of the health system. For this reason endogenous continuous adjustment has been analyzed by the Theory of General Sustainable Equilibrium.

In general, the Theory of Quality, the Fundamental Functions, General Equilibrium, General Sustainable Equilibrium and in the QUALITY VECTOR MODEL satisfy the conditions that:

i. All choices are rational, iteratively undominated and jointly sustainable;
ii. All information is in the form of common knowledge;
iii. All actions are in a framework of cooperation and not of conflict;
iv. All actors assign to health effectiveness the highest possible utility.

Equilibrium is therefore expressed in terms of circularity and not in terms of infinite regression.

We will see that the condition of General Sustainable Equilibrium satisfies the condition of a Nash Equilibrium.

■

[q] such is not the case in Lombardia in the period under scrutiny (1997-2008)

INTRINSIC QUALITY

Intrinsic Effectiveness (q)

We will define:

Intrinsic Effectiveness = q = the capability of the health system to increase the effectiveness of its outputs in terms of health outcomes.

Definition 6: Intrinsic Effectiveness (q)

Effectiveness has a direct impact on health outcomes in strict terms.

In addition, we will demonstrate that Extrinsic Quality and Effectiveness are synonymous only when the conditions of General Sustainable Equilibrium are satisfied.

In mathematical terms:

$$q \mapsto \text{Effective Output}, \text{Output}$$

$$\Delta q \upharpoonleft\mapsto \left\{ \frac{\text{Effective Output} \upharpoonleft\upharpoonleft}{\text{Output} \upharpoonleft}, \frac{\text{Effective Output} \upharpoonleft}{\text{Output} \leftrightarrow}, \frac{\text{Effective Output} \leftrightarrow}{\text{Output} \downarrow} \right\}$$

In the Theory of Quality, Equilibrium and Sustainability we are not interested in the generic Output, but in the desired Standard Output, therefore

$$\frac{\text{Effective Output}}{\text{Output}} = \frac{\text{Effective Output}}{\text{Standard Output}}$$

$$\frac{\dfrac{\text{Effective Output}}{\text{Output}}}{\dfrac{\text{Effective Output}}{\text{Standard Output}}} = 1$$

$$\frac{\text{Effective Output}}{\text{Output}} \cdot \frac{\text{Standard Output}}{\text{Effective Output}} = 1$$

$$\frac{\text{Standard Output}}{\text{Output}} = 1$$

We define the Standardized Weighted Intrinsic Effectiveness of the jth-provider for the ith-proxy variable as

$$q_{ij} = \sum_i \sum_j \frac{V_{\text{DIS W}ij}}{V_{\text{STD C}ij}} \cdot q_{ij}$$

Equation 2: Standard Weighted Intrinsic Effectiveness

and we will determine q in relative terms as:

$$q = \frac{q_{ij}}{q_{std}}$$

Equation 3: Intrinsic Effectiveness

where

q_{std} = is the desired standard effectiveness expected from the providers of the health system;

q_{ij} = is the standardized weighted intrinsic effectiveness of the jth-provider or all the providers of the health system.

Therefore if the q of the health system is:

$q>1$, the health system is overperforming;

$0<q<1$, the health system is underperforming;

$q=1$, the health system as a whole has achieved the desired effectiveness.

In all the applications of the Theory of Quality, Equilibrium and Sustainability to the Lombardia health system we have assumed $q=1$.

Although effectiveness as a quality measure of care based on administrative data cannot be definitive, it can be used to flag potential quality problems and success stories, which can then be further investigated and studied[62].

Hospital associations, individual hospitals, purchasers, regulators, and policymakers at the local, State, and Regional levels can use readily available hospital administrative data to begin the assessment of quality of care[63].

We define the standardized inpatient quality variables[64,65,66,67,68] of the Standardized Weighted Effectiveness (q_j) as:

Definition 7: Proxy Effectiveness Indicators

Ex-ante indicators are proxy, or indirect, measures of quality. They are based on accreditation standard requirements:

q1j = Compliance to accreditation standard requirements

Ex-post indicators for inpatient procedures include procedures for which mortality has been shown to vary across institutions and for which there is evidence that high mortality may be associated with poorer quality of care:

q2j = Hospital mortality for inpatient procedures

q3j = Hospital mortality for inpatient conditions

q4j = Mortality within 30 days from discharge

Utilization indicators examine procedures whose use varies significantly across hospitals and for which questions have been raised about overuse, underuse, or misuse:

q5j = Utilization of procedures

Appropriateness indicators examine the appropriateness of the utilization of a DRG based prospective payment system. They are designed using an age- and sex-adjusted population-based denominator and discharge-based numerator. These indicators represent procedures whose use varies widely across relatively similar geographic areas with (in many cases) substantial inappropriate use:

q6j = Up-coding

q7j = Cream skimming

q8j = Repeated readmissions

Accessibility and customer satisfaction indicators reflect the rate of hospitalization accessibility and customer satisfaction in the area for specific procedures.:

q9j = Waiting lists

q10j = Customer satisfaction

and

$V_{DIS\ WEIGHT}$ = the relative discriminating weight of the ith-quality indicator;

$V_{STD\ COEFFICIENT}$ = the standardization coefficient of the ith-quality indicator

Effectiveness indicators have to be standardized[69] in order to take into account the epidemiological and demographic differences characteristic of each provider[r].

Effectiveness indicators have to be weighted in order to take into account their discriminating[s] value[70].

Intrinsic Efficiency (L)

We define:

Intrinsic Efficiency = L = the capability of the health system to increase its output at constant input, to maintain a constant output at decreasing input or to increase its output more than proportionally to the increase in its input.

Definition 8: Intrinsic Efficiency (L)

Efficiency is internal to the system and does not have a direct impact on the quality of external health outcomes in strict terms.

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[r] For a detailed discussion on standardization techniques: A. Pagano. G. Vittadini. *Qualità e valutazione delle aziende sanitarie. Manuale di analisi e misurazione della performance.* 2004 (*Op. Cit.)*

[s] For a detailed discussion on Linear Discriminant Analysis (LDA) in the social sciences: W.R. Klecka. Discriminant Analysis. 1980.

In addition, we will demonstrate that Intrinsic Quality and Efficiency are synonymous only when the conditions of General Sustainable Equilibrium are satisfied.

In mathematical terms:

$$L \mapsto \text{Output, Input}$$
$$\Delta L \Uparrow \mapsto \left\{ \frac{\text{Output} \uparrow}{\text{Input} \leftrightarrow}, \frac{\text{Output} \leftrightarrow}{\text{Input} \downarrow}, \frac{\text{Output} \uparrow\uparrow}{\text{Input} \uparrow}, \frac{\text{Output} \downarrow}{\text{Input} \downarrow\downarrow} \right\}$$

Note

We will see later that the Theory of Quality, Equilibrium and Sustainability expresses General Equilibrium and General Sustainable Equilibrium utilizing the efficiency parameter L in reversed terms, i.e. as the *in-efficiency* of the health system.

Therefore the lower the *in-efficiency* L, the higher the efficiency. When we say that efficiency increases, we will be saying that *in-efficiency* decreases.

The expression of the L parameter in this form permits the expression of the Extrinsic Composite Quality Function in General Sustainable Equilibrium in Isoquantum terms.

Intrinsic Composite Quality (Q)

It is clear that we need to investigate the nature of the relationship between q and L, as it is evident that, in general, a reduction in effectiveness could frustrate an increase in efficiency, and vice versa. The composite quality of a health system is determined by the relationship between its effective output and its input.

We will define:

Composite Quality = Q = the composite quality of the health system defined by the relationship between effectiveness and efficiency and, specifically, by the relationship between the effectiveness of its outputs and its inputs.

Definition 9: Composite Quality (Q)

In mathematical terms:

$$Q \mapsto q, L$$
$$\Delta Q \mapsto \Delta q, \Delta L \mapsto \left\{ \frac{\Delta\text{Output}}{\Delta\text{Input}}, \frac{\Delta\text{Effective Output}}{\Delta\text{Output}} \right\} \mapsto \left\{ \frac{\Delta\text{Effective Output}}{\Delta\text{Input}} \right\}$$

An assessment of the effectiveness of the outputs, or health outcomes, of a health system needs to be investigated with epidemiological and biostatistical techniques, whereas an analysis of the inputs, or resources, needs to be investigated with demographic, economic and financial techniques.

The relationship between effectiveness and efficiency is therefore of a mixed nature, epidemiological, demographic, economic and financial.

We will now define the standard theoretical relationship between effectiveness and efficiency which defines the composite quality of the health system.

The Intrinsic Composite Quality Function (ICQF)

The composite quality function of a health system is correlated to its intrinsic and extrinsic quality.

Definition 10: Intrinsic Composite Quality Function (ICQF)

We will analyze and estimate the parameters, the variables and the function *f* of Q=*f*(q,L) in the theoretical Cobb-Douglas[t] standard form:

$$Q = kq^{\varepsilon_1}L^{\varepsilon_2}$$

Equation 4: Intrinsic Composite Quality Function (ICQF)

where:

k = a constant to be determined;

ε_1 = the elasticity of Q on q. In mathematical terms:

$$\varepsilon_{Q,q} = \frac{\frac{\partial Q}{\partial q}q}{f(q,L)} = \frac{k\varepsilon_1 q^{\varepsilon_1 -1}L^{\varepsilon_2}q}{kq^{\varepsilon_1}L^{\varepsilon_2}} = \varepsilon_1$$

Equation 5: Elasticity of Q on q

ε_2 = the elasticity of Q on L. In mathematical terms:

$$\varepsilon_{Q,L} = \frac{\frac{\partial Q}{\partial L}L}{f(q,L)} = \frac{kq^{\varepsilon_1}\varepsilon_2 L^{\varepsilon_2 -1}L}{kq^{\varepsilon_1}L^{\varepsilon_2}} = \varepsilon_2$$

Equation 6: Elasticity of Q on L

The Composite Quality Q is characterized by the gradient vector

[t] Simon Blume, *Op. Cit.*: 426

$$DF(q,L)=\begin{pmatrix}\frac{\partial Q}{\partial q}(q,L) & \frac{\partial Q}{\partial L}(q,L)\end{pmatrix}$$

Equation 7: Composite Quality Function Gradient Vector

and the Taylor second order linear transformation

$$F(q+h_1,L+h_2)=F_{q,L}+DF_{q,L}\mathbf{h}+\frac{1}{2}\mathbf{h}^T D^2F_{q,L}\mathbf{h}+R_2(\mathbf{h};q;L)$$
$$\frac{\partial F}{\partial q}=k\varepsilon_1 q^{\varepsilon_1-1}L^{\varepsilon_2};\frac{\partial F}{\partial L}=kq^{\varepsilon_1}\varepsilon_2 L^{\varepsilon_2-1}$$
$$\frac{\partial^2 F}{\partial q^2}=k\varepsilon_1(\varepsilon_1-1)q^{\varepsilon_1-2}L^{\varepsilon_2};\frac{\partial^2 F}{\partial L}=kq^{\varepsilon_1}\varepsilon_2(\varepsilon_2-1)L^{\varepsilon_2-2}$$
$$\frac{\partial^2 F}{\partial q\partial L}=\frac{\partial^2 F}{\partial L\partial q}=k\varepsilon_1\varepsilon_2 q^{\varepsilon_1-1}L^{\varepsilon_2-1}$$

Calculating in point (1,1) **we obtain :**

$$F(1+\mathbf{h})=1+\begin{pmatrix}k\varepsilon_1 & k\varepsilon_2\end{pmatrix}\begin{pmatrix}h_1\\h_2\end{pmatrix}+\frac{1}{2}\begin{pmatrix}h_1 & h_2\end{pmatrix}\begin{pmatrix}k\varepsilon_1(\varepsilon_1-1) & k\varepsilon_1\varepsilon_2\\ k\varepsilon_1\varepsilon_2 & k\varepsilon_2(\varepsilon_2-1)\end{pmatrix}\begin{pmatrix}h_1\\h_2\end{pmatrix}+R(h_1;h_2)=$$
$$=1+kh_1\varepsilon_1+kh_2\varepsilon_2+\frac{1}{2}kh_1{}^2\varepsilon_1(\varepsilon_1-1)+kh_1h_2\varepsilon_1\varepsilon_2+\frac{1}{2}kh_2{}^2\varepsilon_2(\varepsilon_2-1).$$

Equation 8: Composite Quality Function Taylor Second Order Linear Transformation

which is the linear equation of the tangent plane to the hyper-plane Q.

An estimate of the parameters *k,* ε_1 and , ε_2 needs a definition of the conditions under which the health system is in General Sustainable Equilibrium.

■

EXTRINSIC QUALITY

Extrinsic Effectiveness (q)

Once we have determined the Intrinsic Standardized Weighted Effectiveness (q_{ij}), we may now determine the Extrinsic Standardized Weighted Effectiveness (q*).

In the premises, we have already introduced a general definition of effectiveness in relative terms as:

$$q\mapsto \text{Effective Output, Output}$$
$$\Delta q\uparrow\mapsto\left\{\frac{\text{Effective Output}\uparrow\uparrow}{\text{Output}\uparrow},\frac{\text{Effective Output}\uparrow}{\text{Output}\leftrightarrow},\frac{\text{Effective Output}\leftrightarrow}{\text{Output}\downarrow}\right\}$$

We will now substitute the general concept of Effective Output with that of Extrinsic Standardized Weighted Effectiveness (q^*), and that of Output with that of desired Standard Effectiveness (q_{std}), therefore we will utilize a relative definition of Extrinsic Effectiveness (q), as we have done for Intrinsic Effectiveness and just as we will do later for Extrinsic Efficiency L*.

In other words we are not interested in absolute extrinsic effectiveness, but in its ratio to exogenously determined standard effectiveness q_{std}.

We define Extrinsic Effectiveness q in relative terms as:

$$q = \frac{q^*}{q_{std}} = 1$$

Equation 9: Extrinsic Effectiveness (q)

where

q_{std} = is the desired standard effectiveness expected from the providers of the health system;

q^* = is the extrinsic effectiveness of the jth-provider or all the providers of the health system.

Intrinsic and Extrinsic Effectiveness are equal when

$$\frac{q_{ij}}{q_{std}} = \frac{q^*}{q_{std}} = q \text{ if } q_{ij} = q^*$$

In all the applications of the Theory of Quality, Equilibrium and Sustainability to the Lombardia health system we have assumed q =1.

Extrinsic Efficiency (L)

With the same arguments utilized for q, we can demonstrate that:

$$L = L_{ij} = L^*$$

if

$$\frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Standard Output}}$$

$$\frac{\text{Standard Output}}{\text{Input}} = 1$$

In all the applications of the Theory of Quality, Equilibrium and Sustainability to the Lombardia health system we have assumed L=1.

The Extrinsic Composite Quality Function (ECQF)

We will define the ECQF as the function *f* which maximizes the relationship between q and L.

We will express it in linear terms and we will utilize it as a condition of the ICQF as:

$$q + L = G$$

Equation 10: Extrinsic Composite Quality Function (ECQF)

where

G = is the maximum value of *f*(q,L)

■

COMPOSITE QUALITY OPTIMIZATION

The composite quality function of a health system is optimized when both intrinsic and extrinsic quality are maximum, which corresponds to the point where they are equal.

Definition 11: Composite Quality Optimization

We will define the point of quality optimization as the tangent point of the ICQF and the ECQF:

$$f(q,L) \equiv kq^{\varepsilon_1}L^{\varepsilon_2} = Q$$
$$g(q,L) \equiv q + L = G$$

We will utilize the Lagrange transformation

$$La = (q,L,\mu) \equiv qL - \mu(q + L - G)$$

where

$$\frac{\partial La}{\partial q} = L - \mu = 0 \rightarrow \mu = L$$

$$\frac{\partial La}{\partial L} = q - \mu = 0 \rightarrow \mu = q$$

therefore $q = L$

and since

$$\frac{\partial La}{\partial \mu} = -(q + L - G) = 0$$

and

$$q + L - G = 0$$

we substitute

$$q = L$$

and

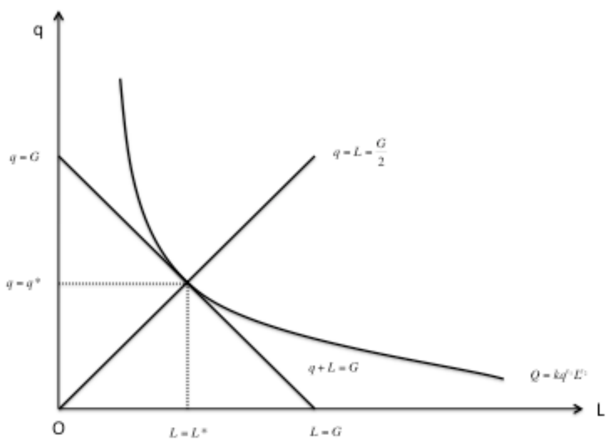
$$2q = G \rightarrow q = \frac{G}{2}$$

$$2L = G \rightarrow L = \frac{G}{2}$$

Equation 11: Composite Quality Optimization

In graphic terms (Exhibit 23:Composite Quality Optimization)

Exhibit 23:Composite Quality Optimization



We have demonstrated that q and L are maximum when they are equal to G/2.

We now need to determine the value of optimum composite quality G under the condition that the health system is in General Equilibrium and General Sustainable Equilibrium.

In order to do so, we must first assess the fundamental functions which determine the epidemiological, demographic, economic and financial equilibrium of the health system, secondly the conditions of general equilibrium and the conditions under which such equilibrium is sustainable.

In the meantime, we will also analyze the conditions of short and long term disequilibrium, and we will demonstrate that disequilibrium is not sustainable in the long term.

Finally, we will be able to analyze the dynamics of Composite Quality in a scenario of General Sustainable Equilibrium.

Part III
The fundamental functions

THE EPIDEMIOLOGICAL FUNCTION (EF)

The resources effectively absorbed by a health system are correlated to demographic exogenous variation, to variation in the prevalence and the incidence of disease, to the epidemiological complexity and severity of inpatient and outpatient cases, to the capacity utilization rate and the hospitalization rate, to the intensity of care and to variation in the effectiveness of the health system.

Definition 12: Epidemiological Function (EF)

We will define the epidemiological function H_e with the identity

$$H_e = f(v, w, s, q, p, i, u, h, x_d, \Pi)$$

and the equation

$$H_e = vwsqupx_d\Pi = x_1qhx_d\Pi$$

Equation 12: Epidemiological Function (EF)

which satisfies the condition for a Restricted Nash Equilibrium with a Redistribution Agreement because a reduction of effectiveness q implies a reduction in the resources absorbed.

The EF variables are:

Epidemiological Variables

p and *i* = prevalence and incidence. Prevalence and Incidence are defined and accounted for in the EF according to the following definition:

$$i = \text{incidence}=\frac{\text{number of new cases of disease in the population in a definite period } (\Delta\Pi_M)}{\text{total number of healthy people at the beginning of the period}(\Pi-\Pi_{M_i})}$$

$$p = \text{prevalence}=\frac{\text{number of ill people in a definite period } (\Pi_{M_f})}{\text{population in a definite period}(\Pi)}$$

(Manzoli, Villari, Boccia. Epidemiologia. 2008:19-26, op. cit.)

$$u\text{=capacity utilization rate}=\frac{\text{number of ill people who utilize hospital services in a definite period } (\Pi_h)}{\text{number of ill people in a definite period } (\Pi_{M_f})}$$

$$h = \text{hospitalization rate}=up$$

$$\Pi = \Pi_{M_f} + (\Pi - \Pi_{M_f})$$

$$\Pi_{M_f} = \Pi_h + (\Pi_{M_f} - \Pi_h)$$

$$i = \frac{\Delta\Pi_M}{\Pi - \Pi_{M_i}}$$

$$p = \frac{\Pi_{M_i} + i\left(\Pi - \Pi_{M_i}\right)}{\Pi} = \frac{\Pi_{M_i} + \Delta\Pi_M}{\Pi} = \frac{\Pi_{M_f}}{\Pi}$$

$$h = up = \frac{\Pi_h}{\Pi_{M_f}} \cdot \frac{\Pi_{M_f}}{\Pi} = \frac{\Pi_h}{\Pi}$$

$$\Pi_h = up\Pi = h\Pi$$

d = a measure of the diagnoses per patient[71], defined in the interval (d≥1)[u]. For example in Lombardia the ICDM classification of diseases is in use, and the 3M HCFA Grouper transduces the ICDM codes into DRGs[72];

t = a measure of the therapies per patient, defined in the interval (t≥1)[v]. For example in Lombardia the ICDM classification of diseases is in use, and the 3M HCFA Grouper transduces the ICDM codes into DRGs;

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[u] in Italy the diagnoses per patient increased from 2.0 in 1998 to 2.4 in 2008 (EXP= 0.0180) [Ministero della Salute 2010].

w =*f*(*d,t*) = Case Weight or Relative Case Weight – A Exhibit assigned to each DRG code which represents the expected resource utilization for that patient group compared to the average resource utilization for all patients. For instance, a relatively uncomplicated hospital admission such as Pulmonary Embolism would have a weighting of approximately 1 while a more complex admission such as Respiratory Neoplasm, would have a case weight of over 2.0 *w* is defined in the interval (*w*>*0*). *w* can either determine complexity in iso-resource DRGs or any other convenient measure of intensity of care;

s = a measure of the severity of the disease, defined in the interval (s>0). APR iso-severity DRGs utilize *s* in addition to *w* to determine the absorption of resources. In the case study of Lombardia, where an iso-resource and not an iso-severity prospective payment system is in use, *s* will be assumed equal to 1;

h = the cumulative health care utilization rate per 100[w] members of the population, defined in the interval (0≤h≤1). In the case of hospital care, *h* is the number of admissions in percent of the resident population[x];

Quality Variables

q = a measure of the effectiveness of the health system[y], defined in the interval (0<q≤1). The value and meaning of *q* when the health system is in a condition of General Equilibrium and General Sustainable Equilibrium will be analyzed in detail in the Isoquantum Extrinsic Quality Function (IEQF) and the QUALITY VECTOR MODEL;

m = the intra-hospital mortality rate per 100 patients, defined in the interval (0≤m<1). An increase in *m* usually determines and increase in *w, s* and q, since the latter should account for the higher resources absorbed in an end-of-life situation[z]. In the

[v] In Italy the therapies per patient increased from 1.6 in 1998 to 2.5 in 2008 (EXP=0.0450) [Ministero della Salute 2010].
[w] *h* is often defined *per* 10,000. Here we utilized the percent notation.
[x] Waiting lists affect effectiveness q.
[y] The quality of the health outcomes will be analyzed in the chapter on the standardized weighted extrinsic quality parameter q.
[z] *m* as a clinical outcome will be analyzed in the chapter on the standardized weighted extrinsic quality parameter q.

mathematical expression of EF the effect of *m* on H_e is indirect, since it has only a direct effect on *w, s* and effectiveness q;

P_m = the number of deceased patients, where P_m+P_v=*P*, and *P*=hx_d*Π*. In fact:

$$\frac{h\Pi - P_m}{1-m} = \frac{P_v + P_m - P_m}{1-m} = \frac{P_v}{1-m} = h\Pi$$

Demographic Variables

Π* = the demographic population (Π>0);

x_d *= the proportion of the demographic population of a specific sub-system (0≤x_d ≤1), for example the population of Lombardia.

The demographic variables are always exogenous (*).

Transformation Variables

v = a measure of the intensity of resources required per unit of intensity of care *ws,* defined in the interval (*v*>0). In the DRG system the variable *v* is the Case Mix Adjusted Cost Per Admission (CMAA), a measure of a hospital's average cost per admission, adjusted for complexity, equal to a hospital's total reported costs divided by its total reported admissions divided by the hospital's CMI. *v* is an economic variable which is utilized in the epidemiological function H_e in order to transform the results in terms of resources utilized and render it comparable with the financial function H_f. The variable *v* will be analyzed in detail in the Economic Function.

The X_1 Hyper-Plane Vector In A Prospective Payment Health Financing System

In a prospective payment health financing system the *vws* hyper-plane vector is defined as

$$x_1 = v \cdot ws$$

Equation 13: X1 Vector In A Prospective Payment System

which is a measurement that characterizes the intensity of resources required to care for a hospital's case in consideration of its complexity and severity.

In the QUALITY VECTOR MODEL, *x1* represents a measure of all the resources absorbed per single patient, inpatient and outpatient.

The variable *w* can be considered a *horizontal weight*, i.e. a weight that defines the complexity of a case relatively to other cases, whereas the variable *s* can be considered a *vertical weight*, i.e. the severity of the single case.

The variable *v* determines how much resources the health system absorbs per unit of *ws*.

The *x1* vector is a very convenient way to express, for example, a DRG or an APR-DRG.

■

The X_1 Hyper-Plane Vector In A *Per Diem* Health Financing System

In a *per diem* health financing system the *x1* vector is defined as

$$x_1 = \xi \cdot x_2 x_3$$

Equation 14: X1 Vector In A *Per Diem* Payment System

where

x2 = is the average length of stay (ALOS) of inpatients, defined in the interval x2≥1;

x3 = is the *per diem* reimbursement, defined in the interval x3≥0;

ξ = a constant which accounts for particular conditions which justify a different reimbursement, defined in the interval ξ>0;

■

The GE, GSE and QUALITY VECTOR MODEL are based on a prospective tariff-based payment health financing system, but can be easily adjusted to a *per diem* system by simply substituting the variables which define the vector *x1.*

Example

The Martian population increases from 1000 to 1500 citizens and the intensity of care case mix index from 1.0 to 1.2.

The mayor of Mars manages to reduce the hospitalization rate from 20% to 10%.

Is the public health intervention sufficient to maintain H_e constant?

In addition, the Martian private health providers complain that the increase in complexity has increased costs and reduced profits, and ask for a revaluation of the Martian DRGs.

Is a revaluation possible without increasing H_e?

Answer:

$$\Delta H_e = (1500 \cdot 10\% \cdot 1.2) - (1000 \cdot 20\% \cdot 1.0) = -20$$

The reduction in the hospitalization rate *h* has more than compensated the increase in the exogenous variables *w** and Π*, therefore a revaluation of the DRGs is possible, to the general happiness of private hospital providers.

Application

Lombardia, in the period from the health reform of 1997 to 2008, has been characterized by statistically significant exponential growth rates (r=0.02415; Pr>|t|=<.0001) of the EF which has increased from 4175 m€ to 5482 m€[aa].

The reduction of the hospitalization rate *h* (r=-0.01682; Pr>|t|=<.0001) has not fully compensated the growth in the Italian population (r =0.00530; Pr>|t|=<.0001), the growth of the resident population of Lombardia xd (r=0.00332; Pr>|t|=<.0001), the case mix index *w* (r=0.02128; Pr>|t|=<.0001), the mortality *m* (r=0.03851; Pr>|t|=<.0001) and the vector *x1* (r=0.03236; Pr>|t|=<.0001), which has increased more than proportionally to complexity *w*.

It can also be observed that the average length of stay[bb] ALOS (*x2*) does not show a significant trend, as is generally expected by the introduction of a DRG prospective payment system[cc], whereas the *per diem* reimbursement (*x3*)[dd] is characterized by a significant growth rate (r = 0.03909; P<.0001).

[aa] Only prospective payment financing has been considered. Extra budget financing and losses coverage of public hospitals have not been considered. Their effects will be analyzed in the chapter on the Economic Function.
[bb] The ALOS x2 parameter has been determined taking into account all hospital inpatient and outpatient days. If ALOS is calculated taking into account only >1 inpatient days, it could result in a higher Exhibit. In Lombardia it is approximately of 8 days.
[cc] V. Louis et al. *op. cit.*

Lombardia has therefore positioned itself on a higher value of the epidemiological function *He* (Exhibit 25).

Exhibit 25: Lombardia Epidemiological Function (EF)

Lombardia Epidemiological Function (EF)	***YEAR 1997***	***YEAR 2008***	***EXP e^{r11}***	***Square Correlated-R***	***Pr>/t/***
Π_{ITALY}	56.904.379	60,045,068	0,00530	0,90	<.0001
$x_{d\text{ - LOMBARDIA}}$	15,7%	16,2%	0,00332	0,98	<.0001
w^c	0,9	1,2	0,02128	0,85	<.0001
m	1,4%	2,3%	0,03851	0,95	<.0001
s^b	1	1			
q^b	1	1			
h^d	24,1%	19,8%	-0,01682	0,79	<.0001
P	2.145.882	1.928.618	-0,00820	0,52	<.0047
x_1^c	1.945	2.842	0,03236	0,97	<.0001
x_2	6.7	6.5	0.00673	0,14	<.1301
x_3	292	437	0.03909	0,94	<.0001
H_e * a	**4.175**	**5.482**	**0,02415**	**0,96**	**<.0001**

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

a/million euro

b/Severity s and Effectiveness q are not in use in Lombardia, and therefore equaled to 1

c/ in Lombardia the parameter *w* is calculated only for inpatient cases with an average length of stay higher than 1 day. In all the Exhibits the vector x1 corresponds to the DRG financed hospital public expenditure divided by the total number of inpatient plus outpatient cases

d/ *h* is calculated as the total number of inpatient plus outpatient cases divided by the Lombardia population

---

[dd] here defined as $x_3 = \frac{x_1}{x_2}$. For a detailed analysis see *infra.*

Conclusions

The conclusions regarding the long term sustainability of the EF of the Lombardia health system that we could infer from Exhibit 25 alone are confounding.

The Italian population and the population living in Lombardia are growing, an index of a probable increasing strain on the health system; the complexity of the cases, the cost per admission and the mortality rates are increasing, a probable index of aging or increasing acuity; the hospitalization rate, however, is decreasing.

The parameter s is not in use, therefore little do we know about the severity of the cases.

The meaning of the relative effectiveness parameter q will be analyzed later, since some additional considerations need to be made.

It is clear that the EF as such is not sufficient for a comprehension of the quality, sustainability and equilibrium of a health system.

THE FINANCIAL FUNCTION (FF)

The resources available for a health system are positively correlated to the propensity of the system to invest in health care.

Definition 13: Financial Function (FF)

We define the financial function (FF) as the identity

$$FF = f\left[g\left(x_c \circ x_b \circ x_a\right), Y^*\right]$$

and the R^4 equation

$$FF = x_a x_b x_c Y^*$$

Equation 15: Financial Function (FF)

which does not satisfy the condition of Restricted Nash Equilibrium with a Redistribution Agreement. In the next chapter we will adjust the FF in order to satisfy the Restricted Nash Equilibrium with a Redistribution Agreement.

The variables are:

Financial Variables

Y^* = the wealth of the system, defined in the interval: ($Y^*>0$). The most common measure is the nominal gross domestic product of a nation (nGDP);

x_a = the percentage of Y^* dedicated to health care, defined in the interval ($0 \le a \le 1$);

x_b = the Capitation Unified Allocation System (CUAS), defined as a percentage of $x_a Y^*$ dedicated to a particular health care sub-system, defined in the interval ($0 \le xb \le 1$). In the case study of Lombardia, x_b represents the percentage of national health resources allocated to Lombardia. A federal system would increase x_b;

x_c = the percentage of $x_a x_b Y^*$ dedicated to a particular health care sub-sub-system, defined in the interval ($0 \le xc \le 1$). In the case study of Lombardia, x_c represents the percentage of Lombardia health resources allocated to hospitals;

The Capitation Unified Allocation System xb

When health financing resources are pooled centrally, as it is in Europe, they are generally allocated to health sub-systems on the basis of horizontal and vertical capitation[73].

In the FF, *per capita* horizontal capitation financing is defined as

$$FF_{procapite_{horizontal}} = \frac{x_a Y}{\Pi}$$

Capitation is then adjusted with a system of weights (*weight capitation formulae*) in order to take into account age differences, socioeconomic disadvantaged areas, etc (vertical equity capitation).

The result of both the horizontal and vertical equity capitation is defined by the ratio[ee]

$$\frac{x_b}{x_d}$$

therefore

$$FF_{procapite_{national}} = \frac{x_a Y}{\Pi} \cdot \frac{x_b}{x_d}$$

[ee] The definition of the methods of vertical equity capitation is beyond the scope of this study.

In Europe the building political pressure towards an allocation policy of resources not based upon capitation but upon local contribution, i.e. the so called federal movements, would alter the FF as

$$FF_{procapite_{federal}} = \frac{x_a Y}{\Pi} \cdot \frac{\gamma_i}{x_d}$$

where

γi = the share of Y generated by the sub-system i.

A political pressure towards federalism is likely to arise when

$$\frac{\gamma_i}{x_d} > \frac{x_b}{x_d}$$

therefore

$$\gamma_i > x_b$$

which is exactly the case of Lombardia.

In general the Capitation Unified Allocation System is in a condition of indifference when

$$\frac{\Delta\gamma}{\gamma} = \frac{\Delta x_b}{x_b}$$

and

$$x_b = \frac{\Delta x_b}{\Delta\gamma}\gamma$$

therefore the general definition of FF should be

$$FF = x_a \cdot \frac{\Delta x_b}{\Delta\gamma}\gamma \cdot x_c \cdot Y$$

Equation 16: General Definition of the Financial Function (FF)

However in this study we will not utilize the general definition of the FF but the restricted one, since we maintain that a modification in the criteria of allocation of the resources, where richer sub-systems would benefit from a higher health expenditure, would alter the general assumption of equity and universal coverage which underlies the present theory of equilibrium, and render the health system not sustainable in the long run.

■

The Health Spending Propensity φ And The Relative Propensity Φ

We define

$$\varphi = x_a x_b x_c$$

Equation 17: Health Spending Propensity

as the percentage of Y* dedicated to a particular health care sub-sub-system, defined in the interval ($0 \le \varphi \le 1$).

In the FF, φ can be considered as the portion of resources Y dedicated to health care, whereas (1-φ) is the portion dedicated to non-health care applications.

Therefore φ is the propensity of the system to invest in health care

$$x_a x_b x_c = \varphi$$

therefore

$$FF = \varphi Y^*$$

and the ratio

$$\Phi = \frac{\varphi}{1-\varphi} \rightarrow (0 \le \Phi < 1)$$

is the relative propensity of the system to invest in health care in relation to non-health care.

In the case study of Lombardia, φ represents the percentage of total national financial resources allocated to the Lombardia hospital system.

The FF states that, if Y* decreases, health resources can be maintained at a definite level only by increasing the propensity φ of the regulator to allocate national resources to health care, at the expense of (1-φ).

On the other hand, if Y* increases, health resources can be maintained unvaried by reducing φ.

■

Example

A severe economic crisis hit Martian economy, reducing the nGDP by as much as 5%. However Martians are not willing to reduce the total resources allocated to non-health applications.

What will happen to φ (the percentage of resources allocated to hospital care)?

Answer: since Y decreases but $(1-\varphi)Y$ must remain constant, φ must decrease.

Application 1

In Lombardia, in the period 1997-2008, the increase in the national nGDP (r =0.03770; Pr>|t|=<.0001), in the resources dedicated to health care (r =0.02293; Pr>|t|=<.0001) and in the resources dedicated to Lombardia (r =0.00788; Pr>|t|=<.0283) has allowed a less than proportional reduction in the resources dedicated to hospital care (r =-0.04435; Pr>|t|=<.0001). The overall result in Lombardia has been a reduction in the hospital spending propensity φ[ff] from 0.40% to 0.35% (r =-0.01354; Pr>|t|=<.0001).

Exhibit 27: Lombardia Financial Function (FF)

Lombardia Financial Function (FF)	*YEAR 1997*	*YEAR 2008*	*EXP e^{r11}*	*Square Correlated-R*	*Pr>|t|*
Y^a	1.048.766	1.572.243	0,03770	0.99	<.0001
x_a	5,4%	6,9%	0,02293	0.94	<.0001
x_b	14,5%	15,5%	0,00788	0.33	<.0283
x_c^c	50,4%	32,4%	-0,04435	0.94	<.0001
φ	0.40%	0.35%	-0.01354	0.98	<.0001
H_f *a	**4.175**	**5.482**	**0,02415**	**0,96**	**<.0001**

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

[ff] The public hospital expenditure of Lombardia φY in the period 1997-2008 has not included the *"funzioni non tariffabili"*, i.e. the expenses which are reimbursed retrospectively and on purely politically discretionary basis. In fact since they are both retrospective and politically discretionary, they are treated as a political exogenous intervention P* (see *infra)* to re-equilibrate the balance sheets of some hospitals.

a/million euro

c/ only DRG-financed public expenditure has been considered

Constant Health Spending Propensity

Following the 2008 financial crisis many governments have declared their intention to curb public expenditure but their willingness to keep health care budgets uncut.

The meaning of this is not clear, since if H_f was growing at an exponential rate keeping its absolute value fixed for a fiscal year is, in fact, a violent reduction.

In mathematical terms

Health spending propensity is <u>constant</u> if the growth rate of health financing equals the growth rate of the nominal gross domestic product.

Definition 14: Constant Health Spending Propensity

In fact if

$$H_f = \varphi Y$$

and

$$H_{f0}e^{r_f t} = \varphi_0 e^{r_\varphi t} Y_0 e^{r_y t}$$

we assume[gg]

$$t=1$$

then

$$\frac{\varphi_0 Y_0}{H_{f0}} = \frac{e^{r_f}}{e^{r_\varphi} e^{r\gamma}}$$

and since we are investigating constant health propensity

$$e^{r_\varphi} = 1$$

$$\frac{\varphi_0 Y_0}{H_{f0}} = 1$$

[gg] The effect of t≠1 will be analyzed in the section dedicated to dynamic equilibrium.

we transform logarithmically and we determine the condition for constant health propensity spending as

$$r_f - r_\gamma = 0$$

Equation 18: Constant Health Spending Propensity

■

Application 2

In Italy in the period 2009-2012, as an effect of the cost containment measures imposed by the IMF (International Monetary Fund)[74], the health spending propensity φ will peak in 2010 (7.4%) and decrease to 7.2% in 2012[75], and its exponential growth trend EXP$\left(r_f - r_\gamma\right)$, which has characterized the Health Reform since 1995, will decrease from 0.02167 to -0.00460.

As a direct consequence, the exponential growth of health financing which has amounted to 0.06063 (R = 0.99; P<.001) in the period 1997-2008 will decrease to -0.00460 in the period 2009-2012 (Exhibit 28).

The meaning of this policy is that, if the actual value of Y* in 2012 is lower than expected, the resources available for health care will be two times lower: the first because φ is lower, the second because Y* is lower.

If, in consideration of a lower Y*, in 2012 the government will decide to increase the FF, he will have to increase φ at the expense of (1-φ) applications.

Exhibit 28: Italy Financial Function (FF)

Italy Financial Function	*1997*	*2008*	*EXP$_{1997-2008}$*	*2009*	*2010*	*2011*	*2012*	*EXP$_{2009-2012}$*[hh]
Y[a]	1,048,766	1,572,243	0.03770	1,520,870	1,554,347	1,606,014	1,669,371	0.03105
xa	5.44%	6.90%	0.02293	7.30%	7.40%	7.30%	7.20%	-0.00460
xb	1	1	0.00000	1	1	1	1	0.00000
xc	1	1	0.00000	1	1	1	1	0.00000
φ	5.44%	6.90%	0.02293	7.30%	7.40%	7.30%	7.20%	-0.00460

---

hh in Exhibit 9. EXP has been calculated as: $EXP = \dfrac{\ln\left(\dfrac{b}{a}\right)}{t_b - t_a}$

Hf[a]	57,014	108,485	0.06063	111,024	115,022	117,239	120,195	0.02646
r_f-r_y[ii]			0.02293					-0.00460

Source: Minef

a/million euro

Conclusions

The conclusions regarding the long term sustainability of the FF of hospital care in the period 1997 – 2008 of the Lombardia health system that we could infer from Exhibit 28 alone are even more confounding than the EF.

In fact it appears that on one hand the financial resources available for the health system have grown (*Y*, xa, xb*) but on the other the regulator of the system is exponentially willing to invest less on hospital care (*xc*), with the total effect of actually reducing the hospital spending propensity (φ).

The picture is even more confounding if we look at the whole health system in Exhibit 10, where we can deduce that the system (Italy) is willing to reduce the total health spending propensity φ from 2010 onwards[76], and that the exponential growth which has characterized the *post-reform* period 1997-2008 of 0.06063 will be reduced to 0.02646 in the period 2009-2012.

It is clear that the effects of a reduction of H_f and φ on H_e cannot be inferred upon by the sole analysis of the financial resources available.

The effects of efficiency in the utilization of the financial resources has to be investigated.

[ii] in the case of Exhibit 2.1 (r_f-r_y) coincides with r_{xa} since at the national health system level x_b and x_c are equal to 1.

THE EFFICIENCY ADJUSTED FINANCIAL FUNCTION (EAFF)

The financial resources efficiently available for a health system are positively correlated to the resources available for health care and to the efficiency of the health system.

Definition 15: Efficiency Adjusted Financial Function (EAFF)

We define the Efficiency Adjusted Financial Function (EAFF) as the FF which satisfies the Restricted Nash Equilibrium with a Redistribution Agreement:

$$H_f = F\left[(x_c \circ x_b \circ x_a), L, Y\right]$$

and the R^5 equation

$$H_f = \frac{x_a x_b x_c Y^*}{L}$$

Equation 19: Efficiency Adjusted Financial Function (EAFF)

where the variables are:

L = a measure of the intrinsic quality, i.e. a measure of the efficiency in the utilization of the financial resources available, defined in the interval ($1<L\leq2$). The meaning of L will be analyzed in detail in the chapter dedicated to Efficiency (L).

NOTE

Once again we will underline the fact that efficiency L is the denominator of the EAFF, which means that L is in reality a deflator of the FF since it is a measure of the *in-efficiency* of the health system.

Conclusions

The resources available for a health system are different from the resources efficiently available.

Intuitively the more inefficient the use of the financial resources, the lesser the resources available for an effective epidemiological utilization.

We will see in the chapter dedicated to composite quality (Q) how effectiveness (q) is correlated to efficiency (L).

THE ECONOMIC FUNCTION (ECF)

The financial resources efficiently utilized by a health system are equal to the financial resources available minus the excess profits or excess costs of the health providers.

Definition 16: Economic Function (EcF)

The ECF simply states that, from the point of view of the health system, excess costs (losses) or excess profits[jj] are a measure of the resources wasted to an otherwise efficient utilization.

The ECF highlights, coherently with the Restricted Nash Equilibrium with a Redistribution Agreement condition, that an increase in losses or profits alters the sustainability of the equilibrium of the health system.

The R^3 economic function ECF is defined by the equation

$$H_{eco} = \varphi Y - |C_{std} - C_{act}|$$

Equation 20: Economic Function (ECF)

determined in the interval

$$0 < H_{eco} \leq \varphi Y$$

The Economic Variables

Cstd = Total Standard Costs – The Total Standard Cost of health care for the patient population that is associated with a group of providers. The Cstd includes a reasonable return on capital for the investor[kk];

Cact = Total Actual Costs – The Total Actual Cost of health care for the patient

---

[jj] see *infra*

[kk] the definition of a health investment risk premium β is not analyzed in this paper.

population that is associated with a group of providers;

We will define the losses or excess profits[ll] B (beta) of the ith-provider as

$$\left|C_{std} - C_{act}\right| = B$$

Equation 21: Beta of Losses and

Excess Profits

determined in the interval

$$B \geq 0$$

therefore

$$H_{eco} = \varphi Y - B$$

The Case Mix Adjusted Cost Per Admission *v* (CMAA)

In the EF we defined the vector *x1* =*vws*.

We can now define *v* in economic terms as

$$\begin{cases} x_1 = \dfrac{\varphi Y - B}{qhx_d \Pi} \\ x_1 = vws \end{cases}$$

therefore

$$v = \frac{\varphi Y - B}{wsqhx_d \Pi}$$

Equation 22: Case Mix Adjusted Cost Per Admission (CMAA)

which is the equation of the intensity of resources required per unit of intensity of care *ws,* defined in the EF as the economic transformation variable *v*.

In a classical iso-resource DRG system the variable *v* is the Case Mix Adjusted Cost Per Admission (CMAA), a measure of a hospital's average cost per admission, adjusted for complexity, equal to a hospital's total reported standard costs divided by its total reported admissions by the hospital's CMI.

In the Theory of Quality, Equilibrium and Sustainability *v* is equal to the financial resources efficiently utilized divided by the number of admissions multiplied by the hospital's complexity, severity and effectiveness. the Theory of Quality, Equilibrium

[ll] Specifically paid-out profits. In case profits are reinvested, B is reduced.

and Sustainability therefore predicts that a decrease in effectiveness q will likely result in an *increase* in the Case Mix Adjusted Cost Per Admission (CMAA).

In the GE and GSE the economic function H_{eco} is equal to H_f only if B=0.

In other words we assume that excess profits and excess costs are resources wasted to an epidemiological utilization, therefore the CMAA ought to be adjusted accordingly.

■

Example 1

On Mars there are two hospitals, one is private for profit and the other is public, both with a Cstd of 100$.

The public provider generates losses of -10$ and the private provider excess profits of +10$, therefore the private provider insists on the fact that private management is more efficient, and asks for a privatization of public hospitals.

What should the Governor of Mars do?

He should utilize the Heco!

The private for profit Heco is:

$$H_{eco_{pri}} = 100 - |100 - 90| = 90$$

and the public is

$$H_{eco_{pub}} = 110 - |100 - 110| = 100$$

The resources efficiently utilized for health care are higher for the public hospital, because the private for profit provider generates excess profits (+10$) which he invests (and usually loses) in the stock exchange markets, whereas the public provider generates excess costs (losses) (-10$).

However the private for profit provider argues that 110$ are necessary for the public hospital, whereas only 100$ are necessary for the private for profit one.

The question is correct, and we will see in the following chapters which is the Condition of Indifference (A) and the Intrinsic Quality (L).

Example 2

The Martian private providers want a revaluation of *v* because (they say!) revenues cannot cover costs, where in reality they pay out dividends.

Is it possible?

No, because the Martian president utilizes the EcF and if excess profits B increase *v* is automatically devalued.

Example 3

A Martian private provider invests as little equity as possible in his hospitals, but nonetheless is granted huge profits by the health system, which he pays out and invests (and unfortunately very often loses) in the stock exchange markets.

Is it possible?

No, because if B exceeds a predetermined value, *v* and *x1* are automatically devalued.

The Indifference Coefficient (A) Between Public and Private Provision of Health Care

The situation described in Example 1 is actually very common.

Several health systems are characterized by the coexistence of public and private, the latter both for profit and not for profit, health care providers.

For the health system the cost of utilizing public and not for profit private health providers consists often, albeit not always, into higher operational costs which generate losses, and which then have to be refinanced by the health system.

On the other hand, the cost for the health system of utilizing private for profit health providers consists often, albeit not always, into granting profits in excess of a reasonable rate of return.

In all the other cases B is usually equal to 0, since private losses in limited liability and public companies must either be refinanced by shareholders or the company goes bankrupt, whereas profits in public and not for profit providers have to be reinvested.

The question arises as to which is the condition of indifference between losses and excess profits.

We have defined B as

$$\left| C_{std} - C_{act} \right| = B$$

and we define the Indifference Coefficient A as

$$A = \frac{B_{pub}}{B_{pri}}$$

Equation 23: Indifference Coefficient (A)

Bpub = the losses of the ith-public provider;

Bpri = the excess profits of the ith-private provider.

If

A=1, we have a condition of indifference;

A<1, private excess profits are higher than public losses;

A>1, public losses are higher than private excess profits.

■

Example 4

On Mars there are two other hospitals, one is private for profit and the other is public, both with a Cstd of 100$.

Given the same Cstd, the public provider absorbs 110$ and the private for profit 100$, therefore the private provider insists on the fact that private management is more efficient, and asks for a privatization of public hospitals.

What should the Governor of Mars do?

He should utilize the Indifference Coefficient A!

The private for profit Bpri is:

$$B_{pri} = \left| 100 - 90 \right| = 10$$

and the public Bpub is

$$B_{pub} = \left| 100 - 110 \right| = 10$$

therefore

$$A = \frac{B_{pub}}{B_{pri}} = \frac{10}{10} = 1$$

Since A=1, the public hospital and the private for profit one are in a condition of indifference.

In other words, the same amount of resources is wasted as excess profits and as excess costs.

However the private for profit provider argues that still 110$ are necessary for the public hospital, whereas only 100$ are necessary for the private for profit one.

The question is again correct, and we will see in the following chapter the role of the Efficiency L.

Application

In Lombardia hospital providers are both private for profit, private not for profit and public.

Further investigation should asses if and in which amount the former generate excess profits and the latter losses, and therefore there is room for improvement of the EcF[mm].

Conclusions

The EcF improves the understanding of the functioning of the health system, however it is clear that it alone cannot determine if the system is sustainable in the long term or not, and under which conditions it remains sustainable.

[mm] Further research should assess the cumulative losses and excess profits in the Lombardia health system.

THE EFFICIENCY FUNCTION (L)

The efficiency of a health system is correlated to the available financial resources, to the standard and to the actual costs of the health system

Definition 17: Efficiency Function (L)

Efficiency (L) defined is a measure of the efficient use of the financial resources available for health care.

Since the payor of the health system has to finance H_{eco} the system operates under the necessary condition that $H_{eco} = H_f$,

$$\begin{cases} H_{eco} = \varphi Y - \left| C_{std} - C_{act} \right| \\ H_f = \dfrac{\varphi Y}{L} \end{cases}$$

and we can express the economic function H_{eco} in terms of the financial function H_f, and define L as

$$L = \frac{\varphi Y}{\varphi Y - \left| C_{std} - C_{act} \right|}$$

Equation 24: Efficiency Function (L)

determined in the interval

$$1 \leq L < +\infty$$

which satisfies the Restricted Nash Equilibrium with a Redistribution Agreement because an increase in the Standard Costs, or in the difference between Standard and Actual Costs, alters the jointly stable equilibrium between the FF and the EAFF.

L is a measure of the efficiency of a health system in reversed terms, in terms of the financial resources wasted by the health system in the form of excess profits of private hospitals beyond a reasonable return on equity and of the losses of public hospitals.

Example

On Mars there are two hospitals, one is private for profit and the other is public, both with a Cstd of 100$.

The public provider absorbs 110$ and generates losses of -10$ and the private provider absorbs 100$ and generates excess profits of +10$, therefore the private provider insists on the fact that the intrinsic quality of private management is higher, and asks for a privatization of public hospitals.

What should the Governor of Mars do?

He should utilize the Efficiency Function (L) !

The private L is:

$$L_{pri} = \frac{100}{100 - |100 - 90|} = \frac{100}{90} = 1.1$$

and the public L is

$$L_{pub} = \frac{110}{110 - |100 - 90|} = \frac{110}{100} = 1.1$$

The Effciciency L is the same.

We may now answer the question repeatedly put forward by private for profit providers in criticizing the H_{eco} and A : "110$ are necessary for the public hospital, whereas only 100$ are necessary for the private for profit one".

The ratio between the resources dedicated and those effectively absorbed by the public and private for profit health providers are the same, although they appear at first glance to be different, because L, a measure of the efficiency of the resources utilized, is the same.

The public hospital does absorb more financial resources, but more economic resources are efficiently utilized.

Conclusions

The main hypothesis underlying intrinsic quality L is that a health system is different from an economic system, since a health system does not waste resources only when all the available resources H_f are utilized for health care, and when Cstd=Cact.

PART IV
A theory of EQUILIBRIUM

GENERAL EQUILIBRIUM (GE)

General Equilibrium analyzes the static and dynamic conditions of equilibrium as expressed by time trend regression of the epidemiological, demographic, economic and financial variables.

Static Equilibrium (SE)

The SE defines the conditions of macro equilibrium regardless of the time variable *t*.

The health system is in static macro equilibrium when the resources efficiently available equal the resources effectively absorbed.

Definition 18: Static Equilibrium (SE)

In the general form

$$\begin{cases} \dfrac{H_{f0}}{H_{e0}} = 1 \\ H_{e0} - H_{f0} = 0 \end{cases}$$

We transform logarithmically and we express the condition for SE as

$$\ln H_{f0} - \ln H_{e0} = 0$$

Equation 25: Static Equilibrium (SE)

Application

In the period 1997-2008 the Lombardia hospital system has been in static equilibrium SE; in fact the increase in hospital expenditure H_e has been compensated by an increase in the financial resources available for hospital care H_f , even if the percentage of resources actually dedicated to hospital care xc has decreased.

The parameters *s* (severity), L (efficiency) and q (effectiveness) are equal to 1 because their values have not yet been assessed in Lombardia.

Exhibit 29: Lombardia Static Equilibrium (SE)

Lombardia Static Equilibrium (SE)	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***
Y	1,048,766	1,091,361	1,127,091	1,191,057	1,248,648	1,295,226	1,335,354	1,391,530	1,429,479	1,485,377	1,544,915	1,572,243
x_a	5.44%	5.46%	5.60%	5.89%	6.11%	6.14%	6.16%	6.49%	6.77%	6.71%	6.65%	6.92%
x_b	14.53%	14.41%	15.35%	14.79%	14.03%	16.25%	15.75%	15.06%	15.58%	15.66%	15.99%	15.54%
x_c	50.38%	51.14%	45.19%	43.86%	45.23%	38.08%	38.08%	37.01%	34.42%	34.02%	32.64%	32.43%
φ	0.40%	0.40%	0.39%	0.38%	0.39%	0.38%	0.37%	0.36%	0.36%	0.36%	0.35%	0.35%
L	1	1	1	1	1	1	1	1	1	1	1	1
III	56,904,379	56,909,109	56,923,524	56,960,692	56,995,744	57,321,070	57,888,245	58,462,375	58,751,711	59,131,287	59,619,290	60,045,068
xd	15.68%	15.72%	15.76%	15.81%	15.85%	15.89%	15.97%	16.07%	16.13%	16.14%	16.17%	16.23%
w	0.94	0.95	0.97	1.03	1.06	1.10	1.14	1.15	1.15	1.16	1.16	1.15
m	1.80%	2.20%	2.30%	2.30%	2.30%	2.43%	2.67%	2.53%	2.80%	2.84%	2.91%	3.01%
s	1	1	1	1	1	1	1	1	1	1	1	1
q	1	1	1	1	1	1	1	1	1	1	1	1
h	24.05%	24.45%	23.79%	23.58%	24.07%	23.70%	22.72%	22.59%	22.38%	22.17%	20.28%	19.80%
P	2,145,882	2,186,844	2,134,131	2,122,773	2,173,742	2,158,507	2,100,745	2,121,939	2,120,474	2,115,774	1,955,529	1,928,618
x1	1,945	2,010	2,053	2,145	2,226	2,281	2,348	2,374	2,448	2,508	2,743	2,842
x2	6.7	6.6	6.5	6.4	6.2	6.0	5.9	5.8	5.8	5.9	6.4	6.5
x3	292	305	315	335	359	382	399	411	420	424	430	437

H_{f0}	4,175	4,395	4,380	4,553	4,839	4,924	4,933	5,037	5,190	5,307	5,363	5,482
H_{e0}	4,175	4,395	4,380	4,553	4,839	4,924	4,933	5,037	5,190	5,307	5,363	5,482
Hf0/He0	1	1	1	1	1	1	1	1	1	1	1	1

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia

a/million euro

Conclusions

The SE yields useful *ex-post* information regarding the epidemiological, demographic, economic and financial utilization of the resources of the health system, but it doesn't allow a comprehension of the evolution and the long term sustainability of the system.

■

Dynamic Equilibrium (DE)

The health system is in dynamic equilibrium when the temporal variation of the resources efficiently available equals the temporal variation of the resources effectively absorbed.

Definition 19: Dynamic Equilibrium (DE)

The special theory of dynamic equilibrium incorporates the effect of time *t* as an independent variable in the form $H_e(t) = (h \circ g)(t)$ for the epidemiological equilibrium and $H_f(t) = (h \circ g)(t)$ for the financial equilibrium.

The DE assumes that the system is in an initial state of equilibrium[nn] at t_0, therefore:

$$H_{e0} = H_{f0} \rightarrow \frac{H_{f0}}{H_{e0}} = 1 \rightarrow \ln H_{f0} - \ln H_{e0} = 0$$

Since $f(t) = (1+i)^t = e^{rt}$ and $r = \ln(1+i)$, where *r* is the instantaneous growth rate and *i* the compound annual growth rate (CAGR), the dynamic form of EF and FF is:

[nn] Static Initial Disequilibrium (DD-SID) will be analyzed as a special case of Dynamic Disequilibrium.

$$\begin{cases} \dfrac{H_f}{H_e} = \dfrac{H_{f0}e^{r_f t}}{H_{e0}e^{r_e t}} = 1 \\ H_e - H_f = H_{e0}e^{r_e t} - H_{f0}e^{r_f t} = 0 \\ \int H_e - \int H_f = 0 \end{cases}$$

Starting from a condition of initial equilibrium, the health system remains in dynamic equilibrium if

$$\frac{\Delta H_e}{\Delta t} = \frac{\Delta H_f}{\Delta t}$$

In differential terms

$$\frac{d}{dt}(H_e) = \frac{d}{dt}(H_f)$$

We transform logarithmically and we calculate the derivative

$$\begin{aligned}
&\frac{d}{dt}(H_e) = \frac{d}{dt}(H_f) \\
&\frac{d}{dt}\left(\ln H_e\right)\cdot H_e = \frac{d}{dt}\left(\ln H_f\right)\cdot H_f \\
&(r_v + \ldots + r_\pi)H_e = (r_{xa} + \ldots + r_Y)H_f \\
&\frac{H_f}{H_e} = 1 \text{ only if} \\
&\frac{(r_v + \ldots + r_\pi)}{(r_{xa} + \ldots + r_Y)} = \frac{r_e}{r_f} = 1 \\
&\text{therefore} \\
&r_e - r_f = 0
\end{aligned}$$

In addition, we may demonstrate with the Taylor polynomial of the second order that He and Hf are infinites of the same order since

$$\lim_{t\to\infty}\frac{H_f e^{r_f t}}{H_e e^{r_e t}} = \lim_{t\to 0}\frac{1 + r_f e^{r_f t} + \frac{1}{2}r_f{}^2 e^{r_f t}}{1 + r_e e^{r_e t} + \frac{1}{2}r_e{}^2 e^{r_e t}} = 1 \textbf{ only if } r_e = r_f \to r_e - r_f = 0$$

We may conclude that the health system is in dynamic equilibrium DE when

$$(r_e - r_f) = 0$$

Equation 26: Condition of Dynamic Equilibrium (DE)

The primitive function F of the definite integrals of H_e and H_f is

$$\int_t^{t+n} H_0 e^{rt} dt = F(t+n) - F(t) = H_0 \left[\frac{1}{r} e^{rt} + C \right]_t^{t+n}$$

Equation 27: Cumulative Dynamic Equilibrium (DE)

which is null if

$$\int H_e = \int H_f$$

Application

In Lombardia the scenario changes dramatically if we move from an apparently sustainable situation of static equilibrium (SE) in 2008, as outlined in Exhibit 29: Lombardia Static Equilibrium (SE), to a situation of dynamic equilibrium (DE) as outlined in Exhibit 30.

In fact if the exponential trends of the period 1997-2008 are projected to year 2050, the percentage of national resources dedicated to health care reaches 18.1% of nGDP, three times as much as in 2008 and four points higher than in the USA today, and the percentage *xb* dedicated to Lombardia increases to 21.6%, more than one fifth of the national budget.

On the other hand, in order to keep the system in equilibrium, Lombardia would be obliged to decrease the resources dedicated to hospital care *xc* to as little as 5% of the resources dedicated to health care.

Such a scenario is clearly neither realistic nor apparently sustainable.

Exhibit 30: Lombardia Dynamic Equilibrium (DE)

Lombardia Dynamic Equilibrium (DE)	***YEAR 2008***	***EXP e^{42r} 1997-2008***	***YEAR 2050***
Y^a	1,572,243	0.03770	7,658,665
x_a	6.9%	0.02293	18.1%
x_b	15.5%	0.00788	21.6%
x_c	32.4%	-0.04435	5.0%
φ	0.35%	-0.01354	0.20%
L^b	1	0.00000	1

Π_{ITALY}	60,045,068	0.00530	75,027,550
$x_{d\text{ - LOMBARDIA}}$	16.2%	0.00332	18.65%
w	1.2	0.02128	2.8
m	3.0%	0.03851	15.2%
s^b	1	0.00000	1
q^b	1	0.00000	1
h	19.80%	-0.01682	9.8%
P	1,928,618	-0.00820	1,366,590
x_1	2,842	0.03236	11,063
H_f	5,482	0.02415	15,119
H_e	5,482	0.02415	15,119
DE	**1**	**0**	**1**

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

a/million euro

b/ not in use in Lombardia, and therefore equalled to 1.

Conclusions

It is therefore evident from Exhibit 30: Lombardia Dynamic Equilibrium (DE) that dynamic equilibrium DE is inapt to describe some sort of endogenous or exogenous adjustment that the system must introduce in order to correct some temporal trends that are not sustainable in the long term.

Therefore, before attempting to analyze the special conditions of general equilibrium GE, we will analyze the effects both of initial disequilibrium and dynamic disequilibrium DD.

In other words, we will analyze if it is possible for the system to tolerate disequilibrium and in which amount.

■

Dynamic Disequilibrium (DD)

The special theory of dynamic disequilibrium DD analyzes both static initial and dynamic disequilibrium.

The health system is in dynamic macro disequilibrium when the growth rate of the resources efficiently available is lower than the growth rate of the resources effectively absorbed.

Definition 20: Dynamic Disequilibrium (DD)

The health system is in disequilibrium when $H_e > H_f$.

The special case of $H_e < H_f$ has not been considered, since resources in excess would immediately be allocated to (1-φ) applications.

We introduce the variable D which is a measure of the disequilibrium, and equal to the financial debt of the health system.

The compound cost and growth of debt[77] have not been analyzed[oo].

Static Initial Disequilibrium

The system is in static initial disequilibrium if

$$\begin{cases} \dfrac{H_{f0}}{H_{e0}} = \Delta_0 \rightarrow 0 < \Delta_0 \leq 1 \\ H_{e0} - H_{f0} = D_0 \rightarrow D_0 \geq 0 \end{cases}$$

and

$$\ln H_{f0} - \ln H_{e0} = \ln \Delta_0$$

Equation 28: Condition of Static Initial Disequilibrium

From substitutions we obtain

$$\begin{cases} H_{f0} = \Delta_0 H_{e0} \\ H_{e0} - \Delta_0 H_{e0} = D_0 \end{cases}$$

and

[oo] The debt/GDP ratio evolves according to the identity: $\Delta(D/Y)_t=((r-g)/(1+g))(D/Y)_{t-1}-pb$, where D is the debt stock, Y is the GDP, r is the nominal interest rate, g is the nominal growth rate, pb is the primary fiscal balance as a share of GDP, and Δ indicates a change over the previous year. The debt ratio is constant when: $pb=(D/Y)(r-g)/(1+g)$ [Horton, Kumar, Mauro, *Op. cit.*].

$$D_0 = (1-\Delta_0)H_{e0}$$

Equation 29: Static Initial Disequilibrium-Debt

where if $\Delta_0 \to 1 \therefore D_0 \to 0$

Example

The Martian health minister states that the health system epidemiological function needs 100$.

If the financial resources available are insufficient and a maximum of 10$ of debt is sustainable, what will the financial budget be for the year 20000?

Answer:

$$\Delta_0 = 1-\frac{D_0}{H_{e0}} = 1-\frac{10\$}{100\$} = 0.9 \to H_{f0} = \Delta_0 H_{e0} = 0.9\cdot 100\$ = 90\$$$

Application

Lombardia is in a condition of static initial equilibrium[78].

Dynamic Disequilibrium

The system is in dynamic disequilibrium if

$$\begin{cases} \dfrac{H_{f0}e^{r_f t}}{H_{e0}e^{r_e t}} = \Delta_0 e^{\delta t} \to (0 < \Delta_0 \le 1; \delta \le 0) \\ H_{e0}e^{r_e t} - H_{f0}e^{r_f t} = D_t \to D_t \ge 0 \\ \int H_e - \int H_f = \int D_t \end{cases}$$

and

$$\ln H_{f0} - \ln H_{e0} - \ln \Delta_0 = (r_e - r_f + \delta)t = 0$$

therefore

$$r_e - r_f + \delta = 0$$

Equation 30: Condition of Dynamic Disequilibrium (DD)

From substitutions we obtain

$$D_t = (1-\Delta)H_e = (1-\Delta_0 e^{\delta t})H_{e0}e^{r_e t}$$

Equation 31: Dynamic Disequilibrium-Debt

where if $\delta = 0 \therefore \Delta = \Delta_0 \therefore D_t = D_0$, which is a measure of the disequilibrium at a definite time *t.*

The primitive function F of the definite integral is

$$\int_t^{t+n} H_0 e^{rt} dt = F(t+n) - F(t) = H_0 \left[\frac{1}{r}e^{rt} + C\right]_t^{t+n}$$

Equation 32: Cumulative Dynamic Disequilibrium

which is a measure of the year-to-date disequilibrium in a definite time interval (t+n).

Example 1

The Martian hospital system absorbs 100$ per year and is growing at a rate of 6% from an initial state of disequilibrium of 10$.

The president of Mars, however, has limited the growth of health financing to 3% *per annum*.

What will the debt be in the year 20050?

Answer: the initial

$$\Delta_0 = 1 - \frac{D_0}{H_{e0}} = 1 - \frac{10\$}{100\$} = 0.9$$
.

Since

$$\delta = r_f - r_e = 3\% - 6\% = -3\%$$
$$\Delta_{20050} = \Delta_0 e^{\delta t} = 0.9 \cdot e^{-0.03 \cdot 50} = 0.201$$
$$H_{e20050} = H_{e0} \cdot e^{r_e t} = 100 \cdot e^{0.06 \cdot 50} = 2009\$$$
$$D_{20050} = (1-\Delta_{20050})H_{e20050} = (1-0.201)2009 = 1604\$$$

The debt will be of 1604$, 16 times the hospital expenditure of the year 20000!

The future President will have quite a problem.

Example 2

The Martian president now wants to know from the public health experts how much debt will their hospital system accumulate in 50 years (even if no politician would ever ask that!).

Answer:

$$\Delta_0 = 1 - \frac{D_0}{H_{e0}} = 1 - \frac{10\$}{100\$} = 0.9 \rightarrow H_{f0} = \Delta_0 H_{e0} = 0.9 \cdot 100\$ = 90\$$$

$$H_{e20050} = H_{e0} e^{r_e t} = 100 \cdot e^{0.06 \cdot 50} = 2009\$$$

$$H_{f20050} = H_{f0} e^{r_f t} = 90 \cdot e^{0.03 \cdot 50} = 403\$$$

$$\sum D_t = \int_1^{50} H_{e0} e^{r_e t} dt - \int_1^{50} H_{f0} e^{r_f t} dt = H_{e0}\left[\frac{1}{r_e} e^{r_e t} + C\right]_1^{50} - H_{f0}\left[\frac{1}{r_f} e^{r_f t} + C\right]_1^{50} =$$

$$= 100\$\left[\frac{1}{0.06} e^{0.06t}\right]_1^{50} - 90\$\left[\frac{1}{0.03} e^{0.03t}\right]_1^{50} = 100\$\left[\frac{1}{0.06}(20.09 - 1.06\right] - 90\$\left[\frac{1}{0.03}(4.48 - 1.03\right] =$$

$$= 31717\$ - 10350\$ = 21367\$$$

The last president is going to have a very, very big problem!

Application

The hypothetic Italian national goal of limiting public health financing to 7.4% of nGDP[79], even taking into account an exogenous logistic demographic reduction of the population from 60 to 55 million inhabitants[pp], is still unrealistic unless the epidemiological function is not limited as well (Exhibit 31).

In fact such a financial goal would generate in Lombardia alone 92 billion euro of debt within 2050, 16 times the present current expenditure.

[pp] OECD, *Op. Cit.* Not all forecasts agree. For example ISTAT forecasts 61,716,517 inhabitants in Italy in the year 2050, 6 million more than those forecast by OECD [http://demo.istat.it/uniprev/index.html?lingua=ita, accessed June '10].

Exhibit 31: Lombardia Dynamic Disequilibrium (DD)

Lombardia Dynamic Disequilibrium (DD)	*YEAR 2008*	*EXP e^{42r} 1997-2008*	*YEAR 2050*
Y^a	1,572,243	0.03770	7,658,665
x_a*	6.9%	0.00161	7.4%
x_b	15.5%	0.00788	21.6%
x_c	32.4%	-0.04435	5.0%
L^b	1	0.00000	1
Π_{ITALY}*	60,045,068	-0.00178	55,710,000
$x_{d\text{ - LOMBARDIA}}$	16.23%	0.00332	18.65%
w	1.2	0.02128	2.8
m	3.01%	0.03851	15.2%
s^b	1	0.00000	1
q^b	1	0.00000	1
h	19.80%	-0.01682	9.8%
P	1,928,618	-0.00820	1,366,590
x_1	2,842	0.03236	11,063
H_f	5,482	0.00284	6,175
H_e	5,482	0.01707	11,226
Δ	1.0	-0.01423	0.6
D(t)	0		5,051
D(t-t+n)	0		92,072

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

a/million euro

b/ not in use in Lombardia, and therefore equaled to 1.

Conclusions

It is evident that even the theory of initial static and dynamic disequilibrium is insufficient to describe the behavior of a system not in equilibrium, since some sort of exogenous variable must necessarily intervene to limit the effects of disequilibrium in the long term.

■

Dynamic Re-Equilibrium (DR)

The health system is in dynamic macro re-equilibrium if the exogenous intervention of the system is sufficient to re-equilibrate the health system.

Definition 21: Dynamic Re-Equilibrium (DR)

We introduce the variable P* (Rho) as a measure of the exogenous financial intervention required by the system in order to limit the effects of dynamic disequilibrium.

The exogenous financial intervention has the goal of compensating for endogenous disequilibrium without intervening in the fundamental causes of such disequilibrium.

The variable P* intervenes in the exogenous form:

$$\begin{cases} \dfrac{H_f P^* e^{\rho t}}{H_e} = \Delta \\ H_e - H_f = D_t \\ \int H_e - \int H_f = \int D_t \end{cases}$$

and

$$\ln H_{f0} - \ln H_{e0} - \ln \Delta_0 + \ln P_0 = 0$$

which is the condition for the system re-equilibrium.

In other words the system is in equilibrium if the growth rate ρ of the exogenous variable P* manages to re-equilibrate dynamically δ.

The health system is in Dynamic Macro Disequilibrium if

$$r_e - r_f + \delta - \rho = 0$$

Equation 33: Condition of Dynamic Re-Equilibrium (DR)

From substitutions we obtain

$$D_t = (1 - \frac{\Delta}{P^*})H_e$$

Equation 34: Dynamic Re-Equilibrium-Debt

where if $\delta = 0 \therefore \Delta = \Delta_0 \therefore D_t = D_0$.

Example

The minister of public finances of Mars promises to intervene to readjust the deficit between the health expenditure (100$) and the financial resources available(90$). However he is only a demagogue, and therefore he only re-equilibrates the initial disequilibrium (Δ_0 =1 with P_0^*=1.11), and not the higher growth rate of health expenditure (δ=0.03) which is really only a problem of the next minister.

What will happen in 50 years?

Answer: the deficit will be

$$D_{20050} = (1 - e^{0.03 \cdot 50}) H_{e_{20050}} = 3.5 H_{e_{20050}}$$

which is 3.5 times the current health expenditure of the year 20050!

The last finance minister cannot afford to be a demagogue!

Application

In Lombardia in order to achieve the budgetary goal of health expenditure x_a at 7.4%, the exogenous intervention P* required by the year 2050 should be 1.8 times the FF, a clearly not sustainable trend.

Exhibit 32: Lombardia Dynamic Re-Equilibrium (DR)

Lombardia Dynamic Re-equilibrium (DR)	*YEAR 2008*	*EXP e^{42r} 1997-2008*	*YEAR 2050*
Y^a	1,572,243	0.03770	7,658,665
x_a^*	6.9%	0.00161	7.4%
x_b	15.5%	0.00788	21.6%
x_c	32.4%	-0.04435	5.0%
L^b	1	0.00000	1
Π_{ITALY}^*	60,045,068	-0.00178	55,710,000
$x_{d\text{ - LOMBARDIA}}$	16.23%	0.00332	18.65%
w	1.2	0.02128	2.8
m	3.01%	0.03851	15.2%
s^b	1	0.00000	1
q^b	1	0.00000	1
h	19.80%	-0.01682	9.8%

P	1,928,618	-0.00820	1,366,590
x_1	2,842	0.03236	11,063
H_f	5,482	0.00284	6,175
H_e	5,482	0.01707	11,226
Δ	1.0	0.00000	1.0
D(t)*	0		5,051
D(t-t+n)*	0		92,072
P*	1.0	0.01423	1.8

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

a/million euro

b/ not in use in Lombardia, and therefore equalled to 1.

Conclusions

It is clear from the example that even the hypothesis of exogenous initial re-equilibrium is not realistic over large periods of time, without taking into account the fact that the resources needed for P* must be diverted from (1-φ) applications, thus altering the initial economic sustainability of the system.

The DR has the only effect of re-equilibrating the health system by shifting D to the general system.

The D equations of the DR are consequently unaffected by the parameter P*.

It is clear that the DR is only a short term solution to temporary health system disequilibria and not a long term sustainable condition.

■

General Equilibrium (GE)

The health system is in a state of general equilibrium if exogenous re-equilibrium equals endogenous disequilibrium.

Definition 22: General Equilibrium (GE)

The system is in general equilibrium only when $P^* = \Delta$

The conditions of SE, DE, DD and DR are all special conditions of GE.

In other words, they are determined by the relationship between endogenous disequilibrium Δ and exogenous disequilibrium P*.

In fact

$$
\begin{aligned}
&\xrightarrow{SE} \Delta_0 = 1 \\
&\xrightarrow{DE} \Delta_0 e^{\delta t} = 1 \\
&\xrightarrow{DD-SID} \Delta_0 < 0 < P_0 \\
&\xrightarrow{DD-DD} \Delta_0 e^{\delta t} < 0 < P_0 * e^{\rho t} \\
&\xrightarrow{DR} 1 = \Delta_0 e^{\delta t} < P_0 * e^{\rho t} \\
&\xrightarrow{GE} 1 = \Delta_0 e^{\delta t} = P_0 * e^{\rho t}
\end{aligned}
$$

Equation 35: Condition of General Equilibrium

Application

We assumed that in Lombardia GE could be achieved with a *cœteris paribus* reduction in the financial resources allocated to hospital care *xc*.

In such a case Δ and P* would be equal to 1, and the condition for GE would be satisfied. It is clear, however, that such an intervention would clearly be unrealistic, unless, of course, some sort of space age technology could allow the hospitalization rate to diminish as much as 3.5 times the actual one (Exhibit 33).

Otherwise it would become necessary to intervene simultaneously on multiple epidemiological, economic and financial variables to achieve a sustainable GE.

This consideration brings about the main axiom of the GSE, which will be analyzed in the following chapter.

Exhibit 33: Lombardia General Equilibrium (GE)

Lombardia General Equilibrium (GE)	***2008***	***EXP***	***2050***
Y	1,572,243	0.03770	7,658,665
x_a*	6.9%	0.00161	7.4%
x_b	15.5%	0.00788	21.6%
x_c	32.4%	-0.03012	9.2%
L	1	0.00000	1
Π*	60,045,068	-0.00178	55,710,000
xd	16.23%	0.00332	18.65%

w	1.2	0.02128	2.8
m	3.01%	0.03851	15.2%
s	1	0.00000	1
q	1	0.00000	1
h	19.80%	-0.01682	9.8%
P	1,928,618	-0.00820	1,366,590
x1	2,842	0.03236	11,063
H_f	5,482	0.01707	11,226
H_e	5,482	0.01707	11,226
Δ	1.0	0.000	1.0
D(t)	0		0
D(t-t+n)	0		0
P*	1.0		1.0

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

a/million euro

b/ not in use in Lombardia, and therefore equalled to 1.

Conclusions

It is now clear that the findings of the theory of general equilibrium (GE), even if useful from a technical point of view, are unsatisfactory from the point of view of describing the conditions and the parameters of long term sustainability.

In fact, if equilibrium is achieved thru exogenous intervention P*, the only effect is that disequilibrium D will be shifted at the system level.

We argue that equilibrium is sustainable when the endogenous epidemiological variables readjust endogenously *in continuum* to maintain the system in equilibrium.

Part V
A theory of SUSTAINABILITY

GENERAL SUSTAINABLE EQUILIBRIUM (GSE)

General Sustainable Equilibrium analyzes equilibrium in terms of the endogenous circular and exogenously determined continuous iterations which determine one of the several Nash Equilibria.

The Sustainability Function (SF)

The epidemiological, economic and financial conditions of general equilibrium of a health system are positively correlated to the wealth of the system.

Definition 23: Sustainability Function (SF) In Terms Of The Wealth Of The System

Until now, according to the SE, DE, DD, DR and GE, the Financial Function H_f has been considered a variable dependent from the need of resources H_e necessary to guarantee a constant health outcome.

If the system is in disequilibrium, the exogenous variable P* (rho) intervenes to re-equilibrate the health system, only by shifting disequilibrium to another level inside the system[qq].

[qq] Foreign debt, i.e. shifting debt outside the system, as happened in Greece in 2009-2010, has not been considered in this paper.

Now in the SF(E*) the terms of the relationship will be reversed; the system is in sustainable equilibrium if, given an exogenous variation in the population and wealth of the system E*+ΔE*, the epidemiological, financial and economic endogenous variables react *in continuum* to maintain the system in general equilibrium GE, without the necessity of exogenous intervention P*, therefore

$$\frac{\Delta}{P*} = 1$$

The variables E* and η* that we assume exogenous in the GSE are defined by the financial variable Y*, the demographic variable Π*, the disequilibrium Δ and the re-equilibrator P* in the identity

$$E* \equiv f(Y*, \Pi*, \Delta, P*)$$

and in the equation

$$E_0 * e^{\eta * t} = \frac{Y_0 * e^{\upsilon * t}}{\Pi * e^{\pi * t}} \cdot \frac{P_0 * e^{\pi * t}}{\Delta_0 e^{\delta t}}$$

The R^8 sustainability function E* in the GSE is

$$E* = \frac{Y*}{\Pi*} = vwsq \frac{x_d h}{x_a x_b x_c} L \frac{\Delta}{P*} = x_1 q \frac{x_d h}{x_a x_b x_c} L$$

Equation 36: Sustainability Function (SF)

The epidemiological, financial and economic sustainability of a health system is positively correlated to the *per capita* nominal gross domestic product of the system[rr].

Definition 24: Sustainability Function (SF) In Terms Of The Nominal Gross Domestic Product (nGDP)

Application

In Lombardia the SF has increased from 18439€ to 26184€ *per capita* in the period 1997-2008 at an exponential growth rate of 0.03239[ss].

[rr] When health care is considered, the system may not be confined to the "*state*". It the case of the default of Greece in 2010 when the EC intervened to finance health care and pharmaceutical expenditure. In this case P* from the EC has shifted D to the European level.

If such growth persists throughout 2050, the SF(E*) remains in equilibrium[tt].

Exhibit 34: Lombardia Sustainability Function (SF)

Lombardia Sustainability Function (SF)	*1997*	*2008*	*EXP*	*2050*
Y*/Π*	18,430	26,184	0.03239	102,078
x_a	5.4%	6.9%	0.02293	18.1%
x_b	14.5%	15.5%	0.00788	21.6%
x_c	50.4%	32.4%	-0.04435	5.0%
L	1	1	0.00000	1
xd	15.7%	16.2%	0.00332	18.65%
w	0.9	1.2	0.02128	2.8
m	1.8%	3.0%	0.03851	15.2%
s	1	1	0.00000	1.0
q	1	1	0.00000	1.0
h	24.05%	19.80%	-0.01682	9.8%
P	2,145,882	1,928,618	-0.00820	1,366,590
x1	1,945	2,842	0.03236	11,063
E*	18,430	26,184	0.03239	102,078

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

Conclusions

The SF further improves the understanding of the long term sustainability of a health system.

Most of the current government planning of health expenditure is based on the SF[80], as is the Italian stability plan for 2010-2013[81].

[ss] $$\exp = \frac{\ln\left(\frac{E_{2008}*}{E_{1997}*}\right)}{2008-1997}$$

[tt] the effects of the so called *"federalism"* have not been considered. In fact should federalism be implemented, some regions would have a higher E* than the others, therefore their SF would improve whilst the SF of the others would decrease. This is contradiction with the universal coverage postulate of the GSE.

Mainly the nGDP (Y*), debt (D) and the demographic resident population (Π*), together with some parameters regarding the effects of aging and the active population[uu], are considered.

However we argue that forecasting E* with some adjustment is not sufficient to explain how will the health system adjust to presently unforeseen logistic effects.

In particular, there is a worldwide *consensus* that the growth of E* in GIIPS EC countries will not be in line with the immediately post euro period[vv].

General Sustainable Equilibrium (GSE)

The health system is in General Sustainable Equilibrium if the epidemiological, financial and economic variables which define the sustainability function adapt continuously and endogenously to continuous local and temporal exogenous variation of the wealth of the system.

Definition 25: General Sustainable Equilibrium (GSE)

We transform the SF logarithmically and we calculate the derivative $f^1(t)$ with $\Delta t=1$

$$\eta^* = (r_{x1} + r_q + r_{xd} + r_h + r_L - r_{xa} - r_{xb} - r_{xc})$$

where

$$\eta^* t = (r_Y * - r_\pi *)t$$

We have now defined the amount of endogenous variation required by the health system given an exogenous variation in the wealth of the system with respect to the time *t* variable.

We are now interested in the spatial adjustment of the health system, or, in other words, in how the growth rate η^* adjusts to continuous variation in each of the r_{ij} growth rates.

We therefore express the SF in multivariate total differential terms as

uu the long term predictability of the effects of aging on health are controversial (OECD, *op. cit.*)

vv see Uri Dadush, *Op. Cit.*

$$\Delta\eta^* \equiv F\left(\eta_0 * + \Delta\eta *\right) - F\left(\eta_0 *\right) \approx F\left(\eta_0 *\right) + \frac{\partial F}{\partial r_{x1}}\Delta r_{x1} + \ldots \frac{\partial F}{\partial r_n}\Delta r_n$$

Equation 37: Total Differential of Sustainability Function (SF)

therefore in general terms we will express the Condition of General Sustainable Equilibrium as

$$\Delta\eta^* = \Delta r_i + \cdots + \Delta r_k$$

Equation 38: Condition of General Sustainable Equilibrium (GSE)

We define the **Condition of General Sustainable Equilibrium (GSE)** the identity between the variation in the sustainability function and the variation in the total epidemiological, economic and financial differential function.

Definition 26: Condition Of General Sustainable Equilibrium (GSE)

■

The GSE may be expressed in the less intuitive form of compound annual growth rate (CAGR) with the transformation

$$\xrightarrow{1} e^{rt} = (1 + CAGR)^t$$
$$\xrightarrow{2} CAGR = e^r - 1$$
$$\xrightarrow{3} r = \ln(1 + CAGR)$$

Application

In Lombardia in the period 1997 – 2008 the logarithmic SF of the health system has evolved according to Exhibit 17.

The derivative $f^{[1]}$ has evolved according to Exhibit 18, where the trends of the exponential growth rates of the independent variables have already been analyzed in Exhibit 30.

Exhibit 19 highlights the continuous variation of the partial differentials of the independent endogenous epidemiological, economic and financial variables, which have adapted to total differential variation in the E* of the SF.

As expected from the condition of circular relationship which characterizes General Sustainable Equilibrium in terms of Nash Equilibrium as opposite to the condition of

General Equilibrium in terms of regression covariance, here both linear and non-linear regressions of the $\frac{\partial F}{\partial r}$ do not yield any significant correlation[ww].

Exhibit 35: Lombardia General Sustainable Equilibrium: LN(F(t))

Lombardia General Sustainable Equilibrium (GSE)												
LN(F(t))	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***
Y*	27.7	27.7	27.8	27.8	27.9	27.9	27.9	28.0	28.0	28.0	28.1	28.1
Π*	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9
E*	9.8	9.9	9.9	9.9	10.0	10.0	10.0	10.1	10.1	10.1	10.2	10.2
xa	-2.9	-2.9	-2.9	-2.8	-2.8	-2.8	-2.8	-2.7	-2.7	-2.7	-2.7	-2.7
xb	-1.9	-1.9	-1.9	-1.9	-2.0	-1.8	-1.8	-1.9	-1.9	-1.9	-1.8	-1.9
xc	-0.7	-0.7	-0.8	-0.8	-0.8	-1.0	-1.0	-1.0	-1.1	-1.1	-1.1	-1.1
L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
xd	-1.9	-1.9	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8
h	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.5	-1.5	-1.5	-1.6	-1.6
x1	7.6	7.6	7.6	7.7	7.7	7.7	7.8	7.8	7.8	7.8	7.9	8.0
E*	9.8	9.9	9.9	9.9	10.0	10.0	10.0	10.1	10.1	10.1	10.2	10.2

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia

Exhibit 36: Lombardia General Sustainable Equilibrium: F[1]

Lombardia General Sustainable Equilibrium (GSE)											
F[1]	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***
Y	0.040	0.032	0.055	0.047	0.037	0.031	0.041	0.027	0.038	0.039	0.018
Π	0.000	0.000	0.001	0.001	0.006	0.010	0.010	0.005	0.006	0.008	0.007
η*	0.040	0.032	0.055	0.047	0.031	0.021	0.031	0.022	0.032	0.031	0.010
xa	0.005	0.025	0.051	0.036	0.006	0.003	0.053	0.042	-0.010	-0.009	0.039
xb	-0.008	0.063	-0.037	-0.053	0.147	-0.031	-0.045	0.034	0.005	0.021	-0.029
xc	0.015	-0.124	-0.030	0.031	-0.172	0.000	-0.029	-0.072	-0.012	-0.041	-0.007
L	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
xd	0.002	0.003	0.003	0.003	0.003	0.005	0.006	0.004	0.001	0.002	0.003

[ww] SAS 9.1

h	0.016	-0.027	-0.009	0.021	-0.015	-0.042	-0.006	-0.009	-0.010	-0.089	-0.024
x1	0.033	0.021	0.044	0.037	0.024	0.029	0.011	0.031	0.024	0.089	0.036
η*	0.040	0.032	0.055	0.047	0.031	0.021	0.031	0.022	0.032	0.031	0.010

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia

Exhibit 37: Lombardia General Sustainable Equilibrium: Total Differential

Lombardia General Sustainable Equilibrium (GSE)

$\frac{\partial F^{[1]}}{\partial r}$	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*
Y	-0.008	0.023	-0.008	-0.011	-0.006	0.011	-0.014	0.011	0.001	-0.022
Π	0.000	0.000	0.000	0.005	0.004	0.000	-0.005	0.002	0.002	-0.001
η*	-0.008	0.023	-0.008	-0.016	-0.010	0.011	-0.009	0.010	-0.001	-0.021
xa	0.020	0.026	-0.015	-0.030	-0.003	0.051	-0.011	-0.052	0.001	0.048
xb	0.072	-0.101	-0.015	0.199	-0.178	-0.013	0.078	-0.028	0.016	-0.050
xc	-0.139	0.094	0.060	-0.203	0.172	-0.029	-0.044	0.061	-0.030	0.035
L	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
xd	0.000	0.000	0.000	0.000	0.003	0.001	-0.002	-0.003	0.001	0.001
h	-0.044	0.018	0.030	-0.036	-0.027	0.037	-0.004	0.000	-0.079	0.065
x1	-0.012	0.023	-0.007	-0.013	0.005	-0.018	0.020	-0.006	0.065	-0.054
η*	-0.008	0.023	-0.008	-0.016	-0.010	0.011	-0.009	0.010	-0.001	-0.021

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia

Conclusions

It is evident that the GSE can be adapted to any type of variation considered exogenous.

The GSE can be considered, paraphrasing a well known physicist[82], a *mollusc* which adapts itself *in continuum* to exogenous variation in order to maintain the health system in general sustainable equilibrium.

In addition, it is evident that the system is in a condition of circular iterative endogenous adjustment in response to continuous exogenous variation as predicted by Nash Equilibrium Game Theory.

The last argument to be analyzed is the relationship in a condition of GSE among Intrinsic Quality, Extrinsic Quality and Composite Quality.

EXTRINSIC QUALITY IN GENERAL SUSTAINABLE EQUILIBRIUM

The Isoquantum Quality Function (IQF)

In a condition of GSE, the product of extrinsic effectiveness and efficiency is constant and equal to 1.

Definition 27: Isoquantum Quality Function (IQF)

We express extrinsic effectiveness q in terms of the SF as

$$q = E * \frac{x_a x_b x_c}{vwshx_d} \cdot \frac{1}{L}$$

Equation 39: Extrinsic Effectiveness q in Terms of the SF

We have demonstrated that in General Sustainable Equilibrium

$$\Delta\eta^* = \Delta r_i + \cdots + \Delta r_k$$

If the health system is in a condition of General Sustainable Equilibrium variation in all non-quality coefficients is in equilibrium and therefore equal to zero then

$$\Delta r_q + \Delta r_L = \Delta\eta^* + \cdots + \Delta r_k = 0$$

Therefore if the health system is in GSE,

$$E * \frac{x_a x_b x_c}{vwshx_d} = 1$$

and

$$qL = 1$$

which satisfies the condition of Restricted Nash Equilibrium with a Redistribution

Agreement, defined in the interval

$$1 \le L < \infty \text{ and } 0 < q \le 1$$

■

We define the Isoquantum[83] Quality Function as

$$qL = 1$$

which is unitarily elastic, in fact

$$\varepsilon_q = \frac{f'(L) \cdot L}{f(L)} = \frac{-L^{-2} \cdot L}{L^{-1}} = -1$$

In a condition of GSE, an increase in effectiveness q must correspond to an improvement in efficiency L, and vice versa.

Example

The two managers of a public and a private for profit hospital with a standard cost of 100$, with respectively -10$ of losses and +10$ of excess profits, declare to the journalists of the national press that they want higher quality for the patient and ask for additional resources (+20$) to the President of Mars.

Apart from the ongoing elections campaign, should the President finance the +20$?

No, because if they reduce profits and losses B, they reduce inefficiency and they may improve effectiveness q without the necessity of additional resources.

In fact

B_{pub}=10-10=0, B_{pri}=10$-10%=0

L_{pub}=1.1-0.1=1.0, L_{pri}=1.1-0.1=1.0

$q_{pub} \approx 0.91 + 0.08^{xx} \approx 1.0$, $q_{pri} \approx 0.91 + 0.08 \approx 1.0$

Application

In Lombardia in the period 1997–2008, the IQF is shown in Exhibit 21.

Exhibit 38: Lombardia Isoquantum Quality Function (IQF)

Lombardia Isoquantum Quality Function (IQF)	***1997***	***2008***	***EXP***	***2050***
qL	1.0	1.0	0.00000	1.0
E*	18,430	26,184	0.03239	102,078
x_a	5.4%	6.9%	0.02293	18.1%
x_b	14.5%	15.5%	0.00788	21.6%
x_c	50.4%	32.4%	-0.04435	5.0%
xd	15.7%	16.2%	0.00332	18.65%
s	1.0	1.0	0.00000	1.0
h	24.05%	19.80%	-0.01682	9.8%
x1	1,945	2,842	0.03236	11,063
GSE	1.0	1.0	0.00000	1.0

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

The Extrinsic Composite Quality Function (ECQF) in General Sustainable Equilibrium

We have defined the Composite Quality Function in its general form as

$$Q = kq^{\varepsilon_1} L^{\varepsilon_2}$$

where the parameters k , ε_1 and ε_2 had to be estimated in a condition of General Sustainable Equilibrium.

We now express the CQF in General Sustainable Equilibrium in terms of the SF as

---

[xx] $\Delta q \approx f'(L_0)\Delta L$

$$Q = qL = E * \frac{x_a x_b x_c}{x_1 h}$$

and since in General Sustainable Equilibrium is

$$E * \frac{x_a x_b x_c}{vwshx_d} = 1$$

in GSE the CQF is

$$Q = qL = 1$$
where
$$k = 1$$
$$\varepsilon_1 = 1$$
$$\varepsilon_2 = 1$$

Lemma 1

We have demonstrated that the CQF is Lagrange optimized when

$$q = L = \frac{G}{2}$$
and since
$$qL = 1$$
$$\frac{G}{2} \cdot \frac{G}{2} = 1$$
$$G^2 = 4$$
$$G = \pm 2$$
$$G \equiv \{G > 0; G \in \mathbf{R}\}$$
the CQF is optimized when
$$G = 2$$
and
$$q + L = 2$$
$$q = 1$$
$$L = 1$$

■

Lemma 2

If in General Sustainable Equilibrium the CQF is optimized when

q=L

and

$$qL = E * \frac{x_a x_b x_c}{x_1 h}$$

$$q^2 = E * \frac{x_a x_b x_c}{x_1 h}$$

$$q = \sqrt{E * \frac{x_a x_b x_c}{x_1 h}}$$

since

$$q = L = \frac{G}{2}$$

extrinsic effectiveness (and efficiency) is optimized when

$$G = 2\sqrt{E * \frac{x_a x_b x_c}{x_1 h}}$$

■

Lemma 3

We have calculated that the second order Taylor polynomial linear transformation of the CQF is

$$F(q + h_1, L + h_2) = F_{q,L} + DF_{q,L}\mathbf{h} + \frac{1}{2}\mathbf{h}^T D^2 F_{q,L}\mathbf{h} + R_2(\mathbf{h}; q; L) =$$
$$= 1 + kh_1\varepsilon_1 + kh_2\varepsilon_2 + \frac{1}{2}kh_1{}^2\varepsilon_1(\varepsilon_1 - 1) + kh_1h_2\varepsilon_1\varepsilon_2 + \frac{1}{2}kh_2{}^2\varepsilon_2(\varepsilon_2 - 1)$$

We may demonstrate that if

$$k = 1$$
$$\varepsilon_1 = 1$$
$$\varepsilon_2 = 1$$

$$F(\mathbf{a} + \mathbf{h}) = Q = qL = 1$$

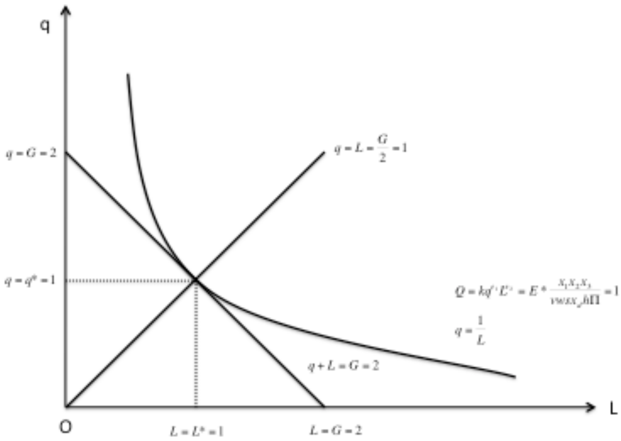
In fact given an arbitrary point **p**(q,L) such as **p**(1.100,0.091), where **h**(0.100,-0.009), which is located on the CQF, and therefore satisfies the GSE condition qL=1,

$$F(\mathbf{a} + \mathbf{h}) = 1 + h_1 + h_2 + h_1 h_2 = 1 + 0.100 - 0.091 - 0.009 = 1$$

■

In graphic terms (Exhibit 39: Optimum Composite Quality in General Sustainable Equilibrium)

Exhibit 39: Optimum Composite Quality in General Sustainable Equilibrium



Conclusions

We have demonstrated that in GSE:

$$Q=qL=1$$

$$k=1$$
$$\varepsilon_1=1$$
$$\varepsilon_2=1$$

It follows that efficiency and effectiveness are correlated and that, in order for the health system to remain in general sustainable equilibrium, an increase in effectiveness must correspond to an increase in efficiency which satisfies the relationship qL=1.

In the Part dedicated to the QUALITY VECTOR MODEL we will define a (L,q) coordinate system and (L,q) vectors to analyze the relative position of the providers of the health system and their dynamic displacement towards optimum composite quality (1,1).

In the Part dedicated to Other Applications of the Theory of Quality, Equilibrium and Sustainability we will analyze some applications of the Composite Quality Q.

The General Definition of the Epidemiological Function (EF)

We have defined in the Fundamental Functions the EF as

$$H_e = vwsqhx_d\Pi$$

we may now define the EF in general terms as

$$H_e = vws\frac{q_j}{q_{std}}hx_d\Pi$$

In the Theory of Quality, Equilibrium and Sustainability, the Epidemiological Function depends both from:

- the exogenous desired standard effectiveness;
- the actual intrinsic standardized weighted effectiveness.

Therefore in the general definition of the EF, given an Extrinsic Standardized Weighted Quality, a higher exogenous desired effectiveness q_{std} reduces the actual q of the health system.

This implies that a modification of q_{std} will modify q, the EF and, ultimately, the GSE.

This is coherent with the GSE postulate, where any exogenous variation will induce a continuous re-adjustment of the health system.

■

Example 1

The press of Mars is attacking the heart surgery centers because they have a higher intra-hospital mortality rate (4%) than the Jovian standard (2%), therefore health resources are not utilized as effectively (q=2%/4%=0.5<1) as they should (q=2%/2%=1).

What does the Governor of Mars do, taking into account that he campaigned for higher health quality?

Instead of improving q by reducing mortality from 4% to 2%, which would take a considerable effort, he unethically demonstrates that on Mars there are very specific metabolic conditions which explain a higher standard mortality rate (q_{std}=5 %), therefore: q=5%/4%=1.25 !!!

The bad news for hospital providers is that, since q>1, the Governor of Mars may enact guidelines which reduce costs (C_{std}) and reduce the H_e accordingly.

Or better, he may just declare that 5% has been overestimated, that 4% is reasonable, go back to q=1, and leave everything as it is.

Or, even better, admit that the Martian mortality is too high, reduce waste L and improve q to the Jovian 2%.

No political escape from the GSE!

PART VI
the QUALITY VECTOR MODEL

THE THEORETICAL QUALITY DISTRIBUTION (TQD)

We have defined the CQF in a condition of GSE as

$$Q=1$$

and

$$q = \frac{1}{L}$$

defined in the interval

$$0<q\leq 1 \text{ and } 1\leq L<\infty$$

In differential terms

$$\frac{\Delta q}{\Delta L} \approx f'(L_0)$$

$$\Delta q \approx f'(L_0)\Delta L$$

therefore

$$f(L_0 + \Delta L) \approx f(L_0) + f'(L_0)\Delta L$$

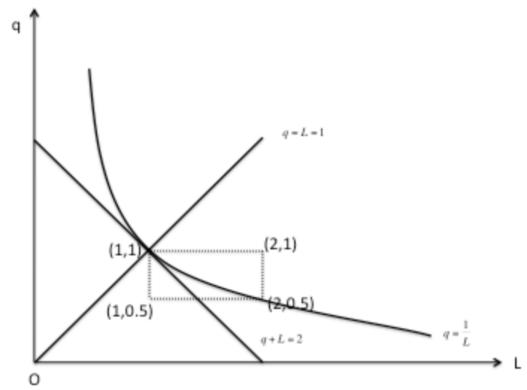
and

$$q \approx f(L_0) + f'(L_0)\Delta L$$

■

We may now introduce a (L,q) coordinate system where we may plot the relative position of the N providers of the health system in (L,q) coordinates. The area of the inliers will be in the rectangle with (L,q) coordinates (1,1; 1,0.5; 2,1; 2,0.5). (Exhibit 40: (Lq) Coordinate System).

Exhibit 40: (Lq) Coordinate System



For a population of N providers, since efficiency L is being treated as the independent variable, we calculate the actual L_{act} , we define the theoretical effectiveness of the health system q_{the} and we determine the theoretical composite quality distribution as

$$q_{the} = \frac{1}{L_{act}}$$

where

$$q_{the} L_{act} = 1$$

Equation 41: Theoretical Composite Quality Distribution (TCQD)

We define the optimum L=1 and q=1 point as the 0^{th} (zeroth) point, where efficiency and effectiveness are maximum.

Example

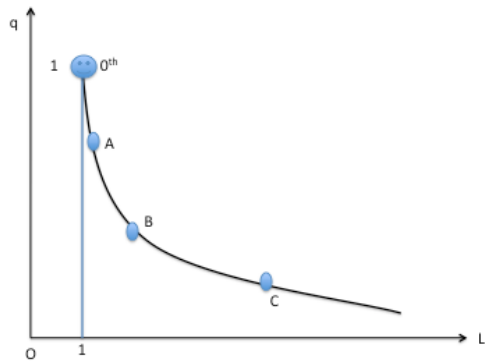
Given 3 providers A (Private for profit), B (Private not for profit) and C (Public) with the L_{act} defined in Exhibit 24, we calculate q_{the} and determine the theoretical distribution of composite quality qL=1, with the optimum L=1 and q=1 defined as the 0^{th} point.

Exhibit 41: Composite Quality Theoretical Distribution (TQD)

Provider	***L_{act}***	$q_{the} = \frac{1}{L_{act}}$	$q_{the} \approx f(L_0) + f'(L_0)\Delta L$	***TQD***
0^{th}	1.000	1.000	1.000	1.000
A	1.100	0.909	0.909	1.000
B	1.300	0.769	0.744	1.000
C	1.800	0.556	0.473	1.000

In graphic terms[yy] (Exhibit 25):

Exhibit 42:Plot of the Theoretical Quality Distribution (TQD)



The private for profit provider A has a much higher efficiency than the public one C, therefore we expect a much higher effectiveness q.

On the other hand, the public provider C has ample room to improve its effectiveness q by reducing the waste of resources L and not by increasing its exogenous health financing.

[yy] q and L axis not to scale

Conclusions

The TQD yields preliminary information as to the actual distribution of standardized weighted efficiency L along the QIC.

In other words, it is useful to assess if the health system in its pursuit of a higher effectiveness will be able to exploit a situation of a high inefficiency in its use of economic resources.

THE ACTUAL COMPOSITE QUALITY DISTRIBUTION

We now define actual composite quality distribution R as

$$q_{act} L_{act} = R$$

where R>0 is a point in the coordinate system qL.

We may easily demonstrate that in the QUALITY VECTOR MODEL theoretical and actual composite quality distributions intersect when

$$\begin{cases} L_{act} = \dfrac{R}{q_{act}} \\ L_{act} = \dfrac{1}{q_{the}} \end{cases}$$

and

$$R = \frac{q_{act}}{q_{the}}$$

Example

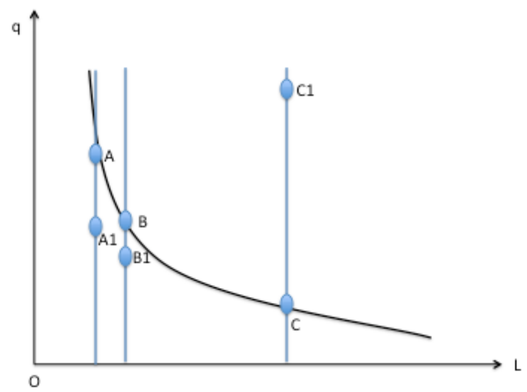
Given 3 providers A1 (Private for profit), B1 (Private not for profit) and C1 (Public), where $q_{std} = 20$, the Actual Quality Distribution (AQD) is as follows (Exhibit 43: Composite Quality Actual Distribution (AQD)):

Exhibit 43: Composite Quality Actual Distribution (AQD)

Provider	L_{act}	q_{the}	*TQD*	q_j	q_{act}	*R*
0^{th}	1.0	1.000	1.000			
A1	1.1	0.909	1.000	16.7	0.833	0.916
B1	1.3	0.769	1.000	14.3	0.714	0.928
C1	1.8	0.556	1.000	20.0	1.000	1.800

In graphic terms (Exhibit 44: Plot of the Actual Composite Quality Distribution (R))

Exhibit 44: Plot of the Actual Composite Quality Distribution (R)



The public hospital C1 does waste much more resources than the private for profit A1, but it has a much higher standardized weighted effectiveness q.

Therefore whilst the main target of A1 will be to increase its effectiveness q, the public C1 will have to concentrate on the reduction of inefficiency, and private not for profit B1 shall have to improve both effectiveness and efficiency.

Conclusions

Both the TQD and the AQD yield useful information regarding the distribution of efficiency and effectiveness in a health system when the system is in a condition of GSE.

However we have demonstrated that a health system is in GSE when its epidemiological, financial and economic variables adapt continuously to continuous exogenous variation.

In the QUALITY VECTOR MODEL we will define the dynamics of adaptation of the health system to optimum efficiency and effectiveness.

THE QUALITY VECTOR MODEL

The theory of GSE assumes that equilibrium is sustainable when it is in a continuous dynamic endogenous adjustment to exogenous variation.

Consequently the QUALITY VECTOR MODEL does not analyze efficiency and effectiveness in absolute static terms but in relative dynamic ones.

The QUALITY VECTOR MODEL analyzes the relative performance of the providers of the health system in terms of displacement and relative velocity[84] towards optimum efficiency and effectiveness.

Definition 28: QUALITY VECTOR MODEL

The methodology utilized is vector analysis in a Euclidean coordinate system, which allows for a considerable simplification in calculi.

The Displacement[zz] of the Health System From Optimum Composite Quality

We have defined:

0^{th} = the optimum composite quality point with coordinates (1,1);

R = the actual composite quality point with coordinates (L_{act}, q_{act})

We may now define the vector R0 as

$$\overrightarrow{R0} = (L_{act} - 1, q_{act} - 1)$$

Equation 42: Vector R0 in the QUALITY VECTOR MODEL

[zz] Distance is always positive whereas displacement may be positive or negative, as is the case in the QUALITY VECTOR MODEL.

and the displacement R0 as

$$\left\| \overline{RO} \right\| = \sqrt{\left(L_{act} - 1\right)^2 + \left(q_{act} - 1\right)^2}$$

Equation 43: Displacement R0 in the QUALITY VECTOR MODEL

which is maximum for the diagonal

$$\left\| \overline{R0_{MAX}} \right\| = \sqrt{\left(L_{MAX-1}\right)^2 + \left(\frac{1}{L_{MAX}} - 1\right)^2}$$

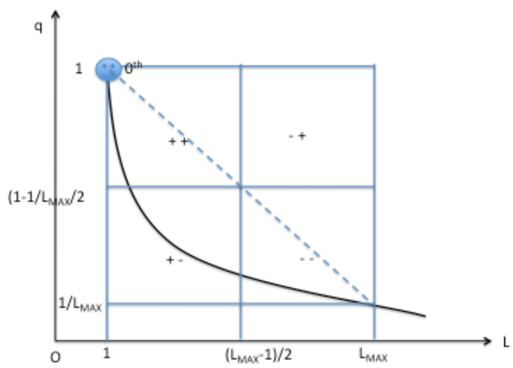
Equation 44: Maximum Displacement R0 in the QUALITY VECTOR MODEL

In the QUALITY VECTOR MODEL the lower the displacement R0, the higher the composite quality qL.

In the QUALITY VECTOR MODEL REFERENCE FRAME we distinguish the 0^{th} point and four square sections defined by the intersections of q=1, L=1, L_{MAX}, $1/L_{MAX}$,(L_{MAX}-1)/2 and (1-1/L_{MAX})/2.

In graphic terms (Exhibit 28):

Exhibit 45: QUALITY VECTOR MODEL REFERENCE FRAME



0^{th} point = maximum efficiency, maximum effectiveness, zero displacement;

Section:

++=high efficiency, high effectiveness, minimum displacement

+-=high efficiency, low effectiveness

-+=low efficiency, high effectiveness

--=low efficiency, low effectiveness, maximum displacement

Example 1

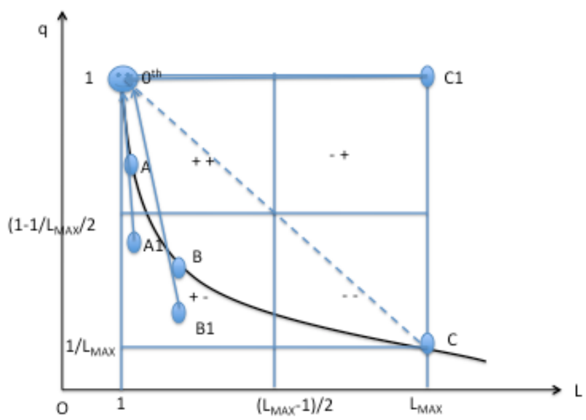
Given 3 providers A1 (Private for profit), B1 (Private not for profit) and C1 (Public), the displacements from the 0th point are as follows (Exhibit 29):

Exhibit 46: Displacement of the Health System from Optimum Quality

Provider	L_{act}	q_{act}	$\|\|\overline{R0}\|\|$
A1	1.1	0.833	0.195
B1	1.3	0.714	0.414
C1	1.8	1.000	0.800

In graphic terms (Exhibit 30)

Exhibit 47: Plot of the Displacement of the Health System from Optimum Quality



In the QUALITY VECTOR MODEL the private for profit provider A1 has a lower displacement to cover in order to attain maximum composite quality (R0=0.195), whereas the public one, even if he has already attained maximum effectiveness, has to recover from maximum inefficiency and has to cover a displacement of 0.800.

The Relative Velocity[aaa] ω of the Health System Towards Optimum Composite Quality

In the QUALITY VECTOR MODEL we may now proceed to rank yearly the providers on the basis of their relative change in displacement (relative velocity) towards maximum composite quality.

We define velocity as

$$\text{velocity} = \frac{\text{displacement}}{\text{time}}$$

and Relative Velocity ω for Δt=1 as

$$\omega = \frac{\left\|\overline{R0}_{t_0}\right\| - \left\|\overline{R0}_{t_0+n}\right\|}{\left\|\overline{R0}_{t_0}\right\|}$$

Equation 45:Relative Velocity in the QUALITY VECTOR MODEL

where the higher the relative velocity, the higher the performance .

Example 2

Given 3 providers A1 (Private for profit), B1 (Private not for profit) and C1 (Public), the Relative Velocity ω from the 0th point in the year 20000 and the following 20001 is as follows (Exhibit 31):

Exhibit 48: Relative Velocity in the QUALITY VECTOR MODEL

Provider	$L_{act\text{-}20000}$	$q_{act\text{-}20000}$	$\left\|\overline{R0}\right\|_{\text{-}}$ **20000**	$L_{act\text{-}20001}$	$q_{act\text{-}20001}$	$\left\|\overline{R0}\right\|_{\text{-}}$ **20001**	ω
A1	1.1	0.833	0.195	1.2	0.900	0.224	-0.15
B1	1.3	0.714	0.414	1.4	0.600	0.566	-0.36
C1	1.8	1.000	0.800	1.5	1.000	0.500	0.38

[aaa] Speed is always positive whereas velocity may be positive or negative, as is the case in the QUALITY VECTOR MODEL.

The C1 public provider has made the greatest effort towards optimum efficiency and effectiveness (ω=0.38), by improving its efficiency (L from 1.8 to 1.5) and maintaining its effectiveness.

The not for profit provider has lost both efficiency and effectiveness (ω=-0.36), whereas the for profit one has increased its excess profits (L from 1.1 to 1.2) but also its effectiveness (q from 0.833 to 0.900), with an ω of -0.15.

Conclusions

The QUALITY VECTOR MODEL is based on the findings of the Theory of Quality, Equilibrium and Sustainability.

By defining a (Lq) coordinate system it permits the utilization of vectors which greatly simplify the calculi and the synthesis of the dynamics of the providers of the health system towards optimum sustainable equilibrium.

The QUALITY VECTOR MODEL also allows a comparative simultaneous synthetic graphical representation of the velocity of all the providers of the system.

The concept of velocity summarizes all the findings of the Theory of Quality, Equilibrium and Sustainability in one vector.

PART VII
Other Applications of the Theory of Quality, Equilibrium and Sustainability

TOTAL COMPOSITE QUALITY

We define total effectiveness q_{tot} as

$$q_{tot} = qhx_d\Pi$$

therefore we can express the EF as

$$H_e = vws\frac{q_{tot}}{hx_d\Pi}hx_d\Pi = x_1 q_{tot}$$

which determines the resources absorbed by the health system in terms of total standardized weighted effectiveness q_{tot}

Since in GSE

$$H_e = H_f$$

then

$$x_1 q_{tot} = \frac{\varphi Y}{L}$$

and we can define Total Composite Quality as

$$q_{tot}L = \frac{\varphi Y}{x_1}$$

Equation 46: Total Composite Quality

An increase in φY has no effect on Total Composite Quality if x1 increases proportionally.

Application

In Lombardia in the period 1997-2008 the φY has increased from 4,175 to 5,482 m€ at an exponential rate of 0.02415 (P<.0001) whereas the vector x1 has increased at a higher rate of 0.03236 (P<.0001), thus reducing the Total Composite Quality index (r=-0.00820)

Exhibit 49: Lombardia Total Composite Quality

Lombardia Total Composite Quality	***YEAR 1997***	***YEAR 2008***	***Parametro Esponenziale e^{rt}***	***R-quadr corr***	***Pr>|t|***
φY^a	4,175	5,482	0.02415	0.96	<.0001
x_1	1,945	2,842	0.03236	0,97	<.0001
$q_{tot}L$	2,145,882	1,928,618	-0.00820		

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

a/million euro

THE VECTORS X1 AND X3 IN TERMS OF TOTAL COMPOSITE QUALITY

In the Theory of Quality, Equilibrium and Sustainability the vector x1 is defined as

$$x_1 = \frac{\varphi Y}{q_{tot}L}$$

and since

$$x_1 = x_2 x_3$$

we define the vector x3 as

$$x_3 = \frac{\varphi Y}{q_{tot} L} \cdot \frac{1}{x_2}$$

which is unitarily elastic.

In the Theory of Quality, Equilibrium and Sustainability, in a condition of GSE, an increase in total standardized weighted effectiveness q_{tot} should account for an increase in the vectors x1 and x3 only if contemporarily efficiency L is improved or the average length of stay x2 is reduced more than proportionally[85,86].

An outright increase in the φY will have the only effect of increasing x1 or x3.

Application

In Lombardia in the period 1997-2008 the coefficient $\frac{\varphi Y}{q_{tot} L}$ has increased from 1945€ to 2845€ at an exponential rate of 0.03236 (P<.0001).

The vector x1 has increased at the same rate and, since x2 has not scored a significant trend and has remained unchanged (r=0.00673, P<.1301), x3 has also increased (r=0.03909, P<.0001).

Exhibit 50: Lombardia Vectors x1 and x3

Lombardia Vectors x1 and x3	***YEAR 1997***	***YEAR 2008***	***Parametro Esponenziale e^{rt}***	***R-quadr corr***	***Pr>|t|***
x_1	1.945	2.842	0,03236	0,97	<.0001
x_2	6.7	6.5	0.00673	0,14	<.1301
x_3	292	437	0.03909	0,94	<.0001

$\frac{\varphi Y}{q_{tot}L}$	1,945	2,842	0.03236	0,97	<.0001

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

Conclusions

In Lombardia in the period 1997-2008 there is the possibility that an increase in the financial resources available has been utilized only for an increase of x1 and x3.

A breakdown of the q_{tot} and L variables of the $q_{tot}L$ parameter of Total Composite Quality is necessary in order to assess the cause of its reduction (r=-0.00820)[bbb] in Lombardia in the period 1997-2008.

In the same period, the ratio of the financial resources available to the composite quality of the system has increased at an exponential rate of 0.03236 (P<.0001).

THE AVERAGE LENGTH OF STAY (ALOS) X2

We define the Total Number of Hospital Patients (Inpatients + Outpatients)

$$P = hx_d\Pi$$

Equation 47: Total Number of Hospital Patients

and the Total Number of Patient Days

$$D = x_2 hx_d\Pi$$

Equation 48: Total Number of Patient Days

therefore

$$x_2 = \frac{D}{P}$$

Equation 49: Average Length of Stay (ALOS)

Since

$$x_1 = x_2 x_3$$

[bbb] Exhibit 10.

and

$$x_2 = \frac{x_1}{x_3}$$

we may also define x2 as

$$x_2 = \frac{v}{x_3} \cdot ws$$

Equation 50: Average Length of Stay in Terms of Complexity and Severity

and

$$D = \frac{v}{x_3} \cdot ws \cdot P$$

Equation 51: Total Number of Patient Days in Terms of the Intensity of Care and the *per diem* Reimbursement

which states that the ALOS x2 and the total number of patient days D are directly proportional to the complexity and severity of the patient cases and to the ratio between the intensity of care and the per day reimbursement.

THE ROLE OF THE ALOS X2 IN A PROSPECTIVE AND *PER DIEM* PAYMENT SYSTEM

In the Theory of Quality, Equilibrium and Sustainability

$$x_3 = \frac{\varphi Y}{q_{tot} L} \cdot \frac{1}{x_2}$$

Equation 52: Vector x3 in Terms of the Financial Function FF and Total Composite Quality TCQ

since

$$x_1 = \frac{\varphi Y}{q_{tot} L}$$

we can express x3 in terms of x2 as

$$x_3 = x_1 \cdot \frac{1}{x_2}$$

Equation 53: Vector x3 in terms of Vector x1 and the ALOS x2 which is unitarily elastic

$$\varepsilon_{x_2} = \frac{-(x_2)^{-2}(x_2)}{(x_2)^{-1}} = -1$$

Since in a *per diem* payment system

$$x_3 = \overline{x_3}$$

a prospective DRG-based payment system and a *per diem* payment system are indifferent when

$$\begin{cases} \overline{x_1} = x_2 x_3 \\ x_1 = x_2 \overline{x_3} \end{cases}$$

therefore

$$x_2 \overline{x_3} = x_2 x_3$$

and

$$\overline{x_3} = x_3$$

Equation 54: Condition of Indifference between a Prospective and a *per diem* Reimbursement Payment System

PROVIDERS' MARGINAL UTILITY (MU)

Starting from a condition of indifference where

$$\begin{cases} x_3 = \overline{x_1} \cdot \dfrac{1}{x_2} \\ x_1 = x_2 \overline{x_3} \end{cases}$$

In a *per diem* payment system the ith-provider has differential a marginal utility MU[ccc] in increasing x2 equal to

Definition 29: Marginal Utility in a *Per Diem* Payment System

---

[ccc] Time variable costs on incremental daily basis (catering, hospital linen, etc) are not significant. Case variable costs do not depend on the ALOS.

$$MU = f'(x_2) = \overline{x_3}$$

Equation 55: Marginal Utility in a *per diem* Payment System

In a prospective DRG-based payment system, where x1 is fixed and predetermined, the ith-provider has a differential marginal utility MU in reducing x2 equal to

Definition 30: Marginal Utility in a *DRG-based* Payment System

$$MU = g'(x_2) = -\overline{x_1} x_2^{-2}$$

Equation 56: Marginal Utility in a Prospective Payment System

Since

$$f'(x_2) > g'(x_2)$$

because

$$\frac{x_1}{x_2} > -\frac{\overline{x_1}}{x_2^{\ 2}}$$

the ith-provider in a *per diem* payment system has a much stronger interest in increasing x2 than the same ith-provider in reducing it in a prospective DRG based payment system.

PROVIDERS' ISOSTATIC (ISCU), ISODYNAMIC (IDCU) AND TOTAL CUMULATIVE UTILITY (TCU)

The Isostatic Cumulative Utility (ISCU) of the ith-provider is equal to the increase in case reimbursement from x1,1 to x1,2 when the ALOS x2 is unchanged.

Definition 31: Isostatic Cumulative Utility (ISCU)

It is defined as

$$ISCU = x_2^{\ 1}\left(x_{3,1}^{\ \ 2} - x_{3,1}^{\ \ 1}\right)$$

Equation 57: Isostatic Cumulative Utility (ISCU)

where x3,1 and x3,2 are respectively the x3 variable referred to x1,1 and x1,2.

■

The Isodynamic Cumulative Utility (IDCU) of the ith-provider in reducing x2 when x1 is unchanged is determined by the integral defined in the interval (1≤x2≤*ul*[ddd])

Definition 32: Isodynamic Cumulative Utility (IDCU)

$$IDCU = \overline{x_{1,1}} \int_{x_2^{\,2}}^{x_2^{\,1}} x_2^{\,-1}\, dx_2 = \overline{x_{1,1}} \left[\left(\ln|x_2| + C \right) \Big|_{x_2^{\,2}}^{x_2^{\,1}} \right] - x_{3,1}^{\,1} \left(x_2^{\,1} - x_2^{\,2} \right)$$

Equation 58: Isodynamic Cumulative Utility (IDCU)

■

The Total Cumulative Utility (TCU) of the ith-provider in reducing x2 when x1,1 has been increased to x1,2 is

Definition 33: Total Cumulative Utility (TCU)

$$TCU = \overline{x_{1,2}} \int_{x_2^{\,2}}^{x_2^{\,1}} x_2^{\,-1}\, dx_2 - \left[x_{3,1}^{\,1} \left(x_2^{\,1} - x_2^{\,2} \right) \right] =$$

$$= \overline{x_{1,2}} \left[\left(\ln|x_2| + C \right) \Big|_{x_2^{\,2}}^{x_2^{\,1}} \right] - \left[x_{3,1}^{\,1} \left(x_2^{\,1} - x_2^{\,2} \right) \right]$$

Equation 59: Total Cumulative Utility (TCU)

■

In graphical terms (Exhibit 31):

B1-x3 = *per diem* payment system line;

x1,1 and x2,2 =the DRG based prospective payment system indifference unitarily elastic curves;

C-D1 = increase in x3 due to a reduction of x2 for a fixed x1,1;

C-C2 = increase in x3 due to an increase in x1,1 to x1,2 for a fixed x2;

C-D3 = compound increase in x3 due to an increase in x1 and a reduction of x2;

MU = tanC, tanC2, tanD1, tanD3;

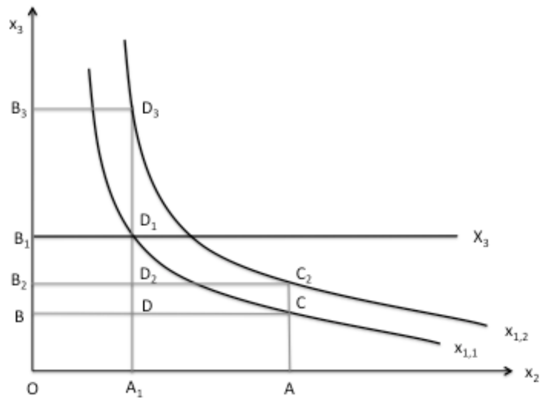
ISCU = C-C2-B-B2

IDCU = C-D-D1, C2-D2-D3

TCU = C-D-D3-C2

[ddd] upper limit of ALOS

Exhibit 51: Plot of the Isostatic, Isodynamic and Total Cumulative Utility



Example 1

The Martian private health care providers operate in a MARTIAN M-DRG prospective payment system, with an average DRG of 1500$ and an ALOS of 7.5 days.

They complain as loudly as possible that 1500$ (200$ per day) are not enough to cover fixed labor costs, which are calculated on a time basis, and ask for a revaluation.

The President accepts and revaluates M-DRG to 2250$ (+100$ per day).

Did he make the right choice?

No, because if he utilized the Theory of Quality, Equilibrium and Sustainability he would have found out that Martian private health care providers could achieve the same ISCU of +100$ per day by reducing the ALOS to 5 days.

Example 2

Now the ever unhappy Martian private health care providers complain that they have reduced the ALOS to 5 days, but that an increase of 100$ per day is not enough, since such an increase does not account for the Martian inflation of 2%.

The President of Mars grants an increase from 100$ to 102$.

Did he make the right choice?

No, because if he utilized the Theory of Quality, Equilibrium and Sustainability he would know that the IDCU of Martian private providers is:

$$1500\$(\ln 7.5 - \ln 5.0) - 200\$(7.5 - 2.5) = 108.2\$$$

Therefore if the ALOS is reduced to 5 days, an increase of 8.2% per case is achieved.

The IDCU is greater then the ISCU.

Example 3

Some Martian private health care providers are smarter than the others, since they know that the IDCU is greater than the ISDU, so in addition to the revaluation of the M-DRG from 1500$ to 2250$ they reduce the ALOS from 7.5 to 5 days.

However they keep complaining that +750$ per case is still not enough.

Are they saying the truth?

No, because the cumulative advantage TCU has to be calculated with the Theory of Quality, Equilibrium and Sustainability, and it is equal to the area D-D2-C-C2 of the graph plus the area D3-D2-C2.

In mathematical terms

$$2250\$(\ln 7.5 - \ln 5.0) - 200\$(7.5 - 5.0) = 412\$$$

Martian private providers are earning an additional 750$+412$=1162$ per case, almost twice as much as they earned before.

The Martian President should go back to undergraduate mathematics!

Application

In Lombardia in the period 1997-2008 the increase in x3 has been entirely due to an increase in x1, since x2 has remained unchanged, therefore on average no isodynamic effects have been exploited by the health system.

The ISCU has increased of 897€, whereas the increase in the IDCU and the TCU are virtually insignificant.

Exhibit 52: Lombardia the Isostatic, Isodynamic and Total Cumulative Utility

Lombardia Isostatic, Isodynamic and Total Cumulative Utility	YEAR 1997	YEAR 2008	Parametro Esponenziale e^{rt}	R-quadr corr	Pr>|t|
x_1	1,945	2,842	0,03236	0,97	<.0001
x_2	6.7	6.5	0.00673	0,14	<.1301
x_3	292	437	0.03909	0,94	<.0001
ISCU		897			
IDCU		0.51			
TCU		21.21			

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

Conclusions

In Lombardia from the marginal and cumulative point of view the only variable which has been affected is the vector x1 thru the ISCU.

On average, no dynamic x2 effects have been exploited.

Further investigation should verify if this is a consequence of the extreme rigidity of the labor markets and if it is labor costs which are the cause of an increase in φY not compensated by an increase in Total Composite Quality $q_{tot}L$.

TOTAL PATIENT DAYS (D)

We have defined the total number of hospital patients (inpatients + outpatients)

$$P = hx_d\Pi$$

and the total number of patient days

$$D = x_2 h x_d \Pi$$

therefore

$$x_2 = \frac{D}{P}$$

Since

$$x_1 = \frac{D}{P} x_3$$

we can now express the condition of GE in terms of the ALOS as

$$\frac{\varphi Y}{L} = x_3 \frac{D}{P} q h x_d \Pi$$

and

$$D = \varphi Y \cdot \frac{P}{q_{tot} L} \cdot \frac{1}{x_3}$$

Equation 60: Total Patient Days (D) in Terms of Total Composite Quality

where in General Sustainable Equilibrium the coefficient

$$\frac{P}{q_{tot} L} = 1$$

if

$$qL = 1$$

which is the composite quality Q of a health system in GSE.

In the Theory of Quality, Equilibrium and Sustainability, if the health system is in a condition of GSE, the total number of patient days is directly proportional to the number of patients and to the financial resources available, and inversely proportional to composite quality and the *per diem* reimbursement.

Application

In Lombardia the number of total patient days D has decreased at an exponential rate of -0.01493 (P<.0001) in the period 1997-2008, more than proportionally than the reduction in the number of total patients P (r=-0.00820; P<.0047).

This is due to the fact that *per diem* reimbursement x3(r=0.03909; P<.0001) has grown more than the financial resources available φY (r=0.02415; P<.0001).

The breakdown of the Total Composite Quality has yet to be analyzed.

Exhibit 53: Lombardia Total Patient Days (D)

Lombardia Total Patient Days (D)	*YEAR 1997*	*YEAR 2008*	*Parametro Esponenziale e^{rt}*	*R-quadr corr*	*Pr>|t|*
P	2,145,882	1,928,618	-0.00820	-0.52	<.0047
φY^a	4175	5482	0.02415	0.98	<.0001
$q_{tot}L$	2,145,882	1,928,618	-0.00820	-0.52	<.0047
x3	292	437	0.03909	0.97	<.0001
D	14,277,175	12,539,007	-0.01493	-0.89	<.0001
$\frac{P}{q_{tot}L}$	1	1			

Source: ISTAT, Osservatorio Epidemiologico Regione Lombardia, SAS 9.1

a/million euro

THE DIMENSIONING OF HOSPITAL BEDS CAPACITY

We may now determine the capacity of a health system in terms of hospital beds in a condition of General Sustainable Equilibrium.

We define a Hospital Bed Equivalent (HBE) as the number of hospital beds necessary for a certain number of D at a saturation σ, with (0<σ≤1).

Definition 34: Hospital Bed Equivalent (HBE)

In mathematical terms

$$HBE = \frac{D}{365} \cdot \frac{1}{\sigma}$$

and since

$$D = \varphi Y \cdot \frac{P}{q_{tot} L} \cdot \frac{1}{x_3}$$

in a condition of GSE we define HBE as

$$HBE = \frac{\varphi Y}{365} \cdot \frac{P}{q_{tot} L} \cdot \frac{1}{x_3} \cdot \frac{1}{\sigma}$$

and since in GSE

$$\frac{P}{q_{tot} L} = 1$$

then

$$HBE = \frac{\varphi Y}{365} \cdot \frac{1}{x_3} \cdot \frac{1}{\sigma_{GSE}}$$

Equation 61: Number of Hospital Beds Equivalent in General Sustainable Equilibrium

HOSPITAL BEDS FINANCING

We may now define the Financing per Hospital Bed Equivalent in the Theory of Quality, Equilibrium and Sustainability as

$$\frac{\varphi Y}{HBE} = x_3 \cdot 365 \sigma_{GSE}$$

Equation 62: Hospital Beds Financing in a *per diem* Payment System

or

$$\frac{\varphi Y}{HBE}=\frac{x_1}{x_2}\cdot 365\sigma_{GSE}$$

Equation 63: Hospital Beds Financing in a Prospective Payment System

In the Theory of Quality, Equilibrium and Sustainability, if the system is in GSE, the capacity of a health system in terms of hospital beds is inversely proportional to their saturation σ_{GSE}, and the Financing per Hospital Bed Equivalent is higher the higher the saturation σ_{GSE}.

Application

Exhibits 34, 35 and 36 analyze HBEs relatively only to inpatient hospital stay, whereas the previous Exhibits have hitherto analyzed total patients stay, inpatient and outpatient.

The reason is that in Lombardia, from a technical point of view, only a bed where a patient has stayed for more than 1 night is considered an hospital bed, whereas if the stay is ≤1 night it is considered a "technical bed", with various consequences on the minimum accreditation requirements.

In Lombardia in the period 2000-2008, the total number of HBEs has decreased (-4954; -11%)(Exhibit 34).

Private hospitals have increased (+2365; +19%) (Exhibit 35) whereas public hospitals have decreased (-7319; -24%) (Exhibit 36).

It appears however that variation in the HBE is due to variation in the number of patients moving from public to private hospitals (+12,065; +4%), and to a general reduction in the number of patients (-121,063; -9%), rather than to a reduction in the ALOS x2 and to an increase in saturation σ.

The combined effect of all the variables has increased the Financing per Hospital Bed Equivalent from 90,869€ to 122,736€ (+35%).

Exhibit 54: Lombardia Hospital Beds Equivalent – All Hospitals

Lombardia Hospital Beds All Hospitals	*YEAR 2000*	*YEAR 2008*	*Delta*	*Delta %*
HBE	43,491	38,537	-4,954	-11%

D	11,976,738	10,901,758	-1,074,980	-9%
φY^a	3,952	4,730	778	20%
x_3	330	434	104	31%
σ_{GSE}	75.4	77.5	2.1	3%
x_2	9.0	9.0	0.0	0%
P	1,323,242	1,202,179	-121,063	-9%
$\frac{\varphi Y}{HBE}$	90,869	122,739	+31,870	+35%

Source: Osservatorio Epidemiologico Regione Lombardia, CRISP–Centro di Ricerca Interuniversitario per i Servizi di Pubblica Utilità Università degli Studi Milano Bicocca, CESP–Centro di Studio e Ricerca sulla Sanità Pubblica

Exhibit 55: Lombardia Hospital Beds Equivalent – Private Hospitals

Lombardia Hospital Beds Private Hospitals	*YEAR 2000*	*YEAR 2008*	*Delta*	*Delta %*
HBE	12,558	14,923	2,365	19%
D	3,203,919	3,687,449	483,530	15%
φY^a	1,230	1,673	443	36%
x_3	384	454	70	18%
σ_{GSE}	69.9	67.7	-2.2	-3%
x_2	9.3	10.3	1.0	11%
P	343,728	355,793	12,065	4%

$\frac{\varphi Y}{HBE}$	97,946	112,108	+14,162	+15%

Source: Osservatorio Epidemiologico Regione Lombardia, CRISP–Centro di Ricerca Interuniversitario per i Servizi di Pubblica Utilità Università degli Studi Milano Bicocca, CESP–Centro di Studio e Ricerca sulla Sanità Pubblica

a/million euro

Exhibit 56: Lombardia Hospital Beds Equivalent – Public Hospitals

Lombardia Hospital Beds Public Hospitals	***YEAR 2000***	***YEAR 2008***	***Delta***	***Delta %***
HBE	30,933	23,614	-7,319	-24%
D	8,772,819	7,214,309	-1,558,510	-18%
φY[a]	2,722	3,057	335	12%
x_3	310	424	114	37%
σ_{GSE}	77.7	83.7	6.0	8%
x_2	8.9	8.5	-0.4	-5%
P	979,514	846,386	-133,128	-14%
$\frac{\varphi Y}{HBE}$	87,997	129,457	+41,460	+47%

Source: Osservatorio Epidemiologico Regione Lombardia, CRISP–Centro di Ricerca Interuniversitario per i Servizi di Pubblica Utilità Università degli Studi Milano Bicocca, CESP–Centro di Studio e Ricerca sulla Sanità Pubblica

a/million euro

Conclusions

As predicted by the GSE in the Theory of Quality, Equilibrium and Sustainability, in Lombardia, in the period 2000-2008, due to the fact that the average length of stay

x_2 and saturation σ have remained virtually unchanged, the principal effect of the increase in hospital financing (+778 m€; +20%) has been an increase in the revenues per day x_3 (+104€; +31%) and in Financing per Hospital Bed Equivalent (+31,870€, +35%).

Lombardia once again appears to be governed more by increasing revenues and costs than by direct intervention into the operational parameters of hospital management.

CONCLUSIONS

We will try to draw the conclusions of this research in a concise manner in order to avoid falling into the fallacy: few facts, lots of conclusions.

The *cæteris paribus* trend of growth of the Lombardia Hospital System epidemiological, demographic, economic and financial variables analyzed in this research in the period 1997-2009 is not sustainable in the long-term, for the purpose of this research to the year 2050.

Even if in the period 2002-2009 some financial and epidemiological adjustment has indeed been attempted (as highlighted by the Financial Function), in particular with yearly activity budgetary financial constraints and compulsory transfers from acute to ambulatory care (as highlighted by the Epidemiological Function), by means of which short-term financial equilibrium has temporarily been maintained, this same adjustment does not guarantee long-term epidemiological, demographic, economic and financial sustainability (as highlighted by the Sustainability Function).

The Italian Ministero dell'Economia e delle Finanze is indeed intervening in curbing the growth rate of public health expenditure by fixing it at a definite percent of the national gross domestic product (circa 7.2%). Most of the savings are based on the reduction of personnel.

Since health funds are allocated on a capitarian basis, the same savings will be required on the part of Lombardia.

However, if savings are being made, the underlying epidemiological trends (increase in complexity, invariance in the acute inpatient cases length of stay, increase in intensity), as highlighted by the Epidemiological Function, have not been addressed yet, which introduces the bi-faced question if such savings are sustainable or if their epidemiological effects are acceptable.

If there is an almost general consensus among both health operators and regulators in Lombardia that both effectiveness and efficiency are the main drivers of the long term sustainability of a health system, it appears from the first applications of the model presented here, that the Lombardia Hospital System is still governed by a tendency to manage the short term effects of rising medical, labor and variable costs in general, than by a much more challenging direct intervention into the epidemiological and operational parameters governing the health system in the long term.

Certainly, an excellent clinical effectiveness has been achieved, even if, in order to be sustainable in the long term, increases in clinical quality must be proportional to the reduction in the economic waste of financial resources, both in the form of excess costs of the public providers and excess profits in the private ones.

Once again, the authors of this paper argue that there can be no health without equity, no equity without quality, and no quality without sustainability.

Analytical Index

(L) · 33, 53, 54, 66, 85, 86, 88, 92, 93
(q) · 53, 60, 65, 86, 117

A

A · 90
accelerated · 47
Accessibility and customer satisfaction indicators · 62
actual composite quality · 128
Actual Costs · 32, 86
admissions · 33, 35, 44, 72, 73, 87
ALOS · 33, 35, 74, 75, 138, 139, 140, 141, 142, 143, 144, 146, 149
Appropriateness indicators · 61
APR-DRG · 74
average length of stay · 35, 44, 74, 75, 76, 137, 151

B

B · 32, 87
Bpri · 90
Bpub · 90

C

Cact · 32, 86, 93
capacity utilization rate · 70
Capitation Unified Allocation System · 35, 78
Case Mix Adjusted Cost Per Admission (CMAA) · 35, 73, 87
chronic diseases · 44
chronic illness · 42
clinical outcomes · 43
CMI · 35, 73, 87
Cobb-Douglas · 64
complexity · 35, 38, 41, 43, 46, 50, 70, 72, 73, 74, 75, 77, 87, 139
composite quality · 49, 53, 54, 55, 63, 64, 65, 67, 68, 69, 117, 119, 122, 126, 127, 128, 129, 130, 133, 135, 136, 138, 145, 146, 147
compound growth rates · 44
computational equations · 50
conditions of dynamic equilibrium · 49
conditions of static macro equilibrium · 49
Constant Health Spending Propensity · 82
continuous equilibrium · 45
continuum · 48, 49, 109, 111, 116
coordination among health providers · 42
cost containment · 44, 83
Cost Drivers · 43
cost growth · 43
cost per admission · 35, 73, 77, 87
Council of the European Union · 45
Cstd · 32, 86, 88, 90, 92, 93, 123

D

d · 32, 35, 71, 72, 76
debt · 50, 51, 52, 100, 101, 102, 103, 110, 113
deficit · 52, 106
demographic growth · 50
demographic system · 46
demographic variables · 45, 53, 73
Demographic, Epidemiological, Economic and Financial Sustainability · 45
dependency rates · 45
depletion of ecosystems · 41
differential · 44, 48, 49, 97, 113, 114, 125, 140, 141
discrete equilibrium · 45
discriminating weight · 62
disequilibrium · 56, 69, 99, 100, 102, 104, 105, 106, 108, 109, 110, 111
displacement R0 · 131
DRG · 35, 61, 72, 73, 74, 75, 76, 82, 87, 140, 141, 142, 143, 144
DRGs · 32, 35, 43, 44, 71, 72, 75
dynamic disequilibrium · 49, 56, 99, 100, 101, 104, 105
dynamic equilibrium (DE) · 56, 98
dynamic model · 49
dynamic re-equilibrium · 49, 56

E

EcF · 89, 91
economic function · 49, 86, 88, 92
economic sustainability · 45
economic system · 46
economic transformation variable · 87
ECQF · 67
EF · 70, 73, 75, 76, 77, 84, 87, 96, 122, 123, 135
effective · 46, 53, 63, 86
effectiveness · 33, 34, 39, 46, 53, 54, 55, 56, 59, 60, 62, 63, 64, 65, 66, 70, 72, 73, 76, 77, 86, 95, 117, 118, 121, 122, 123, 126, 127, 128, 129, 130, 131, 132, 134
efficiency · 33, 39, 43, 44, 46, 53, 54, 55, 56, 62, 63, 64, 66, 84, 85, 86, 91, 92, 93, 95, 117, 118, 121, 122, 126, 127, 129, 130, 131, 132, 134
efficiency adjusted financial function · 49, 55, 56
EFFICIENCY ADJUSTED FINANCIAL FUNCTION (EAFF) · 85
efficient · 42, 53, 86, 88, 90, 92
efficiently · 45, 46, 85, 86, 88, 92, 93, 94, 96, 100
end-of-life situation · 72
endogenous · 40, 49, 50, 54, 56, 99, 105, 108, 109, 111, 113, 114, 130
epidemiological function · 35, 49, 55, 56, 70, 73, 76, 101, 103
epidemiological sustainability · 45
epidemiological system · 46
epidemiological, demographic, economic and financial variables · 54

epidemiological, demographic, financial and economic variables · 50, 113
Equilibrium · 22, 34, 47, 49, 54, 55, 56, 59, 60, 63, 65, 66, 67, 68, 69, 70, 72, 94, 95, 96, 97, 98, 99, 105, 106, 107, 108, 113, 114, 115, 116, 117, 119, 120, 123, 135, 136, 137, 139, 148, 149, 151, 154
equity · 22, 41, 46, 78, 79, 89, 92, 154
Euclidean coordinate system · 49, 130
European Observatory on Health Systems · 45
Ex-ante indicators · 61
excess costs · 86, 88, 91
excess profits · 32, 86, 87, 88, 89, 90, 91, 92, 93, 118, 134
exogenous · 39, 40, 45, 46, 47, 49, 50, 54, 56, 70, 73, 75, 81, 99, 103, 104, 105, 106, 107, 108, 109, 110, 111, 113, 116, 123, 127, 130
exponential · 40, 41, 47, 49, 50, 51, 52, 53, 75, 82, 83, 84, 98, 111, 114, 136, 137, 138, 147
exponential growth · 40, 50, 51, 52, 53, 75, 83, 84, 111, 114
Ex-post indicators for inpatient procedures · 61
Extrinsic Quality · 34, 54, 59, 72, 117

F

federal · 36, 78, 79
financial and economic turmoil · 41
financial function · 35, 49, 55, 56, 73, 77, 92
financial sustainability · 45
financial system · 46
Financial Variables · 78
Financing per Hospital Bed Equivalent · 148
fiscal and economic sustainability · 45
funzioni non tariffabili · 81

G

general equilibrium · 42, 48, 49, 56, 69, 99, 109, 110, 111
general sustainability · 45
general sustainable condition · 45
general sustainable equilibrium · 48, 49, 110, 116, 122
general sustainable equilibrium (GSE) · 48, 110
general theory of equilibrium (GSE), · 48
global payment · 44
growth of costs · 41

H

h · 33, 72, 75, 76, 95, 99, 104, 106, 109, 112, 115, 116, 119, 121
health care costs · 43
health care market · 43
health care system · 43
health insurance premiums · 43
health reform · 38, 47, 52, 75
Health Spending Propensity · 80, 82, 83
health system · 22, 34, 38, 39, 45, 46, 47, 48, 50, 53, 54, 55, 56, 59, 60, 62, 63, 64, 65, 66, 67, 68, 69, 70, 72, 74, 77, 79, 84, 85, 86, 89, 91, 92, 93, 94, 96, 97, 100, 101, 105, 107, 110, 111, 112, 113, 114, 116, 117, 122, 123, 126, 128, 129, 130, 135, 144, 146, 147, 149, 154
health technology assessment (HTA) · 42
horizontal and vertical capitation · 78
horizontal weight · 74
Hospital Bed Equivalent (HBE) · 148
hospital utilization · 42
hospitals · 36, 43, 60, 61, 75, 78, 81, 88, 89, 90, 92, 93, 149
hyper-plane · 49, 65, 73

I

ICQF · 64, 67
information · 43, 44, 96, 128, 129
inpatient · 35, 60, 61, 70, 74, 75, 76, 149
input · 62, 63
integration of care · 44
intensity of care · 35, 42, 43, 70, 72, 73, 74, 87, 139
interactions · 50
International Monetary Fund · 45
Intrinsic Quality · 33, 54, 63, 85, 88, 93, 117
intrinsic quality function · 49
Isodynamic Cumulative Utility (IDCU) · 33, 142
iso-resource · 35, 44, 72, 87
iso-severity · 35, 44, 72
Isostatic Cumulative Utility (ISCU) · 141
Italian population · 75, 77

L

L · 33, 53, 62, 63, 64, 66, 67, 68, 85, 86, 88, 91, 92, 93, 95, 108, 112, 115, 116, 118, 120, 121, 122, 124, 125, 126, 127, 128, 131, 134, 137, 138
limits to human development · 40
logistic · 47, 50, 53, 103, 113
logistic growth · 47, 53
Lombardia · 32, 35, 36, 38, 47, 60, 66, 67, 71, 72, 73, 75, 76, 77, 78, 79, 80, 81, 84, 91, 95, 96, 98, 99, 101, 103, 104, 106, 107, 108, 109, 111, 112, 114, 115, 116, 119, 136, 137, 138, 144, 145, 147, 149, 150, 151, 152
long term · 22, 39, 40, 41, 44, 45, 47, 48, 69, 77, 84, 91, 96, 99, 104, 107, 109, 112, 113, 154
losses · 32, 75, 86, 87, 88, 89, 90, 91, 92, 93, 118

M

m · 33, 52, 72, 75, 76, 95, 99, 104, 106, 109, 112, 136, 152
marginal utility MU · 140, 141
market · 43, 44
maximizing global synergies · 41
Medicare per capita spending · 42
mortality · 33, 42, 44, 61, 72, 75, 77, 123, 124
mortality rates · 42

N

nominal gross domestic product · 36, 78, 82, 111

O

OECD (Organization for Economic Co-operation and Development) · 45
optimum composite quality · 32, 130
outcomes · 34, 41, 42, 44, 59, 62, 64, 72
outpatient · 70, 74, 75, 76, 149
output · 62, 63

P

patient · 32, 35, 71, 72, 74, 86, 118, 139, 146, 147, 149
payment · 35, 38, 43, 44, 46, 61, 72, 73, 74, 75, 140, 141, 142, 143
payment incentives · 43
payment methodologies · 43
Payment reform · 44
per diem · 35, 74, 75, 139, 140, 141, 142, 146, 147, 148
P · 34, 73
population aging · 45
population growth · 45
predictability · 41
preference sensitive care · 42
prevalence of severe chronic illness · 42
price · 43
Principle of Computational Equivalence · 50
private · 46, 75, 88, 89, 90, 91, 92, 93, 118, 127, 129, 132, 143, 144, 149
proxy · 38, 59, 61
public · 45, 46, 50, 51, 52, 74, 75, 76, 81, 82, 88, 89, 90, 91, 92, 93, 103, 106, 118, 127, 129, 132, 134, 149
public debts · 51
public expenditure · 51, 76, 82
public health expenditure · 50, 52

Q

q · 33, 34, 53, 59, 60, 63, 64, 65, 66, 67, 68, 72, 76, 77, 86, 95, 109, 112, 117, 118, 120, 121, 122, 123, 124, 125, 126, 127, 129, 131, 134
quality · 22, 32, 34, 35, 38, 39, 41, 42, 43, 44, 45, 49, 53, 54, 55, 59, 60, 61, 62, 63, 64, 65, 67, 68, 72, 77, 85, 86, 93, 117, 118, 123, 126, 128, 129, 130, 131, 132, 133, 135, 138, 146, 154
quality of care · 41, 42, 55, 60, 61
QUALITY VECTOR MODEL · 34, 49, 56, 72, 74, 122, 128, 130, 131, 132, 133, 143, 144, 146

R

randomness · 50
readmission · 44
reference frame · 47
Regression, correlation and significance statistical analyses · 49
reimbursement · 33, 35, 36, 74, 75, 139, 141, 146, 147
Relative Propensity · 80
Relative Velocity ω · 133
right to health · 41, 159

S

s · 35, 41, 42, 51, 72, 73, 74, 76, 77, 87, 95, 109, 112, 119
SAS 9.1 software · 49
severity · 35, 44, 70, 72, 73, 74, 77, 95, 139
short term · 45, 107
space · 46, 108
Special Commission on the Health Care Payment System · 44
stability · 40
Standard Costs · 32, 86
standardization coefficient · 62
static equilibrium (SE) · 55, 98
static model · 49
sub-system · 33, 35, 36, 73, 78, 79, 80
supply sensitive care · 42
survival · 43
sustainability · 22, 39, 41, 44, 45, 48, 49, 54, 55, 56, 60, 66, 67, 77, 84, 96, 107, 109, 110, 111, 112, 113, 114, 123, 135, 136, 137, 139, 148, 149, 151, 154
system incentives · 44

T

t · 35, 47, 48, 52, 56, 71, 72, 75, 76, 81, 82, 94, 96, 100, 102, 104, 107, 109, 113, 115, 136, 137, 145, 147
Taylor second order linear transformation · 65
teaching hospitals · 42
The Case Mix Adjusted Cost Per Admission *v* (CMAA) · 87
THE ECONOMIC FUNCTION (ECF) · 86
The economic variables · 86
THE EFFICIENCY FUNCTION (L) · 92
The Indifference Coefficient (A) · 89
theoretical composite quality · 126
theory of general equilibrium · 48
time · 38, 43, 46, 47, 48, 49, 56, 94, 96, 102, 107, 113, 143
· 135
Total Composite Quality
Total Cumulative Utility (TCU) · 35, 141, 142
total differential variation · 48, 114
total effectiveness q · 135
Total Number of Hospital Patients · 138
Total Number of Patient Days · 138, 146
transparency · 43
trend correlation · 49
trends · 47, 98, 99, 114

U

univariate · 49
universal coverage · 41, 46, 53, 55, 79, 112, 159
Utilization indicators · 61

V

v · 35, 73, 74, 87, 89
value- based purchasing decisions · 43
value-based · 43, 44
vector · 64, 73, 74, 75, 76, 87, 130, 136, 137, 145

vector R0 · 130
vectors · 49, 122, 137
vertical weight · 74

W

w · 35, 72, 74, 75, 76, 95, 99, 104, 106, 109, 112
waste of resources · 40
weight capitation formulae · 78

X

x2 · 33, 35, 74, 75, 76, 95, 137, 138, 139, 140, 141, 142, 144, 145, 149, 150, 151
x3 · 35, 74, 75, 76, 95, 137, 138, 139, 141, 142, 144, 145, 147, 150, 151, 152
x_a · 35, 78, 81, 83, 84, 95, 98, 104, 106, 108, 112, 115, 116, 119
x_b · 35, 78, 81, 83, 84, 95, 98, 104, 106, 108, 112, 115, 116, 119
x_c · 36, 78, 83, 84, 95, 98, 104, 106, 108, 112, 115, 116, 119
x_d · 36, 73, 75, 76, 95, 99, 104, 106, 108, 112, 115, 116, 119

Y

*Y** · 36, 78

Γ

γi · 36, 79

Ξ

ξ · 36, 74

Π

Π · 34, 73, 75, 108, 111, 112, 113, 115, 116

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