IQuaL: a dynamic model for assessing the impact of public policies on sustainable development

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ABSTRACT

This paper is made up of two parts: the first part presents the general structure and technical aspects of the IQuaL (Individual Quality of Life) model. IQuaL is a system dynamic model, built within the capability approach tradition to study the impact of alternative patterns of public expenditure on the well-being of a heterogeneous population. The overlapping-generations structure of the model gives it an intertemporal, long-term dimension, thereby allowing a sustainable development perspective. It focuses on three main functionings (health, education and environment) and studies the various stages leading from public expenditure to functionings and to well-being. The second part focuses on the results of the simulations carried out by the model. The paper shows the key variables that affect the impact on well-being of changes in public expenditure, and explores, with reference to Italy, their crucial role and inter-dependencies. Finally, the implemented analyses provide useful and tangible advices for policy makers who have to implement policies of sustainable human development.

1. The IQuaL Model: general features

IQuaL (Individual Quality of Life) is a model built within the capability approach tradition. This means that it makes use of the basic building blocks of that tradition, such as the consideration of different functionings and conversion factors. Its main aim is the representation of the process through which the individual well-being is generated, starting by a certain level of public expenditure. The basic structure of the IQuaL model is showed in fig. 1, which can be read from left to right. The starting point of the model is represented by the public expenditure which is allocated to some "basic components" (K,J,X) of services and then translated into three "services" (output) which, in turn, are transformed into functionings through conversion factors. The functionings considered by

IQuaL are: “being healthy”, “being educated”, “living in a safe environment”. One of the IQuaL’s specificities is that it takes into account six populations (male and female: young, mature, old people), and this allows studying the well-being effects of public expenditure changes with a high level of detail. The fact that three generations are studied has some positive consequences: it gives the model an inter-temporal dimension and allows a sustainable development perspective over a long period horizon (a century). The model’s basic structure can be adapted to a reasonable wide range of countries. Essentially, the well-being generation process occurs over four stages. At a first one, a given flow of public expenditure is allocated to budget “sectors“ (corresponding to education, health, environment). At a second stage, expenditure within each sector is allocated to the purchase of specific “basic components”, namely physical or monetary inputs which, at the third stage, translated into four “services” (output), according to a Leontiev-type technology. Finally, services are transformed into the above mentioned functionings through conversion factors[1]. The first three stages are modelled by means of a spreadsheet (Excel), while the last one is modelled through i-think, a software of the system dynamics tradition. IQuaL does not incorporate agents’ rationality assumptions, and this makes it different from models belonging to the Computable General Equilibrium tradition. Similarly, it does not assume optimisation processes[3], and this render it different from engineering models (for instance MARKAL-TIMES). An important characteristic of IQuaL that must be stressed is its focus on the public expenditure flows and the connection between them and agents’ well-being. Thus, to some extent, IQuaL resembles the Public Choice models which study the impact of public investments on the well-being of different classes of people. Nevertheless, three IQuaL’s distinctive elements are worth noting: its focus on the inter-generational dimension, that is sustainability. This aspect is usually not taken into account in the micro-simulations about public policies. Secondly, IQuaL’s focus on public expenditure and its disregard of the taxation dimension and the national income-revenue-expenditure dynamics. Such an aspect was important in MiSS, a model that can be considered as an ancestor of IQuaL (Canova et al. 2004). Thirdly, no behavioural assumption about the dynamics voter-elected is made in IQuaL, differently from the public choice models. Thus, we can conclude by saying that IQuaL is a very specific model which certainly belongs to the sustainable development models set is characterised by a strong connection with the capability approach and system dynamics tradition.

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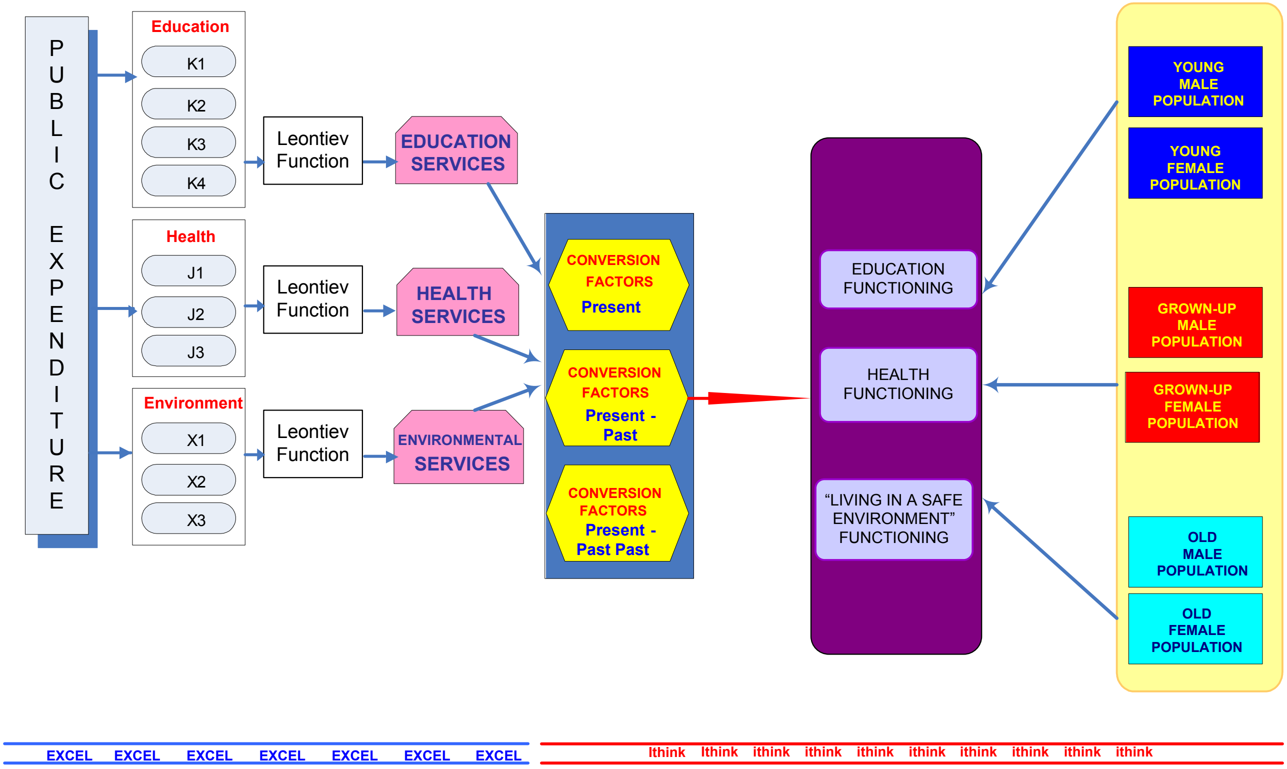
[1] See Chiappero, Salardi (2007)

[3] This occurs to the limited extent exposed in par. 2.1

Figure 1. Model structure



2. Formal structure

2.1 A preliminary view

In this paragraph we present the formal structure of the IQuaL model. We start with an oversimplified description, barely focused on the basic relationships, and we move later on to a more detailed and technical presentation.

In the simplified version, there are two agents, the Individual and the Government. Since IQuaL aims at being a model for policy choice, the Government makes all the relevant choices, while the Individual reacts. Assume that there exists just one service which is liable to influence the Individual's well being. The Government faces a budget of given size, I, and it has to choose a vector of s inputs $(\mathbf{k} \in R^s)$ such that $\mathbf{pk} \le I$, where $\mathbf{p} \in R^s$ is a vector of (given) input prices.

We assume that Government's objective, in choosing $\mathbf{k} \in R^s$, is to maximize the output of the service according to a production function $\mathbf{T}[.]: R^s \to R$, so that its decision problem can be summarized as follows:

$$\max_k \mathbf{T}[\mathbf{k}] \text{ s.t. } \mathbf{pk} \le I$$

Finally the Individual converts the service into a functioning (and into well-being) according to some conversion coefficient t: $S = tT[\mathbf{k}]$.

Although in this form the model is trivial, the only relevant choice being a technique choice, this simple example shows clearly the three stages of which the full model also consists : a budgeting stage; a production stage; a conversion stage. In the full model, however, all of these stages will become more complex. Also, Government and Individual are the agents in the full model, although the Individual will be replaced by a population of individuals; more precisely, by more than one population.

Before proceeding to the full model, there is an issue which is worth a preliminary discussion, namely, the issue of measurement units for the service output. This is an inescapable problem in a computable model, and the more so if one thinks that the full model has more than one service, with obvious comparison issues.
In IQuaL we adopted the following solution. We assumed that, in the production of the services that we consider, complementarity among factors is more important than substitution: i.e., in providing for instance, educational services, an ideal combination of factors (teachers, teaching equipment, books, buildings, etc.) is needed, while alternative combinations would be inefficient (i.e. on the one hand they involve an excess expenditure on some over-provided inputs, while on the other hand, some other inputs actually constrain service production). Formally, this amounts to assuming that our production functions are Leontiev type:

$$\mathbf{T}[\mathbf{k}] = \min\left[\frac{k_1}{\alpha_1}, \frac{k_2}{\alpha_2}, ..., \frac{k_s}{\alpha_s}\right]$$

The α_i's coefficients are to be interpreted as amounts of the corresponding i-th factor per person who is meant to benefit from the service (an example, is the teacher /pupil ratio). A given set of coefficients α_i defines a *technique* for producing that specific service. Given a choice of technique, the coefficients are fixed, but in principle it is possible that there exist different techniques (each characterized by a different set of α_i coefficients), which can be used.
This formulation has three advantages: first, it is consistent with the practice of describing the condition of health, and education systems and of environment by using per capita indicators (in addition to teacher/pupil ratio, think for instance of hospital beds to population, etc.); secondly, it provides a simple answer (in principle at least) to the question "Which of the indicators is really relevant ?", the answer being: "The scarcest one". Finally, and more to the point of measurement, output is measured as the number of persons served when the service is produced according to a specified technique. The "according to a specified technique" qualification must be kept in mind, as the evidence show non negligible variations in observed coefficients for service production, for instance across countries Some of such variations may simply be due to inefficiency, while some other may reflect different choices of technique. In this latter case, in our formulation, the same input flows might lead to different output levels (number of persons served) depending on which (efficient) technique is adopted. The more reasonable interpretation of this property is that different techniques may lead to differences in the qualitative level of the service. We shall discuss this issue at some length in the case of education.
The one we have discussed so far is however an aggregate measure of output. In the model we consider the ratio of persons served to the number of persons which in principle should benefit from the service as the measure of how much of the service actually reaches the individual. So, while we ignore differences of exposure to services within a particular class of population (age and gender) we however can take into account differences across classes.

2.2 The full model: population

We now turn to the full model, starting from the population. As it was said before, the Individual of the initial example is replaced by six populations (Young, Mature and Old, further distinguished by gender), with an exogenous dynamics over time.

The three cohorts overlap during each period. If we consider the year as the measurement unit for time and assume that n cohorts are simultaneously alive each year, this means assuming: either the maximum length of life is n years (a new cohort is born each year) or a new cohort is born every μ years (and the maximum length of life would be $n\mu$ years). We follow the second convention, with an amendment. In the full model, μ=25 and therefore the maximum life length is 75 years.

The amendment arises from a need for realism. In the real world, in fact, there are not three overlapping cohorts, but slightly more than one hundred (slightly more than 100 years is the maximum human life length) while a new cohort is born each year. Then population change is in general smooth: each year a new cohort enters, while some members of the older cohorts exit the population. Wars and natural catastrophes make exceptions to this smooth movement, in that sharp decreases in population occur. In our model, instead, population may well decrease "smoothly" each year, but when it increases (a new cohort enters) this happens in a discrete fashion, each 25 years. This is why we adopted a "compromise" view of population and assume that a given cohort not only can decrease, but also increase in size year by year, so that increases in population can be thought of a smooth, or in principle more smooth than a strict interpretation of our model would imply.

2.3 The full model: the budgeting stage

It is through the existence of a budget constraint that scarcity (and therefore efficiency considerations) appear in IQuaL. Instead of just one service, the full model includes three services (Health, Education, Environmental protection). Therefore, while Government is still conceived as an atomistic agent, its budgeting problem is made more complex by heterogeneity of individuals and by the existence of more services. The government must not only choose how to produce the service for the Individual, but how much of each service to produce for each type of individual. Since moreover we assume that the budget constraint is intertemporal, this introduces a further dimension, namely, intergenerational allocation in the public finance problem. As regards the "how to produce" problem, we shall stick to the assumption, that at time t, inputs to the production of the i-th service are chosen according to the following problem

$$\max_{k^i_t} \mathbf{T}\left[\mathbf{k}^i{}_t\right] \text{ s.t. } \mathbf{p}^i\mathbf{k}_t{}^i \leq B_t^i$$

where B_t^i is the budget allocation at time t to the i-th service, under the intertemporal budget constraint.

$$\sum_{t=0}^{T} \beta^t \left[\sum_{i=1}^{3} B_t^i\right] \leq \mathbf{I}$$

Where $\beta < 1$ is a discount rate and $\mathbf{I}$ is the intertemporal budget size. β is a purely financial factor which summarizes the cost of transferring funds across time, and has nothing to do with time preference on the side of the government.

The determination of B_t^i is therefore the non-trivial part of the decision problem: as soon as a non-utilitarian approach is taken, no simple maximization algorithm makes sense for this problem. In the paragraph on simulations, alternative paths for the B_t^i allocations under an intertemporal budget constraint will be considered.

2.4 The full model: the production stage

As regards the production stage, we stick to the assumption that all services are produced according to a Leontiev technology. Details on the production of each service are contained in paragraphs that follow.

2.5 The full model: the conversion stage

Finally, each individual (more precisely, each type) converts the services available to him/her into functionings according to a set of type- and service-specific conversion coefficients. Two important features of this "conversion stage" must be stressed.

First, individuals are assumed in general to have memory , i.e. they convert into functionings not only the services which are currently available, but also those which have been available in the past. In paragraph 7 we shall compare settings with memory with other memoryless settings. In the Appendix we discuss in more depth the way we model memory. However, to understand the main consequence of our modelling strategy consider, say, education. In our model, when we assume memory, the education functionings are cumulated over the first 25 years of the individual life (when he/she is "young"). This "stock" is then converted into a new functioning as soon as the individual becomes mature (on his/her 26th birthday) until he/she becomes "old", on his/her 51st birthday.

We shall however restrict memory to one life age. For mature people, only what happened to them when young matters; for old persons, only what happened to them when grown-up. Secondly, the actual level of a given functioning (in this model, health) might depend not only on the flow of strictly health-related services, but also on the level of other services: in this model, health depends on health services and on past education and the current environmental condition. The paragraph on health contains details on the dependence of health on education and environment.

3. The Education Service

As it often happens with services production, the main problems arise when one tries to correctly specify inputs and outputs of the production process and consequently when one turns to measure them. Education is no exception.

On the output side, the main issue is the relationship (and the distinction) between quantity and quality. At the individual level, quality is clearly relevant and the problem is how to infer quality from available quantitative indicators. The most naïve approach simply interprets quantity as quality: education is the measured by the time spent at school or by the education grades attained (primary, lower secondary, upper secondary, etc.). A much more sophisticated approach measures the increase, attributable to additional education, in individual earnings, thereby entrusting the markets with the task of evaluating the quality of education.

This is the prevailing tradition in the economics of education, whose state of the art is summarized in some excellent chapters of Hanushek-Welch (2006). An alternative

approach consists in constructing specific quality indicators, such as the scores attained by students in tests provided by independent institutions. Among these, it is worth remembering the Association for the Evaluation of Educational Achievement which started out in 1964 , with the First International Mathematics Study, until the recent Trends in International Mathematics and Science Study (TIMMS (2004) and Progress in International Reading Literacy Study (PIRls (2003)). The Program for International Student Assessment (PISA), was created by OECD in 2000.
Only recently economists have begun to consider these direct output indicators (Barro and Lee (1997 and 2000) and Hanushek-Kim (1995)).
In contrast with the individual's viewpoint, for the policy-maker the alternative between quality and quantity is far from trivial. From a collective viewpoint, it is not clear that a high-quality education concentrated on few privileged individuals is definitely better than a lower-quality education, spread on the majority of the population.
As regards inputs, three basic groups are usually considered: school inputs in a strict sense (teachers' number and quality, availability of textbooks, of suitable school buildings, of teaching equipment); family inputs, usually summarized by parental education level; and social inputs, a heading which covers a wide range of general cultural, social and economic characteristics of the surrounding society.
Inputs of the first group are of particular interest, since they are more easily influenced by policy, relative to others which can be influenced only in the long run or indirectly. However, a relatively frequent finding in the literature is that the relevance of this group of inputs is limited (an example of this sceptical conclusion is Hanushek-Kim (1995)). However, as Hanushek himself stresses (Hanushek-Woessman (2007)) it would be wrong to conclude bluntly that school inputs are irrelevant; instead, the evidence points out the inadequacy of currently used measures of both output and inputs. Also, we should not forget that other studies (such as for instance Barro-Lee (1997)), have less pessimistic findings about the relevance of school inputs.
For the purposes of our model, the output of the education sector is measured as the number of persons receiving education services of a given quality. Then we must choose a reference level of quality and then estimate the technical coefficient according to which that quality level is attained. Our approach, as in the case of health, is based on an international comparison.
On the output side, we considered the PISA database (OECD 2004) rather than TIMMS (2004) or PIRLS (2003), since PISA is interdisciplinary and because of the larger sample size. On the input side, we used some monetary indicators, namely total current expenditure on education, expenditure for teachers' salaries, and capital account expenditure on education (by expenditure we mean here government expenditure). Data are obtained from OECD Online Database and refer to 2003. Since expenditures are expressed in national currencies, they have been converted to Euro PPP. A total of 27 countries is in the sample. For each country, we computed the per-pupil values of: current expenditure other than teacher salaries; teacher salaries; capital account expenditure. Finally, we considered the average PISA score of each country (PISA assesses mathematical, reading, science and problem-solving skills, yielding separate scores besides the average one). Then each country can be described by a vector

$\mathbf{y}_i = \begin{bmatrix} s_i \\ -c_1^i \\ -c_2^i \\ -c_3^i \end{bmatrix}$ where s_i is the average PISA score of country i, and c_1^i, c_2^i, c_3^i are respectively the per-pupil values of current expenditure other than teacher salaries , teacher salaries and capital account expenditure. If for some j and I it happens that $\mathbf{y}_i \leq \mathbf{y}_j$ (with at least one strict inequality), then the i-th country is discarded. We then get the efficient frontier depicted in the following table:

Tab.1 – Education at international level

Countries on the frontier	**Average PISA score**	**Current exp. Other than teacher salaries**	**Teacher salaries**	**Capital account exp.**	National score/Finland's score
		(**Mln Euro 2003 PPP** per pupil)			
Finland	545.8956	0.001658	0.003144	0.000582	1
Korea (Republic of)	541.2938	0.000963	0.002434	0.000909	0.99157
Japan	531.7888	0.000626	0.00471	0.000615	0.974159
Australia	526.1483	0.001002	0.003273	0.000242	0.963826
Belgium	517.5894	0.000461	0.005261	0.000232	0.948147
Czech Republic	511.1574	0.000879	0.001814	0.000239	0.936365
Ireland	505.5423	0.00066	0.003619	0.000381	0.926079
Germany	502.5276	0.000629	0.00365	0.000331	0.920556
Austria	498.3498	0.00152	0.005944	0.000217	0.912903
Hungary	494.0566	0.0006	0.002472	0.000184	0.905039
Poland	492.8081	0.000672	0.001622	0.000123	0.902752
Slovak Republic	488.4925	0.000554	0.001354	0.000131	0.894846
Portugal	470.2865	0.000191	0.004275	0.000135	0.861495
Greece	461.6673	0.000205	0.003154	0.000522	0.845706
Turkey	426.5352	3.88E-05	0.000639	0.000106	0.781349
Mexico	393.5574	9.05E-05	0.001325	4.07E-05	0.720939

The countries included in the frontier represent different choices of (efficient) techniques for producing education. Finland's score is the highest while Mexico's is the lowest (i.e. they correspond to the best and the worst practice). Portugal's score corresponds to the average of the frontier. In the simulations we shall use the Finnish coefficients.

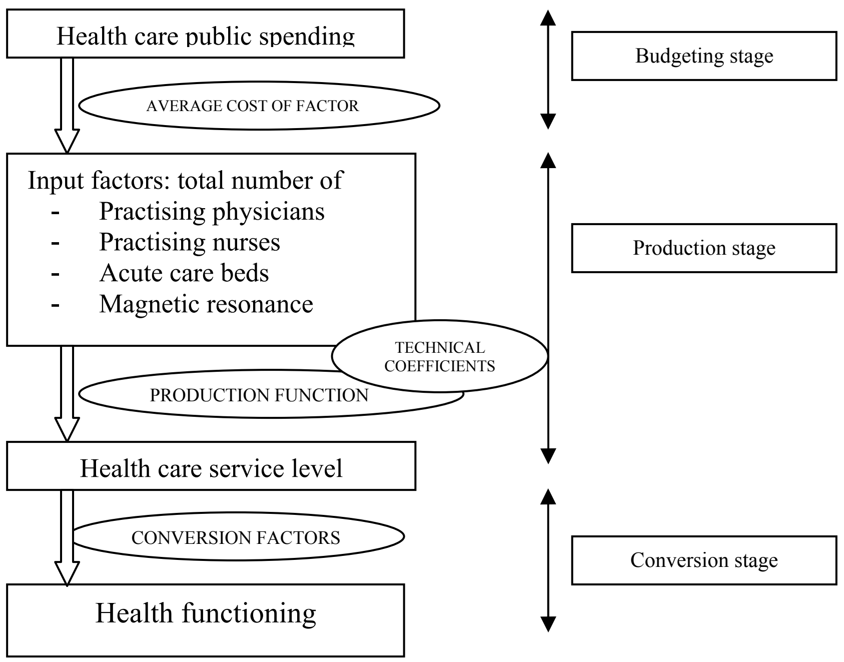
4 The Health Service

Health condition is absolutely one of the most important elements to evaluate quality of life and human well-being. Amartya Sen wrote frequently about the importance of the health functioning: *"One of the complications in evaluating health states arises from the fact that a person's own understanding of his or her health may not accord with the appraisal of medical experts. More generally, there is a conceptual contrast between "internal" views of health (based on the patient's own perceptions) and "external" views (based on the observations of doctors or pathologists). Although the two views can certainly be combined (a good practitioner would be interested in both), major tension often exists between evaluations based respectively on the two perspectives"* (Sen 2004). That is exactly what the IQuaL model aims to do: to combine the "external" view, that is the output of the production stage, with the "internal" view, through the conversion stage.

A good individuals' health status should be a major target for policy makers, but, at the same time, it is a relevant means to determine some other key issues, such as employment rate, income level and social inclusion. Progress in health care and the development of new medicine have contributed to great improvements in health status in developed countries. But at the same time, health care spending has never been so high, consuming a growing share of GDP. A number of recent studies have compared the health systems of various countries. They all agree that population's health status is determined more by life styles and socio economic factors (i.e. eating habits, tobacco and alcohol consumption) than by the health service level. Nevertheless, we will focus on the second one, since our purpose is deepen the effect of public policies on individual well-being, in order to enlighten which strategy could be the most powerful to reach the target. Even if some policies (such as information campaign on correct diet or HIV prevention) could impact on lifestyles and then on health, we assume that the only way to improve health status could be reduce to: the medical staff, the technology available and the hospital facilities. We will explain the chosen proxy variables and how they "produce" the service.

The following figure could help to sum up the structure: starting from the budgeting stage the model obtains the total amount of each production input. In the production stage they are transformed through the Leontiev technology (using some technical coefficients that we will define afterwards) into the maximum number of persons to whom the "ideal" health service is provided (see paragraph 2 on the formal structure). Finally the model converts this service into the functioning (that is the "internal view", based on the individual perception).

Figure 2: Health sector scheme



Following the IQuaL model structure, our description starts from the public health expenditure. Then we analyse the main component of the health production function and finally we derive the health service and the health functioning.

4.1 Health care spending in Italy (the budgeting stage)

Analysing health care expenditure is quite a complex issue and we need some comparing parameters. How could we say if a certain amount of spending is fair or insufficient? We should compare these data with other developed countries to better understand the Italian situation.

In 2005 in Italy total health care expenditure (public and private) accounted for 8.8% of GDP. Together with pension spending, it represents the higher percentage of public expenditure, and they are both supposed to grow in the future years, due to the aging population. Still considering European Union and the U.S., we could say that, even if the aging process is stronger in Italy, public health spending in our country has been almost constant from 1990 to 2003 (Table 2). From 1990 to 2003 it seems that private expenditure has grown faster than the public one, in order to cover the health care needs (Table 3).

Figure 3: Over 65 population (as % of total, source OECD)

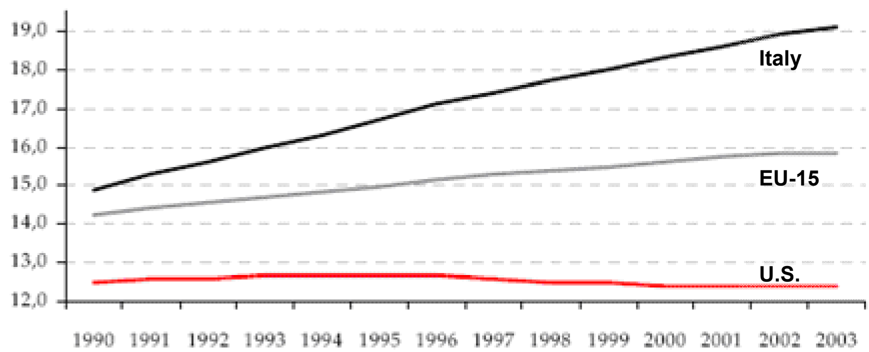


Table 2 - Current public expenditure in health as a percentage of GDP

	1990	2003	change
France	6.3	7.5	1.2
Germany	6.2	8.4	2.2
Italy	6.1	6.2	0.1
Spain	5	5.3	0.3
UK	4.7	5.6	0.9
US	4.6	6.6	2
EU-15	5.4	6.5	1.1

Source: Ministero della salute

Table 3 - Current private expenditure in health as a percentage of GDP

	1990	2003	change
France	2	2.4	0.4
Germany	2	2.4	0.4
Italy	1.3	1.8	0.5
Spain	1.4	2.2	0.8
UK	0.9	1.1	0.2
US	7	8.2	1.2
EU-15	1.7	2.5	0.8

Source: Ministero della salute

4.2 The production stage: basic inputs

In the IQuaL model we can run different scenarios, changing the assumptions on health care spending. Starting from the budgeting stage, the model derives how many production factors could be acquire and then, through the production stage, which is the level of service that could be provided. First, we need to identify the production factors that allow the supply of health care; second, we should define some best practice at international level to derive the technical coefficient for the production function of the model. The assumptions of the model are summarized in the table below.

Table 4 - Health Indicators and data

Indicators	Reasons for including it	Selected input	Cost of the input	Best practice (Japan)
Medical staff	Medical assistance, possibility to see a doctor when needed	Practising physicians, density per 1 000 population[4]	Annual average salary for a physician in a public hospital	2 physicians/1000 pop
Nurses	Primary health care, physicians assistance	Practising nurses, density per 1 000 population[5]	Annual average salary for a nurse in a public hospital	7,8 nurses/1000pop
Hospitals' reception	Accessibility to health care, possibility of hospitalization	Acute care beds, density per 1 000 population[6]	Cost in € of 1 acute care bed in a public hospital	8,5 beds/1000pop
Technology	More precise diagnostic, prevention	magnetic resonance imaging units (MRI) per million population[7]	Cost in € of 1 magnetic resonance imaging unit	23 MRI/ million pop

In defining the production factors, we refer to a reasonable literacy on these issues. Our analysis is focused on four input factors: the number of practising physicians and nurses, the number of acute care beds and the number of magnetic resonance imaging unit.
We decide to consider only "acute" care beds[8] to not include the effect of population aging (best represented by long term beds). Moreover, all these variables measure "technical equipments", while it is impossible to evaluate the efficiency of these assets (for example: we do not know if all the MRI units are working).

4.3 Health: international assessment

To perform a more precise investigation, we compared some international data. The reference is OECD health database for 30 developed countries (OECD 2006): the most complete statistics refer to 2003. The first step is to verify if the chosen variables are significant to explain the health status. We set up a brief cross-section analysis: assuming life expectancy at the age of 65 as a proxy of the population health, all the input variables show a good correlation with the output. The second step is the international assessment. Actually, the level of the production factors could be meaningless if we do not have any reference parameters. Otherwise, it could be difficult to appreciate if a certain level of input is fair or insufficient. Using the same OECD data, we compared national health systems (in terms of expenditure, resources and performance) to find out, as in the previous educationa case, a sort of "efficiency frontier". We could define the best practice in terms of efficiency: given a certain spending, which national health system does garantee the best health status (measured by the life expectancy at age 65)?

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[4] Source: ISTAT - Italian Labour Force Survey. www.istat.it/English/Labour/Labour-for/index.htm (Quarterly sample survey).

5 Source: Ministry of Health.Publication available on Internet (www.ministerosalute.it). 'Personale delle ASL e degli Istituti di cura pubblici' (published annually).

[6] Data source: ISTAT "Struttura e attività degli istituti di cura".

[7] Source: Ministry of Health.Publication: "Attività gestionali ed economiche delle ASL e Aziende ospedaliere", Annuario Statistico del Servizio Sanitario Nazionale (published annually). Publication available on Internet web site of the Ministry of Health

[8] Acute care beds are "beds accommodating patients where the principal clinical intent is to do one or more of the following: manage labour (obstetric), cure illness or provide definitive treatment of injury, perform surgery, relieve symptoms of illness or injury (excluding palliative care), reduce severity of illness or injury, protect against exacerbation and/or complication of an illness and/or injury which could threaten life or normal functions, perform diagnostic or therapeutic procedures" (OECD 2006).

The per-capita public spending in the health sector has a high standard deviation in different countries: the minimum value is 267 dollars (in PPP) in Mexico while Luxemburg has the highest value, around 4164 dollars. The average value is 1765 dollars, very similar to the Italian one (1717 dollars).

Table 5 - per capita spending distribution in 2003 (OECD countries, dollars PPP)

Mean	1765
St.Dev.	862
Median	1840
Max	4164 (Lux)
Min	267 (Mex)

Source: OECD Health data 2006

For each input variable listed in Table 4, we normalize the international data and calculate a national score combining these inputs with an output variable that is the life expectancy at age 65.
Table 6 reports the top ten countries referring to the score and the relative data on per capita spending.

Table 6 - International assessment

Country	**Score***	**Per capita expenditure ($ in PPP)**
Japan	3.88	1833
Austria	3.56	2085
Switzerland	3.43	2227
Luxemburg	3.39	4164
Iceland	3.36	2628
United States	3.24	2559
Germany	3.23	2366
Norway	2.97	3147
Italy	2.97	1717
Belgium	2.97	2283
**Score scale is from 0 to 5 Reference year:2003*		

Japan results to be the most efficient country: Japanese has the highest score, with a public per-capita spending of 1833 dollars. That is why we decide to consider the Japanese system as our "best practice" and apply the Japanese coefficients to the production function. These coefficients are listed in the last column of Table 4.
To sum up, we evaluate the Italian health system performance referring to the Japanese excellence. The output of the production function tells us the quality of the service in a range between 0 and 1. For example if the result is 0.75, it means that the Italian health system can serve excellently the 75 per cent of the whole population.

4.4 Health: the conversion stage

The last stage of the model operates the conversion of services into functionings. As we said in paragraph 2, this step is performed through conversion factors. Moreover the model includes in this stage same interdependency among functionings. The health functioning level depends on one hand on the individual conversion of health services, on the other hand on the influence of other functionings level, namely education and environment. In other words, the health functionings results from:

- Health care service, converted through individual conversion rates (for details see Chiappero-Martinetti, Salardi 2007)
- Educational functioning: accordingly with a large literature, we assume that this functioning enhances the individual ability to improve his/her own health functioning. Of course, this interdependence mechanism is quite articulated, for instance: the more an individual is educated, the more his/her income grows, so he/she is less vulnerable to disease, disability and premature death. The model considers only a direct relation in an intertemporal dimension: health depends on past education.
- "Living in a safe environment" functioning: the individual functioning deriving from air quality, water pollution, toxic waste and all the other current environmental conditions should be considered when evaluating the health functioning.

Formally, the final level of health functioning, considering the memoryless case, is calculated as follows:

$$HF_{t,i} = HS_t \times cf_i + EdF_{(t-1),i} \times I_{Ed} + EnF_{t,i} \times I_{En}$$

where

$HF_{t,i}$ is the health functioning for the i-th individual type at time t

HS_t is the health care service level, which is the same for every individual at time t

cf_i is the conversion rate for the i-th individual type

$EdF_{(t-1),i}$ is the educational functioning for the i-th individual type at time (t-1)

$EnF_{t,i}$ is the "living in a safe environment functioning for the i-th individual type at time t

I_{Ed} and I_{En} are the interdependence coefficient

This aggregation method is quite simple but the model could perform also more complicated equations. The inter-functioning dependence can be modulated in the model in a very flexible way, simulating different scenarios (low/high dependence, independence, intertemporal dependence, intergenerational dependence).

5. The Environmental Service

The importance of natural environment as a determinant of individual well-being is enlightened by Duraiappah (2004), who uses the term of *ecological security*. This is the reason for which we decided to include in our model the functioning of *living in a safe environment*.

Because, then, the capability approach is focused on the constituents of well-being, we concentrated here on the dimension of perception, choosing the components of natural environment which are perceived by people as particularly relevant[9] for their quality of life.

Besides, the territorial unit of analysis, for the same reasons, is that of cities above 100,000 people[10], because we reasonably assume that environment plays a key role in affecting well being of inhabitants in a similar context.

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[9] According to the most recent surveys from Eurobarometer (2004) and ISTAT (2000-2001), where environmental risks are more important than education in respondents' attitudes (16,8% vs. 6,3%)

[10] A further development should be to disaggregate population in different groups (i.e., people living in cities with less than 100,000 people and people living in cities with more than 100,000 people)

Finally, with regards to the inputs of the production function of the service *living in a safe environment*, we chose only supply measures, selecting indicators (taken from APAT, 2006) which only contain information about the availability of resources and say anything about how the same resources are used (i.e., efficiency indicators).
Going deeper into the choice of the inputs, we followed the relevant literature regarding environmental issues: on one side, we chose two components (waste and mobility) because they represent the most diffused problems of people living in great cities, according to the before mentioned surveys; on the other side, the third component (available green areas) was chosen because it is a positive element in the perception of environmental quality of people.
To quote data from the Multi-Purpose ISTAT Survey (2000-2001): 31% of Italian household finds relevant the problem of waste; 46,5% of households says that traffic congestion is a decisive issue in affecting quality of life; and 55,9% of households has open access to green areas.
We now present, for each of the dimensions chosen, the reasons for which we think they are important in affecting environmental quality; the selected indicators for our analysis and the available indicators in terms of costs of the input. The following table summarizes all the information:

Table 7 – Environmental Service: indicators and data

	Reasons for including it	**Selected indicator**	**Cost of the input**	**Best practice**
Differentiated waste[11]	Energetic efficiency; Increase of awareness and civicness of community	Kilograms of differentiated waste	€ /kg of differentiated waste	35% of differentiated waste[12]
Sustainable mobility	High correlation with air pollution and acoustic pollution; High correlation with energetic efficiency	Km/ person of public transport network available	Operative cost per km of public transport network	3,79 m/person in Livorno[13]
Available green areas[14]	Ecological function (oxygen production, climate mitigation) Social function (aesthetic role of landscape, sports, scientific research) Economic function (agriculture, tourism, energy supply) Environment as a *receptor*	Squared metres/ person available	Cost in € of 1 metre of green areas	28,93 squared metres/ person[15]

Having shown the main features of each functioning, it is worth summing up the strength points of IQuaL as follows:

- The consideration of aspects which are different from income but have a strong impact on people well-being, namely education, health and environment.

[11] We have to remark that Italian context is characterized by an extreme level of heterogeneity (north/south, great cities/small towns); this aspect is not caught when focusing on the aggregate national level
[12] Decreto Ronchi, D.Lgs. 22/1997: we chose this benchmark to take indirectly account of heterogeneity. A European best practice (50% of differentiated waste is not a credible objective in terms of policy in Italy)
[13] There is not in literature a reference regarding the optimal level of public transport supply: we decided to refer to Italian data, choosing the highest value
[14] An important point to make regards the way in which green areas are classified: each municipality has its system, so that comparisons between data are not straightforward
[15] Taking account of the problems with classification, we chose the average value of the 4 highest levels (Genova, Bologna, Palermo and Cagliari) as it is confirmed by APAT (2006)

- The fact that such aspects are not synthesised by a single indicator but have more that one dimension. For instance, health depends on doctors, nurses, acute care beds and MRI. Thus, IQuaL is able to capture the plurality of variables below each functioning.
- The disaggregation of population into six age classes which allows a higher level of accuracy in analysing agents well-being compared to the traditional studies based on a single representative agent.
- The consideration of three generations which allows to study the influence that each generation has on another one's well-being.
- The considerable flexibility that characterises the IQuaL model and permits easy changes in the hypotheses and assumption underling each scenarios.

6. Simulations and well-being scenarios

In principle, each of the pieces composing the model can be modified to produce alternative simulation scenarios: public expenditure, technical coefficients which contribute to generate the services' level, prices of the basic components, conversion rate, classes of population[16]. In this paper, however, we concentrate on a range of cases meant to show how memory and interdependence (previously defined) may influence our evaluation of alternative paths of public expenditure allocation. Given this specific goal, the figures that will be showed must be considered neither a forecast nor a quantitative information to be directly used in decisions about public policies in Italy or elsewhere. Rather, all the simulations must be considered as quantitative reflections about possible, future scenarios of some relevant functionings. Thus, the IQuaL model is simply a tool for quantitative reasoning in a context whose main aim is the understanding of "what happens" to some key variables "if" other variables assume some specific values. The "if" clause is very important and must not be neglected. This caveat is particularly relevant if one thinks of the long simulation horizon (one century) that we adopt in IQuaL. This is necessary in order to take into proper account intergenerational and other dynamic links; however, if we used the model for true forecasting, we should include features such as technical progress, product innovation or changes in absolute and relative prices which instead are absent in this paper.

7. Quantitative framework

Population

In paragraph 2 we exposed our modelling strategy as regards population, and in particular its being composed by six groups. Here we describe instead the data on population that we exogenously introduced in the model for simulations. Total population in the model reproduces actual Italian population since 1950 up to 2001, and the forecasted population until 2049. As it will be remembered, the length of each age of life in the model is 25 years. However, as regards the six groups, our "young" population is assumed to have the same size and dynamics of the Italian population between 0 and 18 years of age (distinguishing between male and female population), "mature" reproduce the Italian

[16] IQuaL incorporates also alternative weight structures for aggregating the level of functionings in a unique index of well-being. Due to the subjectivity of such an aggregation and the qualitative differences among functioning, this option will not be implemented and discussed in this paper.

population between 19 and 64 years, and the "old" population corresponds to Italy's population older than 64. Having all life ages of the same length greatly simplifies computations; data choice was meant to give age groups sizes more consistent with the intuitive notion of "young", "mature" and "old"
More precisely, for the period 2001-2051, forecasted population is taken from ISTAT 2003; for years 1982-2001, we used official data reconstructing population in the inter-Census years (ISTAT 2006). For years 1950-1981 we first obtained from 1951, 1961 ,1971 and 1981 Censuses the stocks of the three age groups; then we computed the inter-Census stocks assuming exponential growth of each group. Finally, we took the male/female proportion in the inter-Census years to be an average of the actual proportions across the two neighbouring Censuses.

Conversion rates
Chiappero-Martinetti and Salardi (2007) provide estimates of the conversion factors for the three services for Italy. We include in the simulations some of their results. Since the measurement units involved in the estimation do not exactly coincide with ours, for obvious reasons of data availability, we did not simply feed the estimated values into our model. We adopted instead the orders of magnitude of the conversion rates which emerge from the estimates. More precisely, suppose that
t_s^j is the estimated conversion rate for service 's' and population 'j' (j= "young women", "young men", "mature women", "mature men",… etc.) we defined

$$\bar{t}_s = \max_j t_s^j$$

and used the ratio

$$\beta_s^j = \frac{t_s^j}{\bar{t}_s}$$

as the conversion rate to be used in the simulations. The table in the appendix shows the values of the β_s^j's.
As regards the inclusion of memory in the conversion, we simply assume that (if memory is present), each individual adds to his/her current level of a given functioning the level of the same functioning cumulated during his/her previous age of life. As regards the effects of interdependence on health, we assumed that with low interdependence, the individual adds to his/her current level of the "being healthy" functioning the level of the past "being educated" functioning and the current environmental functioning, both multiplied by a coefficient of 0.01. High interdependence has instead a coefficient of 0.1.

Public finance simulations
As we said before, we compare alternative paths of budget allocation which are exogenously chosen, instead of being derived from a specific model of public choice. We now expose the different paths that we shall be considering.
A) **Baseline case**: public expenditure per head is kept constant over all the period. We assume that the initial values of the stock factors (namely, acute care beds and magnetic resonance units for health; urban green areas and local public transport network for environment) are 1% of the value which would be needed to serve the entire population. The level of constant per head public expenditure and the levels of per head expenditure

on individual services are set at values such that the proportion of persons served to actual population reaches the value 0.999 in year 100, for all services. The values are in the table below.

	Education	Health	Environment	Total
Total Expenditure in year 1 (Mln €)	60413	33511	17753	69413
Per-capita expenditure in year 1 (€)	815	442	213	1470

B) **"Actual" expenditure:** public expenditure per head is kept constant over all the period. We assume that the initial values of the stock factors are 1% of the value which would be needed to serve the entire population. The level of constant per head public expenditure and the levels of per head expenditure on individual services are set at values such that total simulated levels of expenditure in year 52 equal the actual values reached in Italy, on average, in the years 2000-2001-2002 (ISTAT 2004) . In the light of the previous description, the adjective "actual" should be viewed as no more than a label. First, actual expenditure on health services in the mentioned years did not cover only the cost of physicians, nurses, acute care beds and magnetic resonance units, which are our only inputs, but also other components, such as bureaucratic costs and so on. Secondly, except for years 2000-2001-2002, the "actual" scenario is a virtual one, in that it embeds the assumption that per capita public expenditure is constant in real terms over the century, which was certainly not the case in Italy between 1950 and 2001.

	Education	Health	Environment	Total
Total Expenditure in year 1 (Mln €)	49756	62888	9112	121756
Per capita expenditure year 1 (€)	1054	1332	193	2578

C) **Time reallocation of expenditure:** public expenditure per head is reallocated over time, under the same intertemporal budget constraint as in the baseline case. Public expenditure per head grows by 1% per year from year 1 to 20. Later, it decreases by 1% until 40, by 0.5% until 80 and it is constant afterwards. Initial values are the same as in the baseline case

D) **Time-and-sector reallocation of expenditure:** public expenditure per head is kept constant over time, at its baseline level. The initial values of expenditures on the individual services are also the same as under the baseline case. However, expenditure on education increases by 1% per year until year 40, then decreases until year 80 by 1% per year and it is constant afterwards. Health expenditure decreases until year 20 by 1%, then until year 60 by 0.5%. As a consequence, the ratio between served persons and actual population reaches 0.99 in year 100 for education and environment, while the ratio decreases (as regards health) to 0.66.

These four public finance scenarios have been run under different assumptions regarding memory and interdependence: no memory/memory; no /low /high interdependence (see the definitions in paragraph 2.32 above).

As a whole, we have 24 different cases (summarized by the following table), each one determining 18 distinct paths of functionings. In the following paragraphs we shall select a small subset of these cases for our discussion of the relative effects of memory, interdependence on alternative public expenditure paths.

Tab. 8 Synthesis of IQuaL Scenarios

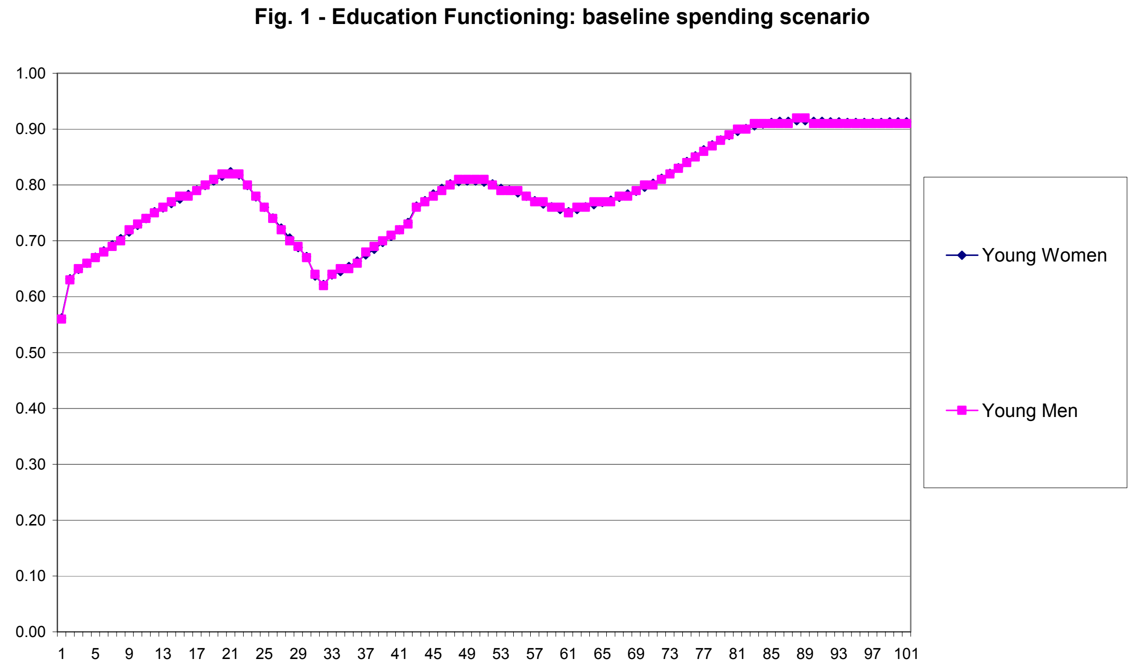
	Memoryless Cases			Memory Cases		
	No Memo No int	**No Memo L Int**	**No Memo H Int**	**Memo No int**	**Memo L Int**	**Memo H Int**
Scenario A Baseline	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**
Scenario B Actual Expenditure	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**
Scenario C Time Reallocation of Expenditure	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Scenario D Time-and-Sector Reallocation of Expenditure	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**

8 Scenarios

8.1 Baseline Scenario

In this paragraph we show the trends that each functioning assumes in the baseline scenario in the case of no memory and no inter-dependence (A1). For each functioning, the numbers which are showed in the y axis of the figures can be interpreted as the percentage of each class of population that receives a service whose quality standard was defined in Canova et al. 2007. Given the fact that the technical coefficients of the production function were defined on the basis of international (Education and Health) or national (Environment) comparisons, it is possible to say that the service offered is consistent with a best practice. As mentioned above, the baseline scenario tends to be characterised by an increasing trend. In some cases, given optimistic assumptions about public expenditure or interdependence between functionings, the percentage of population that receives a service can be larger than one. Fig. 1 focuses on Education. It proposes the trends of the two relevant populations that are Young Women and Young Men. Two points are worth noting: given the fact that the education service is offered only to young people, the figure shows just the trends of the two young populations. Moreover, since the conversion rates of the male and female classes are equal, the two lines overlap. Secondly, it is interesting to observe a non monotonic profile. This is due to the dynamics of the young population in Italy whose share on total population decreases and increases in some periods.

Fig. 2 and 3 show the trends of the six populations for the “being healthy” and “Living in a safe environment” functionings. The former figure enlightens a strong increase in the functioning level due to a rapid accumulation of stocks in the first years. Because of the different conversion rates, this occurs strongly for Young people and to a lesser extent for Mature and Old people. The consequence of such an accumulation is the fast closing of the distance between the level that the functioning assumes in the last year and its level in the first year. In particular, all the classes of population close half and 75% of the gap respectively in 4 and 8 years. In Fig. 3, the six populations are characterised by different trends, however smoother than in the being healthy functioning. In fact, half and 75% of the gap are closed respectively around the 33rd and 66th year.



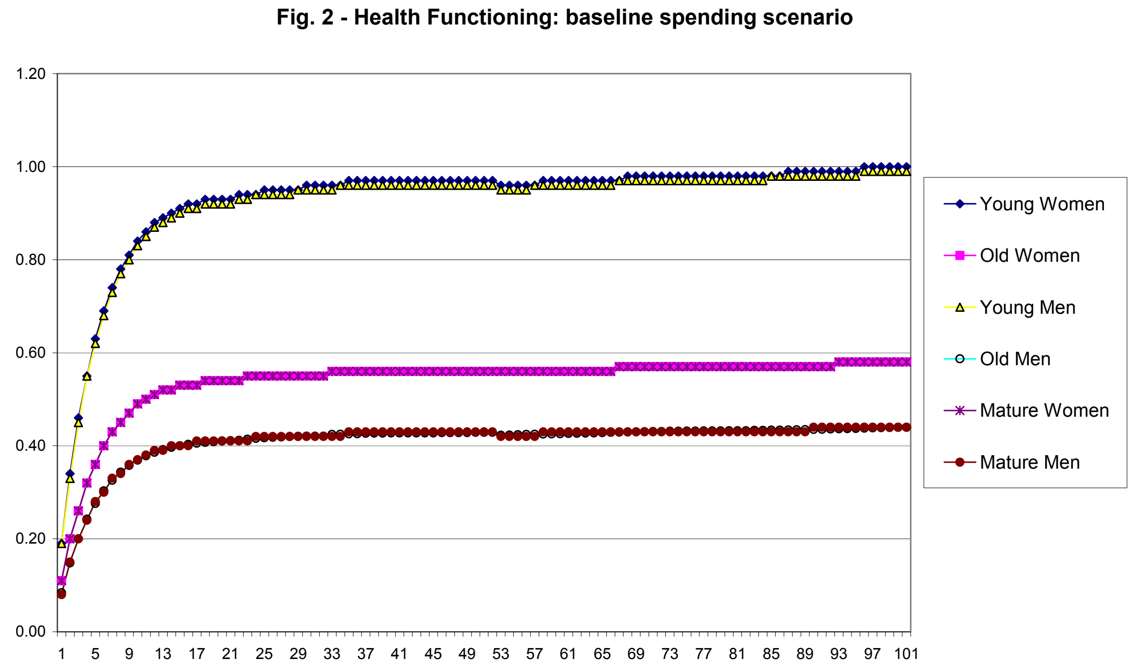
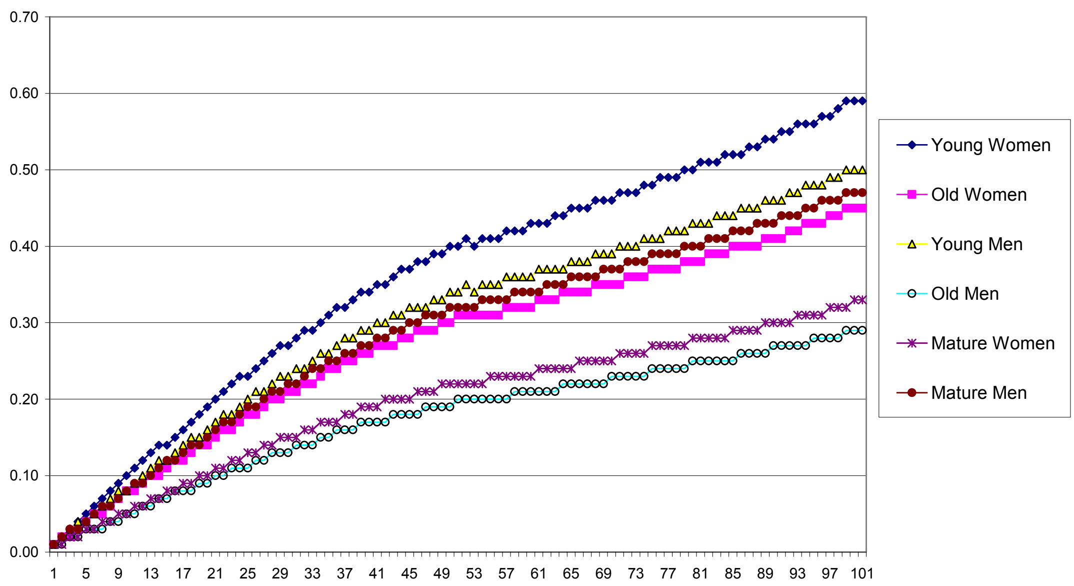


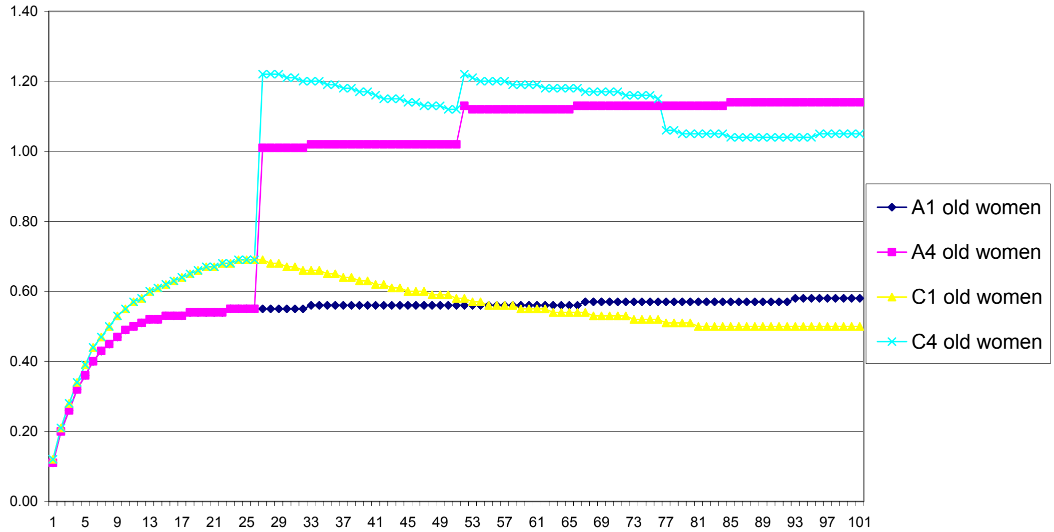
Fig. 3 - Living in a Safe Environment Functioning: baseline spending scenario



8.2 Role of Memory

To discuss the role of memory, we shall start from an easy exercise, taking one specific functioning (being healthy) and a specific population (old women) in the baseline expenditure scenario, and comparing the consequences of the alternative assumptions of memory and absence of memory. So we compare scenarios A1 and A4. The effect is clear from figure 4 below. The two paths coincide until year 26. This depends on the fact that women who are old during the first 25 years have no memory in any case (they have been young and mature before the starting date of the model). Instead, women who are old in the following years have had a past which is included in the simulation range, and it is here that memory matters. The level of the functioning in year 100 is 5.273 times the functioning in year 1 under A1, while it is 10.875 under A4.
Another way to look at the role of memory is to consider scenarios C1 and C4. In both cases, total expenditure, as well as health expenditure is shifted back to the early generations and away from the latest. Figure 4 shows this: after year 58, the condition of old women becomes worse under C1 relative to A1, while it was better or the same in the previous years. If one considers instead A4 relative to C4, i.e. the same change in expenditure allocation, but with memory, it is in year 76 that the condition of old women becomes worse in C4 with respect to A4. Moreover, the size of the loss is different. Under C1, the functioning in year 100 is 4.277 times the initial value, against the 5.273 for A1 (-19%). Under C4 and A4 the corresponding figures are 8.75 and 9.875 (-11%).
The reason for these results lays in the fact that memory makes current expenditure similar to capital account expenditure. Earlier health expenditure on mature health may compensate later reduction in health expenditure for the old.

Fig. 4 - Health Functioning for Old Women: the role of memory

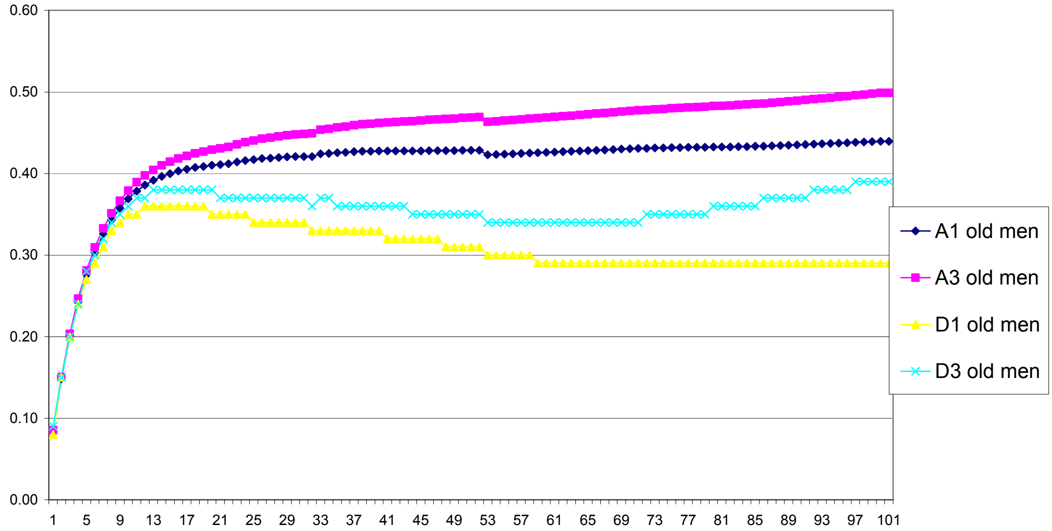


8.3 Role of Interdependence

As in the previous paragraph, the role of interdependence can be evaluated in simple, trivial way and in a slightly more sophisticated one. We now consider the being healthy functioning for old men. The comparison between A1 and A3 (baseline expenditure scenario without and with interdependence, respectively) shows clearly the effect of interdependence in making possible an always higher level of functioning (in the final year, the level of functioning with A3 is 10.9 % higher than underA1). If we now consider the scenarios D1 and D3, we expect the level of being healthy functioning to be lower, at least in the first decades, with respect to A1 and A3, since the D scenario entails a prolonged decrease in health expenditure per head, matched by corresponding increases in education and environment expenditures. If however we look at the data, we find that the value of the functioning along the A1 path is (on the 100 years average) 33% higher than along the D1 path, whereas the same ratio is 26% if one considers A3 vis-à-vis D3. Also, along the A1 path the value in year 100 is 5.23 times the initial value, while is 3.625 the initial value on D1 (-31%). The corresponding figures for A3 and D3 are 5.851 and 4.333 (-26%).

This results suggest, that, although a reallocation of expenditure away from health may actually reduce the level of the "being healthy" functioning, this reduction is mitigated by a sufficiently high degree of dependence of health on other functionings. As an "extreme" version of this suggestion, one might conclude that some of the expenditure on health is in excess, and might be more efficiently re-directed towards other services.

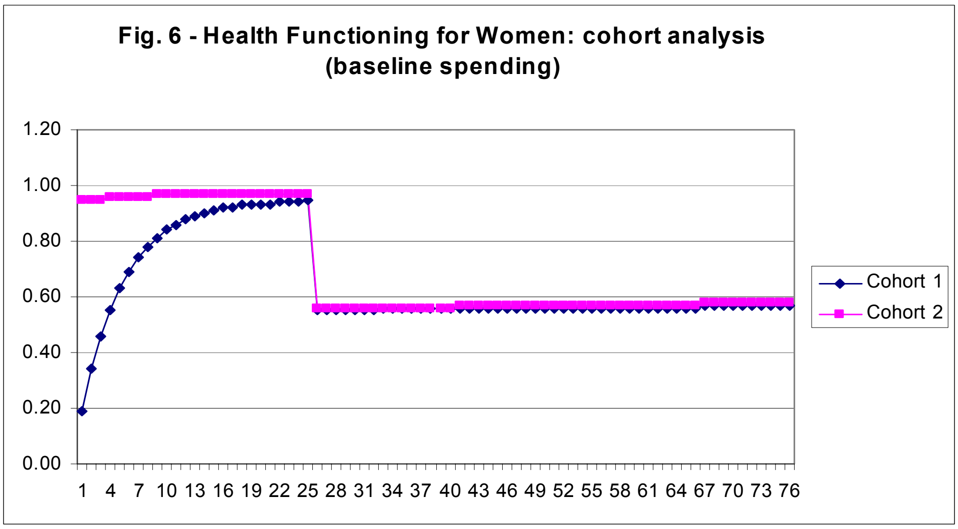
Fig. 5 - Health Functioning for Old Men: the role of interdependence (no memory)



8.4 Cohort Analysis

So far, we have considered the paths of the "being healthy" functioning for given populations (old men, old women) over time, without considering what happens, under different expenditure patterns, to individuals who are first young, then mature and old in the last part of their lives. In this paragraph we devote some space to these issues. We can do this with some degree of approximation. Every time we divide individuals into large age groups, and attribute to these groups some specific properties, it becomes unavoidable to introduce discontinuities, since individuals leave one group and enter the next one at discrete intervals. In this model, for instance one is young until he/she is 25, mature until 50 and old afterwards. This rather rigid structure replaces, in models with large age groups, the real-world smooth transition from youth to maturity and old age. Consequently, the conversion rate too may change abruptly and therefore we observe "steps" in the level of functioning which are not due to discrete changes in input services.

We shall examine two cohorts. The first (cohort 1) is born in year 1, and disappears entirely in year 75; the second one (cohort 2) is born in year 25 and dies in year 100. These are the only two cohorts whose life spans are entirely contained in the simulation horizon. This is why we focus on them. Again, we shall consider the "being healthy" functioning for women. Figure 6 describes the path for the two cohorts under the baseline hypothesis (no memory, no interdependence).



The periods on the horizontal axis must not be interpreted as calendar dates, but as years of age: then at t=10 we compare the functioning for a woman of cohort 1 when she was ten (which happened in year 10) with the functioning for a woman of cohort 2 when she also was ten (which however happened in year 35). When young, the woman in the first cohort experienced an increasing level of "being healthy", due to the fast increase in stocks of health-producing inputs. Afterwards, the level of the service stabilizes at the very high level reached during the "take-off" years, but then it is the conversion rate which drops (see the Appendix). When young women of cohort 2 are born, the level of service is already high, so that they enjoy a better youth than their mothers did when young. From that moment on, the condition of the two cohorts coincide.

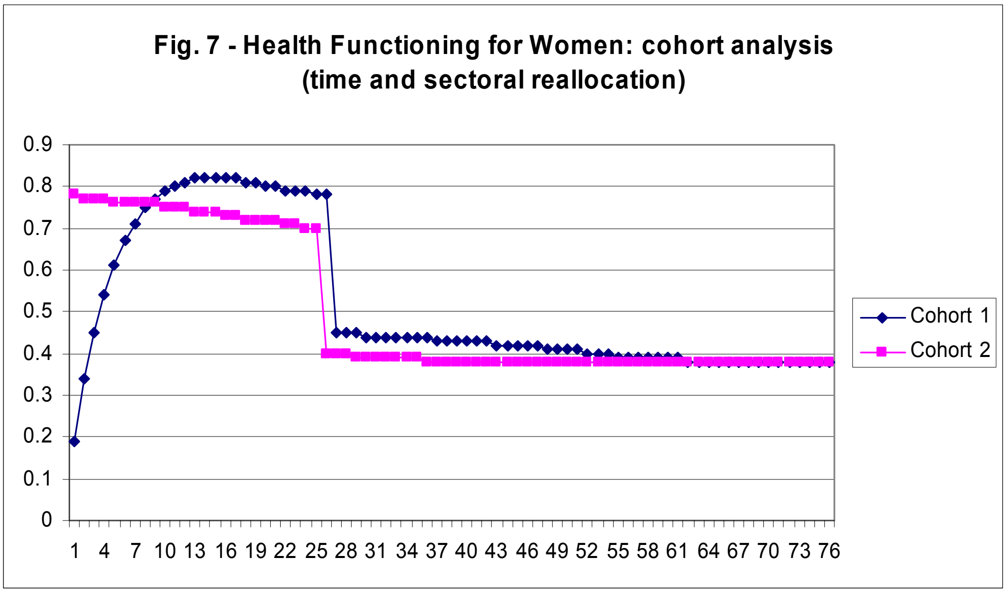


Figure 7 offers the same comparison, under the D path of public expenditure. During their youth, women of cohort 1 experience again a sharp increase followed by a mild decrease in the level of the functioning, due to the reallocation of expenditure. Again, as young become mature, their conversion rate drops, but the persistent reduction in per capita health expenditure causes a further, smooth decrease in the functioning. Women of cohort 2, instead, experience a smooth decrease in the functioning during all of their life (apart from the stabilization in the last decades), together with the sharp drop at the passage from youth to maturity.

9 Conclusions

In this paper we have discussed the structure and the outcomes of some simulations run using the IQuaL model. We focused in particular on the role of memory and interdependence among functionings to show that alternative patterns of public expenditure can receive significantly different evaluations according to how much relevant these effects are considered. Neglecting these two factors may induce to overrate the redistributional effects of: a) policies concentrating the spending efforts in earlier period; b) policies which redistribute resources away from those services which however benefit from the production of other services. In this model, health services are the example for this case.
In principle, one might construct examples where expenditure on health is so high and dependence from other services so strong that it would be possible to improve the level of health by reducing health expenditure and properly reallocating it to education and environment protection and enhancement.
The third force driving our results are conversion rates, especially if one looks at the problem from the viewpoint of cohort analysis. When conversion rates change strongly with age, neglecting such change might lead to undervalue the redistributing effect (across generations) of alternative policies.

Disclaimer
Any opinions expressed in this paper are solely those of the authors and not those of the organization with which the author is affiliated.

Appendix

Input prices
Except for Education (where all input indicators are monetary), in the two remaining cases we need data on input prices in order to choose the optimal input combination. More precisely, simulations incorporate the following price data:
Magnetic Resonance Unit : € 1.200.000
Acute care Bed : € 200.000
Yearly salary (Physician): € 50.000
Yearly salary (Nurse): € 35.000
Costs of managing one Ton of differentiated waste: € 120
Cost of one m^2 of urban green: € 670
Cost of 1 Km of Local Public Transport Network : € 6387

Conversion rates
The following table shows the conversion rates for each functioning (K: Education, Y: Health; X: Living in a Safe Environment) and class of population (YF: Young Female; OF, Old Female; YM: Young Male; OM: Old Male; MF: Mature Female; MM: Mature Male).

Education	KYF	KOF	KYM	KOM	KMF	KMM
	1.00	0.00	1.00	0.00	0.00	0.00
Health	**YYF**	**YOF**	**YYM**	**YOM**	**YMF**	**YMM**
	1.00	0.00	0.99	0.00	0.58	0.44
Living in a Safe Environment	**XYF**	**XOF**	**XYM**	**XOM**	**XMF**	**XMM**
	1.00	0.76	0.85	0.49	0.55	0.80

Population

Consider a population with n overlapping generations, where new cohort is born every μ years (and the maximum length of life is be $n\mu$ years). Take the population who is alive at time t , composed by old persons born at time $k\mu$ (*k generation*), grown-up persons born at time $(k+1)\mu$ and young persons born at time $(k+2)\mu \le t$. Obviously, k depends on *t*, but we shall stress this dependence not to overload the notation. Define x_t^y, x_t^g, x_t^o as the services that are available, at time t, to a young individual, a grown-up individual and an old individual respectively. Also, for simplicity, suppose that services coincide with functionings, i.e. the conversion coefficient is 1.

Across their lives, old individuals have been exposed to the following services (functionings):

$x_{k\mu}^y, x_{k\mu+1}^y, \dots, x_{(k+1)\mu-1}^y, x_{(k+1)\mu}^g, x_{(k+1)\mu+1}^g, \dots, x_{(k+2)\mu-1}^g, x_{(k+2)\mu}^o, \dots, x_t^o$

Similarly for grown-up persons :

$x_{(k+1)\mu}^y, x_{(k+1)\mu+1}^y, \dots, x_{(k+2)\mu-1}^y, x_{(k+2)\mu}^g, \dots, x_t^g$

Finally, for young persons we have:

$x_{(k+2)\mu}^y, \dots, x_t^y$

We can then define, at time t , an *Index of Life-age Effective Services* (*IES index)*

(1) $X_t^p \equiv f_x\left(x_{(k+2)\mu}^p, x_{(k+2)\mu+1}^p, \dots, x_t^p\right)$

(2) $X_{(k+2)\mu-1}^p \equiv f_x\left(x_{(k+1)\mu}^p, x_{(k+1)\mu+1}^p, \dots, x_{(k+2)\mu-1}^p\right)$

(3) $X_{(k+1)\mu-1}^p \equiv f_x\left(x_{k\mu i}^p, x_{k\mu+1}^p, \dots, x_{(k+1)\mu-1}^p\right)$

IES can be interpreted as a summary statistics of the services which have been available to individuals during a specific age of their life: youth (p=y) grown-up age (p=g) and old age (p=o). Then, for a person who is young at time t, only expression (1) makes sense, for a person who is grown-up at time t, expressions (1) and (2) make sense (with p=g in expression (1) and p=y in expression 2). For old persons at time t all of the three expressions are meaningful with p=o in (1), p=g in (2) and p=y in (3)

In the present version of the model, IES are sums (for instance: $X_t^o \equiv \sum_{i=(k+2)\mu}^{t} x_i^o$), which means that at the end of a life age what matters is the cumulate level of the functioning over that age). Alternative formulations are also possible (for instance a "discounted" sum $X_t^o \equiv \sum_{i=(k+2)\mu}^{t} \gamma^{i-(k+2)\mu} x_i^o$, that for $\gamma < 1$ implies that the most recent levels of he functioning are the least important, while $\gamma > 1$ has the opposite meaning); or $X_t^o = \min\left[x_{(k+2)\mu}^o, x_{(k+2)\mu+1}^o, \ldots, x_t^o\right]$, etc.

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