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Abstract: *The continuous aging of the EU population poses important challenges to the sustainability of welfare states. Part of the solution is to ensure that people not only live longer but also better (i.e., can function independently while remaining free of disease and disability), which may be achieved through better nutrition. In order to test that proposition, we develop a behavioural model of diet quality choice and health determination. The simultaneous equation model, which accounts for the endogeneity of dietary and other lifestyle choices, is applied to a sample of older people from Italy and allows for the possibility of bi-directional causality between diet and health.*

1. INTRODUCTION

The European Union (EU) is currently undergoing a second demographic transition due to the low fertility and increase in life expectancy of its population. After reaching a post-war peak around 1965 (van de Kaa, 1987), the fertility rate of the EU 25 declined well below the replacement rate (2.1) to reach 1.46 in 2001, with only Ireland currently exceeding that threshold value (Vos, 2009). Meanwhile, life expectancy is lengthening almost linearly in the EU as in most developed countries, with no sign of deceleration. Although that evolution has been ongoing for almost 200 years, recent gains in life expectancy have largely been achieved by unprecedented reductions in old-age mortality, hence defying the limits to human longevity set by many scientists only three decades ago (Christensen et al., 2009). Altogether, those demographic changes imply that the EU population is aging rapidly, as indicated by the sharp increase in the share of the population in older age categories (Lanzieri, 2010).

In turn, the aging of the EU population raises a whole range of potential issues, including: the funding of pensions as the dependency ratio rises; difficulties for both governments and families to provide adequate care to the elderly; an increasing cost of health care as the expanding "oldest-old" population group is also the most susceptible to disease and disability; shortages of workers and skills; and even a decline in overall productivity and growth of the economy (Andreason & Miller, 2011). Although the importance of some of those problems may be exaggerated (Cutler et al., 1990), the consensus view considers that the evolution of mortality, disease and disability rates in elderly people represents a fundamental challenge to the sustainability of modern societies (Christensen et al., 2009). The good news is that scientific evidence is accumulating that aging processes are fundamentally modifiable rather than immutable (Christensen et al., 2009) and it is in particular believed that nutritional factors can be used to slow functional decline and the onset of age-related chronic diseases (Horwath, 2002).

That evidence, however, is not sufficient to conclude that the promotion of healthy eating to achieve healthy aging would be an effective policy for three reasons. First, the benefits from nutritional changes measured in strictly-controlled laboratory studies may be misleading, because unconstrained consumers urged or incentivized to improve their diets in one dimension may operate substitutions leading to a worsening of diet quality in another dimension, with an ambiguous overall effect on health. Although not specifically for the older population, this has been repeatedly found in relation to the impact of “fat taxes”. Hence, Mytton et al. (2007) reported in a UK study that taxing the principle sources of saturated fat would, paradoxically, result in an increase in the incidence of cardiovascular diseases due to an unexpected rise in salt intake. Second, epidemiological models do not always appropriately account for the fact that diets and other lifestyle factors result from choices, hence leading to endogeneity issues, confounding, and biased inference (Zohoori & Savitz, 1997; Chen et al., 2002). Finally, the question of what obstacles older individuals might face when endeavoring to improve the quality of their diets remains largely unexplored.

Against this background, we propose to develop a behavioural model of diet quality choice and health determination in order to contribute to the current debate on the promotion of healthy eating for healthy ageing. The specific objectives are to: 1- analyse the influence of diet quality on health of older people; 2- identify the main drivers of diet quality in older populations; and 3- clarify the direction of causality between diet quality and health for that population group.

The paper makes several contributions to the existing literature. At an empirical level, we are not aware of any previous attempt at applying the household theory of health production specifically to older people. Given the particularities of that demographic group (e.g., low opportunity cost of time, short planning horizon), it is likely that older individuals behave differently from the general population in relation to nutritional health issues, which gives relevance to our inquiry. Further, at a more conceptual level, we extend the theoretical and empirical framework to allow for the possibility that while diet quality influences health, health may also influence diet quality, as the ubiquity of weight-reducing diets might suggest. Indeed, the relationship from health status to diet seems particularly relevant for the older population, as that demographic group is the most subject to food related chronic diseases (e.g., diabetes or high blood pressure). Although intuitively obvious, the influence of health status on dietary and other lifestyle choices has, surprisingly, not been properly addressed in published studies (Chen et al., 2002; Contoyannis & Jones, 2005; Balia & Jones, 2008). Hence, by estimating a simultaneous system of diet quality choice and health status determination, we are able to shed new light on the potentially bi-directional nature of the causal relationship between diet and health.

The next section presents the theoretical framework for the analysis the diet-health relationship, the data, empirical model and estimation strategy. Section 3 presents the results and is followed by a conclusion.

2. METHODS

2.1.1 THEORETICAL FRAMEWORK

The dynamic nature of the diet-health relationship implies that time must be included in the modelling framework. However, the data used in the empirical section prevents us from estimating a fully dynamic model. As a compromise between realism and empirical tractability, we therefore consider a one-period optimization problem in which an older person's past health decisions are captured by an initial health stock. Our model of lifestyle and health production function represents an extension of that of Contoyannis & Jones (2004), and its specification starts with the utility maximization problem:

$$\max_{C,M} U(C,H,M) \qquad (1)$$

where *U* is a neoclassical utility function, which depends first on the consumption *C* of an aggregate of all market goods and services that do not influence health[1]. Utility is also function of the commodity "good health", denoted by *H*, which depends itself on an initial health stock H_0 and investments in *J* health inputs M_j as described by the health production function:

$$H = H(H_o, M) \qquad (2)$$

The *J*-vector *M* of health inputs can include medical care and lifestyle factors such as diet, smoking, alcohol consumption and physical activity. Those health inputs also enter the utility function (1) directly since it is likely that they influence well-being of the older consumer other than through health – for instance, it is evident that consumption of particular foods generates hedonic rewards. Taking the aggregate consumption good *C* as numeraire, the budget constraint is:

$$C + \sum_{j=1}^{J} p_j M_j \leq I \qquad (3)$$

where p_j denotes the price of the *j*-th health input. This specification treats income as exogenous and departs from Grossman's original model of health investment (Grossman, 1972) in that the consumer does not choose to allocate time to wage-earning activities. This assumption is justified by the specific population of interest, which includes many retired individuals. Finally, it is assumed that consumption of market goods and health inputs requires time and a related constraint is therefore imposed:

$$\tau_c C + \sum_{j=1}^{J} \tau_j M_j \leq T \qquad (4)$$

[1] The aggregation assumption is made for simplicity of exposure and C could equally represent a vector of market goods and services that do not influence health.

Where τ_c and τ_j denote the amounts of time to consume the market goods and health inputs. The utility maximization problem is solved by defining the Lagrangian function:

$$\max_{C,M} L = U(C, H(H_o, M), M) + \lambda\left[I - C - \sum_{j=1}^{J} p_j M_j\right] + \mu\left[T - \tau_c C - \sum_{j=1}^{J} \tau_j M_j\right] \quad (5)$$

The first-order conditions lead to the following equilibrium equations:

$$\begin{aligned} &U_c = \lambda + \mu\tau_c \\ &U_j + U_H H_j = \lambda p_j + \mu\tau_j \text{ for j=1,...,J} \\ &\mu\left[T - \tau_c C - \sum_{j=1}^{J} \tau_j M_j\right] = 0;\ \mu \geq 0 \end{aligned} \quad (6\ a,b,c)$$

where U_c, H_j and H_j denote the partial derivatives of the utility and health production functions. The left hand-sides of equations (6 a-b) are the marginal utilities of the market goods and health inputs, the latter having both a direct component U_j and an indirect component $U_H H_j$ that operates through the production of health. The marginal products are equated to the shadow prices corresponding to the right hand-sides of (6a-b). Those shadow prices are the sum of a monetary component (λ or λp_j) and a time component ($\mu\tau_c$ or $\mu\tau_j$), which can disappear if the time constraint is not binding. Hence, the equilibrium conditions reflect the extension of the standard consumer model to include a time constraint and household production of health.

Under the assumption of non-satiation, the budget constraint (3) is always binding and we have a square system in *J+3* variables (C, M, μ, λ) and *J+3* equations (6 a-c & 3). The solution of that system[2] is the set of Marshallian demand functions for the market goods and health inputs:

$$\begin{aligned} &C(p, I, T, H_0) \\ &M(p, I, T, H_0) \end{aligned} \quad (7a,b)$$

Importantly, we note that demand for the health inputs depends on initial health stock H_o. Hence, focusing on the lifestyle factor of interest, diet influences health through the production function (2) but health influences diet through the Marshallian demand function (7b). The latter equation could for instance capture the situation of a diabetic person adopting a diet low in saturated fat and sugar as a way of managing his/her disease. Our theoretical model therefore gives a framework to investigate the potentially bi-directional relationship between diet and health. It represents an important departure from the other economic models of diet (or more generally lifestyle) and health of which we are aware (Chen et al., 2002; Contoyannis & Jones, 2004; Balia & Jones, 2008), as those consider that adoption of particular lifestyles is not a function of health. In fact, in making

[2] Without loss of generality we assume that the time constraint is binding.

the choice of lifestyles and other health inputs dependent on health status, our analytical framework shares more similarities with the models used to analyse the demand for curative and preventive medical care (Gilleskie & Harrison, 1998).

2.1.2 DATA

Empirical estimation of the theoretical model – and specifically of the production function (2) and demand equations in (7) – requires data from a variety of domains, covering dietary choices and quality, socio-economic factors including income and prices, and health information. Data-sets providing good-quality information on all these aspects at the individual level are virtually inexistent, which might explain the scarcity of empirical studies exploring the bidirectional diet-health relationship.

For our purpose, we rely on a survey which – albeit not ideal – provide a good approximation to the required information set, the Italian Multipurpose Survey on Daily Life (MSDL).

The MSDL is an annual survey on a multitude of daily life aspects for the Italian population, recording information on social, cultural, environmental, health and economic characteristics of individual respondents and their households. Food consumption habits are measured through a food frequency questionnaire, which is limited to a selection of food categories.

Both surveys are designed to be representative for sub-group of the populations. For our study we employ three annual surveys of the Italian MSDL (2008, 2009, and 2010). These are repeated cross-sections, without a longitudinal dimension. We consider the sub-samples of individuals aged 65 and over and who are retired from work, and after a listwise deletion of incomplete observations, the final sample includes 24970 respondents.

The following description relates each measured variable with the theoretical model described in section 2.1.1.

Health variables. Our measure of current health *(H)* is based on a subjective assessment of own health status (*SUBJHEALTH*), relative to the health status of individuals of the same age. A measure of health stock (H_0) is based on diagnosed diseases (*ILLNESS*). The survey includes information on 15 different disease groups, indicating whether the respondent has been diagnosed each condition. In order to create a single indicator, we weighted each condition according to the disability weights applied to the 2004 Global Burden of Disease Project (WHO, 2008), and the resulting variable was rescaled to a range between 0 (no conditions) and 1 (worst combination of conditions among those included in the survey)[3]. We also included explicit binary variables for two conditions that are most likely to affect weight control behaviours, i.e. diabetes (*DIABETES*) and hypertension (*HYPER*).

We consider the continuous variable for Body Mass Index (*BMI*) in two roles, as a continuous

[3] We opted for the 2004 GBD disability weights because those from the 2010 GBD study adopted a different classification of disease than the one in our data-sets, and their quality and international validity has been recently criticised (Nord, 2013).

variable measuring an health outcome and as a potential determinant of calorie intake. From BMI, we also obtain a binary variable to capture obesity (*OBESE*), hence an health factor explaining subjective health.

Subjective well-being. One of the distinguishing feature of the MSDL survey is the availability of multiple measures of reported satisfaction on income, health, family, friends, leisure, environment, and individual security perception. These measures of subjective well-being are a micro-level adaptation of the country level methodology proposed by the OECD (OECD, 2011) and are based on the recommendations produced by the Stiglitz-Sen-Fitoussi commission (Stiglitz et al., 2009). The individual variables on reported satisfaction are measured on a 4-points Likert scale ("not satisfied at all", "little satisfaction", "reasonably satisfied", "very satisfied") and are correlated between each other. Thus, they were summarized by means of a non-linear Principal Component Analysis (NL-PCA), i.e. an extension of traditional PCA to account for ordinal variables (Linting et al., 2007; Jöreskog and Moustaki, 2006). This resulted in two clearly distinguished indicators of subjective well-being (*SWB*), the first one (*SWBPERS*) mainly summarizing the personal dimensions of subjective well-being (health, family, friends, leisure), the second (*SWBEXT*) related to factors which can be associated with societal trends (satisfaction with the environmental situation and with security in the area where the respondents live). Interestingly, satisfaction with one's income loaded on both components, with a slight prevalence on the former. There are strong grounds to consider subjective well-being as a potential determinant of health behaviours and health outcomes, and especially the personal dimensions and satisfaction with the social network (family, friend, leisure) have been recognised as an important explanatory factor of dietary choices in the elderly (Herne, 1995).

Health inputs, lifestyles and habits

The core health input (*M*) *for* the purpose of our study is dietary quality, which is measured using an index of departure from the nutrient intake levels as recommended by WHO norms. This index, named Recommendation Compliance Index (*RCI*), is bounded between 0 and 1, where 0 represents the maximum possible distance from WHO norms and 1 reflects perfect adherence to the norms (Mazzocchi et al., 2008). The index does not account for energy intakes. Given that the Italian MSDL only records food intakes for a selection of food categories, an absolute measurement of calorie intake is unfeasible, but an index (*CAL*) converting food frequencies into calories and normalized relative to the sample average provides an acceptable proxy. We also consider other variables related to eating habits, which differ across the two data-sets. The Italian MSDL includes an item on self-reported monitoring of salt intakes (*FOODSALT*) and another asking about the use of iodized salt (*IODIZED*). These variables may act as a proxy for past attitudes towards eating healthily, a potential substitute for lagged variables.

Other consumption and lifestyle choices affecting health relate to smoking, drinking and physical activity habits. Only generic measures are available. Smoking status (*SMOKER*) is based in a three-level classification (never smoked, smoked in the past but not currently, and current smoker). Alcohol consumption habits (*ALCOHOL*) follows the same classification. A physical activity measure

(*PHYS*) is also available, and – as for subjective well-being – it was obtained by extracting a single factor from separate ordinal items measuring the intensity of physical activity for home activities and leisure physical activity. Finally, the only measure on the consumption of medicaments (*MEDIC*) is a binary variable reporting whether the respondent as taken any pharmaceutical over the two days before the interview.

Economic variables

Income – or broader economic status – is recognized as a major explanatory factor in the literature on diet quality of the elderly (Herne, 1995). A measure of economic status is based on the self-reported financial resources of the family (*INCOME*), grouped in four levels. A binary variable recording whether the pension is the main source of income for the respondent is also included.

However, one of the main obstacles to this type of studies is the lack of price information, and our data-set makes no exception. Thus, we used separate regional price indices for food, alcohol and tobacco[4] and one overall regional consumer price index for each region and year, based on the standard assumption that prices only vary across regions and over time (see e.g. Deaton, 1988). The (real) price indices (PRICES) consist in the ratio between the food (alcohol, tobacco) price index and the main consumer price index for each of the 20 Italian regions and each of the three considered survey years (all indices are produced by the Italian National Statistical Institute), so that each individual price variable may assume 60 different values depending on the region and survey year of the respondents.

Accessibility and mobility issues

Among the variables which are likely to have a relevant impact on elderly behaviours, in our data-set there are several indicators which can be used as proxy for accessibility of a healthy diet, or measures of other enhancements or constraints to carrying out daily life activities. The first refers to difficulties in accessing an healthy diet, as the survey contains a question about obstacles in accessing a supermarket (*ACCESS*), which has been linked to nutritional risks (Wilson et al., 2004). Furthermore, there are explicit questions about health impairments (*HIMPAIR*) affecting ordinary daily activities (no limitations, minor limitations, major limitations). The quality of public transport (*PUBTRANS*) and whether the respondent drives or not (*DRIVING*) are also two potential factors influencing accessibility of healthy lifestyle choices. Among the determinant of physical activity, also the time spent watching television (*TV*) may be considered as an explanatory variable.

Demographics and other variables

Based on the wide literature on elderly food choice, a set of additional social and demographic variables is considered in this study. The first obvious candidates are age (*AGE*) and gender *(GENDER)*. Because age effects may be non-linear, the age variable was broken down in four binary dummies (age between 65 and 70, 71-75, 76-80, and 81 and above) A binary variable to identify

[4] Unfortunately prices for leisure physical activity and for pharmaceutical products are not provided at the regional level, but could be proxied by the main consumer price index.

individuals living alone (*ALONE*) and one identifying those who live far away from their family (*FAMILYFAR*) are also available. The education variable (*EDUC*) considers various levels of educational attainments. Finally, the dataset includes binary variables for geographical areas (*AREA*).

Table 1 below reports the sample descriptive statistics for all of the variables in our model.

Table 1. Descriptive statistics

Variable	Description	Mean	Std. Dev.	Variable	Description	Mean	Std. Dev.
ACCESS	Difficulty to access supermarkets	0.47	0.67	FOODSALT_2	Salt content - always monitored	0.37	0.48
AGE_1	Aged 66-70	0.27	0.44	GENDER	Gender: female	0.58	0.49
AGE_2	Aged 71-75	0.24	0.43	HIMPAIR_1	Limitation in daily life activities because of health: none	0.44	0.50
AGE_3	Aged 76-80	0.20	0.40	HIMPAIR_2	Limitation in daily life activities because of health: minor	0.36	0.48
AGE_4	Aged 81 or above	0.24	0.43	HIMPAIR_3	Limitation in daily life activities because of health: major	0.20	0.40
ALCOHOL	Drinks alcohol	0.45	0.50	HYPER	Hypertension	0.49	0.50
ALCOHOL_QUIT	Quit alcohol	0.05	0.22	ILLNESS	llness indicator	0.13	0.12
ALONE	Living alone	0.29	0.45	INCOME_1	Income - extremely low	0.06	0.23
AREA_1	Living in the North-West	0.22	0.42	INCOME_2	Income - low	0.42	0.49
AREA_2	Living in the North-East	0.20	0.40	INCOME_3	Income - adequate	0.51	0.50
AREA_3	Living in Central Italy	0.20	0.40	INCOME_4	Income - high	0.01	0.12
AREA_4	Living in the South	0.28	0.45	INCOME_PENS	Pension as main source of income	0.91	0.29
AREA_5	Living in Islands	0.10	0.31	IODIZED	Iodised salt use	0.37	0.48
BMI	Body mass index (continuous)	26.05	3.86	MEDIC	Makes use of medicaments	0.81	0.39
BMI_1	Underweight (BMI<18.5)	0.02	0.12	PHYS	Physical activity level	0.63	0.43
BMI_2	Normal weight (18.5<BMI<25)	0.38	0.49	PRICE - CPI	Consumer price index	127.43	2.21
BMI_3	Overweight (25<BMI<30)	0.46	0.50	PRICE_ALC	Price of alcohol (real)	0.01	0.00
BMI_4	Obese (BMI>30)	0.14	0.35	PRICE_FOOD	Price of food (real)	1.02	0.03
CAL	Calorie intake	1468.65	364.24	PRICE_TOB	Price of tobacco (real)	0.01	0.00
DIABETES	Has diabetes	0.17	0.38	PUBTRANS	Quality of public transport	0.92	0.99
DRIVING	Drives a car	0.40	0.49	RCI	Recommendation compliance index	0.73	0.11
EDU_1	Education - no title, can't read/write	0.03	0.17	SMOKE_QUIT	Quit smoking	0.59	0.49
EDU_2	Education - no title, read and write	0.14	0.35	SMOKER	Current smoker	0.09	0.29
EDU_3	Education - primary school	0.52	0.50	SUBJHEALTH	Perceived health status	3.04	0.79
EDU_4	Education - lower secondary	0.16	0.37	SWBEXT	Subjective well-being (external factors)	-0.01	1.09
EDU_5	Education - upper secondary and above	0.11	0.32	SWBPERS	Subjective well-being (personal factors)	-0.02	1.05
FAMILYFAR	Living far from family	0.20	0.40	TV	Hours spent watching TV	13.24	29.10
FOODSALT_1	Salt content - reduced	0.44	0.50				

2.1.3 SPECIFICATION OF THE EMPIRICAL MODEL AND ESTIMATION STRATEGY

The structural system to be estimated consists of two health production functions (8a and 8b) reflecting the theoretical specification of equation (2), one for subjective health and one for the body-mass index intended as an health outcome, and three demand functions for health inputs (8c to 8e), reflecting equation 7b. The structural specification shown in equation (8) is necessarily incomplete, due to the lack of information on demand and prices for other market goods, including both health inputs and goods not influencing health.

$$SUBJHEALTH = f(RCI, OBESE, ILLNESS, HIMPAIR, SMOKER, ALCOHOL, MEDIC, DEMO, SWB) \qquad (8a)$$

$$BMI = f(CAL, PHYS, DIABETES, HYPER, DEMO) \qquad (8b)$$

$$CAL = f(PRICE, INCOME, BMI, PHYS, DEMO, ILLNESS) \qquad (8c)$$

$$RCI = f(PRICE, INCOME, FOODSALT, IODIZED, ACCESS, DEMO, ILLNESS) \qquad (8d)$$

$$PHYS = f(PRICE, INCOME, PUBTRANS, DRIVING, TV, DEMO, ILLNESS) \qquad (8e)$$

The variable names are those listed in Table 1, while *DEMO* is a variable set of demographics, including age, gender, education, geographic area, living alone, living far from family.

The health commodity (*H* in equation (2)) is measured through the variables *SUBJHEALTH* and *BMI,* the latter in its continuous version. The health stock H_0 is proxied by the variables *ILLNESS* (and also *DIABETES, HYPER* and *HIMPAIR*). Among health inputs (*M*) we include diet quality (*RCI*), calorie intake (*CAL*), smoking status *(SMOKER*), alcohol consumption status (*ALCOHOL)*, medicaments (*MEDIC)* and physical activity (*PHYS*). In our specification, all health inputs (including smoking and alcohol consumption) are treated as endogenous, although we only explicitly estimate the demand for calories, dietary quality and physical activity for which we have continuous dependent variables.

In equation (8a) (subjective) health depends on diet-quality (*RCI*), health stock (*ILLNESS, HIMPAIR*), other health inputs (*PHYS, SMOKER, ALCOHOL, MEDIC)* and obesity (*OBESE*) *as* a health risk factor. We also include subjective well-being (*SWB*) to test whether it has a direct effect on perceived health status. A set of demographic variables completes the specification.

In equation (8b) *BMI* is itself a function of specific health stocks (*DIABETES, HYPER*), but obviously also of energy intakes (*CAL*) and energy expenditure (*PHYS*).

The demand equations (8c), (8d) and (8e) all include on the right-hand side socio-economic status (*INCOME*), the relevant input prices *(PRICE*), and the health stock (*ILLNESS)*. Calorie demand is also influenced by the body-mass index (as a continuous variable, *BMI*), and by the intensity of physical activity (*CAL*). Food preference variables referring to past behaviours and health consciousness (*FOODSALT, IODIZED*) and difficulties in accessing supermarkets (*ACCESS*) *are* specific to the dietary quality demand equation. The variables specific to the demand for physical activity are the quality of public transport (*PUBTRANS*), whether the respondent drives (*DRIVING*) and the number of hours spent watching television (*TV*). Demographic variables (*DEMO*) such as AGE and GENDER*,* and enter all demand equation, while education (*EDUC*), living alone (*ALONE*) and distance from the family (*FAMILYFAR*) are specific to the demand for diet quality.

Given the specification of the 5-equation system in (8), the variables to be treated econometrically as endogenous are *SUBJHEALTH, OBESE, CAL, RCI, PHYS, SMOKER, ALCOHOL and MEDIC*, which represent the health inputs and outputs considered in the structural model. Instead, we assume that the health stock (*ILLNESS, DIABETES, HYPER, HIMPAIR*), economic variables (*PRICES, INCOME*), and the other determinants (*ACCESS, FOODSALT, IODIZED, DEMO, PUBTRANS, TV, DRIVING*) can be treated econometrically as exogenous variables, in that they are determined outside our structural model or in previous periods. The same applies to subjective well-being (*SWB*), which is interpreted as a measure of the stock of well-being built over a lifetime, and not only depending on the current situation, or – in the case of *SWBEXT* it is determined outside the behavioural model.

The cross-sectional nature of the data-set places some limitations, as dynamics (lagged variables) would provide a precious set of exogenous variables, they would allow to capture longer-term effects and account for omitted (unobservable) variables. It is reasonable to assume that within the time span covered by the surveys there is no immediate effect of food choice on health stocks, as it takes longer to observe health outcomes. Still, we have some information on past behaviours, related to habits and lifestyles (e.g. smoking, drinking, salt use in the past, etc.) which may prove useful to capture some dynamic effects and serve as instrumental variables.

Our system meets the necessary condition for identification in terms of exclusion restrictions, that is each equation does not contain the same set of exogenous variables, which allows to distinguish among the structural equations of the system. Furthermore, all equations are overidentified, which opens the way to two-stage least square (2SLS) and three-stage least squares (3SLS) estimation, using as instruments all exogenous variables in the system. This allows to overcome the simultaneity bias which generates biased and inconsistent OLS estimates of the structural coefficients. We provide OLS estimates to assess the extent of such simultaneity bias, which derives from ignoring endogeneity.

The 2SLS method is a limited-information estimation method, as it ignores cross-equation correlations. The gain in efficiency brought by full information methods as e.g. three-stage least squares (3SLS) rely on the assumption that all equations in the system are correctly specified. Any misspecification issue would affect estimates in other equations.

3. RESULTS

System (8) was estimated using OLS, 2SLS and 3SLS and the estimates of standardised coefficients are shown in Table 2. While we present the results separately for health outcomes and health input demands for ease of presentation, the five equations were considered jointly in 2SLS and 3SLS estimation.

The first equation represents the main health production function, and the measured health outcome is the subjective perception of health status. In general, the direction of the effects is consistent with the expectations, regardless of the estimation method, with two exceptions. First, the relationship between consuming alcohol and health outcome is positive and significant according to OLS estimates, but it becomes negative and significant once endogeneity is accounted for. Second, the use of medicaments (over the two days preceding the interview) emerges as a negative factor for health when endogeneity is ignored, but it becomes non-significant in 2SLS and 3SLS, where the variable is treated as endogenous.

Other results (drawing from the 3SLS methods) are in line with the expectations, but it is interesting to explore the size of the effects. Health stock (diagnosed conditions) has obviously a large and significant impact on subjective health, and unsurprisingly freedom from major health-related impairments has a significant positive impact on health perception. Physical activity has a direct positive and significant impact on perceived health, whereas diet quality has a small positive effect on health, but non-significant in 2SLS and 3SLS. The largest negative effect is associated with being obese. Ceteris paribus, females report a worse health. We also confirm that subjective well-being, and especially the factor related to social networks and personal satisfaction, is by itself an important driver of health.

The second health production equation explores the determinants of BMI. Again, addressing endogeneity improves the interpretability of the results. OLS do not find any association between BMI and calorie intake, while allowing for endogeneity shows a relatively large and significant effect. The intensity of physical activity (at home or during leisure time) emerges as a key element to control body mass in the elderly, and its contribution becomes much more conspicuous after treating physical activity as endogenous in 2SLS and 3SLS. Furthermore, BMI drops significantly with age and is higher in the South of Italy. Besides these well-known associations, causal factors generating excess weight are still difficult to identify, and some relationships are hard to explain, like the positive coefficients of diabetes and hypertension, which is not corrected by the simultaneous equations estimation methods.

Table 2. Estimation results: health outcomes (standardized coefficients)

Determinant	Estimation method OLS		2SLS		3SLS	
			Health outcome (perceived)			
Diet quality (RCI)	0.037	***	0.057		0.024	
Physical activity	0.098	***	0.394	***	0.513	***
Obese	-0.016	***	-0.194	***	-0.384	***
Illness index	-0.225	***	-0.199	***	-0.192	***
Current smoker	0.006		-0.046		0.110	
Drinks alcohol	0.039	***	-0.112	***	-0.199	***
Aged 71-75	-0.029	***	-0.015	**	-0.011	
Aged 76-80	-0.032	***	-0.002		0.008	
Aged 81 or above	-0.021	***	0.052	***	0.081	***
Gender: female	-0.034	***	-0.126	***	-0.186	***
Makes use of medicaments	-0.136	***	-0.162	***	-0.038	
Quit smoking	-0.008		-0.029		0.030	
Past alcohol consumption	-0.017	***	-0.040	***	-0.054	***
Subjective well-being (personal factors)	0.145	***	0.111	***	0.097	***
Subjective well-being (external factors)	0.056	***	0.062	***	0.058	***
Limitation in daily life activities because of health: none	0.460	***	0.374	***	0.427	***
Limitation in daily life activities because of health: minor	0.251	***	0.191	***	0.218	***
			BMI health outcome			
Calorie intake	0.010		0.160	***	0.245	***
Physical activity level	-0.021	***	-0.212	***	-0.323	***
Gender: female	-0.084	***	-0.005		0.040	*
Diabetes	0.105	***	0.105	***	0.120	***
Hypertension	0.127	***	0.124	***	0.112	***
Aged 71-75	-0.005		-0.015	**	-0.020	***
Aged 76-80	-0.050	***	-0.073	***	-0.087	***
Aged 81 or above	-0.128	***	-0.189	***	-0.224	***
Living in Central Italy	0.047	***	0.044	***	0.046	***
Living in Islands	0.052	***	0.038	***	0.045	***
Living in the North-East	0.037	***	0.052	***	0.048	***
Living in the South	0.108	***	0.093	***	0.085	***

*** Significant at the 1% s.l.; ** significant at the 5% s.l,, * significant at the 10% s.l.

Table 3 reports the estimates for the three demand equations. One clear result is that food price does matters in determining calorie intakes and dietary quality. Given that no price data are available for physical activity, we proxied price levels with the general price index, which shows a strong negative relationship between the overall price levels and the intensity of physical activity. Table 4 translates the price coefficients into elasticities, although some caution is needed given that both diet quality and the intensity of physical activity are measured through indicators. Thus, a 10%

increase in prices leads to a 3% reduction in calorie intake, but also to a 5% reduction in the diet quality index.

Table 3. Estimation results: demand for health inputs (standardized coefficients)

	Estimation method		
Determinant	OLS	2SLS	3SLS
	Demand for calories		
Price of food (real)	-0.077 ***	-0.036 ***	-0.035 ***
Price of alcohol (real)	0.089 ***	0.073 ***	0.077 ***
Price of tobacco (real)	0.105 ***	0.070 ***	0.077 ***
Income - extremely low	-0.072 ***	-0.062 ***	-0.050 ***
Income - low	-0.059 **	-0.041 *	-0.023
Income - adequate	-0.014	-0.007	0.000
Pension as main source of income	0.001	0.005	0.005
Aged 71-75	-0.007	0.000	0.002
Aged 76-80	-0.018 ***	-0.003	-0.002
Aged 81 or above	-0.025 ***	0.012	0.013
Gender: female	-0.358 ***	-0.388 ***	-0.402 ***
Physical activity level	0.061 ***	0.209 ***	0.243 ***
Body mass index	0.003	-0.107 ***	-0.198 ***
Illness index	-0.024	0.000	0.013
	Demand for dietary quality		
Price of food (real)	-0.093 ***	-0.093 ***	-0.089 ***
Income - extremely low	-0.038 ***	-0.038 ***	-0.041 ***
Income - low	-0.031	-0.031	-0.033
Income - adequate	0.007	0.007	0.008
Pension as main source of income	-0.006	-0.006	-0.008
Aged 71-75	0.006	0.006	0.005
Aged 76-80	-0.027 ***	-0.027 ***	-0.030 ***
Aged 81 or above	-0.057 ***	-0.057 ***	-0.061 ***
Gender: female	-0.007	-0.007	-0.012 *
Education - no title, read and write	-0.016 **	-0.016 **	-0.014 **
Education - primary school	-0.001	-0.001	-0.006
Education - lower secondary	0.030 ***	0.030 ***	0.027 ***
Education - upper secondary and above	0.045 ***	0.045 ***	0.045 ***
Living alone	-0.018 ***	-0.018 ***	-0.001
Living far from family	0.000	0.000	0.005
Salt content - always monitored	0.072 ***	0.072 ***	0.083 ***
Salt content - reduced	0.095 ***	0.095 ***	0.102 ***
Iodised salt use	0.053 ***	0.053 ***	0.043 ***
Illness index	0.001	0.001	0.000
Difficulty to access supermarkets	-0.025 ***	-0.025 ***	-0.030 ***
	Demand for physical activity		
Consumer price index	-0.110 ***	-0.110 ***	-0.093 ***
Income - extremely low	-0.021 *	-0.021 *	-0.042 ***
Income - low	-0.010	-0.010	-0.040 *
Income - adequate	0.024	0.024	0.011
Pension as main source of income	-0.025 ***	-0.025 ***	-0.019 ***
Aged 71-75	-0.038 ***	-0.038 ***	-0.039 ***
Aged 76-80	-0.102 ***	-0.102 ***	-0.104 ***
Aged 81 or above	-0.283 ***	-0.283 ***	-0.286 ***
Gender: female	0.221 ***	0.221 ***	0.220 ***
Subjective well-being (personal factors)	0.103 ***	0.103 ***	0.099 ***
Subjective well-being (external factors)	-0.008	-0.008	-0.006
Drives a car	0.161 ***	0.161 ***	0.155 ***
Hours spent watching TV	-0.037 ***	-0.037 ***	-0.032 ***
Quality of public transport	-0.025 ***	-0.025 ***	-0.022 ***
Illness index	-0.079 ***	-0.079 ***	-0.079 ***

*** Significant at the 1% s.l.; ** significant at the 5% s.l,, * significant at the 10% s.l.

Low incomes generate a lower demand for calories, dietary quality and physical activity, and those at older ages have demand lower dietary quality and – especially – lower physical activity levels. After accounting for endogeneity, higher BMIs generate a lower demand for calories.

The demand for dietary quality is also positively influenced by educational attainments. There is also a relatively strong positive association between health-conscious habits (monitoring salt contents and using iodized salt) and current demand for dietary quality, suggesting some virtuous habit persistence. Instead, difficulties in accessing supermarkets are a significant barrier to consuming a healthy diet.

Even at older ages, physical activity remains a key health input, as demonstrated by its major role in improving subjective health and reducing the body-mass index. However, demand for physical activity (leisure or at home) rapidly decreases with age. While objective health does not seem to affect the demand for calories and dietary quality, it is a significant factor in explaining physical activity. The intensity of physical activity is also driven by the availability of transport means, especially autonomous transport. Those driving a car show on average higher levels of physical activity. Unsurprisingly, time spent watching television has a significant negative association with the levels of physical activity. Subjective well-being, in its personal dimension (hence satisfaction with own social networks, health status, income) generates higher level of physical activity, adding a further positive indirect effect on health beyond the direct effect shown in the health production equation.

Table 4. Price elasticities

	Food	Alcohol	Tobacco	General CPI
Calories	-0.31	0.11	0.59	
	(0.10)	(0.03)	(0.16)	
Dietary quality	-0.48			
	(0.03)			
Physical activity				-4.35

Note: standard error in brackets (Delta method)

In summary, these results suggest that, with respect to age, concerns about inadequate food and physical activity lifestyles of older consumers might best concentrate on the over 80s.

4. DISCUSSION

Despite some data limitations, the empirical models support the theoretical expectation that lifestyles and health are jointly chosen; health affects health input demand and health inputs affect health. The implication is that policies that exogenously improve the demand for health inputs such as physical activity or dietary quality would enhance health (or at least, subjective health) among the older population, but the benefits would be partially offset as improved subjective health fed through to objective health which led to people being less concerned about their diets and lowering their diet quality. This off-setting behaviour, common to risk behaviour in general, means that policy is less effective once endogeneity is explicitly allowed for in the model. From a technical perspective of course it also means that OLS is an inappropriate estimation technique.

It is worth reflecting on the nature of possible policy interventions and how effective these might be in influencing diet quality, BMI and health among older people. Broadly speaking there are two main types of intervention (see Mazzocchi, Traill and Shogren, 2009); the first, may be called information measures and include education, social marketing and nutrition labelling that, in principle, permit consumers to make informed choices. The second group of policies changes the market environment more directly, by changing relative prices (e.g. 'fat taxes') or changing food availability (e.g. reformulation to reduce the levels of 'harmful' nutrients like salt or trans fatty acids in foods). Our model does not permit direct explicit examination of the impact of any of these policy measures, but to the extent that there is an association between the level of a person's general education (which we do model) and their willingness and ability to assimilate new information on nutrition, we might expect that information measures would improve diet quality of the better educated.

Changing the relative price of food to non-foods worsens diet quality, which may argue against imposing VAT on food; it may also argue for measures to reduce the severity of food price spikes which have become a common phenomenon in recent years. Arguably policies to encourage reformulation (which might operate by encouraging voluntary industry action as with the UK's *Responsibility Deal* (Department of Health, http://responsibilitydeal.dh.gov.uk/) or by imposing mandatory standards, as with the Danish ban on artificial trans fats (bekendtgørelse nr. 160 af 11. marts 2003) work by stealth, people not realising they are eating more healthily and thus not engaging in compensatory behaviour.

Since information measures at best enable individual utility maximisation, they do not maximise social utility when there are externalities (in this case mainly health care costs borne through the tax system); only measures which change the market environment are capable of addressing the externality. This is perhaps a more compelling reason to argue for their use than the absence (in some cases) of compensatory behaviour.

If we stick to reformulation (rather than fiscal measures), we might end on a speculative note and argue in favour of public R&D targeted at producing healthier foods for the older consumer, especially if they are not 'sold' as healthy and thus avoid compensatory behaviour.

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