Studies on the Agricultural and Food Sector in Transition Economies

Christine Burggraf

Russian demand for dietary quality: Nutrition transition, diet quality measurement, and health investment theory

Leibniz Institute of Agricultural Development in Transition Economies

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CONTENT

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LIST OF ABBREVIATIONS

$A(t)$	Stock of financial wealth in t
AHEI-2002	Alternate Healthy Eating Index-2002
AHEI-2010	Alternate Healthy Eating Index-2012
aMED-2005	Alternate Mediterranean Diet Score-2005
ANOVA	One-way analysis of variance
AI	Adequate intake level
$\mathbf{b}(t)$	Vector of risky nutrients
BI	Berry Index
BMI	Body Mass Index
CH-DQI-2000	Chinese Diet Quality Index-2000
C-HEI-2005	Canadian Healthy Eating Index-2005
$C_I(t)$	Dual cost function of health investments in t
$C_Z(t)$	Dual cost function of producing household commodities in t
DBS-2009	Dietary Behavior Score-2009
DGAI-2005	Dietary Guidelines for Americans Adherence Index-2006
DHQ	Diet History Questionnaire
D-HDI-2003	Danish Healthy Diet Index-2003
DQI-1994	Diet Quality Index-1994
DQI-2003	Diet Quality Index-2003
DQI-I-2003	Diet Quality Index-International-2003
DQI-R-1999	Diet Quality Index-Revised-1999
DQI-R-2003	Diet Quality Index-Revised-2003
DQI-I_{mod}	Modified Diet Quality Index-International
DQI-SNR-2011	Diet Quality Index-Swedish Nutrition Recommendation-2011

DQS-2002	Diet Quality Score-2002
DQS-2007	Diet Quality Score-2007
DQSNB-1999	Dietary Quality Score Nutrient Based-1999
DR	Acceptable distribution range
$E(t)$	Stock of education capital in t
$\mathbb{E}$	Expected value
FFQ	Food Frequency Questionnaire
$\mathbf{g}(t)$	Vector of healthy nutrients
GFPI-2012	German Food Pyramid Index-2012
$H(t)$	Stock of health capital at time t
$h(t)$	Amount of healthy time in t
HDI-1997	Healthy Diet Indicator-1997
HDI-2011	Healthy Diet Indicator-2011
HDI-2013	Healthy Diet Indicator-2013
HDS-2005	Healthy Diet Score-2005
HEI-1995	Healthy Eating Index-1995
HEI-2005	Healthy Eating Index-2005
HEI-2010	Healthy Eating Index-2010
HEI-f-2000	Healthy Eating Index-frequency questionnaire-2000
HFD-I	Healthy Food Diversity-Index
HFI-2001	Healthy Food Index-2001
HFNI-2006	Healthy Food and Nutrient Index-2006
$I(t)$	Gross investment in $H(t)$ in t
IMI-2011	Italian Mediterranean Index-2011
IR	Interquartile range
$k(t)$	Time as input in $Z(t)$ production in t
$\Bbbk$	Food group
$M(t)$	Medical services as input of $I(t)$ production in t
$m(t)$	Time as input in $I(t)$ production in t
MAI-1999	Mediterranean Adequacy Index-1999

MAI-2006	Mediterranean Adequacy Index-2006
MDP-2002	Mediterranean Dietary Pattern-2002
MDS-1995	Mediterranean Diet Score-1995
MDS-2002	Mediterranean Diet Score-2002
MDS-2003	Mediterranean Diet Score-2003
MDS-2004	Mediterranean Diet Score-2004
MDS-2011	Mediterranean Diet Score-2011
MEDAS-2011	Mediterranean Adherence Diet Screener-2011
MEDAS-2013	Mediterranean Adherence Diet Screener-2013
Med-DQI-2000	Mediterranean Diet Quality Index-2000
Med-DQI-2006	Mediterranean Diet Quality Index-2006
Med-DQI-f-2000	Mediterranean Diet Quality Index incl. tobacco use-2000
MeDiet-2008	Mediterranean Food Pattern-2008
mMDS-2005	Modified Mediterranean Diet Score-2005
mMDS-2014	Modified Mediterranean Diet Score-2014
MS-2003	Mediterranean Score-2003
MSDPS-2009	Mediterranean-Style Dietary Pattern Score-2009
MUFA	Monounsaturated fatty acids
n_a	Adequacy indicator of adequate nutrient intake
n_m	Moderation indicator of moderate nutrient intake
$\mathbf{p_b}(t)$	Vector of implicit risky nutrient prices in t
$\mathbf{p_g}(t)$	Vector of implicit healthy nutrient prices in t
PUFA	Polyunsaturated fatty acids
$p_M(t)$	Unit prices of medical services in t
$p_Q(t)$	Unit prices of consumer goods in t
$Q(t)$	Consumer goods as input in $Z(t)$ production in t
$r(t)$	Market rate of interest in t
M RCI-2008	Recommendation Compliance Index-2008
RDA	Recommended dietary allowances

rMED-2009	Relative Mediterranean Diet-2009
s	Intake share of food units
SFA	Saturated fatty acids
t	time
T	Length of total life-time
UI	Upper tolerable intake level
$U(T)$	Discounted life-time utility at $t = 0$
$\mathbb{V}$	Variance
$\mathbf{X}(t)$	Vector of socioeconomic variables in t
$\mathbf{x}(t)$	Vector of foods consumed in t
$y(t)$	Other income in t
$Z(t)$	Amount of produced and consumed commodities in t
$\delta(t)$	Rate of depreciation of $H(t)$ in t
ρ	Rate of time preference

1 INTRODUCTION

1.1 MOTIVATION

Since the breakdown of the Soviet system, Russians have experienced significant changes in all spheres of daily life. Indeed, with Russia's recent transformation process, the economic, political, and social systems have all changed, including Russia's health care system. Though the macroeconomic conditions of the country have steadily improved, there is still major concern with respect to the health situation in Russia. According to the FEDERAL STATE STATISTICS SERVICE RUSSIA (2014), in 2012 the official life expectancy at birth of 70.24 years for the Russian population (males 64.56 years, females 75.86 years), is nearly equal to the Russian life expectancy in 1987. On average, Russians face a life expectancy that is about ten years shorter than that of their European neighbors. Considering the aging Russian population, excessive smoking and drinking behaviors, as well as unhealthy diets, deaths are mainly caused by non-communicable diseases (COCKERHAM, 1999; ADEYI et al., 2007; SUHRCKE et al., 2007). For example, in 2012, 85.7 % of deaths in Russia were caused by non-communicable diseases (WORLD BANK, 2014). These chronic diseases not only create individual problems, but also an enormous economic burden for households, employers, and public health care systems (ENSOR, 2004). Along this line, Russians' per capita health care expenditure increased from $113.07 current USD in 1995 to $886.88 current USD in 2012. Furthermore, the private health expenditure share in percentage of total health expenditure increased from 26.12 % in 1995 to 39.01 % in 2012 (WORLD BANK, 2014).

Such an epidemiologic transition to the predominance of non-communicable diseases denotes a major challenge for Russia's health care system and requires changes of respective health care strategies in Russia (ROZENFELD, 1996; SUHRCKE et al., 2007; AVKSENTYEVA, 2010). Thus, it is important to understand the causal pathways and mechanisms behind epidemiologic transition. Aside from unhealthy lifestyles like smoking, heavy alcohol consumption, and physical inactivity, nutrition is an important determinant of several chronic diseases such as cardiovascular diseases, diabetes and various forms of cancer (HU et al., 2000; TRAGAKES and LESSOF, 2003; POPKIN, 2006; 2007; ADEYI et al., 2007; SUHRCKE et al., 2007). When considering countries in economic transition with the respective effects on nutrition patterns, it is well understood that improvements in per-capita incomes are generally linked with a major shift in dietary patterns, i.e. a shift away from a relatively monotonous and starchy diet with low fat intakes towards a more varied diet with more fruits and vegetables. Furthermore, the intakes of animal products, fat, and sugar generally increase with increasing incomes; in contrast to a decline in total fiber intakes (POPKIN, 2006; ULIJASZEK, 2007). Along these lines, when considering the income and price elasticities for different food aggregates, studies by STAUDIGEL and SCHROECK (2014) and BURGGRAF et al., (2014d, 2014f, 2014g, 2015a) find that with increasing incomes Russians tend to increase their consumption of animal-based products much more than their consumption of staple foods such as bread. Such an overall shift in dietary patterns, together with the accompanying increase in nutrition-related chronic diseases, is often referred to as *nutrition transition* in its narrow sense (POPKIN and DU, 2003).

In Russia, the increase in nutrition-related chronic diseases is even more troublesome because of preferences inherited from the Soviet period. Under the former Soviet system, meat prices were highly subsidized and Russian nutritionists recommended heavy intakes of livestock products for a full and healthy diet (LIEFERT, 2004; DELLAVA et al., 2010). Therefore, the Russian diet has traditionally been characterized by a considerably high consumption of meat and dairy products; all of these products generally have high fat, protein, and cholesterol contents (LIEFERT, 2004). Furthermore, Russian cuisine has traditionally been low in fruit and vegetable content due to the difficulty of growing fruits and vegetables in the Russian climate (BRAINERD and CUTLER, 2005). Nowadays, rapid shifts in food systems, prices and marketing have boosted the consumption of meat and dairy products towards even higher levels of fat and protein intakes (POPKIN and NG, 2007). Therefore, against the background of Russians' traditional eating habits and recent trends in the prevalence of chronic diseases, Russians' changing nutrition patterns during economic transition are worthy of research attention (HINOTE et al., 2009).

There are hardly any current empirical studies investigating the link between nutritional and economic circumstances in the Russian Federation. Until now, the majority of studies available for Russia have analyzed the health outcomes of Russian's nutrition patterns (e.g., obesity or chronic diseases), whereas only a few studies have focused on the analysis of dietary quality in Russia. ULIJASZEK and KOZIEL (2007) show that the growing prevalence of obesity in Eastern European countries cannot be attributed to increased dietary energy availability, at least at the macro level. These authors show that the obesity patterns observed in East European nations can be explained, for example, by less physical activity and growing real per-capita incomes. DELLAVA et al., (2010) highlight that Russia has one of the highest cardiovascular mortality rates, combined with low nutritional literacy. ZOHOORI et al. (2001) and LIEFERT (2004), as well as HUFFMAN and RIZOV (2007) examine the caloric intake of Russians. These authors show that caloric intake, together with the remarkable overweight and obesity rates, significantly increased during Russia's economic transition. JAHNS et al. (2012) focus on obesity among children in Russia. For 1995, they find a significant positive influence of income on children's energy and fat intake. However, in contrast to the income effects on energy and fat intake, their results also indicate that overweight prevalence does not significantly differ for different strata of parents' income in 1995 and 2002 (JAHNS et al., 2012). For the time period 1995-2005, STAUDIGEL (2012) shows that Russian expenditure elasticities of energy intakes and food aggregates range between zero and one, indicating them as necessitates. Considering the differrences between normal-weight, overweight, and obese households, STAUDIGEL finds that the expenditure elasticities of food quality (in terms of quality differences in the computation of households' price variables) of the meat, bread, fruits, and dairy aggregates are higher for obese households than for normal households. Analyzing the impact of food prices on overweight and obesity, STAUDIGEL (2011) shows that food prices are not major determinants of the body mass index (BMI), and thus obesity, in Russia.

HERZFELD et al. (2014) examine the dynamics of the Russian demand for fat, protein, and food diversity for the period from 1994 to 2005. Their results show that with increasing incomes, households tend to consume more fats and proteins, while food variety increases. Moreover, these authors find habit formation in the Russian demand for food diversity, but not in fat and protein consumption. STILLMAN and THOMAS (2008) investigate the impact of fluctuations in household expenditures on several nutrient intake indicators such as total calorie intake and the percentage of calories from fat and protein. These authors apply GROSSMAN's health investment model (GROSSMAN 1972a, 1972b, 2000) by taking BMI, total energy, and the energy percentage of fat intakes as indicators of the demand for health.[1] Their results indicate that transitory changes in expenditures are positively and significantly associated with total calorie intake, the share of calories from protein and fat, adult BMI, and child weight-for-height.

In sum, previous studies on nutrition in Russia focus on anthropometric outcomes or measure dietary quality by single macronutrient indicators. Nonetheless, such an approach is often too narrow to provide a meaningful picture of overall dietary quality as well as changing nutrition patterns during economic transition. Sometimes this narrow approach might even be misleading.

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1 However, in GROSSMAN's health investment model, the demand for dietary quality should indicate the investment in health rather than the demand for health (see GROSSMAN, 2000). Furthermore, STILLMAN and THOMAS (2008) examine the percentage of calories from fat as an indicator of dietary quality. This indicator setting leads to their statement that dietary quality rises in the sense of an increased energy percentage of fat intakes when household resources increase. However, this statement seems questionable in a country with noticeably high fat and protein intakes where the majority of the population is either obese or overweight.

1.2 RESEARCH QUESTIONS

As discussed in chapter 1.1, nutrition-related chronic diseases have significantly increased during the Russian economic transition, indicating a trend towards unhealthier diets. Nonetheless, current research studies on single aspects of Russian nutrition patterns are insufficient for explaining the overall Russian dietary quality or to link this overall dietary quality to a transformation country's profile, which has to represent an array of economic, nutrition, and epidemiologic transitions. Therefore, in order to close this research gap, the following main research question is outlined for this dissertation:

Main research question: *What are the main determinants of Russian's dietary quality during transformation?*

To answer this main research question, the topic of interest has to be detailed both thematically and methodically as described in the following. An analysis of the Russian dietary quality should start with a description of the overall nutrition patterns of the Russian population. Against the background of the Russian economic transition and the aforementioned effects on nutrition and health, it can be hypothesized that Russia is indeed experiencing a nutrition transition, i.e. a generally positive consumption trend for fats, proteins, fruits, and vegetables, but a negative consumption trend for fiber. For instance, STILLMANN and THOMAS (2008) emphasize in their empirical analysis that increased household incomes in Russia are concurrent with the consumption of foods being richer in fats. This development is in line with the observed increase of the overweight and obesity prevalence in Russia (JAHNS et al., 2003; SEDIK et al., 2003; HUFFMAN and RIZOV, 2007). At the same time, fruit and vegetable consumption in Russia increased between 1992 and 2007 (PAALANEN et al., 2011). However, any particular form of nutrition transition may vary from region to region due to differing traditional eating habits and consumption patterns (POPKIN, 2001, 2002). Therefore, in contrast to the observed nutrition transition patterns in Asia (see e.g., POPKIN et al., 2001; POPKIN and DU, 2003), it has to be considered that the analysis of a Russian nutrition transition is of particular interest because it started at a consumption level of animal fats and sugar that had already been high. Furthermore, it is important to note that the Russian economic transition was disrupted several times by periods of severe economic crises. Therefore, based on the generally observed link between rising incomes and nutrition transition, it can be further hypothesized that declining household incomes during periods of economic crisis will lead to a reversed profile of a nutrition transition. For example, empirical studies have shown that the consumption of fats, particularly animal fats, was considerably lower in the year of the Russian financial crisis in 1998 than in the periods of economic growth from 1994 to 1996 and 2004 to 2005 (STILLMANN and THOMAS, 2008; DELLAVA et al., 2010). Hence, the prevalence of obesity has declined during the financial crisis in 1998 (WANG et al., 2002). This discussion leads to the first two detailed research questions of this inquiry:

Research question 1.1*: Is there an ongoing nutrition transition in Russia, considering traditional eating habits and long-standing consumption patterns?*

Research question 1.2*: Do declining household incomes during periods of economic crisis lead to a reversed profile of a nutrition transition in Russia?*

Furthermore, in order to enable an empirical analysis of Russian dietary quality, it is necessary to operationalize the latent construct dietary quality. Per definition, dietary quality is a complex function of the diet's chemical composition related to the specific macro- and micronutrient needs of the human body (HANSEN, 1973). Hence, dietary quality should not be captured by a single indicator, such as fruit and vegetable consumption, because a single indicator provides too narrow a picture of overall dietary quality (DUBOIS, 2000; KANT, 2004). Multidimensional concepts such as that of dietary quality need to be operationalized through a composite index as outlined by NARDO et al. (2008). Nevertheless, given the tremendous changes in Russia's economic, political, and social conditions during the last two decades, and the fact that diet-related diseases are of major concern to Russian authorities, it is interesting to note that thus far, measuring the overall dietary quality of the Russian population has not been addressed by a composite index. However, especially the Russian case might be quite different due to its history and specific eating habits. Moreover, despite the growing interest in assessing dietary quality over time, only few longitudinal studies have used dietary quality indices to identify trends in dietary behavior (ARABSHAHI et al., 2011). Still, all of these studies focus on dietary quality in industrialized countries rather than dietary quality in transition countries (e.g., HU et al., 2000; FUNG et al., 2007; LEE et al., 2007; ARABSHAHI et al., 2011). Therefore, the next two detailed research questions arise for the analysis of Russians' dietary quality:

Research question 2.1: *How can the overall Russian dietary quality be best operationalized by a composite index construction?*

Research question 2.2: *How did the overall Russian dietary quality, measured by a composite index, change during Russia's transition period?*

In contrast to mainly cross-sectional international nutrition studies (e.g., PARK and DAVIS, 2001; DRESCHER et al., 2009; BINKLEY and GOLUB, 2011), this thesis aims to analyze the influencing factors of Russian dietary quality during the transformation process by a longitudinal analysis. Thereby, healthy diets can, in addition to physical exercise and good healthcare, be considered as a long-term investment in an individual's health. Yet published studies on the widely used household production theory or the goods characteristics approach cannot explain dietary choices by considering this intertemporal health investment character. By contrast, GROSSMAN's health investment model (GROSSMAN, 1972a, 1972b, 2000) addresses this intertemporal aspect by allowing health investments to be considered a choice option for consumers. Nevertheless, GROSSMAN's health investment model is not without criticism. This is because the model's demand function for medical care implies a positive impact of actual health on the consumption of medical care, while empirical studies suggest the opposite (ZWEIFEL, 2012). Furthermore, GROSSMAN limits the variety of health investment input factors in his theoretical model only to medical care (GROSSMAN, 2000). It is therefore necessary to incorporate the role of dietary quality into the health investment model. Based on this discussion, the following three final research questions of this thesis can be derived:

Research question 3.1: *Based upon its theoretical implications, is the Grossman health investment model of practical relevance for health economists?*

Research question 3.2: *Is the health investment model appropriate for providing a comprehensive theoretical framework that describes the effects of dietary quality-specific influencing factors on the healthiness of diets?*

Research question 3.3: *How is Russian dietary quality influenced by socio-economic, socio-demographic, and lifestyle factors considering a comprehensive theoretical model?*

1.3 STUDY OBJECTIVES

This thesis aims to contribute interdisciplinary findings, which benefit from both economic and nutritional approaches, that explain the Russian dietary quality with respect to nutrient deficiencies, but also the increasing prevalence of nutrition-related chronic diseases. Thereby, the main objective of this study is an empirical analysis of Russian dietary quality, as well as its socio-economic, socio-demographic, and lifestyle-influencing factors. Based on this main objective, the following specific sub-objectives are derived that aim to answer the aforementioned relevant research questions of this thesis.

After clarifying the macroeconomic conditions of food demand, the first sub-objective of this thesis is the empirical analysis of trends in Russian food consumption patterns during economic transition. Thereby, it is necessary to consider specific features of Russian food consumption before and after the collapse of the Soviet system such as cultural aspects, food availability, household food consumption budgets, and nutritional education.

The second sub-objective of this study is the development of a composite index to measure dietary quality, which must be explicitly suitable for the analysis of Russian dietary quality. Such a composite index regarding the measurement of dietary quality needs to take into account both the evidenced specifics of Russian dietary patterns, as well as the data restrictions of the employed data set. The respective empirical analysis of this study is supposed to establish if and to what extent dietary quality has changed during the Russian transformation process.

The third sub-objective of this thesis is to analyze the Russian demand for dietary quality using a comprehensive theoretical framework; GROSSMAN's dynamic health investment model provides such an economic framework. However, in order to employ this model for the analysis of dietary quality, this thesis aims at the following two model modifications: first, a change of the specification of the model's inherent health investment production function in order to receive more realistic model implications, and second, the model's adaption to the analysis of the demand for dietary quality. Based on such a modified health investment model, demand functions shall be derived that describe the optimum demand for dietary quality depending on relevant socio-demographic, socio-economic, and lifestyle factors. Afterwards, these theoretically implied relationships between the demand for dietary quality and its influencing factors shall be empirically employed to explain the demand for dietary quality in Russia.

The theoretical and empirical findings of the Russian analysis of dietary quality lead to the fourth sub-objective, which is to provide important suggestions regarding nutrition policy. Identified problematic profiles in the Russian diet, as well as their influencing factors, shall be the basis for designing appropriate educational or market-specific intervention programs, which must be aimed at achieving a healthier Russian diet. Owing to the increased prevalence of nutrition-related diseases and the associated healthcare costs within the Russian population, such official intervention strategies are of tremendous socio-political interest.

1.4 COURSE OF INVESTIGATION

This thesis is divided into six chapters devoted to answering the research questions derived in chapter 1.2 and achieving the main- and sub-objectives presented in chapter 1.3. Except for chapter 2, which introduces the employed data set, every main chapter has its own chapter introduction and conclusions section in order to appropriately address the respective research questions and objectives. In the following, a detailed description of the study organization is outlined and subsequently displayed in Figure 1.

Chapter 2 introduces the employed data set of Phase II of the Russia Longitudinal Monitoring Survey (RLMS-HSE, 1996-2008). The statistical analysis of the RLMS-HSE data set is performed using STATA 14 (STATACORP, 2015). After a detailed description of the RLMS-HSE data set considering the time period 1996-2008 (chapter 2.1), data limitations are discussed (chapter 2.2).

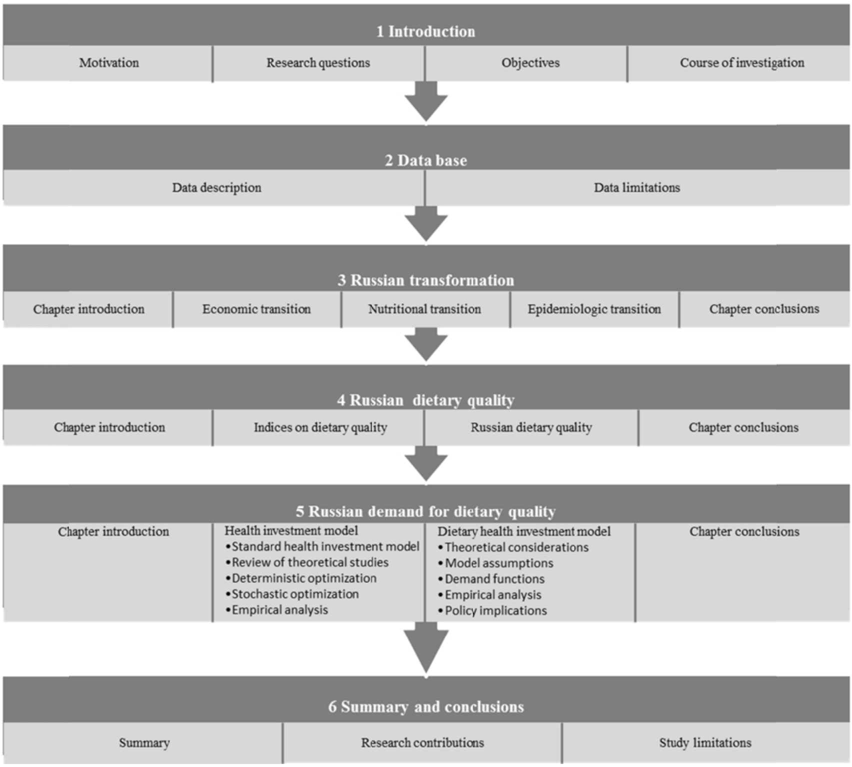
In chapter 3, the concept of nutrition transition is discussed in more detail. Based on this concept's definition, Russian nutrition patterns are analyzed for the observed transition period 1996-2008, considering Russia's macroeconomic transformation (chapter 3.2), nutritional transformation (chapter 3.3), and epidemiological transformation (chapter 3.4) during this period of time.

Chapter 4 is concerned with the theoretical aspects of the measurement of dietary quality by a composite index construction (chapter 4.2) and its empirical application of measuring Russians' dietary quality (chapter 4.3). The chapter begins with a short introduction of the purpose of a priori indices regarding human dietary quality (chapter 4.2.1). After a review of hitherto relevant a priori dietary quality indices (chapter 4.2.2), the appropriateness of relevant index construction criteria is discussed, based upon theoretical considerations or recent knowledge about diet-health relationships (chapter 4.2.3). Furthermore, a summaryzing toolbox is offered, which helps nutritionists to identify those indices whose index construction is most appropriate for their respective study aim; considering, for example, the theoretical framework or the selected method of indicator normalization (chapter 4.2.4). Based on this summarizing toolbox, the Diet Quality Index-International (DQI-I-2003) developed by Kim et al. (2003a) is selected and aligned to Russia's country-specific needs, as well as to technical requirements of a statistically sound composite index (chapter 4.3.1). Finally, the empirical analysis of the modified DQI-I-2003 provides a more thorough picture of Russia's overall dietary quality by identifying if Russians are at risk of either deficient or excessive intake of several nutrients (chapter 4.3.2).

In chapter 5, a comprehensive theoretical framework is developed, which is able to explain the demand for dietary quality. First, Grossman's health investment model is introduced and a critical summary of this model is offered. Thereby, the main criticism lies with the model's demand function for medical care, which implies, inter alia, a rather unrealistic positive effect of the actual health status on the demand for medical care (chapter 5.2.1). Therefore, a literature review of published English-language literature is provided, which addresses this critique regarding the practical relevance of the health investment model (chapter 5.2.2). Second, motivated by this literature review, Grossman's standard model setting is modified by specifying the health investment production function with decreasing returns to scale rather than constant returns to scale. This slightly modified specification is then incorporated into the solution of a deterministic (chapter 5.2.3) and a stochastic intertemporal health investment optimization problem (chapter 5.2.4). Third, the theoretical implications of the newly specified Grossman model are then approved by an empirical analysis of the Russian demand for medical care (5.2.5). Fourth, in order to direct the focus now on the demand for dietary quality, general specifications of dietary quality decision problems are outlined (chapter 5.3.1). Afterwards, these specifications are operationalized within the newly developed dietary health investment model, considering the introduced health investment production function with decreasing returns to scale (chapter 5.3.2). Fifth, demand functions for dietary quality are derived from the theoretical dietary health investment model (chapter 5.3.3). For a better understanding of the issue, the implications of the dietary health investment model are then graphically displayed (chapter 5.3.4). Finally, the Russian demand for dietary quality is empirically analyzed (chapter 5.3.5) and policy implications are derived (chapter 5.3.6).

Chapter 6 summarizes the most important findings (chapter 6.1), outlines the respective research contributions (chapter 6.2), and discusses the limitations of this thesis (6.3).

Figure 1: Course of investigation



Source: Own presentation.

2 DATA BASE

2.1 DATA DESCRIPTION

The empirical analysis of this thesis is based upon household micro data for the time period 1996-2008 of Phase II of the RLMS-HSE. Given the tremendous changes of the Russian economic, political, and social conditions during the last two decades, and the fact that diet-related chronic diseases are of major concern to Russian authorities, the observed time period 1996-2008 covers a considerably long period of an ongoing economic and nutritional transition interrupted by the economic crisis in 1998.

The RLMS-HSE is conducted by the National Research University Higher School of Economics and ZAO "Demoscope", together with the Carolina Population Center, University of North Carolina at Chapel Hill and the Institute of Sociology RAS. The RLMS-HSE is a series of national surveys based on the first nationally representative random sample for Russia. In Phase II of the RLMS-HSE, a multi-stage probability sampling is employed (NATIONAL RESEARCH UNIVERSITY HIGHER SCHOOL OF ECONOMICS et al., 2015). The number of sampled households has been steadily increased by the RLMS-HSE, from 3,750 households in 1996 (with 8,342 adults) to 5,314 households in 2008 (with 11,864 adults).[2] The RLMS-HSE provides socio-economic and demographic variables at the household level, as well as personal characteristics such as various health measures and dietary intake data based upon a 24-hour recall. Furthermore, the RLMS-HSE includes household food consumption data with information on food expenditure and own production of foods. Purchased food items refer to the RLMS-HSE food expenditure data of the last seven days. Data about food home production refer to own production of food in the last 12 months, which is subsequently averaged and adjusted to a seven-day household food basket. Therefore, own production data consider the effects of a typical household's stock-piling of potatoes, canned fruits and vegetables, as well as processed meat and dairy products. These data are representative and of exceptionally high quality. Therefore, they are very useful in the

[2] However, merging the 20+ different household and individual data sets on different survey topics each year shows that a significant portion of households (and individuals) has not been surveyed regarding all the survey topics (e.g., the data set with household income data includes only 3,560 households in 1996). Therefore, after an additional deletion of severe outliers, the number of total observations is reduced to an imbalanced data set with maximally 81,273 observations for the merged data set of eleven waves.

research context of the transition in Russia (NATIONAL RESEARCH UNIVERSITY HIGHER SCHOOL OF ECONOMICS 2015).[3] Furthermore, representativeness of the RLMS-HSE food consumption data is reflected in the similarity of the food consumption aggregates between the employed RLMS-HSE data and data from the FEDERAL STATE STATISTICS SERVICE RUSSIA (2014).

2.2 DATA LIMITATIONS

Besides its manifold and useful information, the RLMS-HSE data have some limitations. First, a major limitation of the RLMS-HSE data is the changing structure of the panel data. For instance, there has been a significant change in the sample design of the RLMS-HSE data after 2008, which was accompanied by the construction of different identification numbers based upon different stratification variables. Furthermore, individual data on 24-hour recalls and interviewer-guided anthropometric measures such as weight and height were only compiled until 2005. These structural changes limit the descriptive analysis of the households' food and nutrient consumption to the time period 1996-2008 and the more detailed analysis of the individuals' nutrient intakes to the time period 1996-2005.

Second, for the panel analysis of individual dietary intakes, 24-hour recall data are restricted by the RLMS-HSE officials to the information on total kcal per day, fat intake, and protein intake for one day per survey wave. However, the habitual intake over a prolonged period of time (e.g., one week) is the value that dietary studies would like to measure (LIVINGSTONE and BLACK, 2003). Furthermore, single 24-hour recalls suffer from random measurement errors and day-to-day intake variations, which can be reduced by averaging food consumption data (TIAN and YU, 2013). Therefore, nutrient contents of the households' seven-day food baskets given by the household food consumption data (including the averaged home production) are employed to support the approximation of an individual's nutrient intake per household member in this study. Given that food consumption is only recorded for the fourth quarter of each year, RLMS-HSE consumption data are not representative of consumption patterns over the whole year. However, since the major objective of this thesis is to investigate changes in nutrition patterns over a transition period of 13 years, RLMS-HSE consumption data allow the researcher to carry out year-by-year comparisons of food consumption (JAHNS et al., 2003).

Third, considering an individual's nutrient intakes, common dietary assessment techniques such as 24-hour recalls or food frequency questionnaires often pose the problem of systematic underreporting of energy intake (MERTZ et al., 1991;

[3] For more information on sampling, survey schedule, quality control, and data summaries, see NATIONAL RESEARCH UNIVERSITY HIGHER SCHOOL OF ECONOMICS (2015).

BRAY et al., 2008). To test for profound underreporting in this inquiry, the reported energy intake in kcal per day has been validated against presumed energy expenditures per day. This method rests on the assumption that energy intake has to equal energy expenditures when an individual's weight is stable. Thereby, weight can be regarded as constant at the group level of adult individuals, i.e. mean individual energy intake has to equal mean individual energy expenditure (LIVINGSTONE and BLACK, 2003). For the Russian data, Table 1 shows the association between the calculated ratio of energy intake to energy expenditure (EI:EE) and BMI. Thereby, the expected ratio of EI:EE is one, while a calculated mean EI:EE with lower values demonstrates the underreporting of energy intakes. As found in other studies, the higher the respondent's BMI, the stronger the significant underreporting. Furthermore, Table 1 shows that the group of females tends to significantly underreport energy intakes.[4] Comparing reported fat intakes with estimated fat intakes from household food consumption data, there is not any systematic under- or overreporting in the RLMS-HSE data set. These results indicate that there is systematic underreporting of reported energy intakes, while nutritionists can possibly rely on the reported fat intake data in terms of analyzing excessive fat intakes.[5]

Table 1: Test for profound misreporting in the 24-hour recall

BMI classification according to World Health Organization (2015c)		Reported Energy Intake/ Energy Expenditure+		Reported En% of fat/ Estimated En% of fat	
		Male	Female	Male	Female
I	Underweight – Severe Thinness	1.04	0.89	1.22	0.98
II	Underweight – Moderate Thinness	0.97	0.89	1.02	1.02
III	Underweight – Mild Thinness	0.94	0.92	1.01	1.06
IV	Normal Range	0.97	0.89	1.08	1.07
V	Overweight – Pre-Obese	0.94	0.85	1.08	1.04
VI	Obese – Class I	0.86	0.80	1.08	1.03
VII	Obese – Class II	0.82	0.73	1.08	1.03
VIII	Obese – Class III	0.73	0.70	1.09	1.05

Source: Own calculations, RLMS-HSE data, 1996-2005.

Note: Considering only individuals with stable weight, where stable weight is assumed for individuals with a weight variation over the observed time period of less than 10 %.
+ EI:EE significantly decreases with a higher BMI classification (I-VIII) and female gender at the 5 % level.

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4 About 32.88 % of the variation in EI:EE can be explained by gender and BMI classification.

5 Although the possible problem of underreporting is mentioned in SEDIK et al. (2003), this problem of a systematic misreporting has not been addressed in hitherto studies applying the RLMS-HSE data set for the analysis of nutrition and obesity problems.

For the subsequent analysis of Russian dietary quality, information is needed on household food consumption, which is directly reported by the RLMS-HSE data set. Nevertheless, for a more detailed analysis, additional information is necessary about individual nutrient intakes. This data have to be approximated according to the following procedure. Based upon the aforementioned shortcomings, the amounts of food items of the seven-day household food basket are converted into the contents of several micro- and macronutrients in g/kcal, using the food composition table of the NutriSurvey program 2007 (ERHARDT, 2010).[6] For the approximation of individual nutrient intakes per household members, nutrient contents per household food basket are subsequently multiplied by the individual energy expenditure in kcal/day to generate individual intake data.[7] Individual energy expenditures are generated according to the most widely used predictive basal metabolic rate, that of HARRIS and BENEDICT (1919), which considers individual gender, age, height, and weight multiplied by the individual physical activity level (PAL). Thereby, the RLMS-HSE information on hours and minutes of sitting, walking, standing, median physical work, and heavy physical work is translated into PAL values. After deducting the time for daily activities from 24 hours, the resulting daily time is considered as sleeping time with a PAL of 0.95. If activity data were missing or if daily activity accounted for more than 20 hours, the average PAL of 1.55 was assigned. The anthropometric measures height and weight are measured by experienced interviewers and thus are free of any underreporting bias. As a measure of an individual's total fat intake, the reported intake data from the 24-hour recall have been employed.

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6 The use of food composition tables is a central feature of epidemiological studies. The tables of the NutriSurvey2007 program contain the total energy value in kcal as well as the contents in g of nutrients including protein, carbohydrates, fat, vitamins and minerals, and other important food components such as fiber and ethanol per 100 g edible portion. The program provides values based upon various national and international food composition tables to increase the level of correctness. Furthermore, the program contains an extensive collection of food databases from all over the world.

7 Energy expenditure and fat intake in autumn/winter are possibly higher than in summer to keep body temperature stable. While this possible bias may affect, for example, the EI:EE ratio, it generally does not have any effect on the observed trends in overconsumption of specific population strata.

3 Russian transformation

3.1 Chapter introduction

As mentioned above, Russians have witnessed a dramatic increase in chronic diseases, which contribute significantly to the worrying morbidity and death rates in Russia (Adeyi et al., 2007; Suhrcke et al., 2007). Thereby, the growth of nutrition-related chronic diseases might be explained by the common link between increasing household incomes during economic transition and changing dietary patterns in the sense of a nutrition transition. Generally, a nutrition transition is marked by a shift away from a relatively monotonous and starchy diet with low fat and high fiber intakes towards a more varied diet that is higher in fruits and vegetable consumption but also higher in the consumption of fats, animal proteins, sugar, and other refined carbohydrates (Popkin et al., 2001). As already experienced in the United States or European countries, such a shift in nutrition patterns is seriously problematic since it increases the risk of various health conditions and chronic diseases, including overweight, obesity, cardiovascular diseases (Hu et al., 2000; Shepard et al., 2001; Popkin and Du, 2003; Popkin, 2006), diabetes (Montonen et al., 2005), and various forms of cancer (Boeing et al., 2007; Popkin, 2007, 2011).

Against the background of Russia's economic transition as well as the increasing prevalence of chronic diseases, such a nutrition transition can be assumed for the Russian population. Results of empirical studies, which investigate the link between nutritional and economic circumstances in Russia, underline this assumption of an ongoing nutrition transition in Russia. Considering caloric intakes, Zohoori et al. (2001) and Liefert (2004), as well as Huffman and Rizov (2007) show that caloric intakes as well as overweight and obesity rates significantly increased during economic growth. Jahns et al. (2012) find a significant positive influence of income on energy and fat intakes of children in 1995. Herzfeld et al. (2014) show that with increasing incomes, households tend to consume more fats and proteins while food variety increases. Finally, the results of Stillman and Thomas (2008) indicate that transitory changes in expenditures are positively and significantly associated with total calorie intake, the share of calories from protein and fat, adult BMI, and child weight-for-height. Considering fruit and vegetable intakes during economic transition, Paalanen et al. (2011) show higher fruit and vegetable intake levels in 2007 than in 1992.

These previous studies on changing nutrition patterns in Russia focus on anthropometric outcomes, energy intakes, or the intakes of specific foods/food groups. For example, these studies analyze either the Russian intake of fats or the intake of fruits and vegetables during transition. Nonetheless, such an approach is too narrow to sufficiently analyze whether there is an ongoing nutrition transition in Russia. Therefore, this chapter elaborates on whether there have been major changes in the Russian nutrition patterns over time – considering the overall consumption trends of fats, protein sources, fruits, vegetables, and fiber – and in which way these changing nutrition patterns are consistent with the definition of a nutrition transition. Furthermore, this chapter investigates whether declining household incomes during periods of economic crisis will lead to a reversed profile of a nutrition transition.

The complex task of analyzing a nutrition transition such as Russia's should include an array of economic, nutrition, and epidemiologic transformations (POPKIN, 2014). Accordingly, this chapter is organized as follows. In chapter 3.2 a short overview of Russia's economic transition is provided, considering household budgets for food consumption as well as aspects of price inflation and income growth. Afterwards, the Russian transition with regard to nutrition patterns is outlined in chapter 3.3, considering the demand for food aggregates in chapter 3.3.1, as well as the more detailed demand for nutrients in chapter 3.3.2. Based on these results, respective health outcomes for the Russian population are outlined in chapter 3.4. In chapter 3.5 important findings are summarized and discussed.

3.2 ECONOMIC TRANSITION

Amongst other applications, consumption aggregates are often used to analyze changes in living standards over time or to assess the distributional impacts of various nutrition programs and policies (DEATON and ZAIDI, 2004). Since the analysis of the Russian food consumption patterns over the transition period includes aspects of changing living standards as well as policies affecting food consumption, Table 2 provides an overview of the real expenditure shares of consumption aggregates for the time period 1996-2008 following the approach of DEATON and ZAIDI (2004). In this study, the components of consumption are aggregated into three main classes: (i) food items, (ii) nonfood items, and (iii) housing. Thereby, the expenditure shares provided in Table 2 reflect the relative importance of each of these consumption aggregates.

Table 2: Russian food and non-food expenditure shares

Year	1996	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008
Expenditure shares of household consumption aggregates in %											
Food	59.06	62.34	54.55	52.92	50.16	46.18	43.77	45.07	40.00	41.86	38.72
Purchases	46.21	47.20	41.73	43.04	41.47	39.02	37.25	38.12	34.17	35.31	32.55
Production	12.85	15.14	12.82	9.88	8.69	7.15	6.53	6.94	5.83	6.55	6.17
Non-food items	23.50	17.24	24.80	30.08	30.58	30.88	30.97	32.41	31.78	34.56	33.70
Health	1.06	1.86	1.95	2.28	2.47	2.51	2.39	2.55	2.40	2.57	2.72
Hygiene	2.05	2.24	1.89	2.40	2.50	2.47	2.37	2.60	2.46	2.63	2.43
Education	0.91	0.96	0.83	1.08	0.93	0.81	0.92	1.05	1.00	0.94	0.88
Other non-foods	19.47	12.19	20.14	24.32	24.67	25.09	25.29	26.22	25.93	28.41	27.67
Housing	8.69	9.75	8.80	9.03	10.56	14.91	15.95	14.16	20.20	14.81	19.29
Utilities	6.94	7.91	6.97	6.64	7.84	11.92	12.83	9.98	15.76	10.19	14.73
Rent	1.75	1.84	1.84	2.39	2.72	2.99	3.12	4.18	4.44	4.62	4.56
Durables	8.75	10.67	11.85	7.97	8.70	8.04	9.31	8.36	8.02	8.77	8.29
Overall	100	100	100	100	100	100	100	100	100	100	100
Monthly total expenditure per capita (real)											
in 2005 US $	130.71	112.05	115.90	125.86	132.17	142.27	152.12	145.96	171.52	179.58	207.96
in RUB	3756.98	3219.77	3330.55	3616.80	3798.04	4088.25	4371.29	4194.33	4928.66	5160.26	5975.93

Source: Own calculations based on RLMS-HSE, 1996-2008.

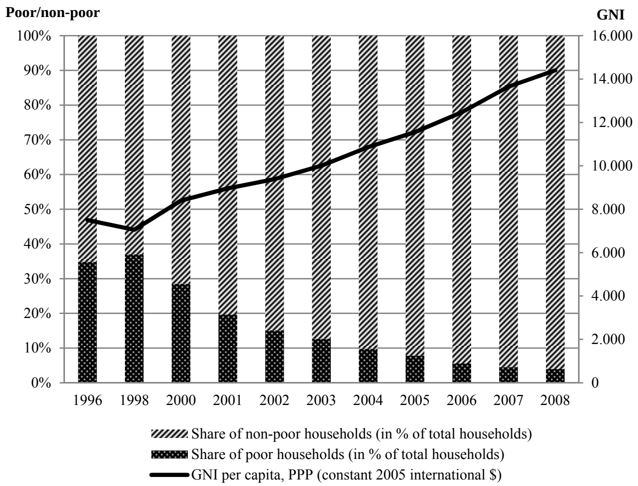
Households in transition countries generally face relatively high levels of economic uncertainty. Due to lacking credit and insurance markets, they have enormous problems smoothing their food consumption against economic shocks (STILLMAN, 2001). Along these lines, measures provided in Table 2 identify tremendous changes in real total expenditures and in food expenditure shares during the observed period of economic transition. Average monthly real expenditures were 3,756 Rubles per capita in 1996. In 1998, the year of financial crisis, average monthly real expenditures dropped to their lowest level of 3,220 Rubles per capita; thereafter, total expenditures increased up to 5,976 Rubles per capita in 2008.[8]

Focusing on food expenditure shares, Table 2 shows that over the observed period food expenditures shares were the highest for food items compared to non-food items and housing. Furthermore, the expenditure shares of total food items and the expenditure shares of home-productions within the food consumption aggregate tend to be relatively higher the lower the real total expenditures are. Therefore, in 1998 when the average real total expenditure per capita was at its lowest level, food expenditure shares reached their highest levels at 62.34 %, with a share of 15.14 % of home-produced food items. Afterwards, with steady

[8] Monthly total expenditures are nearly similar to the equivalent Russian household consumption per capita data provided by the World Bank DataBank (WORLD BANK, 2014).

economic growth and increasing incomes, food expenditure shares dropped down to 38.72 % in 2008, with a share of 6.17 % of home-produced food items.

Figure 2: Development of Russian household incomes



Source: RLMS-HSE data set and World Bank indicators, 1996-2008.

The demand for food and non-food products depends, amongst various socio-demographic factors and preferences, on real household incomes and prices. According to the WORLD BANK (2014), the gross national income (GNI) per capita, based on purchasing power parity converted to international dollars, increased from 1996 to 2008 by 92.08 %, with an annual growth rate of 5.59 %. Thereby, GNI is a central income indicator since this measure equals total incomes of Russian residents earned by labor and property supply. In Figure 2, the GNI development over the observed time period is shown. At the beginning of the observed period the Russian GNI declined until 1998, the year of the financial crisis. Especially during this period of time Russian households were hit by income shocks that included problems of wage arrears, pension arrears, and unemployment. These income shocks affected food consumption significantly since Russian households were only partially able to protect their food consumption from such shocks (MU, 2006).[9] Afterwards, the GNI increased up to its highest level in 2008. Furthermore, Figure 2 reflects the share of poor and non-poor Russian households. The group of poor households indicates households that have incomes lower or equal to the regional poverty threshold. Households with incomes higher than

[9] See also KUHN and STILLMAN (2004) on inter-household transfers regarding the vulnerability of elderly and the role of familial transfers in Russia.

the regional poverty threshold were grouped as non-poor households. As can be seen in Figure 2, with an increasing GNI the percentage of poor households decreased progressively over time in favor of the share of non-poor households. Therefore, Russia's improving macroeconomic performance over the past years involving rising household incomes has reduced the portion of households with incomes below or equal to the poverty threshold from 35 % in 1996 to 5 % in 2008. Thus, this development has reduced the number of food insecure households in Russia (LIEFERT, 2004). Furthermore, keeping food prices constant, increasing household incomes indicate that financial budgets of Russian households allow for quantitatively, as well as qualitatively, higher levels of purchased foods.

Besides household incomes, changing food prices also affect food demand by both income and price effects. With the end of the former socialist system and the ongoing market liberalization, prices of food and non-food products have increased alarmingly. Such food price increases, next to their price effects on food demand, reduce real household incomes and especially affect Russia's poorer households, which have a food expenditure share of more than 50 % (ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, 2009). Hence, the relatively high inflation rates in Russia, which are mainly driven by energy and food prices, have caused tremendous problems for Russian food security. Especially in 1998, food security of the Russian population has been negatively influenced by accelerating food prices. Table 3 provides an overview of the development of the average yearly Laspeyres price indices over the considered time period 1996-2008 for the following eight food aggregates: carbohydrates; milk and dairy products; meat and meat products; other protein sources (such as eggs and fish); fruits; vegetables; fats; and "other foods". In this study, the other foods aggregate includes sweets, snacks, coffee, tea, and non-alcoholic beverages. The presented Laspeyres price indices are calculated based upon the procedure proposed by DEATON and ZAIDI (2004). These calculated price indices are fairly reasonable compared to the Russian all items food price index of the Organization for Economic Co-Operation and Development (OECD, 2014) for the same time period. As can be seen, prices of fruits experienced the highest price increases from 1996 to 2008.[10]

[10] Chapter 3.2 is based on BURGGRAF et al. (2014d).

Table 3: Russian Laspeyres indices for eight food aggregates

Year	1996	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008
Carbohydrates	1.00	1.41	2.77	2.93	3.37	3.82	4.43	4.49	5.09	6.23	7.99
Milk and dairy	1.00	1.50	2.80	3.57	3.83	4.35	4.94	5.83	6.53	9.03	10.25
Meat and meat products	1.00	1.64	3.38	4.48	4.69	4.95	6.08	7.38	7.85	8.68	10.84
Other proteins	1.00	1.67	2.84	3.48	3.85	4.39	5.13	5.50	5.96	7.61	8.94
Fruits	1.00	2.41	3.58	4.55	4.96	5.52	5.92	7.00	8.19	9.92	11.76
Vegetables	1.00	2.14	2.57	3.05	4.06	4.37	4.58	5.52	6.23	9.38	10.14
Fats and oils	1.00	2.44	3.04	3.55	3.98	4.40	4.76	5.07	5.20	7.30	9.04
Other foods	1.00	2.09	2.95	3.48	3.87	4.60	4.90	5.34	6.08	7.21	9.16
All items (OECD)	1.00	1.47	3.29	4.00	4.63	5.26	5.84	6.58	7.22	7.87	8.97

Source: Own calculations based on RLMS-HSE, 1996-2008.

Note: For comparison see the all item Russian food price index of the ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (2014), which is adjusted to the base year 1996.

3.3 TRANSITION OF NUTRITION PATTERNS

3.3.1 Transition of food consumption

After clarifying the macroeconomic conditions of food demand, the focus is now on trends in Russians' food consumption patterns during economic transition. Because of the limited available assortment of food products during Soviet times, Russian food consumption patterns were primarily motivated by availability and prices, but less by preferences for healthy foods; this fact seems to persist, as recent studies on consumer purchase behavior indicate (HONKANEN and FREWER, 2009). Consumers seem to pay less attention to the vitamin, fiber and mineral content of foods and thus to the positive health effects of these nutrients on their body. Moreover, the former Soviet Union prioritized certain foods by providing high subsidies for a set of meat and dairy items. Thereby, the Russian government set consumer prices for livestock goods far below production costs (LIEFERT, 2004). Furthermore, the Soviet Union's medical and nutritional establishments created dietary standards that called for high levels of protein intake. These nutrition guidelines and the promotion of meat and dairy products ended by the 1980s, but the practice seems to prevail since no counter education has been provided (DELLAVA et al., 2010). This is in line with LIEFERT (2004), who states that Russians consider a heavy intake of livestock products necessary for a healthy diet (see also HONKANEN and VOLDNESS, 2006). DELLAVA et al. (2010) conclude that steep price increases for meat and dairy products, especially in times of economic crisis, did not result in long-term dietary shifts. In fact, after a decrease in meat consumption by 27 % in the period 1990-1995 due to the collapse of the managed economy, accompanied by a reduction of the Russian gross national income (GNI) by nearly 40 %, Russian households reverted to prior consumption patterns as incomes increased. Thus, rather high preferences for meat and dairy products might be one reason for the remarkable obesity rates in Russia (HUFFMAN and RIZOV, 2007).

In addition, Russian cuisine has traditionally been low in fruit and vegetable contents due to the difficulty of growing fruits and vegetables in the Russian climate (BRAINERD and CUTLER, 2005). This is in line with results by PAALANEN et al. (2011), who compared fruit and vegetable consumption of people living in Pitkäranta in the Republic of Karelia (Russia) with people living in North Karelia (Finland) for the time period 1992 to 2007. These authors' results document a remarkably lower level of fruit and vegetables in the Russian region, with slightly higher levels in 1997 than in 1992. While in 1992 only 10 % of men and 11 % of women stated that they eat fruits and vegetables on a daily basis, these numbers increased to 24 % and 35 %, respectively, in the year 2007. HERZFELD et al. (2014) find the lowest levels of food diversity, an indicator of adequate fruit and vegetable consumption, in the years of the financial crisis in 1998, with increasing levels afterwards.[11]

Table 4: Development of average annual per-capita food aggregate consumption

	1996	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008
Carbohydrates	240.19	227.12	235.15	243.64	228.67	216.88	221.73	208.70	203.47	196.26	189.37
Milk and dairy	82.17	83.18	85.11	88.89	91.58	92.73	90.22	90.83	92.04	88.77	91.06
Meat products	59.91	46.64	46.91	51.31	58.84	59.94	60.33	60.69	64.24	68.10	67.79
Other proteins	24.99	21.09	23.55	25.30	25.03	25.60	25.59	26.38	26.71	27.33	28.21
Fruits	39.82	22.21	42.69	42.14	44.43	49.22	48.23	45.34	46.75	48.79	47.92
Vegetables	70.37	56.45	65.26	68.13	62.39	61.56	63.05	62.15	60.78	55.35	57.09
Fats and oils	16.57	13.97	16.46	16.98	16.48	15.31	15.18	15.16	14.08	14.81	13.77
Other foods	12.26	11.90	17.41	20.78	21.22	22.48	22.11	21.96	23.87	22.28	21.39

Source: Own calculations based on RLMS-HSE, 1996-2008.

Note: Average per capita consumption is presented in kg/year.

In order to enhance the above discussion, Table 4 provides an overview of how the average consumption of food aggregates in kg/year developed over time based on the RLMS-HSE data set.[12] Again, the following eight food aggregates are considered: carbohydrates; milk and dairy products; meat and meat products; fish and eggs as other protein sources; fruits; vegetables; fats and oils; and other foods.

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[11] In addition, an FAO survey indicates that a considerable share of the working age population in Moscow was affected by a lack of vitamins in the years 1996-1998. MARTINCHIK et al. (2005) show that the average consumption of vitamin A was especially low in the years 1994-1998. The share of schoolchildren and students with vitamin C, B1, B2, B6 and B12 deficiencies rose in the period 1990-1994 (SEDIK et al., 2003).

[12] It is of special interest to also consider the poor's diet separately. This is because with emerging processed food sectors one may find that the efforts to enhance food production and increase food security may miss the major target of improving the poor's diet (POPKIN, 2014). Therefore, in Appendix 1 Table A 1, all numbers are separately provided for households with income above or equal to Russian median income, as well as below median income.

As Table 4 shows, meat intake decreased from 59.91 kg/year in 1996 to 46.64 kg/year in 1998. After the Russian financial crisis and with increasing incomes per capita, average Russian per capita consumption of meat and meat products increased from 46.91 kg in 2000 to 67.79 kg in 2008. Thereby, until 2007 the average per capita intake of meat products of households with incomes above or equal median income has been higher than of households with incomes below the yearly median income, with a steady catching up effect of the poorer households. With a yearly meat consumption rate of about 68 kg/year in 2008, Russians' nearly meet the official guidelines of the Ministry of Health and Social Development of the Russian Federation (MINISTRY OF HEALTH AND SOCIAL DEVELOPMENT OF THE RUSSIAN FEDERATION, 2010), which recommends an annual consumption of 70 to 75 kg meat and meat products. The recommended minimum meat consumption for Russian adults lies between 54 kg and 70.4 kg per year, depending on the geographical area in Russia (GOVERNMENT OF THE RUSSIAN FEDERATION, 2013). Hence, on average Russians' meet their nationally recommended meat intakes but considering the upper tail of the meat consumption distribution, about 37.13 % of the Russian population exceeds its recommended meat intake. For comparison, the U.S. DEPARTMENT OF AGRICULTURE and U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES (2010) recommends a maximum per-capita intake of only 62 kg per year, while the GERMAN NUTRITION SOCIETY (2013) recommends an even lower annual maximum meat intake of about 31.3 kg per capita. Along this line, the World Cancer Research Fund recommends that the consumption of meat, especially processed meat, shall not exceed 26 kg per year.[13] This is because although the intake of meat is expected to prevent iron deficiencies, frequent meat consumption, especially of processed meat, is assumed to not only be associated with an increased risk for colorectal cancer, but also with cardiovascular disease, diabetes, and chronic kidney diseases (MARMOT et al., 2007; CHOI and KIM, 2014; MARCKMANN et al., 2014; SAVVA and KAFATOS, 2014; TÁRRAGA LÓPEZ et al., 2014).[14]

Furthermore, per-capita consumption of carbohydrates decreased from 240.19 kg to 189.37 kg within the time period 1996-2008 with generally higher consumed amounts of carbohydrates in poorer households. Per capita fruit intake decreased from 39.82 kg/per in 1996 to 22.21 kg/year in 1998 and afterwards increased up to 47.92 kg/year in 2008. Fruit consumption in richer households are higher than in poorer households. For example, in 2008 fruit consumption of households with incomes above the median was 52.80 kg/year, while fruit consumption of households with incomes below the median was only 43.73 kg/year. Just as for

[13] Processed meats are defined as meats that are preserved by smoking, curing, or salting, or the addition of chemical preservatives.

[14] Furthermore, evidence suggests that even in diets with little consumption of white or red meat, iron status may not be adversely affected (SAVVA and KAFATOS, 2014).

fruits, the per capita consumption of vegetables decreased from 70.37 kg/year in 1996 to 56.45 kg/year in 1998. But in contrast to the Russian fruit consumption, vegetable consumption shows no significant trend after 1998, with its highest amount of 68.13 kg/year in 2001 and its lowest amount of 55.35 kg/year in 2007. Nonetheless, added together, yearly fruit and vegetable consumption increased both in richer and poorer households during the period of economic growth from 1998 up to 2008. However, average per capita fruit and vegetable consumption is still at a much lower level than in western countries (BRAINERD and CUTLER, 2005; PAALANEN et al., 2011).[15] In contrast to meat consumption, Russians' average fruit and vegetable consumption clearly lies below the recommended intake levels. According to the MINISTRY OF HEALTH AND SOCIAL DEVELOPMENT OF THE RUSSIAN FEDERATION (2010), an annual vegetable intake of 120-140 kg per capita and an annual intake of fruits and berries of 90-100 kg per capita is recommended. Regarding other foods, the RLMS-HSE data suggest an increased consumption of sweets by 46.04 % and a remarkable increase of non-alcoholic beverages such as soda and juice, which are often high in caloric value, by 175.84 %.

Table 5 illustrates the development of the Russian average annual per-capita meat aggregate consumption.[16] Russians consume more raw meat than processed meats such as sausages or smoked meat. Considering the group of raw meat in Table 5, Russian households consumed mainly pork and poultry in 2008. Beef intakes have declined over time for both poorer and richer households, which is possibly due to the strong decline in beef production in Russia after the breakdown of the Soviet Union. By contrast, during 1996-2008 Russians increased their average consumption of processed meat by 44.33 %. This trend can be explained by improved food availability due to new supply chains and increasing wage rates, which make time-consuming homemade meals relatively more expensive than processed foods. While processed foods might be healthful, there is a clear sense in the nutrition world that an excessive intake of processed or ultra-processed food affects weight gains and the prevalence of obesity and other non-communicable diseases (POPKIN, 2014). Processed foods tend to have higher contents of fat, sugar and salt compared to freshly-prepared homemade meals (BINKLEY and GOLUB, 2011). This aspect of hidden fats can be confirmed by considering total fat intakes over time. While the consumption of the separate fat and oil food aggregate decreased over the observed time period, the 24-hour recall data from the RLMS-HSE show that total fat intakes, i.e. fat intakes in energy

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[15] For comparison, total fruit and vegetable consumption in the United States in 2008 was 293.9 kg per capita.

[16] See Appendix 1 Table A 2, where all numbers are separately provided for households with income above or equal to Russian median income as well as below median income.

percentage from foods of all food aggregates, increased between 1996 and 2008 by 17.83 %.

Additionally, it is interesting to note that the per-capita processed meat consumption of poorer households started in 1996 at a lower consumption level than that of households with higher incomes. But in 2008, per capita processed meat consumption of poorer households is higher than that of richer households (see Appendix 1 Table A 2). As POPKIN (2014) points out, the poor across the world are selectively purchasing increasing amounts of processed foods from modern food retailers.

Table 5: Development of average annual per-capita meat aggregate consumption

Year	1996	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008
Beef	15.98	15.81	9.01	9.30	11.18	11.46	10.23	10.19	9.55	11.84	11.25
Pork	21.43	18.58	17.92	17.82	23.60	24.54	21.18	22.48	23.00	25.70	24.44
Poultry	13.03	7.01	9.10	12.91	14.24	13.09	16.27	15.77	19.32	19.44	20.85
Other meat	4.61	4.30	3.71	4.52	4.67	5.20	4.34	3.96	4.23	4.04	5.69
Processed meat	5.10	3.53	4.26	5.26	5.70	6.61	7.69	7.49	8.12	8.00	8.20

Source: Own calculations based on RLMS-HSE, 1996-2008.

Note: Average per capita consumption is presented in kg/year.

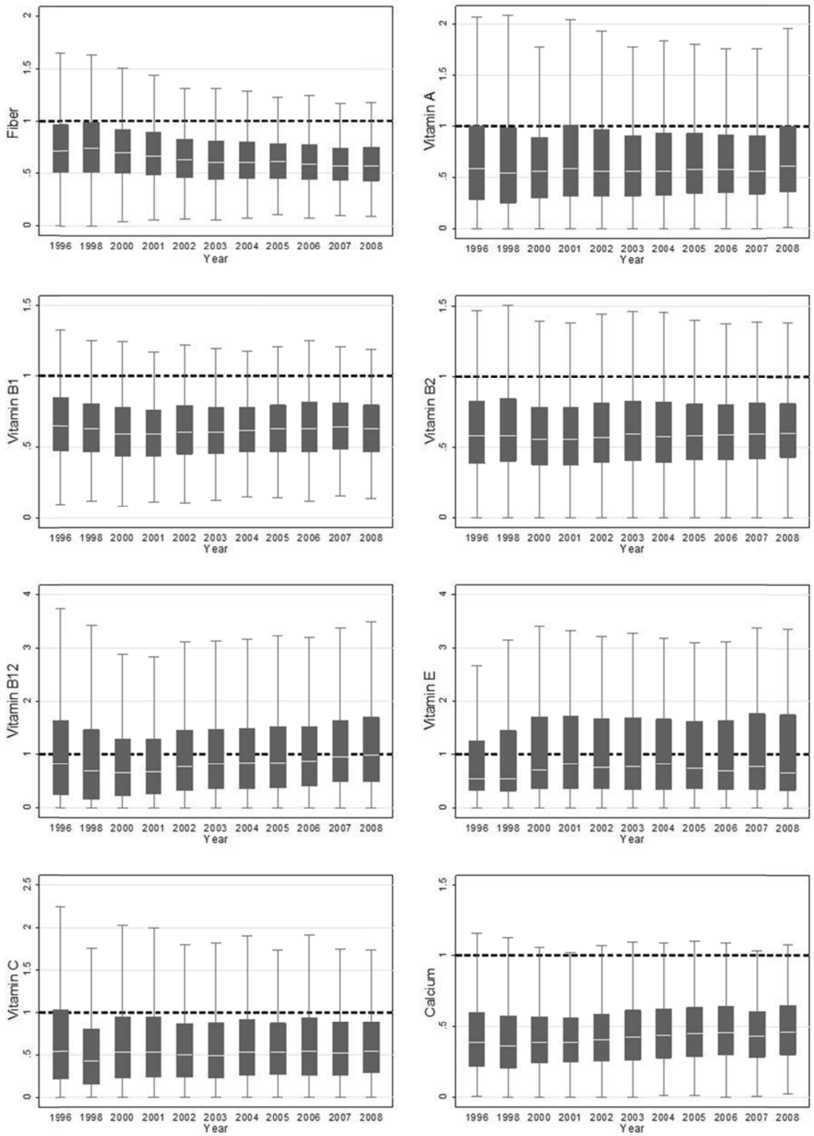
3.3.2 Transition of nutrient consumption

In addition to the above described food consumption data, it is beneficial to provide a more detailed picture of deficient or excessive nutrient consumption during economic transition. Previous studies have found deficient intakes of vitamins A, B-complex, C, and E, as well as calcium and iron in Russia for the period from 1996 to 1998 (SEDIK et al., 2003; MARTINCHIK et al., 2005; OGLOBLIN et al., 2005; PAALANEN et al., 2011). Despite these deficiencies in certain vitamins and minerals, the moderate intake of fatty acids is especially important in the Russian context since overweight and obesity may cause major health problems (SEDIK et al., 2003). Furthermore, POPKIN (2006) implies that fiber intakes generally decrease during economic transition. Nonetheless, fiber is an important component of the human diet because this mainly indigestible part of plant foods has beneficial physiologic effects in humans. Therefore, Figure 3 and Figure 4 illustrate box-and-whisker plots of the relative intake of these selected relevant nutrients for the period 1996-2008.[17] The respective box lines represent the 25th, 50th, and 75th percentiles. The upper (lower) adjacent lines of the box-and-whisker plots are calculated as

[17] Iron is not considered in this analysis because iron availability from plant resources differs significantly from animal resources such as meat due to the fact that human beings can far more readily use iron from foods of animal origin than from fruits and vegetables. Moreover, iron is normally bound to other substances, which may inhibit absorption.

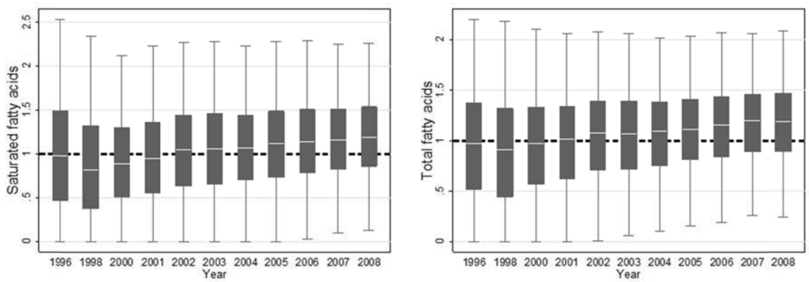
the third quartile +1.5 IQR (first quartile -1.5 IQR). The horizontal lines define the adequate intake levels (AI).

Figure 3: Relative intake of selected vitamins and minerals



Source: Own presentation based on RLMS-HSE, 1996-2008.

Figure 4: Relative intake of saturated and total fat



Source: Own presentation based on RLMS-HSE, 1996-2008.

Relative nutrient intakes are given as the ratio of actual nutrient intake in g/MJ per household food basket to the recommended intake in g/MJ per household. Recommended intakes of vitamin A, B1, B2, B12, C, and E, calcium, fatty acids, and fiber are calculated considering the age and gender of each household member, using the official Russian recommendations of TUTELJAN et al. (2008). If the recommendations in the sense of adequate intake levels (AI) or upper tolerable intake levels (UI) are fulfilled, the mean relative nutrient intake is one. Figure 3 illustrates that the level of vitamin and mineral intakes tends to be the lowest in the crisis year 1998. After 1998, with economic recovery, adequacy levels of vitamins A, B-complex, and C, as well as calcium show a significant positive trend over time. These results are perfectly in line with the results of MARTINCHIK et al. (2005) and OGLOBLIN et al. (2005). Employing Russian 24-hour recall data for the year 2000, MARTINCHIK et al. (2005) show a median vitamin C intake of 53.77 mg for men (44.95 mg for women) and a median vitamin E intake of 16.88 mg for men (11.92 mg for women). Considering the Russian gender-neutral recommended intake level of vitamin C of 90 mg and Vitamin E of 15 mg, these authors' results are mirrored by the present study's results.[18] For calcium intakes, OGLOBLIN et al. (2005) show that in 2003 43.3 % of the Russian population had an insufficient calcium intake. Furthermore, Figure 4 indicates a significant positive trend over time for the relative intake of saturated and total fatty acids, which are considered to increase the risk of chronic diseases if consumed in excess. Thereby, the intake of saturated and total fatty acids becomes increasingly excessive after 2001/2002, meaning that mean actual fat intake exceeds the recommended

[18] Because of only one day recalls, MARTINCHIK et al. (2005) show relatively high standard deviations, especially of vitamin A intakes. These authors present a mean vitamin A intake of 0.52 mg for men with a respective standard deviation of 2.11 mg and a median vitamin A intake of 0.16 mg.

fat intake. By contrast, as observed in other countries experiencing a nutrition transition, the relative intake of fiber decreases with economic growth.

In order to more closely consider the association between household incomes and nutrient intakes, Table 6 reports mean relative nutrient consumption for the population as a whole and according to income quartiles for 2008. Households with higher incomes tend to have a higher relative intake of most vitamins and minerals, reflecting a crucial result in the context of social inequity. However, there is a negative association between the level of household income and fiber intake, which is in line with the results of POPKIN and DU (2003) for China. Furthermore, Table 6 indicates that vitamin E intake is negatively associated with household income, which indicates that households with higher incomes tend to consume lower amounts of vegetable oils, nuts, and whole grains as their major sources of vitamin E. Moreover, Table 6 indicates that the relative intake of (saturated) fatty acids is significantly higher in higher income groups.

Table 6: Mean relative nutrient intakes for total population and income groups

Income Groups by Quartiles*	Lower Income	Lower Middle Income	Upper Middle Income	Upper Income	Total N=4,671
Fiber⁻	0.62 [0.60]	0.60 [0.57]	0.59 [0.57]	0.58 [0.55]	0.60 [0.57]
	(0.45 - 0.79)	(0.43 - 0.76)	(0.42 - 0.73)	(0.42 - 0.72)	(0.43 - 0.75)
Vitamins and minerals					
Vitamin A+	0.66 [0.53]	0.70 [0.57]	0.77 [0.63]	0.80 [0.69]	0.73 [0.60]
	(0.30 - 0.89)	(0.33 - 0.93)	(0.40 - 1.03)	(0.43 - 1.09)	(0.36 - 0.98)
Vitamin B1+	0.63 [0.62]	0.62 [0.61]	0.65 [0.64]	0.65 [0.64]	0.64 [0.63]
	(0.46 - 0.79)	(0.45 - 0.77)	(0.47 - 0.82)	(0.48 - 0.80)	(0.46 - 0.79)
Vitamin B2+	0.60 [0.56]	0.62 [0.58]	0.65 [0.61]	0.67 [0.63]	0.63 [0.60]
	(0.39 - 0.78)	(0.40 - 0.80)	(0.44 - 0.81)	(0.46 - 0.83)	(0.43 - 0.81)
Vitamin B6+	0.76 [0.74]	0.76 [0.75]	0.79 [0.78]	0.80 [0.79]	0.78 [0.77]
	(0.60 - 0.92)	(0.59 - 0.92)	(0.62 - 0.95)	(0.64 - 0.95)	(0.61 - 0.93)
Vitamin B12+	1.04 [0.85]	1.12 [0.92]	1.21 [1.03]	1.32 [1.16]	1.17 [1.00]
	(0.37 - 1.50)	(0.44 - 1.62)	(0.56 - 1.73)	(0.62 - 1.87)	(0.49 - 1.70)
Vitamin C+	0.53 [0.44]	0.58 [0.50]	0.63 [0.55]	0.70 [0.63]	0.61 [0.53]
	(0.19 - 0.77)	(0.27 - 0.84)	(0.31 - 0.87)	(0.36 - 0.98)	(0.28 - 0.87)
Vitamin E⁻	1.10 [0.65]	1.09 [0.72]	1.09 [0.76]	1.01 [0.57]	1.07 [0.65]
	(0.32 - 1.86)	(0.33 - 1.76)	(0.35 - 1.74)	(0.33 - 1.65)	(0.33 - 1.75)
Calcium+	0.44 [0.40]	0.47 [0.45]	0.49 [0.47]	0.53 [0.52]	0.48 [0.46]
	(0.25 - 0.59)	(0.28 - 0.63)	(0.31 - 0.64)	(0.36 - 0.70)	(0.30 - 0.64)
Fatty acids					
Saturated fatty acids+	1.09 [1.07]	1.18 [1.16]	1.22 [1.21]	1.29 [1.30]	1.20 [1.19]
	(0.74 - 1.42)	(0.81 - 1.54)	(0.93 - 1.52)	(0.96 - 1.64)	(0.86 - 1.54)
Total fatty acids+	1.13 [1.14]	1.16 [1.18]	1.19 [1.20]	1.22 [1.23]	1.18 [1.19]
	(0.83 - 1.43)	(0.86 - 1.45)	(0.92 - 1.47)	(0.94 - 1.52)	(0.88 - 1.47)

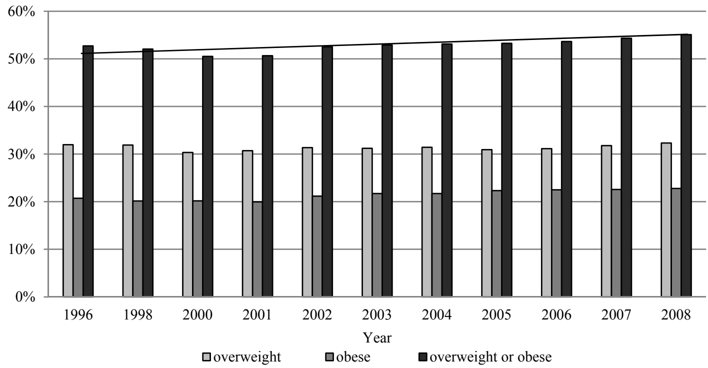
Source: Own calculations, RLMS-HSE 2008.

Note: Median intakes appear in brackets. Interquartile ranges of intakes as the difference between the first and third quartiles appear in parenthesis.
* Boundaries of the four income groups are the three quartile points of the households' income distribution, i.e. household incomes of the lower-income group ≤25th percentile, of the lower-middle income group >25th percentile and ≤50th percentile, of the upper-middle income group >50th percentile and ≤75th percentile, and of the upper-income group >75th percentile.
+ Relative intake increases significantly with higher-income groups at the 5 % level.
⁻ Relative intake decreases significantly with higher-income groups at the 5 % level.

3.4 Epidemiologic transition

According to the World Health Organization (2015a, 2015b), overweight and obesity are expected to rise at an alarming rate, representing one of the greatest public health challenges of the 21st century. Therefore, this section gives an overall view of the current situation and trends regarding overweight, obesity, and diet-related chronic diseases in Russia. Based upon the RLMS-HSE data set, Figure 5 indicates that over 50 % of the Russian population was overweight or obese in 1996, with a significant positive trend towards even higher prevalence rates over the transition period, reaching its highest level of 55.09 % in 2008 (32.32 % overweight, 22.77 % obese).[19] As mentioned above, the growing prevalence of overweight and obesity might be explained by Russians' traditional preferences for animal products, which are usually high in fat, as well as their relatively low intake of fruits and vegetables (LIEFERT, 2004; BURGGRAF et al., 2014d). Figure 5 also illustrates that the percentage of Russians that are overweight or obese fell to its lowest level of 50.51 % in 2000 (30.34 % overweight, 20.17 % obese), which was shortly after the economic crisis in 1998. Indeed, during such a period of tremendous economic stress, a large reduction in the energy density of the average Russian diet occurred due to food shortages, high inflation rates, and low real household incomes (WANG et al., 2002). Measured within this group of obese and overweight, the percentage of obese Russians increased from 39.33 % to 41.33 % within the time period 1996-2008.

Figure 5: Prevalence of overweight and obesity as percentages



Source: Own calculations based on RLMS-HSE, 1996-2008.

Note: The upward sloping line indicates the significant positive trend at the 5 % level. For 2006-2008, due to missing BMI data, the classification of overweight and obesity is based on the individual's simulated BMI, which is calculated based on the according development of the individual's self-reported height and weight.

Aside from problems of physical disabilities as well as psychological problems, overweight and obesity are known to drastically increase a person's risk of diet-related chronic diseases, including diabetes, cardiovascular diseases, and cancer

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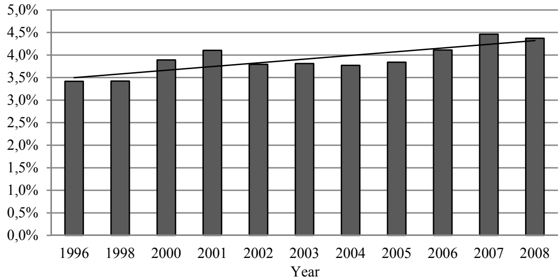
[19] The WORLD HEALTH ORGANIZATION (2015c) defines overweight as a BMI larger than 25 and obesity as a BMI larger than 30.

(WORLD HEALTH ORGANIZATION 2003). Based on the RLMS-HSE data, the association between changing food consumption patterns and the prevalence of chronic diseases can be supported considering the incidence of diabetes. With respect to the development of diabetes rates, interpretation is not as straightforward as with obesity rates because the association between dietary intakes and the incidence of nutrition-related chronic diseases is weaker, especially within a relatively short observation period. However, as presented in Figure 6, the prevalence of diabetes has significantly increased over the observed transition period of 13 years. This result indicates an increasing risk of diabetes with growing household incomes, as well as the possible influence of an overall aging of the Russian population (see BURGGRAF et al., 2014d).

Figure 6: Prevalence of diabetes as percentages



Source: Own calculations based on RLMS-HSE, 1996-2008.

Note: The upward sloping line indicates the significant positive trend at the 5 % level.

Several studies have shown that the incidence of chronic diseases such as diabetes, gallstones, hypertension and heart disease increases with the degree of overweight (FIELD et al., 2001; MOKDAD et al., 2003; SOWERS, 2003; HEDLEY et al., 2004). Therefore, Table 7 shows correlation results between BMI and various health conditions. Thereby, due to categorical self-reported health data, Spearman's nonparametric rank correlation coefficient (SPEARMAN, 1904) is estimated as a nonparametric version of the Pearson correlation. For determining the Pearson correlation coefficient between the continuous BMI values and the other dichotomous health variables such as a positive diabetes diagnosis, the point biserial correlation coefficient is estimated (see ANDERSON, 1994). The respective results indicate that the actual incidence of obesity and hypertension is significantly and positively correlated with the lagged BMI variable five waves before the actual wave. Even after a follow-up period of only five years, the estimated correlation coefficients suggest a moderate positive correlation of lagged BMI with the incidence of obesity and a low correlation with the incidence of hypertension. Furthermore, health criteria such as a positive diabetes diagnosis or being ever diagnosed with a heart attack or stroke are significantly positively correlated with BMI five years before. Finally, higher ranks of the individuals' self-reported health are negatively correlated with the respective BMI five rounds before. In summary, these results may indicate the increased health risks coming from the higher BMI levels of overweight and obese people.

Table 7: Correlation between BMI and health outcomes

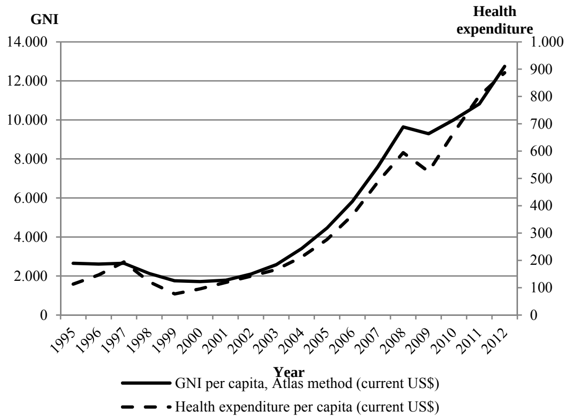
Point biserial correlation with BMI (5 waves lag)	Correlation coefficient	Observations
Obesity [BMI>=30]? [0 no, 1 yes]	0.6567*	105,125
Ever diagnosed with diabetes? [0 no, 1 yes]	0.2169*	114,562
Doctor says high blood pressure? [0 no, 1 yes]	0.3385*	96,796
Ever diagnosed with heart attack? [0 no, 1 yes]	0.0711*	114,827
Ever diagnosed with stroke? [0 no, 1 yes]	0.1032*	114,799
Health evaluation [1 very bad, 5 very good]	-0.2061*	114,627

Source: Own calculations based on RLMS-HSE, 1996-2008.

Note: * $p < 0.05$.

According to ROZENFELD (1996), the above outlined epidemiologic transition with a growing predominance of non-communicable diseases requires changes in health care strategies in Russia, especially those of preventive care. Dietary changes during nutrition transition increase the risk of diet-related chronic diseases (e.g., hypertension and diabetes) and mortality (e.g., POPKIN and KIM, 2001; POPKIN and DU, 2003; POPKIN 2007), which will probably cause tremendous costs for Russia's health care system as well as Russia's national productivity levels. According to the WORLD BANK (2014), Russians' per capita total health care expenditure increased from 113.07 US$ in 1995 to 886.88 US$ in 2012 (see Figure 7). Total health expenditure is the sum of public and private health expenditures and covers the provision of health services, family planning activities, nutrition activities, and emergency aid.

Figure 7: Development of GNI per capita and heath expenditure



Source: Data from World Bank database (WORLD BANK, 2014).

Besides public health care costs, it is especially interesting to focus on private financial health expenditure in order to consider a household's potential financial problems. The private health expenditure share in percentage of total health expenditure has increased from 26.12 % in 1995 to 39.01 % in 2012. Especially worrisome is that out-of-pocket health expenditure, i.e. any direct outlay by households in percentage of private health expenditure, has increased from 64.66 % in 1995 to 87.97 % in 2012. This suggests that although the access to basic public health care is publicly provided, the quality of health services probably varies with household incomes (DENISOVA, 2010). Additionally, informal payments for health care are deeply embedded in the health care system in transition countries (ENSOR, 2004).[20]

3.5 CHAPTER CONCLUSIONS

With the descriptive analysis provided in chapter 3, research question 1.1 – whether there is an ongoing nutrition transition in Russia, considering traditional eating habits and long-standing consumption patterns – has been answered. The provided empirical results on the Russian food and nutrient consumption during the time period 1996-2008 confirm the assumption that Russians' dietary patterns follow the experienced rules of an ongoing nutrition transition in periods of economic growth. Not only has the Russians' consumption of the fruits and vegetables aggregate increased with economic growth and higher household incomes, but so has their consumption of meat products and total fat

[20] Chapters 3.3.2 and 3.4 are based on BURGGRAF et al. (2015b).

intakes. These changing nutrition patterns have two controversial nutrition-related health effects. On the one hand, an increasing and more varied consumption of fruits, vegetables, and meat products reduces the risk of several vitamin and mineral deficiencies, and thus improves dietary quality. On the other hand, the increasing consumption of (saturated) fats in meat and dairy products, accompanied by increasing energy intakes per day, worsens dietary quality because it raises the incidence of overweight and obesity rates, as well as the risk of nutrition-related chronic diseases. This overall development is affected by traditional Russian eating patterns such that Russians' fruit and vegetable intakes are still at considerably low levels, while the rising meat and fat intakes are reinforced by preference structures evolved from the Soviet Systems. Furthermore, as expected by the definition of nutrition transition, the intake of dietary fiber decreases with increasing household incomes.

Additionally, this descriptive analysis answers research question 1.2 – whether declining household incomes during periods of economic crisis lead to a reversed profile of a nutrition transition in Russia. Considering the definition of a nutrition transition, a reversed profile of a nutrition transition can be shown during periods of economic crises such as in the year of the Russian financial crisis in 1998. From 1996 to 1998 the consumption of fruits and vegetables as well as of meat products, fats, and oils decreased. Fiber intakes, on the contrary, are at their highest levels in 1998. This reversed profile of a nutrition transition is mirrored in the decreasing rates of overweight and obesity prevalence from 1996 to 2000.

Since chronic diseases are largely preventable, the observed overall nutrition transition and its accompanying growth of nutrition-related chronic diseases require changes in Russia's health care strategies, especially an increased prominence of preventive intervention strategies in the field of nutrition. Therefore, a more detailed analysis of Russian dietary quality as well as its influencing factors is provided in the following two chapters.

4 RUSSIAN DIETARY QUALITY

4.1 CHAPTER INTRODUCTION

In order to enable an empirical analysis of Russian dietary quality, it is necessary to operationalize the latent construct dietary quality. Per definition, dietary quality is a complex function of the diet's chemical composition related to the specific macro- and micronutrient needs of the human body (HANSEN, 1973). Hence, dietary quality should not be captured by a just single indicator because this tends to provide a too narrow picture of the complex construct dietary quality (DUBOIS, 2000; KANT, 2004). Because of the evidenced various associations between dietary quality and health outcomes, different dimensions of dietary quality need to be taken into account when indicating the level of the healthiness or unhealthiness of a specific dietary pattern (BASIOTIS et al., 1995).[21] This is mainly because the complexity of human diets and the interactions among nutrients complicates the search for associations between single dietary factors and certain health outcomes (BAZELMANS et al., 2006). Thus, dietary quality should ideally be measured by a composite index of overall dietary quality (DUBOIS, 2000; NARDO et al., 2008). It has been shown in empirical studies that such composite indices of overall dietary quality are more strongly related to the risk of chronic diseases than individual indicators of single nutrients or foods. Consequently, these overall indices are more appropriate for identifying individuals with high- versus low-quality diets based on their adherence to nutritional recommendations and, thus, to reduce the risk of nutrition-related chronic diseases (KANT, 1996).

The purpose of diet quality indices is to assess an individual's dietary intake for the promotion of health and prevention of disease (FUNG et al., 2005). Assessing an individual's dietary intake allows for a rapid screening of the dietary quality of a population or different population strata. This assessment of dietary quality further enables the analysis of associations between diet quality (or its components) and respective health outcomes, as well as the analysis of influencing

[21] Conceptual dimensions of dietary quality mirror broad factors of the latent multidimensional concept dietary quality. These dimensions need not to be independent of each other, but existing linkages should be explained (NARDO et al., 2008). Index dimensions can be measured by various indicators (and assessed by sub-indices within the composite). In nutrition literature on dietary quality, generally four dimensions of dietary quality can be distinguished: adequate intakes of foods and/or nutrients, moderate intake of foods and/or nutrients that increase the risk of chronic diseases, overall balance of macro- and micronutrients, as well as variety of foods consumed.

factors of dietary quality. Thus, such an assessment contributes to the derivation of more effective but also more efficient nutrition intervention strategies (SHATENSTEIN et al., 2005). Nonetheless, given the fact that diet-related diseases are of major concern to Russian authorities (see chapter 3.4), it is interesting to note that thus far Russian dietary quality has not been measured by a composite index in any empirical studies. Moreover, despite the growing interest in assessing dietary quality over time, only few longitudinal studies have employed diet quality indices to identify trends in dietary behavior (ARABSHAHI et al., 2011). However, these studies focus on time paths of overall diet quality in industrialized countries such as the United States or Australia (e.g., HU et al., 2000; FUNG et al., 2007; LEE et al., 2007; ARABSHAHI et al., 2011). For transition countries such as the Russian Federation, empirical studies on the development of diet quality are missing. Thereby, the Russian case might be especially interesting due to its traditional eating habits, as well as the recent political, economic, and social changes.

Based upon the above discussion, the aim of this chapter is to investigate the overall dietary quality of the Russian population, as well as trends in dietary behavior, by applying a composite index of overall dietary quality. Hence, this inquiry contributes as follows to the existing literature. First, based on the index construction criteria explicated in the OECD handbook on constructing composite indicators (NARDO et al., 2008) a systematic discussion is provided regarding the most suitable design of the relevant construction criteria of dietary quality indices. Second, this is the first study that offers a summarizing toolbox for nutritionists to help them to identify those indices whose index construction is most appropriate considering their respective study aim, as well as any restrictions given by the study target region and available dietary intake data. Third, after the selection of the DQI-I-2003 as the most suitable index construction for transition countries, this chapter offers a methodological contribution by aligning the DQI-I-2003 to the Russian country-specific needs, as well as to technical requirements of a statistically sound composite index. Fourth, based on the empirical application of the modified DQI-I-2003 to the RLMS-HSE data set, a more thorough picture of Russians' overall diet quality is provided by identifying whether several nutrients are at risk of deficient or excessive intakes, and how nutritional profiles changed over time. Therefore, this study contributes to the very limited literature on longitudinal changes in dietary quality.

Chapter 4 is organized as follows. First, some basic theoretical insights into the construction of dietary quality indices are provided in chapter 4.2.1. A short overview of existing a priori indices on human dietary quality is then presented in chapter 4.2.2. In chapter 4.2.3 the appropriateness of different index construction criteria is discussed based upon theoretical considerations or recent knowledge about the diet-health relationship. Based upon this discussion, a summarizing toolbox is derived in chapter 4.2.4. For the subsequent empirical analysis, the DQI-I-2003 is selected and modified in chapter 4.3.1. In chapter 4.3.2, empirical results are presented. Finally, in section 4.4, the findings of this chapter are summarized and concluded.

4.2 INDICES ON DIETARY QUALITY

4.2.1 A priori indices on dietary quality

In recent years a number of indices used to measure the theoretical construct dietary quality have evolved and in general two different categories can be distinguished: *a posteriori indices* and *a priori indices* (see e.g., KANT, 2004). A posteriori indices define dietary patterns through statistical methods such as factor analysis, cluster analysis, or reduced rank regression using dietary intake data at hand.[22] These exploratory post hoc techniques aggregate intake variables into factors and reveal common underlying patterns of food consumption within a population (NEWBY and TUCKER, 2004; INTERACT CONSORTIUM, 2014). The generalizability of a posteriori defined dietary patterns is often criticized since these dietary patterns are derived specifically for the population under consideration (KIEFTE-DE JONG et al., 2014). This often makes a posteriori derived patterns not reproducible across countries since statistical factors differ across populations and there is no assurance of the conceptual meaning of these factors (KANT, 2004). Furthermore, these a posteriori defined patterns do not necessarily define the healthiest patterns because they are not derived from current nutritional knowledge or evidence-based diet-health relationships (HU, 2002).

For the purpose of this study focus is placed on a priori dietary indices, which are based on current nutrition knowledge. A priori dietary indices determine theoretically-defined dietary components, which are considered important for the promotion of health and reflect a risk-gradient for major diet-related diseases. These single components are then quantified and aggregated to an overall measure of dietary quality (GERBER et al., 2000; WAIJERS et al., 2007). The resulting scoring scale has to reflect the range between the least possible dietary quality up to the optimal dietary quality. However, the accuracy of an a priori index approach is limited by the current level of dietary knowledge regarding the diet-health relationship as well as uncertainties accompanying the index construction process. HU (2002) suggests that the selection of index construction criteria – for example its components, applied normalization methods, and selection of cutoff values – is possibly fraught by subjectivity.

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22 Reduced rank regression is a mixture of a hypothesis-oriented and an exploratory approach. It aims to identify food group combinations that explain a maximum of variation in (disease-related) response variables (MILÀ-VILLARROEL et al., 2011).

The choice of an appropriate a priori dietary index for the analysis of diet quality has to be motivated – amongst practicability, sensitivity, and reliability criteria – by its empirical validation with health outcomes and mortality. Existing a priori diet quality indices have been validated in relation to various health outcomes such as cardiovascular diseases, cancer, or mortality (e.g., McCullough et al., 2000a, 2000b; Seymour et al., 2003; Stoody et al., 2014). However, empirical studies have shown that all of these indices appear to have more or less the same predictive capacity for the risk of chronic diseases (Seymour et al., 2003; Kant, 2004; Waijers et al., 2007; Drewnowski et al. 2009; Wirt and Collins 2009; Stoody et al., 2014). Furthermore, comparing validity results of a priori indices is difficult due to the variability of population groups, length of study follow-up periods, dietary measurement methods, and approaches to adjust for confounders such as BMI, physical activity, age, or education (Waijers et al., 2007; Wirt and Collins, 2009).

Since validation results do not sufficiently facilitate the choice of a specific a priori dietary quality index, the choice of such a dietary quality index should be based on its key issues of index construction, which are as follows: (i) theoretical framework considering index purpose, diet quality dimensions, and index structure; (ii) selection of nutrient- or food group-based indicators; (iii) normalization methods considering scaling procedures, cut-off points, and valuation functions; and (iv) methods to weight and aggregate index components (Nardo et al., 2008). Judging the soundness of the theoretical framework and the fitness of the methodology for the study purpose enables researchers to select the most suitable index out of the vast pool of existing composite indices. Until now, the discussion on index construction criteria has been rather unsystematic and not comprehensive considering the index construction criteria explicated in the OECD handbook on constructing composite indicators (Nardo et al., 2008). Previous studies have a strong focus on indicator selection, scaling techniques, and cut-off points (see e.g., Waijers et al., 2007; Wirt and Collins, 2009; Stoody et al., 2014). Nonetheless, little attention has been given to the other relevant key issues of index construction. However, a consensus regarding all key issues is needed because otherwise subjective decisions may affect diagnostic capacity (Waijers et al., 2007; Drake et al., 2011). Based on their survey results regarding the association of index scores and health outcomes, in their concluding statements Stoody et al. (2014) recommend more research on the methods by which index components are chosen, grouped, and scored. Along these lines, Milà-Villarroel et al. (2011) conclude that although the various indices employed in their study are supposed to measure adherence to Mediterranean diet patterns, correlations between these indices are rather weak, most likely due to many arbitrary choices in a priori index construction, such as those regarding selected indicators, normalization, and aggregation methods.

4.2.2 Review of a priori dietary quality indices

In order to identify relevant a priori dietary indices, a review of published English-language literature from 2008 to 2014 was conducted. Prior to this time period, results are based on the review by WIRT and COLLINS (2009). The electronic database MEDLINE was searched using the following search terms: diet, dietary, food, eating, nutrition, or nutritional, in combination with habit, pattern, patterns, or quality. Thereby, indices with the following specific criteria are excluded from this search: (i) indices on animal feeding; (ii) indices with less than two dimensions (due to the multidimensional character of dietary quality) such as the Recommended Food Score by KANT et al. (2000), which considers only adequate intakes, or the Not Recommended Food Score by MICHELS and WOLK (2002), which considers only moderate intakes, as well as indices exclusively measuring diversity patterns (e.g., the Dietary Variety Score by BERNSTEIN et al. 2002); (iii) indices on specific population groups such as the Diet Quality Score for Pregnancy by BODNAR and SIEGA-RIZ (2002), or the Diet Quality Index for American Prescholars by KRANZ et al. (2006); (iv) indices developed for the prevention of specific diseases such as the adherence to dietary approaches to stop hypertension (DASH diet) by FUNG et al. (2008) or the Heart Disease Prevention Eating Index by LEE et al. (2007); and (v) indices not exclusively based on the assessment of dietary quality such as the Dietary Guideline Index (DGI-2002) by HARNACK et al. (2002) or the Dutch Healthy Diet Index by van LEE et al. (2013), both of which include dietary intake components as well as components on physical activities, or the Overall Nutritional Quality Index by KATZ et al. (2009), which is designed for food labeling purposes.[23] Table 8 provides an overview of all relevant indices, where the main indices are ordered alphabetically. If indices are modifications of an originally defined index, these modified indices are then ordered with regard to content-related proximity with the original index and finally chronologically.

[23] Indices developed for the prevention of a specific disease have been excluded because they are assumed to be inappropriate for assessing and guiding overall dietary quality of individuals generally facing a considerably wide range of different health outcomes.

Table 8: A priori indices on dietary quality

Index (Abbreviation)	Authors (Year)
Danish Healthy Diet Index (D-HDI-2003)	DYNESEN et al. (2003)
Diet Quality Index (DQI-1994)	PATTERSON et al. (1994)
Diet Quality Index (DQI-2003)	SEYMOUR et al. (2003)
Diet Quality Index-Revised (DQI-R-1999)	HAINES et al. (1999)
Diet Quality Index-Revised (DQI-R-2003)	NEWBY et al. (2003)
Diet Quality Index-International (DQI-I-2003)	KIM et al. (2003A)
Diet Quality Index-Swedish Nutrition Recommendation (DQI-SNR-2011)	DRAKE et al. (2011)
Chinese Diet Quality Index (CH-DQI-2000)	STOOKEY et al. (2000)
Mediterranean Diet Quality Index (Med-DQI-2000)	GERBER et al. (2000)
Mediterranean Diet Quality Index incl. tobacco use (Med-DQI-f-2000)	GERBER et al. (2000)
Mediterranean Diet Quality Index (Med-DQI-2006)	GERBER (2006)
Diet Quality Score (DQS-2002)	FITZGERALD et al. (2002)
Diet Quality Score (DQS-2007)	TOFT et al. (2007)
Dietary Behavior Score (DBS-2009)	KANT et al. (2009)
Dietary Guidelines for Americans Adherence Index (DGAI-2005)	FOGLI-CAWLEY et al. (2006)
Dietary Quality Index Nutrient Based (DQINB-1999)	LOEWIK et al. (1999)
German Food Pyramid Index (GFPI-2012)	VON RUESTEN et al. (2010)
Healthy Diet Indicator (HDI-1997)	HUIJBREGTS et al. (1997)
Healthy Diet Indicator (HDI-2011)	CADE et al. (2011)
Healthy Diet Indicator (HDI-2013)	BERENTZEN et al. (2013)
Healthy Diet Score (HDS-2005)	MAYNARD et al. (2005)
Healthy Eating Index (HEI-1995)	KENNEDY et al. (1995)
Healthy Eating Index-2005 (HEI-2005)	GUENTHER et al. (2008)
Healthy Eating Index-2010 (HEI-2010)	GUENTHER et al. (2013)
Healthy Eating Index-Frequency Questionnaire (HEI-f-2000)	MCCULLOUGH et al. (2000a, 2000b)
Alternate Healthy Eating Index (AHEI-2002)	MCCULLOUGH et al. (2002)
Alternate Healthy Eating Index (AHEI-2010)	CHIUVE et al. (2012)
Canadian Healthy Eating Index (C-HEI-2005)	SHATENSTEIN et al. (2005)
Healthy Food Index (HFI-2001)	OSLER et al. (2001)
Healthy Food and Nutrient Index (HFNI-2006)	BAZELMANS et al. (2006)
Italian Mediterranean Index (IMI-2011)	AGNOLI et al. (2011)
Mediterranean Adequacy Index (MAI-1999)	ALBERTI-FIDANZA et al. (1999)
Mediterranean Adequacy Index (MAI-2006)	KNOOPS et al. (2006)
Mediterranean Adherence Diet Screener (MEDAS-11)	SCHRÖDER et al. (2011)
Mediterranean Adherence Diet Screener (MEDAS-2013)	DOMÍNGUEZ et al. (2013)
Mediterranean Diet Score (MDS-1995)	TRICHOPOULOU et al. (1995)
Mediterranean Diet Score (MDS-2002)	HAVEMAN-NIES et al. (2002)
Mediterranean Diet Score (MDS-2003)	TRICHOPOULOU et al. (2003)
Mediterranean Diet Score (MDS-2004)	KNOOPS et al. (2004)
Mediterranean Diet Score (MDS-2011)	CADE et al. (2011)
Modified Mediterranean Diet Score (mMDS-2005)	TRICHOPOULOU et al. (2005)
Modified Mediterranean Diet Score (mMDS-2014)	YANG et al. (2014)
Alternate Mediterranean Diet Score (aMED-2005)	FUNG et al. (2005)
Mediterranean Dietary Pattern (MDP-2002)	SÁNCHEZ-VILLEGAS et al. (2002)
Mediterranean Food Pattern (MeDiet-2008)	SÁNCHEZ-TAÍNTA et al. (2008)
Mediterranean Score (MS-2003)	GOULET et al. (2003)
Mediterranean-Style Dietary Pattern Score (MSDPS-2009)	RUMAWAS et al. (2009)
Recommendation Compliance Index (RCI-2008)	MAZZOCCHI et al. (2008)
Relative Mediterranean Diet (rMED-2009)	BUCKLAND et al. (2009)

Source: Own presentation.

A total of 49 different indices or their variations have been identified, which are primarily based on the Diet Quality Index (PATTERSON et al., 1994), the Healthy Eating Index (KENNEDY et al. 1995), and the Healthy Diet Indicator (HUIJBREGTS et al., 1997). Moreover, in recent years indices that measure the adherence to Mediterranean dietary patterns (e.g., Mediterranean Diet Score by TRICHOPOULOU et al., 1995) have witnessed growing attention. This vast pool of various index constructions makes it difficult for nutritionists to select the most appropriate composite index considering the respective research aim, target region, and data restrictions, as well as the theoretical soundness and methodological fitness of the index construction.

4.2.3 Comparison of dietary quality indices

4.2.3.1 Theoretical framework

Information sources and index purpose

Identifying a sound theoretical framework is the starting point of an index construction (NARDO et al., 2008). A theoretical framework defines the respective latent construct with its dimensions and provides the basis for the subsequent selection and composition of indicators. As NARDO et al. (2008) point out, the quality of a composite index and the soundness of its message depend heavily on the appropriateness of the framework. Hence, it seems to be reasonable to start the discussion of diet quality index construction issues with the consideration of the theoretical framework. It is important to note that human needs in terms of the best composition of nutrients, taking interactions among nutrients into account, are only incompletely known. Nevertheless, dietary guidelines try to reflect the latest evidence on the effects of different dietary patterns on human health. Therefore, indices are generally based on national dietary guidelines and/or current scientific evidence. Additionally, in recent years a number of indices measuring the adherence to Mediterranean diets have evolved because of the significant diet-health relationship for Mediterranean dietary patterns (WIRT and COLLINS, 2009).

Some indices have been primarily developed to assess and guide an individual's diet in the context of public health promotion programs rather than monitoring dietary quality (WAIJERS et al., 2007). These indices definitely ask for simpler food-based indicators and are often based on a direct translation of common dietary guidelines into index components (see e.g., HDI-2013). Yet if dietary indices do not aim to have direct promoting power for healthy eating programs but rather to assess and monitor a population's dietary intake patterns with regard to related health outcomes, then more detailed and elaborated indices are beneficial because a higher degree of elaboration tends to increase the indices' distinctive power. Thereby, the general information of dietary guidelines is often enhanced by additional considerations of the latest epidemiological evidence on the various diet-health relationships. In this line, WIRT and COLLINS (2009) as well as WAIJERS et al. (2007) show that more elaborate indices, which consider the latest epidemiological associations and which are constructed with a more detailed scoring range (e.g., A-HEI-2005, A-HEI-2010), are better health risk predictors than those indices which are developed to simply measure direct adherence to dietary guidelines/recommendations with a strong health promotion purpose (e.g., HDI-2013, DQS-2007).

Furthermore, the majority of dietary indices has been created due to the consensus regarding diet-related chronic diseases in developed countries, such as the U.S. (e.g., HEI-2005, HDI-1997, DGAI-2005). It follows from the multidimensional character of dietary quality that the respective overall indices have to consider at least two dimensions of dietary quality with their according effects on one's health (BASIOTIS et al., 1995) (HDI-1997, DGAI-2005) or the Mediterranean area (e.g., MDS-1995, mMDS-2005). For example, the DGAI-2005 has been developed for the U.S. population with a focus on problems of overconsumption and energy density (FOGLI-CAWLEY et al., 2006). Also, GERBER et al. (2000) exclude calcium intake from the selected intake indicators of the Med-DQI-2000 for the population of southern France, because calcium was not judged sufficiently for the prevention of cardiovascular diseases and cancer. Focusing on the prevention of cardiovascular diseases and cancer, the authors do not consider the importance of adequate calcium intake for the prevention of osteoporosis. By contrast, the DQI-I-2003 as well as the CH-DQI-2000 accommodate coexisting problems of under- and overnutrition, and thus consider adequate calcium intakes as indicators of their diet quality indices. In particular, the DQI-I-2003 aims to assess dietary quality across diverse countries at different stages of nutrition transition and wants to provide a global tool for exploring different aspects of diet quality, which are related to nutrition transition (KIM et al., 2003a).

Dimensions of dietary quality

The index's purpose is closely connected to the question of which dimensions of dietary quality have to be addressed in an index construction. It follows from the multidimensional character of dietary quality that the respective overall indices have to consider at least two dimensions of dietary quality with their according effects on one's health (BASIOTIS et al., 1995). Yet as mentioned above (see footnote 21), generally four dimensions of dietary quality can be distinguished: adequate intakes of foods and/or nutrients, moderate intakes of foods and/or nutrients that increase the risk of chronic diseases, overall balance of macro- and micronutrients, and variety of foods consumed.

All existing indices on dietary quality that follow this multidimensional approach involve at least the adequacy and moderation dimensions. Adequacy refers to the sufficient intake of dietary elements beneficial to health that must be supplied to guarantee a healthy diet. On the contrary, moderation means avoiding the intake of nutrients detrimental to health, i.e. nutrients that increase the risk of chronic diseases if consumed in excess. Controlling for the moderation dimension when analyzing adequate intakes is necessary since a diet that supplies adequate intake levels of vitamins and minerals tends to also be more excessive in fat and cholesterol contents. Additionally, some diet quality indices consider a balance dimension, which addresses the proportionality in macronutrients as energy sources (carbohydrates, proteins, and fats) and/or in fatty acids (saturated fatty acids (SFA), mono unsaturated fatty acids (MUFA), poly unsaturated fatty acids (PUFA)). Especially the unbalanced intake of total fat and of unsaturated fatty acids has been associated with obesity, cardiovascular diseases, and other chronic diseases (WAIJERS et al., 2007; GUO et al., 2013; SCHWAB et al., 2014).

Besides the adequacy, moderation, and overall balance dimensions, several indices (e.g., DQI-R-2003, DQI-I-2003, HEI-1995) take into account food variety (or diversity) as a further dimension. Variety indicates whether the individual's diet is derived from a sufficient variation of different food items. Dietary variety is a possible dimension of overall dietary quality because it is significantly associated with an adequate nutrient intake, i.e. the risk of nutrient deficiencies tends to decrease with greater dietary variety (e.g., ROYO-BORDONADA, 2003; FOOTE et al., 2004; SAVY et al., 2007; ISA et al., 2013). Furthermore, several studies indicate that a higher level of variety within specific food groups, especially within the fruit and vegetable group, may reduce a number of health risks (e.g., JEURNINK et al., 2012; DE OLIVEIRA et al., 2012; ISA et al., 2013). Finally, a higher variety of consumed food items is assumed to reduce the likelihood of an unhealthy exposure to food contaminants contained by some of these consumed food items (LOEWIK et al., 1999). However, WAIJERS et al. (2007) argue against the need of a variety dimension because of the close link between variety and adequacy, which leads to the potential problem of unaccounted component correlations with the related problem of potential double-counting. Generally, diet quality indices contain a great number of different food and nutrient indicators in their adequacy dimension, which can only be successfully achieved with a varied diet. Therefore, in order to avoid problems of double-counting in equally weighted aggregates, WAIJERS et al. (2007) suggest excluding the variety dimension from an index construction.[24] Nevertheless, it is important to note that not all relevant adequacy

[24] Similar to the adequacy dimension, the variety dimension is also negatively correlated with the moderation dimension because increased dietary diversity generally increases daily energy intakes and, thus, decreases the level of moderation. This is also true for food group variety with food groups categorized in carbohydrate foods, protein foods, and fat foods (e.g., LYLES et al., 2006; JAYAWARDENA et al., 2013).

indicators can possibly be considered in an index construction. This fact makes the inclusion of the variety dimension, especially of the within-food group variety of fruits and vegetables, beneficial as long as possible inter-correlation problems are accounted for. To conclude, while the adequacy, moderation, and balance dimensions ought to be included in a composite dietary quality index, including the variety component depends on the chosen number of relevant adequacy indicators in the index construction as well as the consideration of potential correlations between the variety dimension and certain adequacy or moderation components.

Index structure

The structure of the composite has to be determined based on the selected dimensions of dietary quality (NARDO et al., 2008). While composite scores may be useful to provide a first overview of dietary quality, it is beneficial for the analysis of dietary quality if the index construction is structured in a way that the composite is easily decomposable. Such a structure can be achieved if indicators are nested in sub-indices, which can be analyzed afterwards in more detail (NARDO et al., 2008). A nested structure of several sub-indices is preferable for analyzing a population's diet because an aggregation of several dimensions would inevitably lead to a loss of information and would make it more difficult to determine which area of the diet requires additional attention (THIELE et al., 2004; NARDO et al., 2008). In this line, KIM et al. (2003a) point out that indices, which simply aggregate adequacy and moderation components, make it impossible for the researcher to determine whether a low diet quality score is due to deficits or excesses in dietary intakes. THIELE et al. (2004) argue that the process of aggregating the adequacy and moderation dimensions would cancel out important information of deficient and excessive intakes. A further possibility of information loss might arise if certain determining factors are responsible for opposing values of sub-indices, i.e. sub-indices might be affected by the same influencing factors albeit in different directions (RÖDER, 1998; BURGGRAF et al., 2010; BURGGRAF et al., 2012). For example, increasing incomes are found to increase the Chinese consumption of animal products and fatty acids. An increased consumption of animal products possibly improves nutrient adequacy, for example in terms of iron intakes, while it is expected to worsen (saturated) fat moderation (POPKIN and DU, 2003; POPKIN and NG, 2007). Therefore, an aggregated index without explicitly provided sub-indices would make it considerably difficult to determine which area of a population's diet is actually in need of policy attention and which intervention strategies are most appropriate. To conclude, a nested structure of several sub-indices within the composite is desirable when assessing and analyzing a population's dietary quality for the following three reasons: (i) to avoid a loss of information when aggregating beneficial and critical aspects of the observed dietary quality; (ii) to enable separate empirical analyses regarding the effects of influencing factors on sub-components because some influencing factors might have opposite effects on index sub-components, resulting in possibly insignificant estimated effect sizes on overall diet quality; and (iii) to more effectively and efficiently target those aspects of a population's dietary quality by nutritional intervention programs that have been assessed as critical.

Despite the advantages of a nested structure, only the DQI-I-2003, the CH-DQI-2000, MAI-1999, and the MAI-2006 provide such a nested structure. The majority of indices (25 out of 49) do not have a nested structure but provide a specific order of their components, which makes the calculation of sub-indices at least easily achievable by an interested reader (e.g., HEI-2005, mMDS-2005).[25] The remaining reviewed indices provide their indicator scores in an order that is independent of the respective diet quality dimensions. Therefore, for more advanced applications, the interested reader would need to first order indicators according to their dimensions and then calculate sub-scores for a more meaningful analysis.

4.2.3.2 Indicator selection

Food group versus nutrient based indicators

In order to operationalize the selected dimensions of dietary quality, suitable indicators have to be selected. In his survey KANT (1996) differentiates between intake indicators based on food groups (or items), nutrients, or a combination of these two. Both approaches, which use food-based or nutrient-based indicators, have their strengths and weaknesses. The strength of food-based indicators is that interactions of nutrients within products are taken into account. For example, an indicator based on whole grain products considers the fact that the health effect of whole grains is not attributed to fiber alone, but also to other micronutrients, antioxidants, and non-nutritive dietary constituents such as phytoestrogens (WAIJERS et al., 2007). Yet considering the reviewed indices, it seems that these indices primarily focus on adequate fiber intakes, probably due to practicability. The weakness of food-based indicators is that an index based on food groups can result in an increase of food consumption without an important effect on dietary quality, especially when not controlled for moderation (LOEWIK et al., 1999). This is because if indicators are solely based on various food groups (e.g., vegetables, grains, fruits), resulting composites are probably unable to keep track of the large heterogeneity within the considered food groups (WAIJERS et al., 2007).

[25] Thereby, within this ordered structure, single indicators are sometimes already named with respect to the according dimension, such as adequacy of fruit and vegetable intakes, adequacy of whole grain intakes, etc.

To emphasize this problem, SEYMOUR et al. (2003) argue that although the intake of fruits and vegetables has been associated with a lower risk of cardiovascular disease and many diet-related cancers, fruits and vegetables vary in terms of how protective they are. For example, citrus fruits, tomatoes, and cruciferous vegetables are more highly associated with the reduced risk of many chronic diseases than is iceberg lettuce. This heterogeneity aspect makes an analysis at the food group level overly restrictive while the analysis at the extensive food item level is likely impractical. Furthermore, it is quite difficult for most food items to be classified into healthy foods (for adequacy aspects) and unhealthy foods (for moderation aspects), which is the common procedure in index constructions. For example, meat contributes significantly to an adequate level of iron intake. But frequent meat consumption, especially of processed meat, is assumed to be associated with an increased risk for colorectal cancer, cardiovascular diseases, diabetes, and chronic kidney diseases (MARMOT et al., 2007; CHOI and KIM, 2014; MARCKMANN et al., 2014; SAVVA and KAFATOS, 2014; TÁRRAGA LÓPEZ et al., 2014). Therefore, some indices consider the consumption of meat (including red and processed meat) in their adequacy dimension (HEI-1995, HEI-2005, and DGI-2002), while other indices consider them in their moderation dimension (MDP-2002, AHEI-2010, and aMED-2005).[26]

The problem arising from food group indicators is due to the fact that foods generally involve a combination of nutrients that are supposed to be healthy and nutrients that increase the risk of chronic diseases if consumed in excess. So it is essentially more appropriate to concentrate on the dosage of nutrient intakes and their effects on health rather than on foods per se. As VARIYAM et al. (1995) state, foods derive their value by supplying different amounts of nutrients necessary for the production of healthiness and taste. Hence, the concept of dietary quality can be directly related to nutrient intakes with respect to their recommended intake values. Therefore, the dimensions of dietary quality are best captured by nutrient-based indicators.

Considering the aforementioned strengths and weaknesses, the choice of food- or nutrient-based indicators should depend on the index purpose (see chapter 4.2.3.1). If the index has been primarily developed to guide an individual's

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[26] The same is true for milk products because the role of dairy products in regard to health outcomes is rather unclear (KIEFTE-DE JONG et al., 2014). The HEI-1995, the HEI-2005, and the HEI-2010 have included milk as adequacy components, whereas the MDS-2003 considers milk in the moderation dimension. According to WAIJERS et al. (2007) using a range to appraise the intake of meat and dairy seems most appropriate. However, this range is caused by the concurrent importance of the respective adequate and moderate nutrient intakes and, thus, can be much better controlled for by nutrient intakes.

diet in the context of public health promotion programs rather than monitoring a population's dietary quality, indicators should be food group-based because of its practicability and easier comprehensibility. If the applied index does not aim to have direct promoting power for public health but rather to assess the dietary quality of a population (or different strata of population), the dimensions of dietary quality should be directly captured by nutrient-based indicators. As a consequence, it seems appropriate that the HEI-1995, which was developed to assess Americans' dietary quality using broad food group terms, has been modified and improved by the use of more nutritional value-specific food indicators, resulting in the HEI-2005.

Despite the dependence on the index purpose, the choice of food group-based indicators is surely dependent on the type of data available. For example, if nutritionists employ only a short food frequency questionnaire, then food group-based indicators are much more appropriate than nutrient-based indicators due to less qualitative and quantitative information. Furthermore, in favor of practicability with regard to the number of selected indicators, it may also be recommendable to integrate a few particular food group-based indicators, even if the data source would allow nutrient-based indicators. In the thesis author's opinion, it is practicable to resort to specific food groups if the according food items meet the following criteria: (i) they are classifiable as either an adequacy or a moderation indicator without considerable overlaps; (ii) they are almost homogeneous in their nutrient contents rather than evolving problems of substantial heterogeneity within this food group; and (iii) they embrace a great number of highly relevant nutrients, antioxidants, and other components that would otherwise not be considered in the adequacy dimension. For example, whole grain products are easily classifiable as part of the adequacy dimension and embrace a great number of otherwise not considered highly health-relevant food components. Furthermore, empty-calorie products comprise a considerably wide range of highly energy-dense food products, which have to be moderated.[27] Thereby, the moderate-to-strong positive effect of whole grain and the moderate-to-strong negative effect of empty-calorie food groups on health are documented by STOODY et al. (2014). Hence, it is probably more effective and more efficient to assess the food group intake of empty-calorie products and whole grains than assessing all relevant nutrient intakes separately.

Overall diet quality indices that consist solely of food group indicators include the following: DBS-2009, DQS-2007, HFI-2001, mMDS-2014, rMED-2009, MS-2003, MSDPS-2009, MeDiet-2008, MEDAS-2013, and MAI-1999. By contrast, the

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[27] Empty-calorie foods indicate foods which are low in nutrient density of various vitamins and minerals but high in energy. Examples are products such as sweets, candy, alcohol, or white bread.

DQINB-1999 and the DQS-2002 contain nutrient indicators only. Generally, the majority of indices includes a combination of nutrient intake and food group intake indicators such as the DQI-I-2003, MDS-2002, and the AHEI-2010. Even if some indices consider primarily nutrient-based indicators, for practicability reasons they often use the whole grain food group in the adequacy dimension (see e.g., DQI-I-2003) and the empty-calorie food group in the moderation dimension (see e.g., DQI-I-2003, HEI-2010).

Specific indicators per diet quality dimension

Indicator selection has to be based on the latest epidemiologic evidence, actual nutrition standards, and on considerations of the country-specific situation (LOEWIK et al., 1999). For example, AGNOLI et al. (2013) define high intakes of six typical Mediterranean foods as beneficial for the Italian diet: pasta, typical Mediterranean vegetables, fruit, legumes, olive oil, and fish. Therefore, food-based intake indicators based on these food groups should be represented for an appropriate measurement of the adequacy dimension within their specific Italian index construction. In their internationally-oriented review, STOODY et al., (2014) present a strong-to-moderate evidence that the adequate intakes of fruits, vegetables, whole grains, nuts, legumes, and unsaturated oils, as well as low-fat dairy, poultry, and fish are associated with a decreased risk of several disease outcomes. Hence, the adequate intake of these food groups seems to be beneficial in diet quality index constructions for international applications.

Yet as mentioned above, in order to more appropriately cope with the heterogeneity of nutrient supply within these food groups, many index constructions are based on nutrient-based indicators. Considering adequate nutrient intakes, FITZGERALD et al. (2002) create their DQS-2002 for the Canadian population based on those 14 nutrients that are considered to be relevant within the newly released U.S./Canadian dietary reference intakes (DRI): protein, vitamins A, C, E, vitamin B-complex, phosphorus, magnesium, iron, zinc, and selenium. Furthermore, country-specific empirical results regarding nutrients that are at risk of deficient intakes should be considered when selecting adequacy indicators. For example, in their diet quality analysis MURPHY et al. (1996) apply those eight nutrients whose intakes fall below two-thirds of the corresponding U.S. reference intake values: protein, calcium, iron, thiamine, riboflavin, preformed niacin, vitamin A, and vitamin C.

According to STOODY et al. (2014), composite indices often consider the moderate intake of (processed) meat, sugar-sweetened foods and drinks, salt, (high-fat) dairy products, and alcoholic drinks as being healthy. Nevertheless, and in line with the above discussion of food- versus nutrient-based indicators, the detrimental effects of these moderation food groups (especially of high-fat dairy products) can be more appropriately analyzed when considering their embodied nutrients. Nutrients considered to be subject to moderate intake are generally total fat, saturated fatty acids, cholesterol, sodium, and sugar (WAIJERS et al., 2007). The intakes of these nutrients are considered as moderation indicators because of evidence-based associations between the intake of these nutrients and the incidence of chronic diseases. For example, SCHWAB et al. (2014) find evidence that saturated fat intake is positively associated with a fasting plasma/serum cholesterol concentration. Furthermore, these authors found a direct association between the intake of major saturated fatty acids and the incidence of diabetes, as well as evidence for a moderate association between total fat intake and body weight. Additionally, total fat intake and incidences of several types of cancer are significantly correlated (ARNADE and GOPINATH, 2006). Cholesterol intake is often considered to be a moderation indicator (STOODY et al., 2014). However, it is the type of fat in the diet that to a large extent determines the amount of cholesterol in the bloodstream; cholesterol in foods shows only a weak relationship with blood cholesterol levels (HU et al., 1997; HU et al., 1999; KRATZ, 2005).

Furthermore, according to common dietary guidelines, a positive association between sugar or salt intake and the risk of nutrition-related chronic diseases is generally assumed (NISHIDA et al., 2004; WORLD HEALTH ORGANIZATION, 2014). This association justifies sugar and salt intakes as compulsory moderation indicators. Nevertheless, salt and sugar indicators are often limited in practical applications because of problems with accurately determining salt and sugar intakes (HUIJBREGTS et al., 1997; GIBSON, 2005).[28] Alcohol, another possible indicator of the moderation dimension, is employed in many indices although the status of alcohol as part of nutrition rather than confounding lifestyle factors is critical (VON RUESTEN et al., 2010). Furthermore, the association between the level of alcohol intake and the respective health effect is not straightforward. In this line, some indicators clearly value a zero or low alcohol intake with the highest score, while others explicitly indicate an alcohol intake within a specific intake range

[28] Measurement of sodium intakes has its limitations in the level of accuracy (GIBSON, 2005; HUIJBREGTS et al., 1997). While it is possible to calculate nutrient intakes from given food quantities, this procedure is not meaningful for estimating salt contents due to person-dependent salting behaviors, which are fairly independent of the consumed food types. This is also true for individual sugar intakes. Besides this measurement problem of sugar intake, until now it is not clear which kind of sugar (free sugar, added sugar, for example in beverages, disaccharide, or fructose) is strongest associated with the incidence of chronic diseases (see e.g., WORLD HEALTH ORGANIZATION, 2003; KELLER et al., 2014; ESFAHANI et al., 2009). Furthermore, available epidemiological data are not sufficient to set an upper limit of sugar intake (MANN, 2012; WORLD HEALTH ORGANIZATION, 2014). In this line Russian authorities do not provide dietary guidelines regarding the upper intake level of sugar, while other guidelines vary in their upper intake limits considerably. Therefore, sugar intake is often considered in the form of empty-calorie foods intake.

(e.g., IMI-2011) with higher scores. Yet the majority of indices value alcohol intakes up to a specific upper tolerable intake level (e.g., one drink with portion size 10 g pure ethanol per day for women and two drinks with 20 g pure ethanol per day for men) with the highest score and intakes above these ranges with lower scores (e.g., DQI-SNR-2011). Finally, as WAIJERS et al. (2007) suggest, intakes of trans-fatty acids may be another indicator candidate for the moderation dimension since the risks associated with high intakes of trans fatty acids are generally acknowledged (see, e.g., DGAI-2005).

The overall balance considering the macronutrient proportionality of protein, fat, and carbohydrates is often addressed by a preferred intake range, i.e. the intake recommendations for these macronutrients are provided as a range including a lower and an upper intake level measured in energy percentage. For example, the majority of indices consider an optimal fat intake range (e.g., DGAI-2005, CH-DQI-2000, HDI-2011) and/or an optimal carbohydrate intake range (e.g., CH-DQI-2000, HDI-2011, DQS-2002). Only some indices address the macronutrient overall balance dimension by the intake ratio of carbohydrates, proteins, and fats rather than separate intake ranges (e.g., DQI-I-2003). While the macronutrient balance is mainly referred to by recommended intake ranges, the fatty acid balance is primarily referred to by intake ratios. A higher consumption of MUFA and PUFA has been reported to be associated with a reduced risk of cardiovascular diseases, while SFA consumption is generally considered to be unhealthy (SCHWAB et al., 2014; STOODY et al., 2014). Hence, several indices assess the ratio of PUFA to SFA (e.g., AHEI-2002), the ratio of MUFA to SFA (MDS-2003), or the ratio of the sum of MUFA and PUFA to SFA (e.g., mMDS-2005). The DQI-I-2003 considers the intake ratio of SFA to PUFA to MUFA. Only some dietary indices address the fatty acid balance dimension by the SFA or PUFA recommended intake range (e.g., HDI-1997). But despite the vast research efforts regarding the healthiest balance of fatty acids, many questions remain unresolved for nutritionists and should be the basis for future research, especially regarding the relative importance of PUFA and/or MUFA versus SFA (SCHWAB et al., 2014).

The variety of dietary patterns generally increases with the number of considered food units. Hence, variety is often operationalized by count measures, i.e. the number of different food units consumed during a certain period of time (DRESCHER, 2007). Thereby, food units counted toward the variety score of diet quality indices consist either of food items or broader food groups. Based on this distinction, three types of variety measures exist: the number of unique food groups reported (between-group variety); the number of unique food items within the food groups reported (within-group variety); and the total number of unique food items reported (overall variety; FOOTE et al., 2004). Thereby, it is often requested that food items from the fat and oil group should not be part of the variety measure since the variety of caloric-rich foods mostly increases energy intakes, and thus, the risk of overweight and obesity (McCrory et al., 1999).

4.2.3.3 Normalization and valuation function

Scaling procedure

Normalization of the reported data is required since dietary variables often have different measurement units. Operational forms of dietary variables include intake amounts in grams or liters, number of servings, and percentage of energy contributed (Kant, 2004). A normalization procedure can be achieved by ranking, standardization, linear scaling techniques, ordinal response scale assignments, etc. (Nardo et al., 2008). The selection of a suitable normalization method is critical with respect to eventual scale adjustments, transformation, or highly skewed indicators (Nardo et al., 2008). Thereby, it has to be considered that a normalization by the ordinal response technique results in less detailed scoring ranges and a loss of information, discriminating power, and predictive capacity of future health outcomes (Panagiotakos et al., 2006; Waijers et al., 2007; Wirt and Collins, 2009; Drake et al., 2011). Especially the dichotomization of an originally continuous variable into scores of zero and one discards most of the original information. For example, the aggregated HFI-2001 with a discrete scoring scale between zero and four (based on four dichotomous indicators) is not significantly associated with all-cause mortality after controlling for potential confounding factors (Osler et al., 2001). Furthermore, the HFI-2001 shows no statistically significant effect on the risk of coronary heart disease or cardiovascular mortality (Osler et al., 2001, 2002). Moreover, dichotomization results in different effect sizes and a moderate-to-substantial decrease in measurement reliability because the remaining information might be quite different from the original. Even the common argument that the categorized but formerly continuous variables would better represent the underlying latent categories breaks down under close examination, especially since categories are simply arbitrary.[29] Finally, it has to be mentioned that technically it is not appropriate to use ordinal measures of diet quality as the dependent variable in regression analysis. However, in behavioral science such a procedure is considered to be feasible if: (i) the theoretical concept being measured by an ordinal scale is assumed to be continuous; and (ii) the variable is normalized by at least five ordinal equidistant categories (Johnson and Creech, 1983; Zumbo and Zimmerman, 1993).

In conclusion, if the index construction aims to assess dietary quality with regard to health outcomes, more detailed scoring ranges are preferable because they increase discriminating ability and predictive power of future health outcomes. For this reason, the DQI-1994 with a discrete scoring scale from zero for the

[29] For a more detailed discussion, see MacCallum et al. (2002).

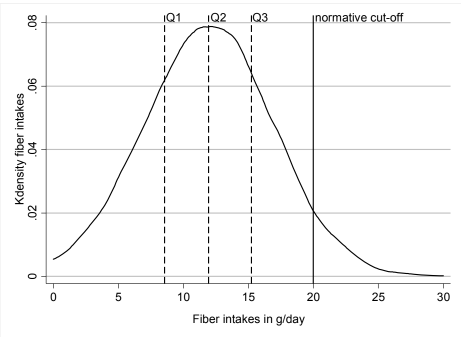
healthiest diet to 16 for the least healthy diet has been revised by the DQI-R-1999 with a more detailed scoring scale from zero to 100, with 100 indicating the healthiest diet pattern. Yet despite these associations, a large number of indices are still exclusively based on dichotomous or non-dichotomous ordinal indicators (e.g., DQI-I-SNR-2011, DQS-2002, HDI-2013, HDS-2005, and MDS-2003). Other indices are solely based on metric indicators normalized by linear scaling technique (e.g., GFPI-2010, HEI-2005). But the majority of indices contain a mixture of both metric and ordinal indicators (e.g., DQI-R-2003 and DQI-I-2003).

Cut-off values

Cut-off values to normalize data should be country-specific (or region-specific) because country-specific recommendations use the best scientific knowledge available for the population under scrutiny (Kim et al., 2003a). Furthermore, cut-off values should be age- and gender-specific or should otherwise take into account different energy needs, except for variables such as fat intakes, which are often already expressed in energy percentages. This is because individuals with higher physiological energy and nutrient needs tend to consume more foods. With this greater food consumption, these individuals would more easily meet equally assessed adequate nutrient intake cut-off values than individuals with lower energy and nutrient needs (Drake et al., 2011). For example, the actual DRIs recommend higher energy intakes and higher intakes of several nutrients (see e.g., vitamin C, thiamin, riboflavin, magnesium, zinc) for men aged between 31-50 years than for women of the same age. If adequate nutrient intake cut-off values are equally set, for example at the women's adequate intake levels, then men would more easily achieve these rather incorrect (i.e. too low for men) intake levels although their nutrient intakes are in fact rather suboptimal. Therefore, the HEI-1995 provides cut-off values for five different energy intake levels (Kennedy et al., 1995). Along these lines, the MAI-2006 adjusts cut-offs to daily recommended energy intakes for men and women. The CH-DQI-2000 provides separate standards for higher and lower intake categories. Other indices apply some density measures to account for different energy intakes, such as the HEI-2005, DQI-SNR-2011, or the MAI-1999.

Aside from these differences, applied cut-off points differ between normative cut-offs and percentile cut-offs. Normative cut-offs are derived from current evidence or the best knowledge available regarding the diet-health relationship. These cut-offs are derived to meet the nutrient requirements of healthy individuals in a particular life stage and gender group. For example, Fitzgerald et al. (2002) use cut-off values derived from estimated average requirement recommendations, i.e. the average daily nutrient intake value, to meet the requirements of 50 % of the healthy individuals in a particular life stage and gender group. In general, normative cut-off values of vitamins and minerals are based upon the availability of recommended intake values such as the recommended dietary allowances (RDA), which are supposed to be set at two standard deviations above the estimated average requirement (FOOD AND NUTRITION INFORMATION CENTER, 2014).[30] For moderation indicators, tolerable upper intake levels (UI) are generally employed as normative cut-off values in index constructions. A tolerable upper intake level is the highest level of daily nutrient intakes that is likely to pose no risk of adverse health effects to almost all individuals in the general population.[31] For the overall balance dimension, cut-offs such as the acceptable distribution ranges (DR) are often used with the intakes specified as a percentage of total energy intakes (FOOD AND NUTRITION INFORMATION CENTER, 2014). However, when employed for an ordinal or even dichotomized indicator, normative cut-offs have the disadvantage that they may lose discriminatory power when almost all subjects fall below or above the normative cut-off (DRAKE et al., 2011). This problematic issue is displayed in Figure 8. Within this fictive fiber distribution, 95 % of the observed individuals would fail the normative Russian cut-off value, i.e. they have a fiber intake below the proposed adequate Russian fiber intake value of 20 g/day (see TUTELJAN et al., 2008). Considering a dichotomous indicator, 95 % of the observed population would receive a score of zero, while only 5 % would receive a score of one, indicating marginal discriminatory power of the normative cut-off value in this example.

Figure 8: Fiber intake Kernel density function of a fictive sample with N=10,000



Source: Own presentation.

Note: The dashed lines Q1, Q2, Q3 indicate the first quartile (25th percentile), second quartile (median), and the third quartile (25th percentile), respectively, while the solid vertical line indicates the normative cut-off value at the adequate intake value.

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30 Adequate intake levels (AI) are applied to compensate for missing nutrient RDAs. They are determined as approximations of nutrient intake by a group (or groups) of healthy people.

31 In order to emphasize the importance of moderation in total fat intake, the DQI-I-2003 uses even more stringent cut-off values than those found in other dietary indices (KIM et al., 2003a).

In contrast to normative cut-offs, percentile cut-offs (e.g., median or quartile cut-offs) simply indicate the intake values below which a given percentage of observations in a group of observations fall. Therefore, percentile cut-offs such as the often-used median cut-off may not be related to healthy intake levels (WAIJERS et al., 2007). Yet, despite this weak diet-health relationship, indices with dichotomous scaled indicators generally use median cut-offs to assure significant discriminatory power (e.g., MDS-2003 and MDS-2011). In Figure 8, the median cut-off of 11.95 g/day is much lower than the recommended adequate intake value of 20 g/day, but it discriminates the observed fictive distribution better than the normative cut-off value. Even more discriminatory power is provided using quartile cut-off values. Nevertheless, if the intake values get normalized proportionally with regard to the normative cut-off levels, resulting in metric scaled indicators (e.g., a score of 0.75 for a 75 % achievement of the adequate fiber intake value), then normative cut-off values provide the most sufficient discriminatory power regarding the healthiness of the respective intake levels. In conclusion, normative cut-offs ought to be preferred for continuous scales if intake recommendations are available. If these are not available, percentile cut-offs with at least three or more ranks on an ordinal scale should be used.

In line with these considerations, the majority of metric scaled indices employ mainly normative cut-offs (e.g., DQI-2003, AHEI-2010), while the majority of ordinal scaled indices generally employ median cut-offs (e.g., MDS-2003, MDS-2011). For example, the mMDS-2005 uses median cut-offs except for alcohol intake, which is scored according to a normative cut-off. Examples of an index with exclusively dichotomous but normative cut-offs are the MEDAS-2011 and MEDAS-2013. The HFNI-2006 also chooses dichotomous normative cut-offs, except for beta-carotene. Furthermore, the DGAI-2005 chooses normative cut-offs except for saturated fat intake in order to increase discriminatory power since normative cut-offs for saturated fat intakes are failed by almost all Americans (FOGLI-CAWLEY et al., 2006).[32] If indicators are categorized by three ranks, cut-offs are often based on the tertiles of the indicator distribution. For example, the rMED-2009 uses cut-offs based on tertiles except for a normative cut-off for alcohol. Other ordinal indices choose both normative and percentile cut-offs. For example, the Med-DQI-2000 uses normative cut-offs according to recommended intake levels if available. If evidence-based recommended intake levels are not available, the Med-DQI-2000 uses tertile cut-offs (GERBER et al., 2000).

[32] The DQI-SNR-2011 chooses normative cut-offs except for SFA and dietary fiber due to missing recommended intake levels for total fiber and actual SFA intake levels not close to the recommended intake level of SFA.

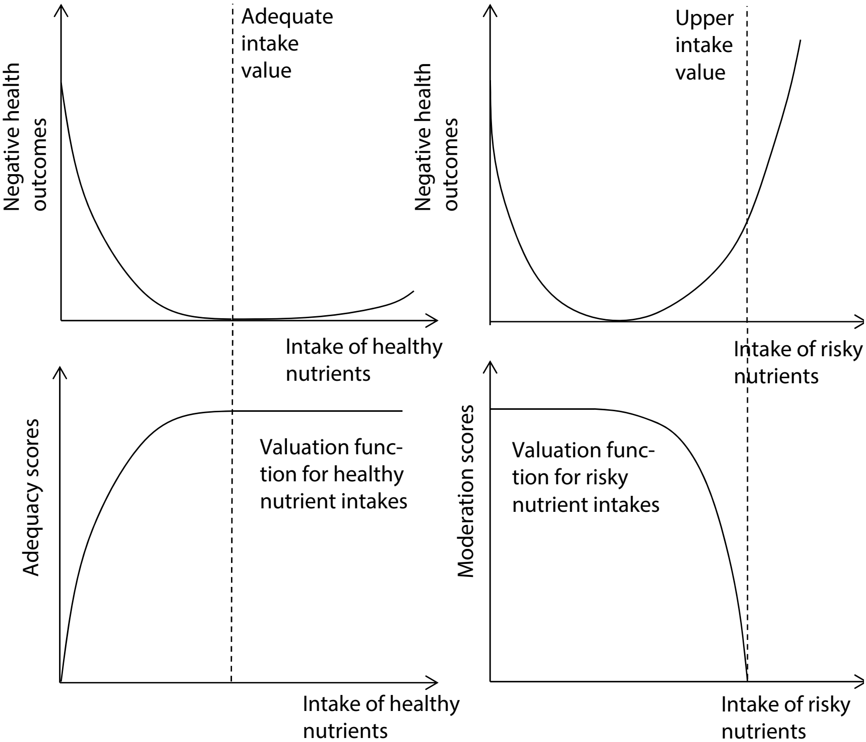
Valuation function

Normalization procedures should take into account the objectives of the composite indicator through a valuation function because the intake of several nutrients and foods is only an instrument that values the health impact of this nutrient or food intake (ANAND and SEN, 2000). Therefore, a valuation function has to assign each indicator a transformation function, which represents the association between the (normalized) indicator value and its assumed health impact value. Therefore, a specific valuation function is always necessary if it is assumed that the marginal health impact of a specific intake indicator varies with its absolute amount. Such an association would ask for a valuation formula with increasing or diminishing returns of this indicator on human health.

Epidemiological research often suggests a U-shaped association between dietary patterns and health outcomes (e.g., IQBAL et al., 2008). This U-shaped function can also be shown for the direct relationships between different nutrient intakes and various health outcomes, for example for iron (PRÁ et al., 2011; MARTINSSON et al., 2014), folate (CHUANG et al., 2011), fat and protein (BASIRI et al., 2009; GUO et al., 2013), alcohol (FEART et al., 2013), retinol (WU et al.; 2014), and sodium (GRAUDAL, 2014). Because of these U-shaped associations, it seems appropriate to assume nonlinear valuation functions. For example, the valuation function of vitamin and mineral intake indicators might be specified as being increasing with diminishing marginal health products until the adequacy cut-off level (e.g., RDA) is reached. After the adequacy cut-off level, valuation scores are often restricted to a maximal achievable score. By contrast, the valuation function of a fat intake indicator might be specified as being decreasing with diminishing marginal moderation scores.[33] Such plausible associations between different nutrient intake values, their respective health effects, and hence appropriate indicator scores are displayed in Figure 9. However, for existing diet quality indices the choice of a specific valuation function is often not explicitly described. In fact, the observed indicators often assume constant health returns yielding a proportional valuation function without further explanation. But certainly more future work on this topic is necessary.

[33] Healthy nutrient valuation scores are often restricted to a maximal achievable score because vitamin and mineral intakes of a diet without supplements are generally assumed to be below the unhealthy intake levels. For fat intakes, it is generally assumed that intake levels of a normal diet are above the lower border of the acceptable intake range.

Figure 9: Association between nutrient intakes and possible indicator scoring values



Source: Own presentation.

Note: For adequacy (moderation) scores, it is assumed here that intakes are generally not above (below) the higher (lower) boarder of a respective range of acceptable intakes.

Additionally, as mentioned in chapter 4.2.3.2, the variety dimension of diet quality indices is generally assessed by count measures. However, count measures count food items regardless of their respective intake shares. Therefore, GOLLOP and MONAHAN (1991) state that the health effects of food variety are not only determined by the number of food units but also by their respective distribution.[34] Considering distribution aspects, which is appropriate especially in the case of

[34] GOLLOP and MONAHAN (1991) also consider the heterogeneity of food items regarding the difference of their product features. Yet, for practicability, differences of food product features are more easily subsumed by the consideration of within-food group variety.

within-group variety, variety scores will increase if food items are more equally consumed rather than being more concentrated. For example, a simple count measure would assign the same scores to the consumption of broccoli and iceberg lettuce within the vegetables group with either consumption shares of 50 % and 50 % or consumption shares of 5 % and 95 %.[35] Such a count measure would disregard the fact that the more concentrated vegetable consumption is nearly exclusively composed by iceberg lettuce and less appropriate. In order to consider distribution aspects, which seems to be especially appropriate for the within-group variance (e.g., for the fruits and vegetables group), there exists a broad pool of possible approaches, such as the Berry Index (BI) of BERRY (1975), the Gollop-Monhan-Index (GMI) of GOLLOP and MONAHAN (1991), and the Healthy Food Diversity-Index (HFD-I) of DRESCHER (2007).[36] Yet despite these approaches, variety aspects in overall dietary index constructions are generally operationalized by simple count measures.

4.2.3.4 Aggregation technique

After normalization and valuation of the indicators, indicators have to be combined into the composite. Since the compensability of indicators is generally assumed, the exclusive aggregation technique in existing diet quality index constructions is a linear aggregation. Applying such a linear aggregation technique, the most naive method of constructing a composite index is obtained with equally weighted indicators (NARDO et al., 2008). This method yields a robust composite index, but validity could be suboptimal if some indicators or dimensions are more effectively related to future health outcomes than others. Furthermore, NARDO et al. (2008) point out that if indicators are grouped into sub-indices, which are further aggregated into the composite, then equal weighting of the indicators implies an unequal weighting of the sub-indices given that the amount of indicators per sub-indices differs. For example, the MDS-2004 consists of the following equally weighted indicators: one indicator regarding the fatty acid balance; five adequacy indicators; and two moderation indicators. Therefore, the MDS-2004 results in an indirect relative weighting of the balance, adequacy, and moderation dimension of 12.5 %, 62.5 %, and 25 %, respectively. Regarding potential inter-correlation between indicators, the question arises whether single indicators in fact measure different aspects of the construct and therefore bear equal weights. If this is not the case, it is permissible to give positively correlated indicators lower weights.

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[35] Sometimes a minimum intake of at least a half serving size per day is requested for a food item to be accounted in the variety score.

[36] For a comprehensive overview, see DRESCHER (2007).

If weights shall be assigned to the indicators of the composite, weights can be determined either on the basis of subjective expert information or from the application of some statistical method. As KATZ et al. (2009) point out, weights have to relate variations in nutrient intake levels to population level variations in health outcomes, for example by theoretical considerations or by correlation factors of those index components most strongly associated with health outcomes. Furthermore, those indicators, which are highly correlated with each other, should get lower weights in order to correct their heavier contribution to the (sub-)index score. However, as DRAKE et al. (2011) point out, determining the acceptable level of correlation between indicators is highly subjective and future research regarding this issue is necessary. For example, HUIJBREGTS et al. (1997) exclude the macronutrient indicators carbohydrate and fat intake in order to avoid correlations with the selected protein intake indicator. DRAKE et al. (2011) adjust the DQI-SNR-2011 for inter-correlation problems by excluding MUFA from the index because of a strong correlation between SFA and MUFA (r=0.65). Nevertheless, they do not adjust the DQI-SNR-2011 for the strong correlation between dietary fiber intake and the fruit and vegetable consumption (r=0.63). Furthermore, in the DGAI-2006 the two indicators fiber intake and percentage of whole grains from total grain intake are equally weighted, although both indicators are possibly highly correlated since whole grains are a major source of fiber intakes.

The majority of hitherto existing diet quality indices use equal weighting (e.g., HEI-1995) to reduce conscious interferences to a minimum and as a consequence of the lack of sufficient information. However, in case weights are assigned within the pool of existing diet quality indices, they are exogenously attributed on the basis of some subjective expert information (e.g., DQI-I-2003, MEDAS-2013).[37] Participatory methods that incorporate various stakeholders such as experts, citizens and politicians are feasible when there is a well-defined basis for a national policy (MUNDA, 2005a, 2005b). For example, DOMÍNGUEZ et al. (2013) weight each item of the MEDAS by evidence-based contribution factors of each component to coronary heart diseases. KIM et al. (2003a) deduce weights for their adequacy, moderation, overall balance and variety dimension of the DQI-I-2003 based on actual literature. However, KIM et al. (2003a) failed to establish a documentary method, which would make the rationale for their weighting system more controllable by inter-subjective comprehensibility and verifiability (see BOHNSACK et al., 2007). Answering a written follow up, Kim argues that the rationale for the weighting system across the four major categories of the DQI-I-2003 was mainly based on a literature review but no empirical testing was done to determine the

[37] The Overall Nutritional Quality Index by KATZ et al. (2009) for food labelling applies theoretically derived weights for all indicators.

weighting system. Yet determining a favorable weighting approach would improve the rigor of future index applications (STOODY et al., 2014).

4.2.4 Overview of diet indices and their construction criteria

Utilizing the above discussion for a comparison, Table 9 provides an overview of existing composite indices of dietary quality considering theoretical background, indicator selection, normalization, and aggregation techniques. According to the above discussion, preferable features of dietary indices, which have to measure dietary quality with regard to future health outcomes, are shaded grey. Thereby, the inclusion of the adequacy, moderation, and balance dimensions is identified as being a preferable feature of dietary quality constructions in order to cope with the multidimensional character of dietary quality. Furthermore, a nested index structure is favored with indicators based on nutrients or a combination of nutrients and some specific food groups. In order to increase discriminatory power, metric or a combination of metric and ordinal scaled indicators are considered to be more beneficial than exclusively dichotomous indicators. Still, the choice of metric scaling is surely dependent on the intake data at hand. Finally, a weighting system is preferable, which has to take into account different diet-health relationships and inter-correlation problems of the index components in an objective and intersubjective comprehensible manner. Using the summarizing toolbox of Table 9, nutritionists are now able to choose an appropriate index construct considering the most suitable construction criteria, the particular target region, and the data base at hand.

Table 9: Index construction criteria

Index	Theoretical Fundament				Dimensions				Dimensional structure			Indicator selection				Normalization					Aggregation technique	
	Recommendation	Mediterranean diet	Additional evidence	Target region (analyzed region)	Adequacy	Moderation	Balance	Variety	Nested	Ordered	Not ordered	Data base	Food groups	Nutrients	both	Dichotomous	Ordinal	Metric	Ordinal/metric	Scoring range	Weighted	Equally weighted
D-HDI-2003 (Dynesen et al., 2003)	x			Denmark	x	(x)				x		13-item short FFQ	x				x			[0;15]		Indicators
DQI-1994 (Patterson et al., 1994)	x			USA	x	x					x	24-hour recall+2 day food record			x		x			[0;16][b]	by number of indicators per recommendation	
DQI-2003 (Seymour et al., 2003)	x		x	USA	x	x					x	68-item FFQ			x		x			[0;16][b]	by number of indicators per recommendation	
DQI-R-1999 (Haines et al., 1999)	x			USA	x	x		x		x[g]		24-hour recall method			x				x	[0;100]		per main component
DQI-R-2003 (Newby et al., 2003)	x			USA	x	x		x		x[g]		FFQ			x				x	[0;100]		per main component
DQI-I-2003 (Kim et al., 2003a)	x		x	Worldwide	x	x	Ratios CH/PR/FA, PUFA/MUFA/SFA	x	x			24-hour recall method			x				x	[0;100]	x	

Index	Theoretical Fundament				Dimensions				Dimensional structure			Indicator selection				Normalization					Aggregation technique	
	Recommen-dation	Mediterranean diet	Additional evidence	Target region (analyzed region)	Adequacy	Moderation	Balance	Variety	Nested	Ordered	Not ordered	Data base	Food groups	Nutrients	both	Dichotomous	Ordinal	Metric	Ordinal/metric	Scoring range	Weighted	Equally weighted
DQI-I-SNR-2011 (DRAKE et al., 2011)	x			Sweden	x	x	PUFA range				x	Modified DHQ			x	x				[0;6]		indi-cators
CH-DQI-2000 (STOOKEY et al., 2000)	x			China	x	x	FA range CH range	x	x			24-hour recall method			x				x	[-74;56]	indicators	
Med-DQI-2000 (GERBER et al., 2000)	x		x	South France	x	x				x		FFQ			x		x			[0;14][b]		indi-cators
MED-DQI-f-2000 (GERBER et al., 2000)	x		x	South France	x	x				x		FFQ			x		x			[0;16][b]		indi-cators
Med-DQI-2006 (GERBER 2006)	x		x	Mediter-ranean region (France)	x	x				x		FFQ			x		x			[0;14][b]		indi-cators
DQS-2002 (FITZGERALD et al., 2002)	x			Canada/ USA (Canada)	x	x	CH range			x		24-hour recall method		x		x				[0;17]		indi-cators
DQS-2007 (TOFT et al., 2007)	x		x	Denmark	x	x				x		48-item FFQ	x				x			[0;12]		indi-cators
DBS-2009 (KANT et al., 2009)	x			USA	x	x				x		FFQ	x				x			[0;36]		indi-cators

Index	Theoretical Fundament				Dimensions				Dimensional structure			Indicator selection				Normalization					Aggregation technique	
	Guide-lines/recomme	Mediterranean diet	Additional evidence	Target region (analyzed region)	Adequacy	Moderation	Balance	Variety	Nested	Ordered	Not ordered	Data base	Food groups	Nutrients	both	Dichotomous	Ordinal	Metric	Ordinal/metric	Scoring range	Weighted	Equally weighted
DGAI-2005 (FOGLI-CAWLEY et al., 2006)	x			USA	x	x	FA range				x	FFQ			x		x			[0;20]		indi-cators[a]
DQINB-1999 (LOEWIK et al., 1999)	x			Nether-lands	x	x						2d food records		x		x				[0;5]		indi-cators
GFPI-2010 (VAN RUESTEN et al., 2010)	x			Germany	x	x	PR and FA products with U-shaped association			x		FFQ	x					x		[0;110]		indi-cators
HDI-1997 (HUIJBREGTS et al., 1997)	x			(Europe)	x	x	PR range PUFA range				x	Cross check DHQ			x	x				[0;9]		indi-cators
HDI-2011 (CADE et al., 2011)	x			(UK)	x	x	FA range CH range PR range PUFA range				x	FFQ			x	x				[0;10]		indi-cators
HDI-2013 (BERENTZEN et al., 2013)	x			(Nether-lands)	x	x	PR range PUFA range				x	FFQ			x	x				[0;7]		indi-cators
HDS-2005 (MAYNARD et al., 2005)	x			UK	x	x	PR range CH range PUFA range				x	FFQ			x	x				[0;12]		indi-cators
HEI-1995 (KENNEDY et al., 1995)	x			USA	x	x		x		x		24-hour recall+ 2d food record			x			x		[0;100]		indi-cators
HEI-2005 (GUENTHER et al., 2008)	x		x	USA	x	x				x		24-hour recall method			x			x		[0;100]	indicators	

Index	Theoretical Fundament				Dimensions				Dimensional structure			Indicator selection				Normalization					Aggregation technique	
	Guide-lines/recomme	Mediterranean diet	Additional evidence	Target region (analyzed region)	Adequacy	Moderation	Balance	Variety	Nested	Ordered	Not ordered	Data base	Food groups	Nutrients	both	Dichotomous	Ordinal	Metric	Ordinal/metric	Scoring range	Weighted	Equally weighted
HEI-2010 (GUENTHER et al., 2013)	x		x	USA	x	x	Ratio (PUFA+ MUFA)/ SFA			x		Not speci-fied			x			x		[0;100]	indicators	
HEI-f-2000 (MCCUL-LOUGH et al., 2000a, 2000b)	x			USA	x	x		x		x		FFQ			x			x		[0;100]		indi-cators
AHEI-2002 MCCUL-LOUGH et al., 2002)	x		x	USA	x	x	Ratio PUFA/SFA				x	FFQ			x			x[d]		[2.5;87.5]		indica-tors[d]
AHEI-2010 (CHIUVE et al., 2012)	x		x	USA	x	x					x	FFQ			x			x		[0;110]		indi-cators
C-HEI-2005 (SHATENSTEIN et al., 2005)	x			Canada	x	x		x		x		FFQ			x			x		[0;100]		indi-cators[c]
HFI-2001 (OSLER et al., 2001)	x			(Denmark)	x	x				x		26-item short FFQ	x			x				[0;4]		indi-cators
HFNI-2006 (BAZELMANS et al., 2006)	x			Belgian	x	x	PR range CH range PUFA range				x	1d food record			x	x				[0;8]		indi-cators
IMI-2011 (AGNOLI et al., 2011)		x		Mediter-ranean region (Italy)	x	x				x		FFQ	x			x				[0;11]		indi-cators

Index	Theoretical Fundament				Dimensions				Dimensional structure			Indicator selection				Normalization					Aggregation technique	
	Guide-lines/recomme	Mediterranean diet	Additional evidence	Target region (analyzed region)	Adequacy	Moderation	Balance	Variety	Nested	Ordered	Not ordered	Data base	Food groups	Nutrients	both	Dichotomous	Ordinal	Metric	Ordinal/metric	Scoring range	Weighted	Equally weighted
MAI-1999 (Alberti-Fidanza et al., 1999)		x		Mediter-ranean region (Italy)	x	x			x			DHQ + weighted record method	x						x	Not provi-ded		per food groups
MAI-2006 (Knoops et al., 2006)		x		(Europe)	x	x			x			DHQ			x			x		Not normali-zed		indi-cators
MEDAS-2011 (Schröder et al., 2011)		x		Mediter-ranean region (Spain)	x	x					x	MEDAS-question-naire	x			x				[0;14]		indi-cators
MEDAS-2013 (Domínguez et al., 2013)		x		Mediter-ranean region (Spain)	x	x					x	FFQ	x			x				[0;13]	indicators	
MDS-1995 (Trichopou-lou et al., 1995)		x	x	Mediter-ranean region (Greece)	x	x	Ratio PUFA/SFA				x	FFQ			x	x				[0;8]		indi-cators
MDS-2002 (Haveman-Nies et al., 2002)		x	x	Western countries (Europe)	x	x	Ratio MUFA/SFA				x	Modified DHQ			x	x				[0;7]		indi-cators
MDS-2003 (Trichopou-lou et al., 2003)		x	x	Greece	x	x	Ratio MUFA/SFA			x		FFQ			x	x				[0;9]		indi-cators
MDS-2004 (Knoops et al., 2004)	x	x		Western countries (Europe)	x	x	Ratio MUFA/SFA				x	DHQ			x	x				[0;8]		indi-cators

Index	Theoretical Fundament				Dimensions				Dimensional structure			Indicator selection				Normalization					Aggregation technique	
	Guide-lines/recomme	Mediterranean diet	Additional evidence	Target region (analyzed region)	Adequacy	Moderation	Balance	Variety	Nested	Ordered	Not ordered	Data base	Food groups	Nutrients	both	Dichotomous	Ordinal	Metric	Ordinal/metric	Scoring range	Weighted	Equally weighted
MDS-2011 (Cade et al., 2011)		x	x	(UK)	x	x	Ratio MUFA/SFA			x		FFQ			x	x				[0;10]		indi-cators
mMDS-2005 (Trichopou-lou et al., 2005)		x		Non-mediter-ranean region (Europe)	x	x	Ratio (MUFA+ PUFA)/ SFA			x		FFQ+ 7d or 14d food record			x	x				[0;9]		indi-cators
mMDS-2014 (Yang et al., 2014)		x		Non-mediter-ranean region (USA)	x	x					x	Lifestyle question-naire with 15-items on diet	x				x			[0;42]		indi-cators[c] (+ wine scores)
aMED-2005 (Fung et al., 2005)		x	x	(USA)	x	x	Ratio MUFA/SFA				x	FFQ			x	x				[0;9]		indi-cators
MDP-2002 (Sánchez-Villegas et al., 2002)		x	x	Mediter-ranean region (Spain)	x	x	Ratio MUFA/SFA			x		FFQ			x			x		[0 %; 100 %]		indi-cators
MeDiet-2008 (Sánchez-Taínta et al., 2008)		x		Mediter-ranean region (Spain)	x	x					x	14-item MeDiet question-naire	x			x				[0;14]		indi-cators
MS-2003 (Goulet et al., 2003)		x		Worldwide (French Canadians)	x	x				x		FFQ	x				x			[0;44]		indi-cators
MSDPS-2009 (Rumawas et al. 2009)		x		Non-Mediter-ranean region	x	x					x	FFQ	x					x[f]		[0;100]		indi-cators

Index	Theoretical Fundament				Dimensions				Dimensional structure			Indicator selection				Normalization					Aggregation technique	
	Guide-lines/recomme	Mediterranean diet	Additional evidence	Target region (analyzed region)	Adequacy	Moderation	Balance	Variety	Nested	Ordered	Not ordered	Data base	Food groups	Nutrients	both	Dichotomous	Ordinal	Metric	Ordinal/metric	Scoring range	Weighted	Equally weighted
				(USA)																		
RCI-2008 (MAZZOCCHI et al., 2008)	x			(World-wide)	F&V	x	FA range PR range CH range			x		FAO statis-tics			x			x		[0;1]	two index variants	one index variant
rMED-2009 (BUCKLAND et al., 2009)		x		Mediter-ranean region (Spain)	x	x				x		DHQ	x				x[e]			[0;18]		indi-cators

Note: The following abbreviations are applied: FA fat, CH carbohydrates, PR proteins, SFA saturated fatty acids, MUFA monounsaturated fatty acids, PUFA polyunsaturated fatty acids; F&V fruits and vegetable group, FFQ food frequency questionnaire, DHQ diet history questionnaire, and FAO Food and Agriculture Organization of the United Nations. The sign x indicates a fit with the respective construction criterion. For balance only ranges of fat, protein, or carbohydrates as well as ranges of saturated fatty acids, monounsaturated fatty acids or polyunsaturated fatty acids are considered. Recommendations include also recommendations by dietary guidelines or food pyramids.

[a] This is valid except for half weights on low fat dairy and low fat meat indicators.

[b] Higher scores indicate less healthy diets.

[c] This is valid except for combined fruit and vegetable group with a doubled score.

[d] This is valid except for multivitamin use.

[e] This is valid except for alcohol.

[f] This is valid except for olive oil.

[g] Thereby, total fat, saturated fat and cholesterol intakes are not part of a pre-defined moderation sub-index.

As Table 9 shows, none of the observed Mediterranean diet quality index constructions seem to properly conform to the theoretical soundness and aforementioned methodological requirements of an appropriate diet quality index construction. Indices measuring Mediterranean dietary quality are generally not nested, have mainly food-based indicators, use (with few exceptions) mainly percentile cut-offs, and often have a considerably low scoring range. Some of these critiques may be explained by data restrictions because Mediterranean diet quality index constructions are often based on the intake data from (short) food frequency questionnaires.

For the assessment of U.S. dietary patterns, which can surely be adjusted to other western countries considering country-specific intake recommendations, the HEI-2010 meets the aforementioned preferable key issues of index construction. The HEI-2010 considers the adequacy, moderation, and balance dimension within an ordered index structure. Based on national dietary guidelines but also additional expert knowledge, the weighted metric food and nutrient indicators of the HEI-2010 sum up to a metric scoring range of [0;100]. However, it would be more beneficial if the ordered structure of the HEI-2010 is enhanced by a nested structure with predefined sub-indices. Furthermore, it has to be noted that this index does not consider a moderate intake of total fat because some types of fatty acids are assumed to be more important in influencing the risk of cardiovascular diseases than the total fat intake (GUENTHER et al., 2013).

For the purpose of this thesis, the summarizing toolbox of Table 9 suggests that the DQI-I-2003 seems to be most appropriate for analyzing transition countries (BURGGRAF et al., 2014a). In contrast to other indices, which have been created due to diet-related concerns of developed countries such as the USA and Western European countries, the DQI-I-2003 is especially appropriate for Russian circumstances because it not only accounts for dietary aspects in relation to chronic diseases but also for problems of deficient nutrient intakes. The DQI-I-2003 therefore provides "a global tool for monitoring healthfulness of diet and for exploring aspects of diet quality related to the nutrition transition" (KIM et al., 2003a). Since not only nutrition-related chronic diseases but also several nutrient deficiencies (see chapters 3.3 and 3.4) are present within the Russian population, the DQI-I-2003 is considered to be the most suitable measure of the Russians' dietary healthfulness.

The DQI-I-2003 is derived from international and national nutrient guidelines and the food guide pyramid (KIM et al., 2003a). It also considers advantages and disadvantages of the DQI-1994, DQI-R-1999, and the CH-DQI-2000. As mentioned in section 4.2.3, the DQI-I-2003 monitors the healthfulness of a diet by assessing four separate sub-indices: (i) variety of the foods consumed, (ii) adequacy of the nutrient intakes, (iii) moderation of foods and nutrients that are predicted to cause chronic diseases, and (iv) overall balance of the macronutrient and fatty acid sources of the diet. For each dimension, as well as for each component within these categories, weighted scores are allocated and summed up, resulting in the total DQI-I-2003. The DQI-I-2003 describes a population's diet quality as an aggregated diet quality measure and, at the same time, the nested structure of the DQI-I-2003 enables the researcher to pinpoint exactly those forms of nutritional deficiencies that need to be improved most (see e.g., BURGGRAF et al., 2012 and BURGGRAF et al., 2014a). Hence, this index is able to provide valuable information for public nutritional education programs (KIM et al., 2003a). Furthermore, this index is very detailed with a mixture of metric and ordinal scaled indicators, which sum up to a total scoring range between zero points and 100 points. Finally, indicator selection and cut-off points are based on dietary guidelines and additional epidemiological evidence.

Despite its various advantages, some construction aspects of the DQI-I-2003 give reason for concern. For instance, for the calculation of the DQI-I-2003 a number of metrically reported nutrition variables need to be normalized by a three-rank ordinal response technique, which means a considerable loss of information and discriminatory power. Furthermore, the development of weights is not intersubjectively comprehensible and verifiable. Finally, the DQI-I-2003 considers a count measure of the variety dimension, ignoring the distributional aspect of dietary variety and potential problems of double-counting adequacy aspects (BURGGRAF et al., 2014a).[38]

4.3 RUSSIAN DIETARY QUALITY

4.3.1 Assessment of the modified DQI-I for Russia

Against the background of the discussion provided in chapter 4.2.4, the DQI-I-2003 is employed for the empirical analysis of Russian dietary quality. Nonetheless, the DQI-I-2003 has to be slightly modified in order to (i) consider evidenced problematic areas of nutrition in Russia, as well as the latest Russian official recommendations, (ii) deal with metric scores for all indicators as well as for the four subscores, and (iii) enhance the original variety count measure by distributional aspects of the within-group variance. Finally, in this inquiry the modified DQI-I-2003 is represented by a formula because an index formula contains mathematical statements on standardization, evaluation and aggregation of the indicators. It thereby allows an analysis of the change in diet quality caused by marginal

[38] Chapter 4.2 results from the author's contribution to the research project of the European network titled Determinants of Diet and Physical Activity (DEDIPAC) Knowledge Hub (KH), which is financed by the German Federal Ministry of Education and Research. In this regard, chapter 4.1 and 4.2 are also part of a manuscript prepared for soon publication together with the co-authors Dr. Ramona Teuber, Dr. Stephan Brosig, and Dr. Toni Meier.

changes in indicator values. Because the weighting system of the DQI-I-2003 is not inter-subjectively comprehensible and verifiable, it has to be assumed for this inquiry that the originally assigned weights for the DQI-I-2003 components already account for potential problems of inter-correlation with other index-components, as well as latest knowledge on the relationships between diet components and health.

In principle, the calculation of the modified Diet Quality Index-International (DQI-I$_{mod}$) adheres to the following formula:

$$DQI_{I_{mod}} = Variety + Adequacy + Moderation + Balance \tag{1}$$

with

$$Variety \quad = w_1 \frac{1}{5} \sum_{\Bbbk=1}^{5} \left(1 - \sum_{x=1}^{x} s_{x\Bbbk}{}^2\right), \tag{2}$$

$$Adequacy \quad = w_2 \frac{1}{10} \left(\sum\nolimits_{a=1}^{8} Min\left[\frac{n_a}{n_{a(AI)}}; 1\right]\right), \tag{3}$$

$$Moderation = w_3 \frac{1}{5} \sum_{m=1}^{5} Min\left[Max\left(\frac{n_{m(UL)} - n_m}{n_{m(UL)} - n_{m(LL)}}; 0\right); 1\right], \tag{4}$$

$$\begin{aligned} Balance \quad &= w_{41}\left[1 - \frac{\frac{1}{3}\sum_{b=1}^{3}\left(s_b - s_{b(MR)}\right)^2}{Max\frac{1}{3}\sum_{b=1}^{3}\left(s_b - s_{b(MR)}\right)^2}\right] + \\ &\quad w_{42}\left[1 - \frac{\frac{1}{3}\sum_{b=4}^{6}\left(s_b - s_{b(MR)}\right)^2}{Max\frac{1}{3}\sum_{b=4}^{6}\left(s_b - s_{b(MR)}\right)^2}\right]. \end{aligned} \tag{5}$$

Equation (1) describes the formulation of the DQI-I$_{mod}$ as a weighted aggregation of the four DQI-I-2003 sub-scores. The functional forms of the four diet quality dimensions are ordered in line with the original DQI-I-2003 and are specified by equations (2), …, (5). Equation (2) addresses the variety sub-index with food items x within each of the five relevant food groups $\Bbbk$ considering the food share indicators $s_{x\Bbbk}$ $\forall\, x = 1, \dots, r$ and $\forall\, \Bbbk = 1, \dots, 5$, whereby $s_{x\Bbbk}$ represents the intake shares of each food item within the food group of $\Bbbk$. Equation (3) addresses the adequacy sub-index with ten adequacy indicators n_a $\forall\, a = 1, \dots, 10$, whereby n_a represents the actual daily intake of adequacy-relevant nutrient a and $n_{a(AI)}$ represents the Russian RDA (or AI) of nutrient a. The moderation sub-index is given by equation (4) considering five relevant moderation indicators n_m $\forall\, m = 1, \dots, 5$, whereby n_m represents the actual daily intake of those nutrients/food groups m that tend to cause the genesis of chronic diseases and

$n_{m(UL)}$ represents the Russian UI (or the upper DR border) while $\mathrm{n_{m(LL)}}$ presents zero (or the lower DR border) of the food group or nutrient. Finally, equation (5) deals with the overall balance sub-index with its indicators marked s_b with $s_b = 1,2,3$ for the proportions of fat, protein, and carbohydrate intakes in energy percentage and $s_b = 4,5,6$ for the proportions of PUFA, MUFA, and SFA intakes in energy percentage. After indicator normalization and valuation according to equations (2), …, (5), index components are weighted by the weights $\mathrm{w_1}$ to $\mathrm{w_{42}}$, which are adopted from the DQI-I-2003, yielding a total scoring range of [0;100]. In the following, the index construction of the DQI-I$_{mod}$ is being explained in more detail for each sub-index separately.

Variety sub-score

The variety sub-score of the DQI-I$_{mod}$ assesses whether the consumed diet derives from a sufficient variation of different food items because eating diversely is internationally recommended for a healthy diet (see e.g., GERMAN NUTRITION SOCIETY, 2013). The variety dimension of the original DQI-I-2003 reflects both between-group variety and within-group variety regarding five food group categories: grains/grain products/potatoes; vegetables/salad; fruits; milk/milk products; and meat/meat products/fish/eggs.[39] However, in the DQI-I-2003, between-group variety and within-group variety are calculated by simple count measures.

Thus, the modified version of the DQI-I-2003 shall also consider distribution aspects of the variety dimension. There exists a broad pool of variety measures, which additionally consider distribution aspects, such as the BI with $BI = 1 - \sum_{x=1}^{n} s_x{}^2$ or the HFD-I with $HFD = (1 - \sum_{x=1}^{n} s_x{}^2) * health\ value$.[40] The BI considers the amount and distribution of the food items consumed. Based on the BI, the HFD-I extends the BI aiming at a complementary association between variety and healthiness of a diet (DRESCHER, 2007). Nevertheless, the HFD-I improperly mixes different dimensions of dietary quality.[41] Therefore, the variety sub-index

[39] The DQI-I-2003 excludes the group of fats and oils since the variety of caloric-rich foods such as fats increases the risk of obesity and overweight (SEA et al., 2004).

[40] The Gollop-Monhan-Index (GMI) of GOLLOP and MONAHAN (1991) considers dissimilarities in product categories with a continuous treatment of product heterogeneity regarding manufacturing. Nevertheless, within a dietary quality index product heterogeneity and dissimilarity are expressed within the indicators on adequate, moderated, and balanced intakes with respect to their health outcomes. Hence, these variety aspects are neglected here.

[41] The HFD-I combines the BI with a health value, which is the mean of the recommended intake shares (called health factors of the HFD-I) of food groups weighted by the actual intake shares of these consumed food groups with regard to all foods consumed (DRESCHER et al., 2009). However, this weighting procedure seems to be inappropriate for considering the healthiness of adequate (or moderate) intake shares. For example, consider a food group that should be consumed with an intake rate of 0.4, but it is actually consumed by an intake rate of 0.9, resulting in a health value contribution of this heavily overconsumed food group

of the $DQI\text{-}I_{mod}$ is based on the BI formula. Thereby, for each of the five respective food groups, a separate BI is calculated to address the within-group variety of food items within each food group. Afterwards the mean of these within-group BIs is calculated yielding a variety sub-index of the $DQI\text{-}I_{mod}$ with the following desired properties: i) it increases with a growing number of food items x consumed within food groups $\mathbb{k}$ (within variety); ii) it gives the highest valuation on equal distribution within each of the five food groups; iii) it increases with an increasing number of food items (overall variety) and food groups (between group variety); and (iv) it is bounded between zero and one. Finally, this normalized and valued variety sub-index is weighted by 20 % of the total $DQI\text{-}I_{mod}$ score, i.e. the maximum variety score equals 20 points. As mentioned above, all weights of the $DQI\text{-}I_{mod}$ are taken from the original DQI-I-2003.

Adequacy sub-score

The adequacy sub-score measures how the physiologically needed amounts of vitamins, minerals, and fiber are actually met by daily nutrition. In the original DQI-I-2003, this sub-index has eight different indicators which, among other factors, are based on the consumption of the fruit, vegetable, and grain food groups. But as mentioned above, if indicators are based on food groups they cannot take into account the enormous nutritional heterogeneity of the various types of food items/nutrients within a food group (WAIJERS et al., 2007). Therefore, the adequacy sub-index of the $DQI\text{-}I_{mod}$ is exclusively calculated via eight nutrient-based indicators. Previous studies found deficient intakes of vitamins A, B-complex, C, and E, as well as calcium and iron among the Russian population for the period from 1996 to 1998 (SEDIK et al., 2003; MARTINCHIK et al., 2005; OGLOBLIN et al., 2005; PAALANEN et al., 2011). Furthermore, POPKIN (2006) implies that fiber intakes generally decrease during a nutrition transition. Hence, essential micronutrients considered to be included in the Russian-specific adequacy sub-index are vitamins A, B1, B2, B12, C, and E, calcium, and fiber.[42] Additionally, indicators regarding the intakes of the essential minerals potassium and magnesium are included as further adequacy indicators because the consideration of only calcium seems to be inappropriate and may be caused by missing studies on the intakes of other minerals. For normalization purposes, the Russian official recommendations of

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of 0.36. The same health value contribution would be assigned to a food group with an actual intake rate of 0.6, which exactly meets the recommended intake rate of 0.6 for this food group. Moreover, such a combination of different aspects of dietary quality in one dimension is not desirable for the research aim of this thesis.

[42] Vitamin B6 strongly correlates with vitamins B1 and B2. Therefore, vitamins B1, B2, B12, but not vitamin B6, are considered to be part of the vitamin B complex in the modified index. Furthermore, as explained in footnote 17, iron is not considered in this analysis.

the Russian Federal Service on Customers' Rights Protection and Human Well-being Surveillance provided by TUTELJAN et al. (2008) are employed.

Considering each adequacy indicator separately, normalized adequacy indicator scores range proportionally on a continuous scale from zero for a 0 % attainment to one for a 100 % attainment.[43] The maximum relation between actual and recommended volumes needs to be limited at one in order to prevent nutrients in oversupply compensating for nutrients in undersupply (see BASIOTIS et al., 1995; KIM et al. 2003a). These normalized and proportionally valued adequacy indicators are then averaged to a total adequacy sub-index, which is weighted by 40 % of the total DQI-I_{mod} score, meaning a maximum of 40 adequacy points. As mentioned, the adequacy weight of 40 % is adopted from the original DQI-I-2003. These 40 adequacy points can also be equally assigned to each of the ten adequacy indicators by a maximum indicator score of four points each.

Moderation sub-score

According to the DQI-I-2003, foods and nutrients considered to be as moderation indicators are total fat, saturated fat, empty-calorie foods, cholesterol, and sodium because they are related to chronic diseases and therefore may need restrictions. Yet, as explained in chapter 4.2.3.2, cholesterol as a moderation indicator is inappropriate because of the low association between cholesterol intakes and blood cholesterol. Furthermore, sodium intakes cannot be reasonably determined by most intake data sets, which is also true for the RLMS-HSE data set. Besides a reasonable exclusion of cholesterol and sodium intake indicators from the moderation dimension, a moderate intake of total energy in kcal can be considered as being an important part of the moderation sub-index since cut-off values of moderate (saturated) fat intake are generally expressed in energy percentage such that absolute energy intake itself is not accounted for (WAIJERS et al., 2007).[44] Additionally, alcohol intake can be regarded as being part of the moderation dimension because alcohol is often recommended to be consumed in moderation up to a UI of 10 g pure ethanol per day for woman (equals one glass of alcoholic beverages) and 20 g pure ethanol per day for men (equals two glasses of alcoholic beverages) (see e.g., GUENTHER et al., 2013; DRAKE et al., 2011). Therefore, the components of the moderation sub-index of the DQI-I_{mod}

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[43] In using interval-scaled continuous scoring systems, the DQI-I_{mod} relies on proportional valuation functions. A discussion on other valuation functions should be part of future research work.

[44] Energy intake is primarily assessed as a proxy for dietary quality in developing countries where energy intake is insufficient (KNUDSEN and SCANDIZZO, 1982; SUBRAMANIAN and DEATON, 1996). By contrast, in industrialized countries it is advisable to assess excessive energy intake in the moderation sub-score of dietary quality indices, a fact that has been confirmed to the author by a written statement from one of the most popular nutritionists, Barry Popkin.

are changed in order to evaluate to what extent excessive intakes of total fat, saturated fat, empty-calorie foods, alcohol, and energy intakes are moderated.

Employing the RLMS-HSE data to the calculation of the $DQI\text{-}I_{mod}$, individual total fat intakes are provided by the 24-hour recalls while saturated fat intakes and (unbiased) energy intakes have to be approximated (see section 2.2). Individual alcohol intakes are calculated as a weighted average of the pure ethanol typically found in alcoholic beverages, as done by TEKIN (2004).[45] Thereby, the RLMS-HSE reports data on individual alcohol consumption in grams of beer, vodka, fortified wine, table wine, and homemade liquor. Regarding the moderation of empty-calorie foods, it is suggested that cakes, cookies, and other pastries, white bread, ice cream, cheese, pizza, and processed meats are the foods with most empty calories (U.S. DEPARTMENT OF AGRICULTURE, 2015). Nonetheless, in order to avoid double counting, cheese, pizza, and processed meats have been excluded from the calculation of the empty-calorie foods intake indicator, because these foods obtain their empty calories mainly from solid fats (U.S. DEPARTMENT OF AGRICULTURE, 2015). When the energy supplied by empty-calorie foods is larger than 10 % of total energy intake per day, the lowest score is assigned.

Similar to the adequacy dimension, normalized and proportionally valued moderation indicators are then averaged to a total moderation sub-index, which is weighted by 30 % (or a maximum of 30 points) of the total $DQI\text{-}I_{mod}$ score. In line with the procedure of the DQI-I-2003, these 30 points can be equally assigned to each of the five moderation indicators by a maximum indicator score of six points each.

Overall balance

The final sub-index of the DQI-I-2003 is the overall balance of macro- und micronutrients. This sub-index addresses the proportionality in the macronutrient energy sources and fatty acids composition. Yet, for the $DQI\text{-}I_{mod}$, country-specific recommendations are taken from TUTELJAN et al. (2008). Furthermore, in the $DQI\text{-}I_{mod}$ macronutrient intakes in energy percentage as well as fatty acid intakes in energy percentage are normalized with a metric scale rather than the originally ordinal scale of the DQI-I-2003. Thereby, deviations from the recommended intakes are addressed by a squared functional specification in order to punish larger deviations more strongly. Hence, at first, the squared deviations of the actual macronutrient and fatty acid intakes from the recommended macronutrient and fatty acid intake shares are calculated. Second, these squared deviations are averaged for both the three macronutrient intakes and the three fatty acid

[45] The algorithm used to construct the measure of ethanol consumption assumes that total amount of ethanol is 5 % in beer, 40 % in vodka and homemade liquor, 20 % in fortified wine, and 12 % in table wine.

intakes. Finally, in order to ensure a normalized boundary between zero and one, the averaged squared deviations are divided by their respective maximal possible averaged squared deviations. The original DQI-I-2003 assigns a maximum score of six points to the macronutrient balance and a score of four points to the fatty acid balance, yielding a total maximum overall balance score of ten points. Again, this weighting procedure is adopted here for the weighting of the DQI-I_{mod} balance dimension.

Table 10 contains the composition of the DQI-I_{mod}, including the four sub-scores of variety, adequacy, moderation, and overall balance. Just as for the DQI-I-2003, the total DQI-I_{mod} is measured on a scoring range of [0;100] with maximal sub-index scores of 20 points for the variety sub-index, 40 points for the adequacy sub-index, 30 points for the moderation, and ten points for overall balance sub-index.

Table 10: Composition of the DQI-I_{mod}

Sub-index	Maximum score per sub-index	Maximum score per indicator	Indicator description
Variety	20	4	BI for within-group variety of the carbohydrates group
		4	BI for within-group variety of meat and meat products
		4	BI for within-group variety of milk and dairy products
		4	BI for within-group variety of the fruits group
		4	BI for within-group variety of the vegetables group
Adequacy	40	4	Adequacy of fiber intakes
		4	Adequacy of vitamin A intakes
		4	Adequacy of vitamin B1 intakes
		4	Adequacy of vitamin B2 intakes
		4	Adequacy of vitamin B12 intakes
		4	Adequacy of vitamin C intakes
		4	Adequacy of vitamin E intakes
		4	Adequacy of calcium intakes
		4	Adequacy of magnesium intakes
		4	Adequacy of potassium intakes
Moderation	30	6	Moderation of total calorie intakes
		6	Moderation of alcohol intakes
		6	Moderation of total fat intakes
		6	Moderation of saturated fat intakes
		6	Moderation of empty-calorie foods intakes
Overall Balance	10	6	Balance of the macronutrient ratio
		4	Balance of the micronutrient ratio
DQI-I_{mod}	100		

Source: Own presentation.

4.3.2 Empirical results

In Table 10, the empirical results of the calculated DQI-I_{mod}, as well as the percentage achievement of the maximum scores, for the observed time period of 1996-2005 are provided. As Table 10 shows, the total Russian DQI-I_{mod} scores have been fairly stable over the observed time period, i.e. the calculated scores range between 48.84 points (in 2002) and 49.85 points (in 2000). Since a trend in the Russian overall dietary quality considering these total scores cannot be noticed for the observed time period, a more detailed investigation of the four sub-indices of the Russians' DQI-I_{mod} is necessary by applying the nested structure of the DQ-I_{mod} (see also BURGGRAF et al., 2014a).

Table 11: DQI-I_{mod} scores

	DQI-I_{mod} measured as															
	Total and component scores								Percentage achievement of maximal scores [in %]							
Year	**1996**	**1998**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**1996**	**1998**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Sub-index variety	8.69	8.61	9.19	9.49	9.73	9.72	10.03	10.05	43.45	43.05	45.93	47.43	48.65	48.61	50.15	50.27
Adequacy of																
Fiber	2.93	2.94	2.87	2.80	2.68	2.66	2.66	2.64	73.20	73.38	71.78	70.10	67.03	66.38	66.55	66.00
Vitamin A	2.56	2.50	2.54	2.58	2.56	2.54	2.55	2.59	64.08	62.55	63.49	64.57	63.99	63.38	63.83	64.80
Vitamin B1	2.75	2.68	2.59	2.56	2.61	2.61	2.62	2.65	68.71	66.96	64.84	63.90	65.32	65.37	65.51	66.34
Vitamin B2	2.63	2.64	2.57	2.56	2.62	2.64	2.59	2.63	65.86	66.00	64.37	63.88	65.39	65.96	64.72	65.75
Vitamin B12	2.77	2.59	2.65	2.68	2.80	2.89	2.89	2.92	69.21	64.76	66.20	66.94	70.02	72.32	72.36	72.99
Vitamin C	2.46	2.17	2.46	2.42	2.33	2.34	2.42	2.38	61.62	54.15	61.49	60.51	58.15	58.40	60.53	59.61
Vitamin E	2.59	2.60	2.81	2.87	2.84	2.85	2.88	2.84	64.73	65.11	70.30	71.81	70.95	71.16	71.91	70.88
Calcium	1.95	1.90	1.95	1.92	1.97	2.01	2.02	2.07	48.68	47.59	48.77	48.06	49.27	50.22	50.43	51.64
Magnesium	2.75	2.70	2.71	2.62	2.56	2.55	2.54	2.53	68.65	67.57	67.86	65.45	64.02	63.64	63.60	63.34
Potassium	3.31	3.21	3.25	3.19	3.16	3.17	3.18	3.17	82.73	80.31	81.19	79.86	79.01	79.35	79.44	79.14
Sub-index adequacy	26.70	25.95	26.42	26.20	26.13	26.25	26.36	26.42	66.76	64.87	66.05	65.50	65.32	65.62	65.89	66.05
Moderation of																
Calories	2.56	2.59	2.60	2.53	2.52	2.51	2.49	2.47	42.71	43.23	43.36	42.23	42.04	41.89	41.53	41.12
Alcohol	3.59	3.58	3.51	3.15	3.20	3.17	3.28	3.36	59.84	59.64	58.52	52.42	53.40	52.83	54.74	56.03
Total fat	1.38	1.91	1.69	1.49	1.36	1.32	1.29	1.18	23.05	31.82	28.17	24.88	22.62	21.95	21.44	19.69
Empty-calorie foods	0.70	0.72	0.53	0.38	0.34	0.30	0.28	0.33	11.63	11.94	8.81	6.41	5.64	4.94	4.72	5.48
Saturated fat	2.56	2.99	2.76	2.61	2.25	2.17	2.08	1.91	42.60	49.88	45.96	43.47	37.55	36.17	34.71	31.85
Sub-index moderation	9.96	11.07	10.40	9.46	8.95	8.75	8.70	8.60	33.20	36.91	34.68	31.53	29.82	29.18	29.01	28.66
Overall balance of																
Macronutrient ratio	3.22	2.75	2.86	2.84	2.72	2.66	2.70	2.63	53.69	45.79	47.64	47.25	45.38	44.31	44.97	43.86
Micronutrient ratio	1.35	1.26	1.46	1.54	1.60	1.61	1.70	1.67	33.78	31.40	36.39	38.48	40.07	40.13	42.55	41.84
Sub-index balance	4.37	3.86	4.20	4.29	4.27	4.22	4.38	4.29	43.73	38.60	42.01	42.87	42.72	42.22	43.76	42.85
DQI-I_{mod}	49.47	49.13	49.85	49.15	48.84	48.74	49.26	49.09	49.47	49.13	49.85	49.15	48.84	48.74	49.26	49.09

Source: Based on own calculations, RLMS-HSE 1996-2008.

The sub-indices and their individual indicators presented in Table 11 show that Russian diets are almost appropriate in some aspects but highly problematic in other ones. For the variety dimension, which indicates several adequacy and moderation aspects of dietary quality but also a reduced risk of the intake of contaminated foods (see chapter 4.2.3.1), Table 11 shows that scores range from 8.61 in 1998 up to 10.05 in 2008.[46] Comparing the respective percentage achievement of the maximal scores, these numbers indicate that food variety increased from a 43.05 % to a 50.27 % achievement of the maximal achievable scores. This development of the variety index is a first proxy of an increased dietary quality during the periods of economic growth and increased household incomes. Along these lines, results from BURGGRAF (2011) suggest that increasing incomes have a positive influence on food diversity in Russian households, amongst other influencing factors such as education, age, urban settlement, and household farming.[47]

For the adequacy dimension of changing intake patterns, the picture is not that clear because the adequacy sub-index is fairly stable with its lowest score of 25.95 (64.87 %) in 1998 and its highest score of 26.42 (66.05 %) in 2000 and 2005. Therefore, it is beneficial to take a more detailed look at the individual indicators of the adequacy sub-index and their changes during the observed time period. As already suggested in section 3.3.2, during the examined period of economic growth, adequate fiber intakes have decreased, just as they have for magnesium and potassium intakes. Fiber and magnesium are largely provided by whole grain products and potatoes, whose consumption is assumed to decrease during economic transition. Potassium is included in an extensive range of food products such as yam, parsley, dried apricots, chocolate, various nuts, potatoes, etc. According to the results presented in Table 11, potassium intakes were considerably high but decreasing during the observed time period, which may also be caused by a decreasing potato consumption from 124 kg per year in 1995 to 109 kg per year in 2005 (FEDERAL STATE STATISTICS SERVICE RUSSIA, 2014). In contrast to the decreasing intakes of fiber, magnesium and potassium, other vitamin and mineral intakes have improved. These positive intake trends are mirrored in the respective

[46] The correlation of the variety sub-score with the adequacy, moderation, and balance sub-scores is significant but considerably low, i.e. the variety correlation coefficient regarding the overall balance sub-score equals 0.19, regarding the adequacy-sub-score equals 0.21, and regarding the moderation sub-score equals minus 0.28.

[47] It is important to note that the Russian household production of agricultural goods is not generally dependent on living in rural areas. In fact, such household production is also carried out intensively by the urban population. The urban population also enjoys better food availability than rural areas (BURGGRAF, 2011). Therefore, BURGGRAF et al. (2014c) suggest that urban developments with allotment sites may take over important functions regarding the Russian food variety and food security.

increasing indicator scores, for example for vitamin C, vitamin B12, and calcium. The orthogonal positive and negative intake trends seem to cancel out each other within the aggregated adequacy sub-index, especially since in the DQI-I$_{mod}$ (just as in the DQI-I-2003) the relative adequate intakes are restricted by a maximum achievement of 100 %.

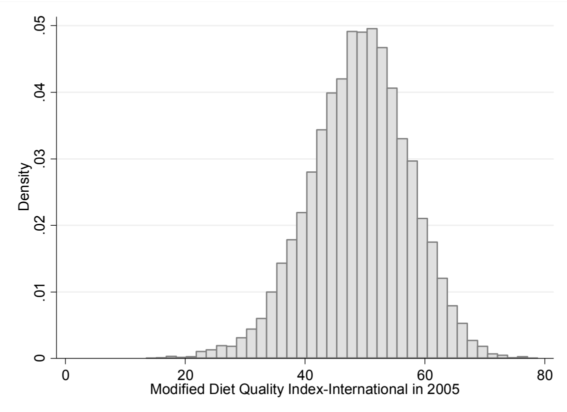
In line with the results of OGLOBLIN et al. (2005), calcium intakes have been alarmingly low with a score of 1.90 in 1998 and 2.07 in 2005, indicating an average adequate calcium intake achievement of only 47.59 % and 51.64 %, respectively. Although Russians have a preference for dairy products, the RLMS-HSE food consumption data suggest a possible explanation for the considerably low calcium intakes. According to this food consumption data, Russians consume relatively high amounts of milk (with only 120 g calcium per 100 g milk), but relatively low amounts of good calcium suppliers such as cheese (with 800-1300 g calcium per 100 g cheese). In contrast to the most inadequate calcium intakes, potassium intakes have been most adequate amongst the considered ten indicators, with a score of 3.17 in 2005, i.e. an average adequate intake achievement of 79.14 %. As mentioned above, these more adequate intakes are possibly due to the fact that potassium is included in a considerable range of different food products.

The moderation of foods and nutrients that increase the risk of chronic diseases worsened over the observed time period, i.e. the moderation score decreases from 11.07 (36.91 %) in 1998 to 8.60 (28.66 %) in 2005. Within this sub-index, the moderation of empty-calorie foods, in particular the consumption of white bread and sugar, as well as the moderation of total fat intakes were especially problematic because their intakes tended to be above the upper recommended intake levels. Thereby, the moderation indicator of empty-calorie foods decreased from 0.72 points (11.94 %) in 1998 down to 0.33 points (5.48 %) in 2005 and the moderation indicator of total fat intakes decreased from 1.91 points (31.82 %) in 1998 down to 1.18 points (16.69 %) in 2005. Within total fat intakes, the moderation of saturated fat intakes worsened during the examined period of economic growth, i.e. a desirable moderation of saturated fats decreased from 2.99 points (49.88 %) in 1998 to 1.91 points (31.85 %) in 2005. In line with these changing food and nutrient intake patterns, the moderation of calorie intakes per day also worsened from 1998/2000 until 2005, which means that on average total daily energy intakes more often tended to be excessive during economic growth. Furthermore, alcohol intakes receive their highest score of 3.59 points (59.84 %) in 1996 and their lowest score of 3.15 points (52.42 %) in 2001. Afterwards, until 2005, alcohol intakes were again more moderated, resulting in higher moderation scores of 3.36 (56.03). Nevertheless, it has to be noticed that alcohol intake data include quite a lot of missing values. If especially strong alcohol drinkers did not report their alcohol intakes, this would indicate a bias of the alcohol intake data towards lower intake rates.

Finally, the overall balance dimension slightly changes over the observed time period. The percentage achievement of maximum scores increases from 38.60 % in 1998 to 43.76 % in 2004. Thereby, the balance of the macronutrient intakes worsens over time (from 53.69 % in 1996 to 43.86 % in 2005) while the balance of the fatty acid intakes improves over time (from 33.78 % in 1996 to 41.84 % in 2005), probably due to a growing consumption of vegetable oils.[48]

For a more detailed analysis of Russian dietary quality, focus is now placed on the distribution of the DQI-I_{mod} in 2005. The distribution of the DQI-I_{mod} in 2005 is illustrated in Figure 10. As can be seen, the calculated DQI-I_{mod} is fairly normally distributed with a mean score of 49.09 and a standard deviation of 8.29. The minimum DQI-I_{mod} is 13.48 and the maximum DQI-I_{mod} is 78.84.

Figure 10: Histogram of the DQI-I_{mod} for the year 2005



Source: Based on own calculations, RLMS-HSE 2005.

48 This micronutrient balance indicator mirrors the balanced intakes of SFA, PUFA, and MUFA, considering positive and negative deviations. By contrast, the moderation indicator of SFA accounts only for positive deviations of SFA intakes from the UI. Hence, the presented decreasing SFA moderation scores (but the increasing micronutrient balance scores) are not contradictory. They might arise from the following two developments: i) the balance of PUFA and the balance of MUFA intakes have improved over time and off-set the SFA balance development (according to the RLMS-HSE data, Russians increased their vegetable oil consumption during 1996-2008); and ii) if SFA intakes increased on average, those individuals with SFA intakes below the optimal intake range might even have gotten closer to the optimum value. This development of the negative SFA intake share deviations might also partly off-set the increased positive SFA intake share deviations from excessive SFA consumption.

To better explain the variations of the Russian DQI-I_{mod} in 2005, a closer look will be taken, first at the distribution according to income groups and second at the regional distribution of the DQI-I_{mod}. As can be seen in Table 12, variety and adequacy sub-scores significantly increase with higher household incomes while the moderation sub-score significantly decreases with higher household incomes.[49] Finally, the overall balance does not significantly vary between the four income groups, possibly due to the two orthogonal developments of macronutrient balance and fatty acid balance. In 2005, the balance of the macronutrient ratio significantly worsened and, at the same time, the balance of the micronutrient ratio significantly improved with higher household incomes.

Furthermore, considering the regional distribution of the DQI-I_{mod} in 2005, Figure 11 displays the mean index scores of DQI-I_{mod} in 2005 for each of the eight broad Russian economic regions: the Moscow and St. Petersburg area, the Central and Central Black Earth region, the North and Northwestern Russian region, the Volga-Vaytski and Volga Basin region, the Ural, the North Caucasus, West Siberia, and East Siberia.[50] With the RLMS-HSE sample, the highest DQI-I_{mod} is found for the metropolitan areas Moscow and St. Petersburg with a mean score of 51.96. This highest score mainly results from the good nutrient adequacy (74.39 %) and food variety (58.13 %) achievements in the metropolitan areas of Moscow and St. Petersburg, which are both the highest for all eight Russian economic regions. The higher food variety and nutrient adequacy is possibly due to better food availability within these metropolitan regions. Also, real household incomes in metropolitan areas of Moscow and St. Petersburg are significantly higher than the Russian average real household incomes, indicating higher food budgets. Nevertheless, people living in the metropolitan areas show on average the worst moderation scores (21.85 %) in 2005; especially for total fat (11.24 %), saturated fat (10.01 %), and empty-calorie products (2.15 %). A slightly lower overall diet score of 49.76 points is found for the Central and Central Black Earth region, which lies at the western border of Russia and covers the region around the Moscow area. The Central and Central Black Earth region is famous for its fertile soil and good climatic circumstances. Possibly caused by these favorable harvesting conditions as well as its favorable location near the western border, variety and adequacy scores of the Central and Central Black region are second-best amongst the eight

[49] In contrast to the intakes of fat and empty-calorie foods, daily energy intakes seem to follow a U-shaped functional association with the amounts of household incomes, i.e. the households within the upper and lower tails of the income distribution show the best calorie moderation, while the households within the interquartile range of the income distribution show the worst calorie moderation.

[50] Results of the one-way analysis of variance (ANOVA) imply a statistically significant differrence in the mean of the DQI-I_{mod} between the eight different regional groups.

Russian economic regions. In contrast to the variety and adequacy sub-indices, the moderation sub-index of the Central and Central Black region performs on average the second-worst amongst the Russian regions (25.00 %).

Table 12: Percentage achievements of the DQI-I$_{mod}$ per income groups

Income groups by quartiles*	Lower income	Lower middle income	Upper middle Income	Upper income
Sub-index variety^{+}	46.88 %	49.07 %	52.21 %	52.58 %
Adequacy of				
Fiber^{-}	69.32 %	64.99 %	65.85 %	63.23 %
Vitamin A^{+}	56.64 %	62.40 %	69.36 %	70.08 %
Vitamin B1^{+}	65.19 %	65.02 %	66.81 %	67.40 %
Vitamin B2^{+}	60.45 %	64.89 %	68.02 %	68.93 %
Vitamin B12^{+}	61.68 %	70.40 %	78.04 %	80.95 %
Vitamin C^{+}	51.89 %	56.89 %	62.10 %	66.48 %
Vitamin E	70.63 %	70.16 %	72.18 %	69.68 %
Calcium^{+}	44.64 %	49.49 %	54.06 %	57.47 %
Magnesium	64.77 %	61.22 %	63.24 %	63.60 %
Potassium^{+}	77.04 %	77.22 %	79.74 %	81.67 %
Sub-index adequacy^{+}	62.22 %	64.29 %	67.94 %	68.91 %
Moderation of				
Calories	45.13 %	37.00 %	39.84 %	42.42 %
Alcohol^{-}	63.89 %	62.38 %	53.42 %	45.15 %
Total fat^{-}	28.71 %	22.19 %	16.07 %	12.55 %
Saturated fat^{-}	45.80 %	34.28 %	25.67 %	24.22 %
Empty-calorie foods^{-}	6.32 %	5.55 %	4.86 %	5.17 %
Total moderation^{-}	35.60 %	30.62 %	26.35 %	24.04 %
Overall balance of				
Macronutrient ratio^{-}	46.51 %	44.94 %	44.47 %	40.56 %
Micronutrient ratio^{+}	39.48 %	40.82 %	43.12 %	43.29 %
Total Overall balance	43.00 %	42.88 %	43.79 %	41.92 %
DQI-I^{+}	48.83 %	48.61 %	49.50 %	49.29 %

Source: Based on own calculations, RLMS-HSE 2005.

Note: Indicators are not presented as scores but as the percentage achievement of the maximal achievable scores.

* Boundaries of the four income groups are the three quartile points of the households' income distribution, i.e. household incomes of the lower income group ≤25th percentile, of the lower middle income group >25th percentile and ≤50th percentile, of the upper middle income group >50th percentile and ≤75th percentile, and of the upper income group >75th percentile.

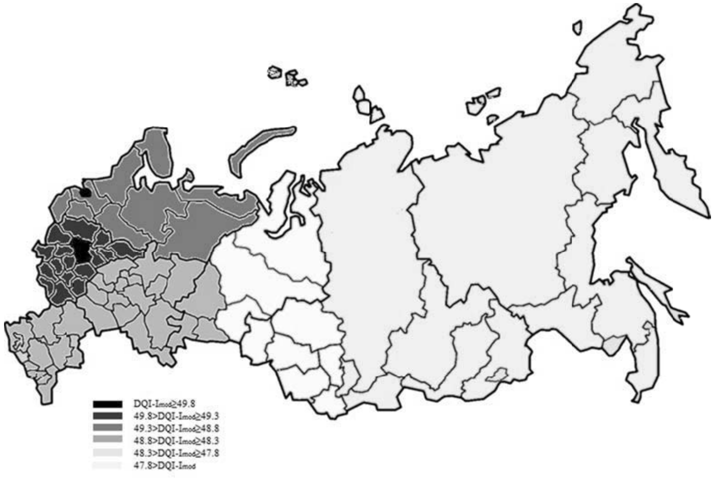
$^{+}$ Relative intake increases significantly with higher income groups at the 5 % level.

$^{-}$ Relative intake decreases significantly with higher income groups at the 5 % level.

The remaining regions receive average DQI-I$_{mod}$ scores lower than the Russian sample average: the North and Northwestern Russian region (48.91 points), the Ural region (48.67 points), the North Caucasian region (48.61 points), the

Volga-Vaytski and Volga Basin region (48.52 points), the East Siberian region (48.20 points), and the Western Siberian region (47.31 points). Hence, the lowest average DQI-I_{mod} score can be identified for the Siberian regions possibly due to the difficulty of growing fruits and vegetables considering the Siberian climatic and soil conditions, while modern supply chains might still not be able to catch up with the related supply problems. Western Siberia especially shows very low variety and adequacy sub-scores, as well as the lowest fatty acid balance.[51] However, the moderation of foods that increase the risk of chronic diseases in Western Siberia (30.01 %) is above the Russian average of 28.66 %, just as it is for the North Caucasus (35.28 %) as well as the Volga-Vaytski and Volga Basin region (31.35 %).

Figure 11: Regional distribution of the DQI-I_{mod} in 2005



Source: Based on own calculations, RLMS-HSE 2005.

4.4 CHAPTER CONCLUSIONS

In chapter 4, research question 2.1 is answered by elaborating on how the overall dietary quality in Russia can be best operationalized. Therefore, hitherto relevant a priori dietary indices are discussed in relation to their construction criteria accounting for theoretical considerations and recent knowledge about diet-health

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[51] In contrast to Western Siberia, markets in Eastern Siberia (including the Far East) import foods from China with increasing import rates (ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, 1998). This fact of growing imports of relatively cheaper Chinese food products may explain the slightly better food variety and adequacy of the East Siberian population in contrast to the West Siberian population.

relationships. This discussion is based on the OECD handbook on constructing composite indicators (NARDO et al., 2008) and aims to be both more systematic and more comprehensive than existing reviews. Preferable features of indices assessing a population's dietary quality are identified and described. For example, the inclusion of the adequacy, moderation, and balance dimensions is valued as being necessary to provide an overall picture of a population's dietary quality. The inclusion of the variety dimension depends on the considered number of relevant adequacy indicators in the index construction and inter-correlation problems of the variety sub-index with other index components. Furthermore, a nested index structure is favored with indicators based on nutrients or a combination of nutrients and food groups. In order to increase discriminatory power, metric or combined metric and ordinal indicator scales are considered as beneficial, with feasibility depending on the intake data type at hand. Finally, a weighting system has to take into account variations in nutrient intake levels to variations in health outcomes and correlations between index components. Based on this discussion, a summarizing toolbox is provided, which helps nutritionists to identify those indices whose concept of index construction is most appropriate for their respective study aim; it also considers regional specifics and data set restrictions. Based on this summarizing toolbox, the DQI-I-2003 has been selected for the empirical analysis of Russian dietary quality for two reasons: the DQI-I-2003 comprises a range of most favorable index construction criteria and the DQI-I-2003 is most appropriate for the analysis of transition countries such as Russia.

With the presented results of the empirical analysis, research question 2.2 is answered by showing how Russian dietary quality changed during the observed transition period. Therefore, the DQI-I-2003 is modified towards the Russian DQI-I_{mod} in order to take into account recent advancements in methodology, regional specifics of the Russian diet, and restrictions based on the RLMS-HSE data set. Afterwards, the Russian DQI-I_{mod} has been empirically assessed. Thereby, it has been revealed that key issues of the DQI-I_{mod} construction have been proven to be beneficial, especially the relatively high degree of elaborateness considering primarily nutrient-based indicators and its nested structure. Both issues significantly contribute to the informative value of this inquiry. As a result, the calculated scores of the DQI-I_{mod} as well as its sub-scores detail what has been found in chapter 3 regarding the Russian nutrition transition. Again, it can be shown that with economic growth and higher household incomes, food variety and the adequate intakes of vitamins and minerals generally tend to improve, while the moderate intakes of (saturated) fats, empty-calorie products, alcohol, and total energy tend to worsen. Furthermore, as noted by the definition of a nutrition transition, the intake of dietary fiber decreases with increasing household incomes. Finally, the nested structure of the DQI-I_{mod} highlights, in an excellent manner, that Russians' of different income groups as well as different economic regions have their own distinct problematic areas of dietary quality. Therefore, Russians are in need of strata-specific intervention strategies, with some of them mainly targeting more adequate nutrient intakes and some of them mainly targeting more moderate intakes of fats and empty-calorie products.

For future research, nutritionists have to pay more attention to the derivation of appropriate valuation functions and a reasonable weighting system, which ought to be inter-subjectively comprehensible and verifiable. Furthermore, with the assessment of Russians' dietary quality, more research is now necessary regarding the influencing factors of dietary quality in order to derive implications for nutrition policy. Such theoretical and empirical work regarding the demand for dietary quality and its influencing factors is presented chapter 5.

5 RUSSIAN DEMAND FOR DIETARY QUALITY

5.1 CHAPTER INTRODUCTION

Russian nutrition transition and its accompanying growth of nutrition-related chronic diseases require changes in Russia's health care strategies, especially in the field of nutrition. In chapter 4, Russians' dietary quality was operationalized considering its multidimensional character. Based on this operationalization, areas of the Russian diet were identified that are evidently in need of improvement. Now, after the assessment of Russian dietary quality, a detailed theoretical and empirical analysis of the influencing factors of the demand for dietary quality is needed to derive effective and efficient nutritional intervention programs. Yet considering the manifold effects of dietary quality on human health suggests the need for more elaborate dietary demand models than those assuming that food demand is affected simply by income and prices. This is because the different dimensions of dietary quality might be affected by different influencing factors. Even if the influencing factors are the same, effect directions and effect sizes of these influencing factors may vary across the different diet quality dimensions. Nonetheless, according to HUSTON and FINKE (2003), studies on the demand for dietary quality have lacked a comprehensive theoretical framework guiding the selection and effects of the manifold diet-specific explanatory factors, considering the multidimensional character of dietary quality. So the question arises, which model is able to provide a comprehensive theoretical framework for the analysis of the demand for dietary quality.

On the theoretical grounds of the household production theory by BECKER (1965), demand for dietary quality is primarily influenced by food prices, wage rates, and knowledge. In this context, a variety of existing studies for industrialized countries indicate that relative prices of healthy and unhealthy foods differ. More concretely, vitamin- and mineral-dense foods such as whole grains and fresh fruits and vegetables are relatively more costly and hence less affordable if economic resources are limited. By contrast, energy-dense foods such as refined grains, sweets and fats cause excessive eating behaviors because technological changes have made them accessible at remarkably low costs (e.g., DREWNOWSKI and DARMON, 2005; ROSIN, 2008). Furthermore, wage rates influence dietary behavior by restricting household budgets. It has been shown that lower-income households tend to select diets high in low-cost meats, inexpensive grains, added sugars and added fats (VARIYAM, 2003; STEWART und HARRIS, 2005; BINKLEY and GOLUB, 2011). Additionally, increasing wage rates make time-consuming homemade meals relatively more expensive than processed foods. However, processed foods tend to have higher contents of fat, sugar, and salt compared to freshly-prepared homemade meals (BINKLEY and GOLUB, 2011). Considering knowledge, individuals with lower nutrition knowledge – often approximated by educational achievement – are frequently found to have unhealthier eating habits (e.g., ADRIAN and DANIEL, 1976; VARIYAM, 2003). This is because higher educational and knowledge levels lead to a better searching ability for nutrition-relevant information and a more efficient use of the information gathered, resulting in healthier food baskets (VARIYAM et al., 1999). Regarding the socio-demographic and demographic control variables, individuals' dietary quality is enhanced, inter alia, with increasing age and female gender (see e.g., VARIYAM et al., 1998).

In order to gain deeper insights into the demand for dietary quality, it is necessary to consider further influencing factors typically involved in dietary choices. Besides sensory motives, which have been identified as a major determinant of consumers' food choices, health issues of vitamin and mineral intakes are also important impact factors of dietary choices (EERTMANS, 2001; BRUG, 2008; BLANCK et al., 2009; HONKANEN and FREWER, 2009; WETTSTEIN et al., 2011). Along these lines, the goods characteristics approach, which became popular through the theoretical work of LANCASTER (1966, 1971), is often applied for the empirical analysis of various nutrient intakes (e.g., EASTWOOD et al., 1986; MORSE and EASTWOOD, 1989; VARIYAM et al., 1995, 1998, 1999). However, in an intertemporal context, the adequate intake of vitamins and minerals can be considered as a long-term investment in an individual's health, in addition to healthy lifestyles and good healthcare. Furthermore, healthy dietary behavior often means sacrificing the pleasure of palatable yet unhealthy diets in return for an increased probability of future healthiness (BLAYLOCK et al., 1999). Without such a sacrifice of pleasure, it would be much easier to improve dietary quality in western countries (BINKLEY and GOLUB, 2011). This trade-off between dietary quality and taste has been intensified with the growth of food processing sectors and food-away-from-home suppliers. These industries increasingly add fats, sweeteners, and salt to their foods, which enhances palatability but also increases nutrition-related health risks (BLAYLOCK et al., 1999; BINKLEY and GOLUB; 2011).

Previous studies employing either the household production theory or the goods characteristics approach have not explained dietary choices by considering the aforementioned multidimensional character of dietary quality, the intertemporal health investment character of vitamin and mineral intakes, and also the health-taste trade-offs of palatable yet risky nutrients. Hence, to explain the decision on the actual composition of nutrients and their future health outcomes, a more realistic dynamic model is needed (ARNADE and GOPINATH, 2006). GROSSMAN's health investment model (GROSSMAN, 1972b, 1972a, 2000) would be able to address this intertemporal diet-health relationship because this model allows for health investments as a choice option for consumers. Thereby, GROSSMAN's model is formulated as a lifecycle household production model in which the stock of health capital is determined endogenously by health investment choices. This is because, conditional on genetics and other exogenous factors, health is a result of individual health investment choices.[52] Nonetheless, for simplification purposes, GROSSMAN limits his detailed analysis of health investment input factors only to medical care. This rather narrow interpretation of health investments tends to overlook the richness of the model's implications. Even GROSSMAN himself notes that many other market goods or services influence an individual's health, such as dietary quality (GROSSMAN, 2000). Therefore, it is necessary to incorporate the role of non-medical inputs such as dietary quality into the health investment model (LEIBOWITZ, 2004). However, GROSSMAN's work has remained as a standard healthcare analysis tool to explain the demand for medical services. In the hitherto existing version, the health investment model has not been specified to consider the demand for dietary quality with its multidimensional nature, nor has it taken account of the health-taste trade-off typically involved in dietary choices.[53] Beyond that, central criticism lies with the model's theoretical implications. GROSSMAN's standard health investment model implies, inter alia, that the demand for health investments by medical care increases with a better health status. Yet empirical studies indicate the opposite, meaning that people tend to consume more medical care if their health status worsens.

Based upon the above discussion, the aim of this chapter is to provide a comprehensive theoretical framework that describes the effects of dietary quality-specific explanatory factors on the demand for dietary quality. This chapter thereby contributes to the literature in the following ways. First, the often criticized inconsistencies between the Grossman model's theoretical implications and its

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52 As GROSSMAN (1972a) states, individuals invest in better health status for two reasons: first, health investments increase the amount of healthy time available in any future instant of life, with healthy time generating direct utility; and second, healthy time is a necessary input factor to indirectly generate utility from increased market incomes or further household commodities, including leisure time.

53 According to GROSSMAN (2000) and CHERN (2003), treating dietary quality as a separate input factor in the health investment model would be technically feasible. However, in contrast to their statements, the model should not retain its original structure if the primary health input is not medical care but the two-dimensional construct dietary quality. This is because dietary quality is a theoretical construct that cannot be purchased on the market itself and hence does not have an observable market price. Even if an implicit price of dietary quality is considered, expenses for dietary quality will not necessarily increase in accordance with the demanded dietary quality, considering the often opposing influences on adequacy and moderation components (see chapter 5.3.1).

empirical results is solved, thus emphasizing its practical relevance. Specifying the model's inherent health investment production function to be of decreasing rather than constant returns to scale, this is the first study that shows that even the standard Grossman model might generate a reasonable demand function for medical care, which implies that sick people use more medical care. Second, the newly derived model implications are then proven for the Russian demand for medical care. Third, after this validation of the practical relevance of GROSSMAN's standard health investment model, this is the first study that enhances the standard health investment model to the *dietary health investment model*, which (i) incorporates basic aspects of LANCASTER's goods characteristics approach, (ii) explains the intertemporal health investment character of vitamin and mineral intakes, (iii) considers the health-taste trade-offs of palatable yet risky nutrients, and (iv) generates a structural demand function for health investments by healthy nutrients, which implies that sick people demand more health investments. In order to keep the model's simplicity as high as possible, the focus is set on the adequacy and moderation dimensions of dietary quality. These two dimensions already fulfill the above-mentioned diet-related aspects of health investments by vitamins and minerals and the health-taste trade-off of palatable yet risky nutrients.[54] Fourth, the theoretically-derived implications of the dietary health investment model are affirmed in an empirical analysis of the Russian demand for dietary quality.

This chapter is divided into two main sub-chapters, 5.2 and 5.3. Chapter 5.2 solves the criticized inconsistency of the standard health investment model, while chapter 5.3 introduces the dietary health investment model. Following this structure, chapter 5.2.1 outlines the basic assumptions of GROSSMAN's health investment model as well as its limitations. A systematic English-language literature review of theoretical studies on GROSSMAN's health investment model, which discusses these model-related limitations, is provided in section 5.2.2. Chapter 5.2.3 presents the deterministic optimization process of GROSSMAN's standard health investment model considering a specification of the health investment production function with decreasing returns to scale. A structural demand function for medical care is derived, which hypothesizes a negative effect of the current

54 Furthermore, the extraordinary importance of these two dimensions is mirrored in the relative sub-index weights, i.e. either directly assigned weights or indirectly assigned weights by the number of equally-weighted indicators per sub-index. Considering the relative adequacy and moderation sub-index weights of the latest relevant dietary quality indices (see chapter 4.2.2), which should indicate the common nutritional expert knowledge regarding the effect strengths of the adequacy and moderation dimension on human health, these two dimensions sum up to an impact weight of 85 % of the total scores.

health status on the demand for medical care.[55] This result is shown to be stable even in the stochastic model setting discussed in chapter 5.2.4. Results of the empirical analysis of the demand for medical care are presented in chapter 5.2.5, and a short summary of the model's practical relevance is given in chapter 5.2.6. Then the focus is set on the newly developed dietary health investment model. Therefore, the concept of dietary quality is described with respect to rational utility-maximizing theoretical models in chapter 5.3.1. In chapter 5.3.2, the dietary health investment model is developed and the dynamic optimization problem is solved by the maximum principle of optimal control. Based on optimality conditions, the structural demand functions for two different aspects of dietary quality are derived in chapter 5.3.3. Afterwards, the dietary health investment model is empirically employed for the analysis of Russian dietary quality. Finally, overall chapter conclusions are provided in chapter 5.4.

5.2 HEALTH INVESTMENT MODEL

5.2.1 Standard Grossman health investment model

Since 1972, GROSSMAN's health investment model has been one of the most important developments in the theory of the demand for medical care (MUURINEN, 1982). The model's basic assumption is that medical care is not demanded for its own purpose, but rather because of its effect on health (GROSSMAN, 2000). Therefore, the health investment model provides a sharp distinction between market goods and commodities (JACOBSON, 2000). In GROSSMAN's approach, direct outlays on medical services and opportunity costs of the time invested in health are inputs that produce investments in a better health status.[56]

In the following, the standard model setting of GROSSMAN's health investment model is briefly presented according to GROSSMAN (2000).[57] In GROSSMAN's model, utility is generated by the amount of healthy time $h(t)$ as well as the consumption of household commodities $Z(t)$. For analytical convenience, an individual's lifetime utility function J is specified as being separable over time, together

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55 As GALAMA et al. (2012) point out, the terminology structural demand function comprises an equation that contains some endogenous explanatory variables, in contrast to reduced-form demand functions, which contain exclusively exogenous explanatory variables. Furthermore, since these structural demand functions are generally derived by employing functional specifications for several explanatory variables, the coefficients in these structural functions are generally functions of the underlying structural parameters rather than structural parameters themselves.

56 Based on GROSSMAN'S standard model assumptions, various health economists have enhanced the dynamic health investment model. These enhancements address, for example, the introduction of uncertainty into the theoretical model (e.g., EHRLICH, 2000) or the distribution of health within the family (e.g., BOLIN et al., 2002b).

57 For more detailed information see GROSSMAN (1972a, 1972a, 2000).

with the assumption of additive separability of preferences. Thus, under conditions of certainty, an individual's lifetime utility function can be expressed as

$$J = \int_0^T U[Z(t), h(t)]e^{-\rho t}\, dt \tag{6}$$

with $h(t) = \phi(H(t))$.

The amount of healthy lifetime in *t* is a function of an individual's stock of health capital in *t*. Furthermore, $U(\cdot)$ and $h(\cdot)$ are assumed to be increasing, strictly concave, and continuously differentiable in their arguments. The parameter ρ denotes the subjective discount rate. KOMLOS et al. (2004) highlight that the higher the subjective discount rate of an individual, the lower the present value of future utility and the greater the individual's impatience and time preference. Compared to individuals with lower time preferences, these individuals value their current pleasure much more than future utility. The utility function in equation (6) is maximized subject to the restrictions set by the individual's health and wealth time paths, as well as the production technology for the production of household commodities and health investments. These restrictions are detailed below.

The stock of health capital $H(t)$ depreciates on a progressive depreciation rate and can be revalued upwards by investments in health capital (GROSSMAN, 2000). Therefore, the equation of motion in health is expressed as

$$\dot{H}(t) = I(t) - \delta(t)H(t) \tag{7}$$

with $H(0) = H_0, H(0) > H_{min} > 0, H(T) \leq H_{min}, H(t) > H_{min}\ \forall\ t \neq T,$

$\delta(t) > 0, \dot{\delta}(t) > 0\ \ \forall\ t \in [0, T],$

where $I(t)$ is the investment in health capital and $\delta(t)$ is the depreciation rate of health capital. The depreciation rate depends on an individual's specific health endowments (e.g., genetic traits), which cannot be controlled for. The stock of health capital at $t = 0$ is indicated by H_0. The end of lifetime T is assumed to occur automatically once $H(t)$ drops to its critical minimum level H_{min}.

Investments in health are produced by medical services $M(t)$ and time invested in health $m(t)$, subject to one's level of knowledge $E(t)$ in the sense of total factor productivity. Under the condition of non-joint production functions, i.e. market goods and time inputs can be additively split between separate production processes for health investments and household commodities, the general form of the health investment function can be expressed as

$$I(t) = f_I\big(M(t), m(t); E(t)\big) \tag{8}$$

with $I(t) \geq 0\ \forall\ t \in [0, T]$.

Furthermore, the consumer produces household commodities $Z(t)$ that are produced by non-medical market goods $Q(t)$ and consumption time $k(t)$, subject to one's level of knowledge $E(t)$. For example, a consumer cooks a meal by using foods and time, prepares clean clothes by using washing powder, water, and time, or generates recreation by using sport equipment and leisure time. These household commodities are produced by

$$Z(t) = f_Z\big(Q(t), k(t); E(t)\big). \quad (9)$$

Over one's entire lifetime, expenditures on medical care and other market goods are restricted by the initial wealth in t plus the wealth surplus in t. Financial wealth $A(t)$ develops over the whole lifetime according to the following equation of motion

$$\dot{A}(t) = w(t)l(t) + r(t)A(t) + y(t) - p_Q(t)Q(t) - p_M(t)M(t) \quad (10)$$

with $A(0) = A_0, A(0) > 0, A(T) \geq 0.$

The individual periodically receives labor income by labor $l(t)$ valued at its wage rate $w(t)$, other non-labor income $y(t)$, and interest revenues on financial assets with the interest rate $r(t)$. Wealth decreases over time by expenditures on market goods $Q(t)$ valued at their market prices p_Q and medical care $M(t)$ valued at the market prices for medical care p_M.

Besides the constraint on wealth, an individual's time is also constrained. This time constraint is given by

$$\Omega(t) = l(t) + m(t) + k(t) + s(t) \quad (11)$$

with $\Omega(t) - s(t) = h(t)$.

Hence, total time $\Omega(t)$ available in t has to be fully divided into labor time $l(t)$, time invested in gross health investments $m(t)$, consumption time $k(t)$, and sick time $s(t)$. Because of the imposed time restriction, time for producing commodities is healthy time $h(t)$, which has to be withdrawn from competing uses for labor and health investments. Sick time is lost for labor and non-market activities.

Nevertheless, despite the above presented theoretical elegance of modeling the demand for health and health investments, GROSSMAN's model is not without criticism (ZWEIFEL, 2012). Indeed, it is often argued that the model fails to account for the uncertainty of one's future health status and the uncertainty of the health investment efficiency (GROSSMAN, 2000). Yet until now, a number of theoretical studies have already introduced uncertainty into the health investment model (see e.g., CROPPER, 1977; EHRLICH, 2000; LAPORTE and FERGUSON, 2007). Beyond that, one central criticism lies with the implications of the model's demand function for medical care (ZWEIFEL, 2012). According to the model's conditional demand function for medical care, the coefficient of health is positive because an increase in the optimal quantity of health is supposed to increase the demand for health inputs (GROSSMAN, 2000). Grossman assumes instantaneous health adjustments, i.e. the optimal quantity of health demanded is interpreted as the optimal stock of health capital, which is assumed to equal the actual stock of health capital (GROSSMAN, 2000). But empirical studies that have tested the implications of GROSSMAN's model (e.g., WAGSTAFF, 1986, 1993; LEU and GERFIN, 1992; ERBSLAND et al., 1995; GALAMA et al., 2012) indicate that actual health has a significantly negative coefficient in the demand function for medical care.[58] This implies that sick people tend to use more medical care (KAESTNER, 2013). Even if a variety of different econometric methodologies and datasets is employed, this inconsistency between the theoretical implications and the empirical results persists (GALAMA and KAPTEYN, 2009). Therefore, WAGSTAFF (1993) suggests a non-instantaneous character for health adjustments and questions the appropriateness of GROSSMAN's underlying assumptions regarding the empirical model specifications. Along these lines, ZWEIFEL (2012) concludes that translating the model's basic optimum conditions into an empirically testable formulation is a major challenge. Hence, the present inquiry aims to address the proposed challenge by deriving an empirical demand function for medical care that indicates a negative health coefficient in the demand function for medical care.

5.2.2 Review of theoretical studies on health investment model

Given the introduced standard model setting, GROSSMAN's health investment model has been enhanced by various authors to overcome the above mentioned criticisms. Therefore, a systematic review of the published English-language literature has been conducted to search for theoretical modifications, which may solve the criticized inconsistencies between the model's theoretical implications and its empirical results. The electronic database MEDLINE has been searched for the following search items: Grossman, health investment, demand for health, longevity, as well as its combinations. Based on the search results of published articles, additional relevant literature has been identified from cited articles. The resulting overview of theoretical studies and modifications of GROSSMAN's health investment model is presented in the following.

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[58] Instrumenting health with childhood health or a binary indicator of one parent's smoking during childhood, GALAMA et al., (2012) estimate insignificant health coefficients. Nevertheless, their individual health expenditure data have been imputed and hence may include potential measurement errors (see GALAMA et al., 2012). Moreover, there are possible concerns regarding the accuracy of the retrospectively recalled childhood health data. Finally, considering strong associations between childhood health as well as childhood and adult socioeconomic status (see e.g., GILMAN, 2002; CURRIE and GOODMAN, 2010), the coefficients of their employed socioeconomic variables in the generally less efficient IV regressions might mitigate the estimation of the instrumented health coefficient due to severe problems of multicollinearity and endogeneity.

Studies on the demand for health

Some of the searched theoretical studies focus solely on the demand for health without further considering the demand for medical care. CROPPER (1981) modifies GROSSMAN's model to define what a person would pay for a change in air quality. JACOBSON (2000), BOLIN et al. (2001), and BOLIN et al. (2002b) restrict their analysis to the optimal demand for health and its distribution among family members. LILJAS (1998, 2000) and TABATA and OHKUSA (2000) investigate how the individual's demand for health would be affected by uncertainty and the introduction of insurance. DUSTMANN and WINDMEIJER (2000) present a life-cycle model for the demand for health in which they distinguish between transitory and permanent wage responses. FORSTER (2001) applies a very basic version of GROSSMAN's model and enhances this to the analysis of separate healthy and unhealthy goods. By simulation, Forster analyses the impacts of various terminal conditions, pathways of health-related consumptions, and health. DIAS (2010) integrates the John Roemer framework of inequality of opportunity into the Grossman model to derive a demand for health and healthy efforts such as avoiding smoking. TABATA (2010) extends the health investment model to a neoclassical infinite horizon growth model with the accumulation of health and wealth and analyzes how policies can enhance health and health investments. JONES et al. (2014) integrate the problem of rational addiction, considering an individual's lifetime smoking consumption pattern, into the Grossman model of health investment. KOKA et al. (2014) simulate the model's optimal health capital lifetime trajectories considering varying assumptions of health depreciation rates and conditional survival probabilities.

Studies on the demand for medical care

Despite the analysis of optimal health levels, an ongoing discussion in the health investment literature is primarily concerned with the optimal demand for medical care. Indeed, various researchers address the impact of uncertainty on the demand for medical care. This is mostly achieved with an analytical solution of a simplified static or two-period model setting. For example, DARDANONI and WAGSTAFF (1987), SELDEN (1993), and CHANG (1996) use a simplified two-period pure investment model to introduce uncertainty surrounding the marginal effectiveness of health capital through the earnings-generating function.[59] These authors concentrate their studies on the demand for medical services with regard to wealth. DARDANONI and WAGSTAFF (1987) show that if uncertainty is introduced into a two-period investment model wealthier individuals will invest more in health

[59] In the pure consumption model the marginal monetary return on health investment is set to zero, whereas in the pure investment model the marginal utility of healthy days is set to zero (see chapter 5.2.3.2.)

capital. DARDANONI and WAGSTAFF (1990) show in a static model setting the effect of uncertainty surrounding the incidence of illness and uncertainty surrounding the effectiveness of medical care on the demand for medical services. ASANO and SHIBATA (2011) analyze how the presence of Knightian uncertainty about the efficiency of health care affects the optimal health investment behavior of individuals in a two-period model.[60] Furthermore, PICONE et al. (1998) and FONSECA et al. (2008, 2009) analyze the effect of uncertainty considering retirement decisions by solving the lifetime model numerically or by simulations. In contrast to the inclusion of uncertainty, EHRLICH and CHUMA (1990) enhance GROSSMAN's health investment model by considering the demand for longevity, i.e. they specify the individual's health investment problem as a fixed endpoint problem. In their continuous version of the health investment model, these authors are the first who explicitly specify the production function for health investments to be of decreesing returns to scale. EHRLICH and CHUMA apply comparative dynamic analysis using path analysis to show the effects of marginal parametric changes on the demand for longevity, health capital, health investment, the shadow price of health, and consumption. Still, theoretical implications of the effect of health capital changes on the demand for medical care remain unconsidered in their study.

Studies on the demand for medical care dependent on health

Results of studies that analyze the impact of one's health status on the demand for medical care do not draw a uniform picture. Applying GROSSMAN's standard theoretical model specified with a health investment function with constant returns to scale, WAGSTAFF (1986), ERBSLAND et al. (1995), and GROSSMAN (1972a, 1972a, 2000) derive a structural demand function for medical care that indicates a strict positive effect of the optimal (and actual) health status on the demand for medical care. However, WAGSTAFF (1986, 1993) and ERBSLAND et al. (1995) also provide empirical evidence showing that better actual health states have a significant negative effect on the demand for medical care, which indicates the opposite of their theoretical implications. MUURINEN (1982) derives a generalized demand for health model by incorporating the stock of knowledge. Just as GROSSMAN does, MUURINEN derives a demand function for medical care that indicates a positive association between health status and medical care. Based on these inconsistencies between theoretical implications and empirical results, WAGSTAFF (1993, 2002) proposes an alternative empirical formulation in which not the actual but the lagged health stock variable negatively affects the current consumption of medical care. This author also provides empirical results to confirm his rather ad hoc empirical model formulation. WAGSTAFF (1993) concludes that his empirical results

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[60] Based on the work of KNIGHT (1921), there is a difference between the unmeasurable risk, i.e. uncertainty, and a measurable risk with predictable outcomes.

do not confirm instantaneous health adjustments. Furthermore, GALAMA et al. (2013), as well as GALAMA and KAPTEYN (2011) specify a health investment function with constant returns to scale but allow for corner solutions in their models. Hence, these authors interpret GROSSMAN's "optimal" health stock as a health threshold that equals the individual's minimum health level. By solely considering people whose health is at the health threshold, these authors derive the same predictions regarding the demand for medical care as GROSSMAN (1972b, 1972a, 2000). However, measured across healthy and unhealthy individuals and allowing for corner solutions, GALAMA and KAPTEYN (2011) state that unhealthy individuals consume more medical care than healthy individuals. Furthermore, based on GALAMA (2011), GALAMA et al. (2012) provide a theoretical framework in which health investments are produced by combining time and medical care according to a Cobb-Douglas production function with constant returns to scale, but health capital is improved by health investments with decreasing returns to scale, i.e. equation (7) of the standard model setting changes to

$$\dot{H}(t) = I(t)^{\alpha} - \delta(t)H(t) \tag{12}$$

with $0 < \alpha < 1$.

With their modified version of the Grossman model, GALAMA et al. (2012) contribute significantly to the health investment literature because they analytically derive a structural demand function for medical care that indicates a negative effect of health capital on the demand for medical care.[61] Also, based on the modifications of GALAMA (2011), GALAMA and VAN KIPPERSLUIS (2010, 2013) enhance GROSSMAN's conceptual framework to understand the observed disparities in health between different groups of socioeconomic status. These authors analyze the effects of socioeconomic status and health on the consumption of curative care as well as healthy household commodities (e.g., consumption of healthy foods, doing sports and exercise) and unhealthy household commodities (e.g.,

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[61] In contrast to EHRLICH and CHUMA (1990), it is not the production function of health investments but the appreciation of health capital that is of decreasing returns in their modified model assumptions (GALAMA, 2011). GALAMA (2011) continues to specify the health investment production function to be of constant returns to scale but assumes the appreciation of health capital (noted in his study as the "health production process") in the motion of health to be of decreasing returns to scale. GALAMA et al. (2012) argue that at higher levels of health investment very expensive treatments often provide only relatively small improvements in health. While this definition of health production is possibly appropriate in cost-benefit analyses, it is rather misleading in the sense of investment models. In GROSSMAN's health investment model, the improvement in health is already generated by the health investment production function, which is by definition the gross increase in health stock. Therefore, EHRLICH and CHUMA (1990) keep health capital accumulation in equation (7) unchanged but specify the health investment production function to be of decreasing returns to scale.

smoking, excessive alcohol consumption) in a generalized model. Finally, in order to address major criticisms leveled at the Grossman model, LAPORTE (2014) outlines a simplified version of the Grossman model with only health capital accumulation but not wealth accumulation over the individual's lifetime. In LAPORTE's version, total lifetime utility depends on health capital and the amount of household commodities, which are substituted by the period's budget function considering full income and health investments. In that case, i.e. health investments are specified within the utility function, an optimal level of health investments can be determined although LAPORTE employs the health investment production function to be of constant returns to scale.[62] LAPORTE's qualitative analysis shows that the amount of health investments increases with decreasing health until the stationary locus for health investments. Furthermore, LAPORTE shows that individuals respond to suddenly lower health states by more health investments.

CROPPER (1977) sets out a model to explain health investments in which the stock of health is deterministic, but the illness threshold is stochastic. By qualitatively solving the model by path analysis, CROPPER presents an optimal strategy in which the amount invested in health increases up to a peak in the early years of life, while the health stock decreases steadily by depreciation. Afterwards, investment in health declines as one's health status decreases. Yet CROPPER does not work with a continuous set of health states but rather with two states: ill or not ill. Hence, illness is assumed to have no impact on the health stock itself. Since this assumption is rather unrealistic for many chronic diseases, CROPPER focuses solely on mild illness. EHRLICH (2000) analyzes individuals' demand for life protection and longevity under uncertainty concerning the arrival time of death and alternative insurance options by path analysis, and derives a path of self-protective expenditures that increase with less healthy time. LAPORTE and FERGUSON (2007) concentrate their study on the utility-generating aspect of health, and solve their theoretical version of the Grossman model by working with phase diagrams. In these authors' deterministic case with a finite horizon, the investment in health tends to increase with decreasing health until the stationary locus of investment in health is reached. Afterwards, health investments decrease with decreasing health capital. In their stochastic case with infinite horizon, investment in health and health status are negatively correlated until the stock equilibrium is reached (especially after illness has occurred). For an overview of theoretical studies regarding the demand for medical care with respect to the influence of health in deterministic and stochastic model settings, see Table 13.

[62] According to this version, health investments do not cancel out with the first derivation of the respective Hamiltonian function, even if they are specified as being of constant returns to scale. In fact, health investments are still included in the first order conditions of the Hamiltonian system by $\frac{\partial U(t)}{\partial I(t)}$.

Table 13: Studies analyzing the effect of health status on the demand for health

Author and publication year	Focus and aim	Model features	Certainty/ uncertainty	Theoretical predictions of the effect of health status on demand for medical care	Empirical testings of these predictions
GROSSMAN (1972a, 1972b)	▪ theoretical model for the demand for health ▪ based on household production theory (BECKER, 1965) ▪ empirical tests of the predictions	▪ discrete time and continuous time frame ▪ empirical formulation of the pure investment model and the pure consumption model ▪ household production of commodities and health investments with constant returns to scale	▪ certainty[a]	▪ positive[b]	▪ not tested for $\frac{\partial M}{\partial H}$
CROPPER (1977)	▪ theoretical focus ▪ explicit recognition of the random nature of illness and death ▪ two models: 1) life-cycle behavior of investment and health capital when the motive for investing in health is to decrease the probability of illness and 2) individual invests in health through his choice of occupation	▪ continuous time frame ▪ no empirical formulation of the model with structural demand functions ▪ stock of health deterministic but with a stochastic illness threshold. i.e. health not continuous but with two states: ill or not ill ▪ illness has no impact on health stock (argument: only mild illness) ▪ investment in health produced with constant returns to scale ▪ no household production of commodities ▪ income is assumed to be constant at each instant of life	▪ uncertainty by a random critical health stock level	▪ solution not quantitative but qualitative ▪ optimal strategy: increase the amount invested in health to a peak in the early years of life and let it decline steadily thereafter with dI/dt <0, not necessarily the case when death is endogenous	▪ not tested
MUURINEN (1982)	▪ theoretical focus ▪ generalized demand for health model by incorporating the stock of knowledge ▪ comparative statics regarding age, education and wealth	▪ continuous time frame ▪ no separation between pure consumption and pure investment model ▪ time preference and interest rate are equal ▪ three stocks: wealth, health, and knowledge ▪ investment in health directly produced by medical care without considering time restriction	▪ certainty	▪ positive	▪ not tested

Author and publication year	**Focus and aim**	**Model features**	**Certainty/ uncertainty**	**Theoretical predictions of the effect of health status on demand for medical care**	**Empirical testings of these predictions**
WAGSTAFF (1986)	▪ focus on empirical tests of the model's predictions ▪ reduced-form and structural demand for health care equations	▪ continuous time frame ▪ pure investment and pure consumption models ▪ household production of health investments with constant returns to scale ▪ recognizing the dependency of the shadow price of initial assets of the entire lifetime profiles of the model's exogenous variables	▪ certainty	▪ positive	▪ negative
WAGSTAFF (1993, 2002)	▪ theoretical focus motivated by the apparent rejections of the model by the data ▪ alternative formulation, in which lagged health stocks affect the current demand for health ▪ empirical tests	▪ discrete time frame ▪ pure investment model to derive the empirical demand function ▪ linear nature of the net investment identity in an ad hoc manner derived ▪ household production approach with constant returns to scale	▪ certainty	▪ negative on lagged health	▪ negative on lagged health
ERBSLAND et al. (1995)	▪ theoretical and empirical focus ▪ explain the impact of environmental pollution on the demand for both health and health care	▪ discrete time frame ▪ theoretical formulation plus the empirical formulation of the pure investment model ▪ production of commodities and health investments with constant returns to scale	▪ certainty	▪ positive	▪ negative
EHRLICH (2000)	▪ theoretical focus on the analysis of individuals' demand for life protection and longevity in a life-cycle context ▪ uncertainty concerning the arrival time of death ▪ alternative insurance options	▪ continuous time frame ▪ household production of commodities and health investments ▪ production of investment in health with decreasing returns to scale ▪ considers only the equation of motion of wealth and not of the health stock ▪ yields a closed-form solution for individuals' value of life-saving that is estimable	▪ uncertainty concerning the arrival of death modeled as Poisson process	▪ analytically derived dynamic path of self-protective expenditures, which depends on the biological rate of increase in the probability of morbidity and hence less healthy time (+) and the change in the value of reducing morbidity and mortality (+/-)	▪ not tested

Author and publication year	Focus and aim	Model features	Certainty/ uncertainty	Theoretical predictions of the effect of health status on demand for medical care	Empirical testings of these predictions
GROSSMAN (2000)	▪ motivated by central criticism of EHRLICH and CHUMA (1990) and RIED (1998) ▪ theoretical focus regarding the model's predictions and extensions (e.g., optimal length of time) ▪ empirical tests of the predictions	▪ discrete time frame ▪ empirical formulation of the pure investment model and the pure consumption model ▪ household production of commodities and health investments with constant returns to scale	▪ certainty	▪ positive[c]	▪ not tested for $\frac{\partial M}{\partial H}$
LAPORTE and FERGUSON (2007)	▪ theoretical focus with the application of stochastic calcus	▪ continuous time frame ▪ pure consumption model since health returns are strictly psychic ▪ a number of simplifications, for example rate of depreciation is constant ▪ nature of the illness: the risk of illness lessens the optimal investment in health at any time, with greater risk having a greater effect ▪ considers only the equation of motion of health investments without considering the wealth aspect	▪ certainty ▪ uncertainty with the motion of health incorporating a Poisson process with only one major illness during life	▪ solution by phase diagrams ▪ deterministic case with finite horizon: negative until stationary locus of health investment, then positive ▪ stochastic case with infinite horizon: negative until the stochastic equilibrium is reached, after illness occurred increasing health investments	▪ not tested
GALAMA et al. (2008)	▪ theoretical focus on the analysis of the influence of individual's health on the decision to retire	▪ continuous time frame ▪ simplified model ▪ without time restriction ▪ household production of investment in health with constant returns to scale ▪ considers corner solutions ▪ optimal health stock interpreted as health threshold (minimum health level individuals demand)	▪ certainty	▪ healthy individuals (whose health is above the threshold): do not invest in health ▪ unhealthy individuals (whose health is at or below the threshold): invest in health, i.e. negative relationship with health	▪ not tested

Author and publication year	Focus and aim	Model features	Certainty/ uncertainty	Theoretical predictions of the effect of health status on demand for medical care	Empirical testings of these predictions
Galama and Kapteyn (2011)	▪ theoretical focus ▪ motivated by the significant criticism of the Grossman model, i.e. the model's prediction that health and medical care are positively related, which is consistently rejected by the data.	▪ continuous time frame ▪ generalized solution relaxing the widely used assumption that individuals can adjust their health stock instantaneously to an "optimal" level without adjustment costs ▪ pure investment model and pure consumption model in the empirical formulation	▪ certainty	▪ for unhealthy people (whose health is at the threshold): positive ▪ across healthy and unhealthy individuals and allowing for corner solutions with the optimal solution as a health threshold: negative	▪ not tested
Galama (2011); Galama et al. (2012)	▪ motivated by limitations of existing Grossman model ▪ derivation of a suitable structural relation between health and health investment ▪ estimation of the health investment equation ▪ test for constant versus decreasing returns to scale	▪ continuous time frame ▪ pure investment and pure consumption model ▪ health investment production function specified to be of constant returns to scale ▪ appreciation of health capital in the equation of motion of health assumed to be of decreasing returns to scale ▪ analytically derived structural demand function for medical care	▪ certainty	▪ negative	▪ negative[d]
Laporte (2014)	▪ addresses criticisms of the Grossman model ▪ graphical approach for understanding the criticisms	▪ a very basic version of the Grossman model ▪ only health capital accumulation but not wealth accumulation over the individual's lifetime ▪ no difference between health and healthy time ▪ constant depreciation rate ▪ total life time utility depends on health capital and the amount of household commodities, which are substituted by the period's budget function considering full income and health investments, ▪ health investment production function with constant returns to scale	▪ certainty	▪ solution by phase diagrams ▪ health declines continuously and health investments increase until the stationary locus for health investments, at which point investments start to decrease ▪ the individual responds to a suddenly lower health state by dramatically increasing her level of investment	▪ not tested

Author and publication year	Focus and aim	Model features	Certainty/ uncertainty	Theoretical predictions of the effect of health status on demand for medical care	Empirical testings of these predictions
GALAMA and VAN KIPPERSLUIS (2010, 2013)	▪ theoretical focus on the analysis of socioeconomic inequalities in health	▪ based on GALAMA (2011)	▪ certainty	▪ negative	▪ not tested

Source: Own presentation.

Notes: [a] Grossman provides some thoughts about a probability distribution of depreciation rates and then concentrates on two possible depreciation rates. After that he states some main results of his analysis without providing the respective mathematical formulation.

[b] See Appendix D of GROSSMAN, 1972b.

[c] Equation 46 of GROSSMAN (2000) is equivalent to its alternative form presented in Appendix D of GROSSMAN (1972b) with $\frac{\partial M}{\partial H} > 0$.

[d] GALAMA et al. (2012) show that using childhood health or a binary indicator for one parent's smoking during childhood as instruments for actual adult health, the health coefficient is no longer significantly negative.

Summary of reviewed theoretical articles

This literature review highlights the widespread application of the Grossman model. Though empirical studies clearly indicate that actual health enters the demand function for medical care with a negative coefficient, the theoretical implications of GROSSMAN's model, as well as its enhancements presented above, do not provide such a clear indication. In fact, GROSSMAN's standard model setting still predicts a positive association between the health status and the demand for medical care to be optimal if the health investment production is assumed to be of constant returns to scale.[63] If the standard model setting is modified, the theoretical implications of GROSSMAN's model vary considerably (see e.g., CROPPER, 1977; GALAMA et al., 2012; GALAMA and VAN KIPPERSLUIS, 2013; LAPORTE, 2014).[64] This is especially true when introducing uncertainty into the model (see e.g., EHRLICH, 2000; LAPORTE and FERGUSON, 2007). Yet in contrast to these modifications, this inquiry aims to underscore the practical relevance of GROSSMAN's standard model setting. Therefore, it has to be analyzed whether the health investment model is able to predict a negative effect of actual health capital on the demand for medical care, even if GROSSMAN's standard model setting is applied without any modification of equations (6), …, (11). To analyze this research question, GROSSMAN's standard model setting is first applied under the assumption of certainty, but the specification of the model's inherent health investment production function is slightly modified. This approach has been suggested by KAESTNER (2013) in his response to ZWEIFEL's criticism (ZWEIFEL, 2012). Afterwards, the analysis determines whether the newly derived implications of the deterministic model setting still hold under the assumption of uncertainty (BURGGRAF et al., 2014e).

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[63] GROSSMAN (2000) states that decreasing returns to scale regarding the health investment production function would unnecessarily complicate his model. Hence, GROSSMAN decides to keep the assumption of instantaneous health adjustments. Furthermore, he questions EHRLICH and CHUMA's statement of non-determinable optimal health investments in his model because in his opinion the discounted marginal health benefit function would depend on $I(t)$ (see relative shadow price of health, chapter 5.2.3.1). Although GROSSMAN correctly argues that the marginal product of health capital would diminish as the health stock rises and therefore the discounted marginal benefits must fall, his line of argumentation fails to consider that it is the discounted marginal benefit in $t+1$ that is affected in by an investment at age t. Hence, with constant returns to scale, an interior solution for the optimal gross investment does not exist. But certainly the optimal investment in health is what rational consumers want to control in order to overcome the discrepancies between actual and desired health stock.

[64] In this thesis, a modification of GROSSMAN's model assumptions is defined as a change in the general model assumptions given by equations (6) … (11) in chapter 5.2.1.

5.2.3 Deterministic optimization problem with decreasing returns to scale

5.2.3.1 Optimum conditions

Since the customer's utility function is assumed to be inter-temporally separable, the customer solves two separate optimization problems: an inter-temporal utility maximization problem and an intra-temporal cost minimization problem (ROE et al., 2010). Beginning with the intra-temporal cost minimization problem, the customer determines those input bundles that minimize the short run costs of attaining health investment $I(t)$ and household commodities $Z(t)$, subject to the constraints imposed by the respective production functions and the given level of knowledge.

Regarding the functional form of the health investment production function, there is still little empirical evidence to support the selection process (see e.g., LEIBOWITZ, 2004; HALL and JONES, 2007; GALAMA et al., 2012). However, productions in the human capital-dependent field of health investments generally provide sufficient justification for decreasing returns to scale because of reasonably less automation and rationalization. Despite this fact, the majority of theoretical studies that utilize GROSSMAN's pure investment model to derive a demand function for healthcare apply a health investment production function with constant returns to scale (e.g., WAGSTAFF, 1986; JOYCE, 1987; WAGSTAFF, 1993; ERBSLAND et al., 2002). However, inspired by the basic theoretical remarks of EHRLICH and CHUMA (1990), in this analysis health investments are assumed to be subject to decreesing returns to scale, i.e. $\theta I(t) > f_I\big(\theta M(t), \theta m(t); E(t)\big)$ with a scaling factor $\theta > 1$. Incorporating decreasing returns to scale leads to increasing marginal costs of health investments, i.e. the higher the input levels of medical care and time, the smaller the marginal health gain and the higher the costs of an additional unit of health investments (BURGGRAF et al., 2014e). Hence, the cost minimizing factor input bundle for producing health investments results in a convex dual cost function of the general form

$$C_I = \nu_I\big(p_M(t), w(t), I(t);\ E(t)\big) \tag{13}$$

with $$\frac{\partial C_I(t)}{\partial I(t)} > 0, \qquad \frac{\partial^2 C_I(t)}{\partial I(t)^2} > 0\ .$$

Since the focus of this chapter is not on the optimal demand for household commodities, the production of household commodities is assumed to be of constant returns to scale for the sake of simplicity, i.e. $\theta Z(t) = f_Z\big(\theta Q(t), \theta k(t);\ E(t)\big)$ with $\theta > 0$. Hence, the cost function of producing household commodities is given by

$$C_Z = \nu_Z\left(p_Q(t), w(t), Z(t);\ E(t)\right) \tag{14}$$

with $\dfrac{\partial C_Z(t)}{\partial Z(t)} > 0, \qquad \dfrac{\partial^2 C_Z(t)}{\partial Z(t)^2} = 0$.

Integrating the time constraint (11), the cost function of health investments (13), and the cost function of household commodities (14) into the wealth constraint (10), the full-wealth constraint (see e.g., BECKER, 1965) of GROSSMAN's problem setting can be written as

$$\dot{A}(t) = r(t)A(t) + w(t)h(t) + y(t) - C_I(t) - C_Z(t). \tag{15}$$

Now, given the cost-minimal factor inputs for time t, the inter-temporal utility maximization problem can be solved. In this regard, the individual chooses the trajectories of health investments and household commodities that maximize the present value of utility subject to the restrictions imposed by the model. In this inquiry, the dynamic optimization problem is tackled by the optimal control theory (see e.g., CHIANG 1992), where the cost-minimal produced amounts of $Z(\cdot)$ and $I(\cdot)$ qualify as control variables. In every time t, household commodities and gross health investments are subject to the individual's discretionary choice and affect the state variables $H(\cdot)$ and $A(\cdot)$, which indicate the stocks of health capital and wealth, respectively. Thus, the task is to choose the optimal control paths that imply the associated state paths over a given health interval $[H_0, H_{min}]$. Because of the terminal state H_{min}, the terminal time T is not fixed but is defined by the minimum stock of health capital (see EHRLICH and CHUMA, 1990), a problem commonly known as a fixed-endpoint problem. Hence, the health investment problem further grows to a problem of optimal longevity.[65] Eventually, for all $h: [0, T] \rightarrow \mathbb{R}_+$ and $Z: [0, T] \rightarrow \mathbb{R}_+$ and all $t \in [0, T]$, the utility maximization problem of GROSSMAN's health investment model can be expressed as

$$\max_{I,Z,T} \int_0^T U[Z(t), h(t)]e^{-\rho t}\, dt \tag{16}$$

subject to

(i) $\dot{H}(t) = I(t) - \delta(t)H(t)$,

(ii) $\dot{A}(t) = rA(t) + y(t) + wh(t) - C_I(t) - C_Z(t)$,

(iii) $I(t) = f_I\big(M(t), m(t); E(t)\big),\ \theta I(t) > f_I\big(\theta M(t), \theta m(t); E(t)\big)$,

(iv) $Z(t) = f_Z\big(Q(t), k(t); E(t)\big)$,

and

[65] Though a fixed endpoint problem is assumed instead of a fixed terminal time T, the model is not solved here for optimal longevity. Based on the research question of this thesis, the focus is set on the model's flow and stock equilibriums given by equations (25) and (28), which equal equations (8′) and (13) of EHRLICH and CHUMA (1990).

(v) $H(0) = H_0, H(0) > H_{min} > 0, H(T) \leq H_{min}, H(t) > H_{min}\ \forall\ t \neq T,$
(vi) $A(0) = A_0, A(0) > 0, A(T) \geq 0,$
(vii) $I \in [0, \infty]$.

For simplicity within the optimization process, wage rates and interest rates are assumed to be constant. Hence, the observed personal wage rate and the person's efficiency in health production are unaffected by the human health capital accumulation (EHRLICH, 2000). Solved by the maximum principle of Pontryagin (see PONTRYAGIN et al., 1967), the Hamiltonian function denoted by $\mathcal{H}$ is defined for all $t \in [0, T]$ as

$$\mathcal{H}(H, A, I, Z, \varphi_H, \varphi_A, t) \quad (17)$$
$$:= U[Z(t), h(t)]e^{-\rho t}$$
$$+ \varphi_A(t)[rA(t) + y(t) + wh(t) - C_I(t) - C_Z(t)]$$
$$+ \varphi_H(t)[I(t) - \delta(t)H(t)]\,.$$

The Hamiltonian is jointly concave in both the state and control variables due to the strict concavity of the utility function, production of health, and the generation of healthy time (EHRLICH and CHUMA, 1990).[66] For the above stated problem, the optimality conditions of the Hamiltonian system can be derived by

$$\frac{\partial \mathcal{H}(t)}{\partial \varphi_H(t)} = \dot{H}(t) = I(t) - \delta(t)H(t), \quad (18)$$

$$\frac{\partial \mathcal{H}(t)}{\partial \varphi_A(t)} = \dot{A}(t) = rA(t) + wh(t) + y(t) - C_I(t) - C_Z(t), \quad (19)$$

$$\frac{\partial \mathcal{H}(t)}{\partial Z(t)} = \frac{\partial U}{\partial Z} e^{-\rho t} - \varphi_A(t) \frac{\partial C_Z(t)}{\partial Z(t)} = 0, \quad (20)$$

$$\frac{\partial \mathcal{H}(t)}{\partial I(t)} = -\varphi_A\,(t) \frac{\partial C_I(t)}{\partial I(t)} + \varphi_H(t) = 0, \quad (21)$$

$$\dot{\varphi}_A(t) = \frac{\partial \varphi_A(t)}{\partial t} = -\frac{\partial \mathcal{H}(t)}{\partial A(t)} = -\varphi_A(t)r\,, \quad (22)$$

$$\dot{\varphi}_H(t) = \frac{\partial \varphi_H(t)}{\partial t} = -\frac{\partial \mathcal{H}(t)}{\partial H(t)} = -e^{-\rho t} \frac{\partial U(t)}{\partial h(t)} \frac{\partial h(t)}{\partial H(t)} - \varphi_A(t) w \frac{\partial h(t)}{\partial H(t)} + \varphi_H(t)\delta(t), \quad (23)$$

with the transversality condition

$$\mathcal{H}(T) = \left[U\big(Z(T), h(T)\big)e^{-\rho T}\right] + \varphi_A(T)\dot{A}(T) + \varphi_H(T)\dot{H}(T) = 0, \quad (24)$$

with

$$\varphi_H(T) = \varphi_H \geq 0, H(T) \leq H_{min}, \frac{\partial \mathcal{H}(T)}{\partial T} < 0,$$

[66] For a detailed presentation of the sufficient condition of the total optimization process, see Appendix 2.

$\varphi_A(T) = \varphi_A \geq 0, A(T) \geq 0.$

Equations (18), …, (23) represent the equations of motion, the standard first order conditions (FOC), and the adjoint equations for the inter-temporal optimization problem (KAMIEN and SCHWARTZ, 1991). It follows from conditions (18) … (23) and the terminal condition (24) that the adjoint variables are positive.[67] Furthermore, note that the condition $H(T) \leq H_{min}$ is sufficient to make $H(t) > H_{min}\ \forall\ t \neq T$. The adjoint variables $\varphi_H(t)$ and $\varphi_A(t)$ are in the nature of Lagrange multipliers of the states $H(t)$ and $A(t)$, respectively. As such, they show by how much lifetime utility will increase if health capital or full-wealth is increased by one unit in t. Therefore, these variables measure the shadow prices of the associated state variables at a particular point in time (CHIANG, 1992).

From equation (21), the flow equilibrium condition of the optimal health investment (see EHRLICH and CHUMA, 1990) can be derived for all $t \in [0, T]$ as[68]

$$\frac{\partial C_I(t)}{\partial I(t)} = \eta(t) \tag{25}$$

with $$\eta(t) = \frac{\varphi_H(t)}{\varphi_A(t)}.$$

Condition (25) implies that the optimal investment in health in t is a function of the shadow price of health capital in t, the shadow price of wealth in t, and the actual marginal costs of health investments in t. If the term of the shadow price of health $\varphi_H(t)$ relative to the shadow price of wealth $\varphi_A(t)$ is defined as the relative shadow price of health capital $\eta(t)$, then it follows that the individual's health investment is optimal if the marginal cost of health investments in t equals the relative shadow price of health capital in t (EHRLICH and CHUMA, 1990).[69] Therefore the optimal level of health investments can be directly determined as an interior solution of the presented optimization problem, i.e. health investments are no longer assumed to be instantaneous as is the case in problems of singular control considering constant returns to scale. With the dual cost function of producing $I(t)$ being a monotonic increasing and convex function in $I(t)$, it

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[67] The assumptions $\frac{\partial C_I(t)}{\partial I(t)} > 0$ and $\alpha > 1$ are sufficient to make $\eta(t) > 0$ as long as all factor prices are larger than zero. Furthermore, due to $\dot{\varphi}_A(t) = -\varphi_A(t)r$, it follows that $\varphi_A(t) > 0$ for all $t \in [0, T]$ under the reasonable assumption that $\varphi_A(0) > 0$ with $A_0 > 0$.

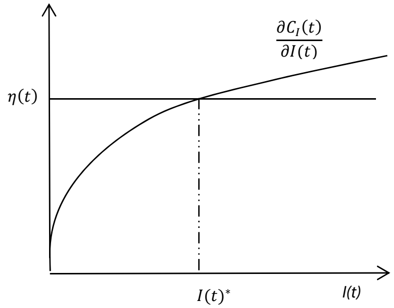
[68] The terms stock and flow equilibrium are used in the sense of GROSSMAN (2000), WAGSTAFF (1986) or EHRLICH and CHUMA (1990). Nevertheless, they differ from the equilibrium conditions with infinite horizon in the sense of a steady state (LAPORTE, 2014).

[69] Since variables $\varphi_H(t)$ and $\varphi_A(t)$ can be interpreted as the shadow price of health and the shadow price of wealth, respectively, $\eta(t)$ is not defined as the shadow price of health as done by EHRLICH and CHUMA (1990) but rather as the relative shadow price of health.

follows from equation (25) and $C_I(t) = \pi_H(t)\, I(t)^{\alpha}$ with $\alpha > 1$ that the optimal investment is $I(t) = \left(\frac{\eta(t)}{\pi_H(t)\,\alpha}\right)^{\frac{1}{\alpha-1}}$.

Furthermore, with all factor prices being positive, $\alpha > 1$, and $\eta(t) > 0$, it follows that $I(t) > 0$. Additionally, by the assumption of a convex cost function of health investments with $\frac{\partial^2 C_I(t)}{\partial I(t)^2} > 0$, the second-order condition gives $\frac{\partial^2 \mathcal{H}(t)}{\partial I(t)^2} = -\varphi_A(t)\frac{\partial^2 C_I(t)}{\partial I(t)^2} < 0$. Hence, the control path given by equation (25) indeed maximizes the Hamiltonian at every point in time (BURGGRAF et al., 2014e). The optimality condition given by equation (25) is illustrated in Figure 12. In this graphic, the optimal health investment in t is achieved at the point at which the increasing function of the marginal cost of health investments intersects the horizontal curve of the relative shadow price of health capital.

Figure 12: Deterministic optimal investment for a flow equilibrium



Source: Based on EHRLICH and CHUMA (1990).

Note: For illustration purpose it is assumed that α=1.2.

From equation (22), which is a backward ordinary differential equation solved by $\varphi_A(t) = \varphi_A e^{-r(t-T)}$, with $\varphi_A(T) = \varphi_A$, it follows by some rearrangements that

$$\varphi_A(t) = \varphi_A(0)e^{-rt}, \tag{26}$$

and from $\eta(t) = \frac{\varphi_H(t)}{\varphi_A(t)}$ it follows that

$$\dot{\varphi}_H(t) = \dot{\eta}(t)\varphi_A(t) + \eta(t)\dot{\varphi}_A(t). \tag{27}$$

Substituting (22), (26), and (27) in (23), the following equation – usually referred to as the continuous stock equilibrium condition for health (see EHRLICH and CHUMA, 1990) – can be derived for all $t \in [0, T]$ as

$$\eta(t)\left[\delta(t)+r-\frac{\dot{\eta}(t)}{\eta(t)}\right]=\frac{1}{\varphi_A(0)}\ e^{(r-\rho)t}\frac{\partial U(t)}{\partial h(t)}\frac{\partial h(t)}{\partial H(t)}+w\frac{\partial h(t)}{\partial H(t)}. \tag{28}$$

According to equation (28) the stock of health capital is optimal if the marginal cost of holding an additional unit of health capital equals the instantaneous marginal benefit from the last unit of health capital acquired.[70] On the left-hand side of equation (28), the marginal cost of holding an additional unit of health capital in t consists of three parts: the interest earnings forgone by holding an additional unit of health capital; the health capital depreciation costs from holding an additional unit of health capital; and the offsetting capital gain from buying the investment good at time t instead of waiting until time $t+dt$. On the right-hand side of equation (28), the marginal efficiency of health capital consists of two parts: the additional wage income from an infinitesimal increase of health capital; and the direct marginal utility of health capital, discounted and normalized with the initial shadow price of wealth.

5.2.3.2 Model specifications

Given the Hamiltonian system with conditions (18) to (24), the structural demand function for medical care can be derived to constitute the model's theoretical predictions. However, since the majority of influencing effects on the demand for medical care remain ambiguous in sign (RIED, 1998), it is preferable to deal with either the pure investment model or the pure consumption model. Furthermore, estimating sub-models avoids using non-linear estimation methods (WAGSTAFF, 1986; GROSSMAN, 1972b). In the pure consumption model the marginal monetary return on investment is set to zero, whereas in the pure investment model the marginal utility of healthy days is set to zero. Grossman himself stresses the pure investment model since the marginal monetary returns of health are generally assumed to have a higher impact on health behavior than the marginal utility of health returns (GROSSMAN, 2000). Furthermore, GROSSMAN's assumption of a zero marginal utility of health return is not as restrictive as it seems at first glance: the consumer still benefits from additional healthy time

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[70] If a constant returns to scale technology is assumed, the dual cost function of health investments will be linear in output $I(t)$, i.e. $\frac{\partial^2 C_I(t)}{\partial I(t)^2}=0$. GROSSMAN's familiar rule for the optimal stock of health capital can now be derived as $\pi_H(t)\left[\delta(t)+r-\frac{\dot{\pi}_H(t)}{\pi_H(t)}\right]=\frac{1}{\varphi_A(0)}\ e^{(r-\rho)t}\frac{\partial U(t)}{\partial h(t)}\frac{\partial h(t)}{\partial H(t)}+w\frac{\partial h(t)}{\partial H(t)}$. Here, the optimal amount of health investments is selected as a singular control in order to maintain this stock equilibrium as long as feasible. That is, consumers adjust to their desired stocks of health capital instantaneously, given the independence of $\pi_H(t)$ and $I(t)$ (GROSSMAN, 1972a). Given this identity of actual and desired stock of health capital, an increase in the demand for health directly increases the demand for health investments, and consequently the demand for medical services (GROSSMAN, 2000).

via increased market incomes and household commodities, including utility-generating leisure time activities. The benefits caused by additional market incomes and household commodities become even higher as the resulting longevity increases.

Applying the pure investment model with $\frac{\partial U}{\partial h} = 0$, the equilibrium condition for health capital (28) can be reduced to the logarithmic form

$$ln\,\eta_i(t) + ln\,\delta_i(t) - ln\,\psi_{1i}(t) = ln\,w_i(t) + ln\frac{\partial h_i(t)}{\partial H_i(t)} \tag{29}$$

with $\psi_1(t) = \frac{\delta(t)}{\delta(t)+r-\frac{\tilde{\eta}(t)}{\eta(t)}}$,

where subscript i denotes reference to the i-th individual. The constructed variable $\psi_1(t)$ indicates the share of the depreciation rate in the adjustment factor of the marginal health capital costs, which consists of depreciation rate, interest rate, and the rate of change of the relative shadow price of health. To develop a demand function for medical care, specific assumptions and approximations need to be created for the functional forms of $h(\cdot)$, $\delta(\cdot)$, and $\psi_1(\cdot)$, as well as the dual cost function $C_I(\cdot)$. In this regard, except for the cost function of health investments, the specifications applied by GROSSMAN (1972b) and WAGSTAFF (1986) are adopted here to approximate the functional forms of $h(\cdot)$, $\delta(\cdot)$, and $\psi_1(\cdot)$. GROSSMAN (2000) approximates the production function of healthy time by the functional form

$$h_i(t) = \Omega - \beta_1\,H_i(t)^{-\beta_2} \tag{30}$$

with $\beta_1 > 0$ and $\beta_2 > 0$.

Therefore, $\frac{\partial h_i}{\partial H_i} > 0$ and $\frac{\partial^2 h_i}{\partial {H_i}^2} < 0$, i.e. the marginal productivity of health capital regarding the production of healthy time is assumed to be positive but decreesing. According to WAGSTAFF (1986) the approximated depreciation rate function takes on the form

$$\ln\delta_i(t) = \ln\delta_0 + \beta_3 t_i + \boldsymbol{\beta_4}'\mathbf{X}_{\mathbf{1},i}(t) \tag{31}$$

with $\beta_3 > 0$ indicating an increasing depreciation rate as the individual ages. Additionally, the components of the parameter vector $\boldsymbol{\beta_4}$ will be positive if the respective individual characteristics of vector $\mathbf{X_1}(t)$ are damaging to health. Against the common simplifying assumption that $\ln\psi_1(t) = 1$ (see e.g., GROSSMAN, 1972a, 1972b), WAGSTAFF (1986) approximates the functional form of $\psi_1(\cdot)$ as

$$\ln\psi_{1i}(t) = \beta_9\,t_i \tag{32}$$

with $\beta_9 > 0$.

Following GROSSMAN (2000), let the short-term commodity cost function $C_Z(t) = Q(t)p_Q(t) + k(t)w(t)$ with $C_Z(t) \geq 0 \; \forall \; t = [0, T]$ be minimized subject to a Cobb-Douglas commodity production function $Z(t) = E(t)\big(Q(t)\big)^{\zeta}(k(t))^{\vartheta}$ with $\zeta + \vartheta = 1$, i.e. a linearly homogenous production function. The constants ζ and ϑ are the output elasticities of market inputs and time for commodity production, respectively. Since $\theta Z(t) = E(t)\big(\theta Q(t)\big)^{\zeta}(\theta k(t))^{\vartheta}$ with scaling factor $\theta > 0$, the assumed commodity production function is of constant returns to scale. Then by Lagrange multiplier method there exists a local extreme with the dual cost function for commodity production of the form

$$C_Z(t) = \pi_Z(t)Z(t) \tag{33}$$

with $\pi_Z(t) = \left[\left(\frac{\zeta}{\vartheta}\right)^{\vartheta} + \left(\frac{\zeta}{\vartheta}\right)^{-\zeta}\right] p_Q(t)^{\zeta}\, w(t)^{\vartheta} E(t)^{-1}$.

Furthermore, the health investment function has to be specified. However, in contrast to GROSSMAN (2000) or WAGSTAFF (1986), in this inquiry a Cobb-Douglas function with decreasing returns to scale is assumed. Therefore, let the short-term health investment cost function $C_I(t) = M(t)p_M(t) + m(t)w(t)$ with $C_I(t) \geq 0 \; \forall \; t = [0, T]$ be minimized subject to a Cobb-Douglas health investment production function $I(t) = E(t)\big(M(t)\big)^{\kappa}(m(t))^{\mu}$ with $\kappa + \mu < 1$ and $\alpha = \frac{1}{\kappa+\mu}$, i.e. the production function is homogenous of degree $\kappa + \mu$. The constants κ and μ are the output elasticities of market inputs and time for health investments, respectively. The parameter α stands for the inverse scale elasticity. Since $\theta I(t) > E(t)\big(\theta M(t)\big)^{\kappa}(\theta m(t))^{\mu}$ with a scaling factor $\theta > 1$, the health investment production function is of decreasing returns to scale, i.e. $\frac{1}{\alpha} < 1$ and therefore $\alpha > 1$. Then by Lagrange multiplier method of this cost minimization problem (see e.g., VARIAN, 2011; BURGGRAF et al., 2014e) there exists a local extreme with the resulting contingent cost-minimizing factor inputs of the following forms

$$M(t) = \left(\frac{\kappa}{\mu}\right)^{\frac{\mu}{\kappa+\mu}} p_M(t)^{-\frac{\mu}{\kappa+\mu}}\, w(t)^{\frac{\mu}{\kappa+\mu}}\, E(t)^{-\frac{1}{\kappa+\mu}}\, I(t)^{\frac{1}{\kappa+\mu}}, \tag{34}$$

$$m(t) = \left(\frac{\kappa}{\mu}\right)^{-\frac{\kappa}{\kappa+\mu}} p_M(t)^{\frac{\kappa}{\kappa+\mu}}\, w(t)^{-\frac{\kappa}{\kappa+\mu}}\, E(t)^{-\frac{1}{\kappa+\mu}}\, I(t)^{\frac{1}{\kappa+\mu}}. \tag{35}$$

and the dual cost function for health investments of the form

$$C_I(t) = \pi_H(t)\, I(t)^{\alpha} \tag{36}$$

where $\pi_H(t) = \left[\left(\frac{\kappa}{\mu}\right)^{\frac{\mu}{\kappa+\mu}} + \left(\frac{\kappa}{\mu}\right)^{-\frac{\kappa}{\kappa+\mu}}\right] p_M(t)^{\frac{\kappa}{\kappa+\mu}}\, w(t)^{\frac{\mu}{\kappa+\mu}}\, E(t)^{-\frac{1}{\kappa+\mu}}$.

Since $\frac{\partial C_I(t)}{\partial I(t)} > 0$ and $\frac{\partial^2 C_I(t)}{\partial I(t)^2} > 0$, marginal costs of health investments are positive and increasing with increasing investment levels. Differentiating equation (36) with respect to investments gives rise to rewriting equation (25) in logarithmic form as

$$ln\,\eta_i(t) = \beta_{01} + \beta_5\alpha\, ln\, p_M(t) + (1-\beta_5\alpha)\, ln\, w_i(t) - \beta_6\alpha\, \check{E}_i + ln\,\alpha + (\alpha-1)\, ln\, I_i(t) \tag{37}$$

with $\beta_{01} = ln\left[\left(\frac{\kappa}{\mu}\right)^{\frac{\mu}{\kappa+\mu}} + \left(\frac{\kappa}{\mu}\right)^{-\frac{\kappa}{\kappa+\mu}}\right]$ and $\kappa = \beta_5$. Parameter subscripts with leading zeros indicate constants.

Finally, knowledge $E(t)$ is measured by an appropriate measurement variable such as the maximal educational level $\check{E}$ with

$$E(t) = e^{\beta_6\check{E}}. \tag{38}$$

5.2.3.3 Structural demand for medical care

Substituting equations (30), …, (38) after some rearrangements into the logarithmic health stock equilibrium condition (29) of the pure investment model, the demand function for health investments is derived in this study as

$$\begin{aligned} ln\, I_i(t) = \beta_{02} &- \frac{\beta_5\alpha}{\alpha-1} ln\, p_M(t) + \frac{\beta_5\alpha}{\alpha-1} ln\, w_i(t) + \frac{\beta_6\alpha}{\alpha-1}\check{E}_i(t) \\ &+ \frac{(\beta_9-\beta_3)}{\alpha-1} t_i - \frac{1}{\alpha-1}\boldsymbol{\beta_4}'\mathbf{X}_{\mathbf{1},i}(t) \\ &- \frac{(1+\beta_2)}{\alpha-1} ln\, H_i(t) + u_{1i} \end{aligned} \tag{39}$$

with $u_{1i} = -\frac{1}{\alpha-1}\ln\delta_0$ and $\beta_{02} = \frac{ln\,\beta_1\beta_2 - \beta_{01} - ln\,\alpha}{\alpha-1}$.

Finally, substituting the demand function for health investments (39) in the logarithmic form of the cost minimizing factor input for medical care (34) yields the structural demand function for medical care derived in this study as

$$\begin{aligned} ln\, M_i(t) = \beta_{03} &- \left(1 + \frac{\beta_5\alpha}{\alpha-1}\right) ln\, p_M(t) \\ &+ \left(1 + \frac{\beta_5\alpha}{\alpha-1}\right) ln\, w_i(t) + \frac{\beta_6\alpha}{\alpha-1}\check{E}_i(t) \\ &+ (\beta_9-\beta_3)\frac{\alpha}{\alpha-1} t_i - \frac{\alpha}{\alpha-1}\boldsymbol{\beta_4}'\mathbf{X}_{\mathbf{1},i}(t) \\ &- (1+\beta_2)\frac{\alpha}{\alpha-1} ln\, H_i(t) + u_{2i}, \end{aligned} \tag{40}$$

with $\beta_{03} = (1-\beta_5\alpha)\ln\left(\frac{\beta_5}{\frac{1}{\alpha}-\beta_5}\right) + \alpha\beta_{02}$ and $u_{2i} = \alpha u_{1i}$.

The present study treats u_i as an error term with zero mean. According to the aforementioned parameter settings, comparative statics of equation (40) are summarized in Table 14. Assuming a decreasing returns to scale technology for the production of health investments, this inquiry provides a demand function for medical services with the following implications: the demand for medical care increases with an increasing wage rate and an increasing educational level, but it decreases with increasing prices of medical services. These results are in line with common results of general household production models and demand theory. Furthermore, based on the assumed functional specifications, the demand for medical care increases with a worsened health status of the individual (see BURGGRAF et al., 2014e). This is because a worsening health status raises the relative shadow price of health capital, which has to equal the marginal cost of health investments under conditions of optimality. Assuming decreasing returns to scale and hence a convex dual cost function of health investments, higher marginal costs of health investments are associated with raised investment levels and hence a higher demand for medical care. Thus, a health investment function with decreasing returns to scale leads to a demand function for medical care that eventually predicts, *inter alia*, an increasing demand for medical care by those with a lower health status. This theoretically-predicted relationship is substantially confirmed by empirical evidence; it therefore solves the criticized inconsistency between the theoretical implications of GROSSMAN's health investment model and existing empirical results by a slight change of the investment function specification. Furthermore, the model no longer assumes instantaneous health adjustments of the actual to the desired stock of health. Therefore, as suggested by KAESTNER (2013), the limitations of GROSSMAN's health investment model are rather a question of fundamental specifications than incorrect model assumptions.[71]

[71] The analysis presented in chapters 5.2.3 and 5.2.5 is based on BURGGRAF et al. (2016). The author of this thesis would like to thank PROF. DR. TITUS GALAMA for his valuable hints and suggestions regarding the theoretical model.

Table 14: Comparative statics deterministic case

	Demand for medical care $[\boldsymbol{ln\ M(t)}]$	
	Magnitude	**Sign**
$ln\ p_M(t)\uparrow$	$-\left(1+\frac{\beta_5\alpha}{\alpha-1}\right)<0$	-
$ln\ w(t)\uparrow$	$\left(1+\frac{\beta_5\alpha}{\alpha-1}\right)>0$	+
$E(t)\uparrow$	$\frac{\beta_6\alpha}{\alpha-1}>0$	+
$t\uparrow$	$(\beta_9-\beta_3)\frac{\alpha}{\alpha-1}=:\begin{cases}>0\ iff\ \beta_9>\beta_3\\ \leq 0\ iff\ \beta_9\leq\beta_3\end{cases}$	+/-
$X_1(t)\uparrow^{*}$	$-\frac{\beta_4\alpha}{\alpha-1}=:\begin{cases}>0\ iff\ \beta_4<0\\ \leq 0\ iff\ \beta_4\geq 0\end{cases}$	+/-
$ln\ H(t)\uparrow$	$-\frac{(1+\beta_2)\alpha}{\alpha-1}<0$	-

Source: Own presentation.

Note: Upward arrows ↑ indicate a monotonic increase of the independent variables, while + and – indicate monotonic increasing and decreasing functions, respectively. * This holds for each element of $\mathbf{X_1}$ and the respective elements of $\boldsymbol{\beta_4}$.

5.2.4 Stochastic optimization problem with decreasing returns to scale

5.2.4.1 Model assumptions

In chapter 5.2.3, the criticized inconsistencies between the theoretical implications of GROSSMAN's health investment model and the respective empirical results have been resolved by a slight change of the investment specification. Nevertheless, the literature review in chapter 5.2.2 has shown that the theoretical implications of the model vary considerably as soon as uncertainty is introduced into the model. Therefore, it is necessary to additionally control if the above implications of the Grossman model hold in a stochastic model setting. Furthermore, a stochastic model setting is more realistic since an individual's health is generally subject to sudden health shocks, which have an increasing likelihood of occurrence with age. This means that health develops with some kind of uncertainty.[72] This uncertainty surrounding health capital might affect the demand for medical care or time invested in health, since with a fluctuation in one's health capital, the return to health investment is also stochastic. Along these lines, LAPORTE and FERGUSON (2007) argue that the most obvious feature of health investments is that they are risky investments.

In order to introduce uncertainty, health capital is modeled here as a linear generalized Brownian motion with drift (or Ito stochastic differential equation). Hence,

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[72] In this inquiry, the terminological differences between risk and uncertainty, i.e. risk is characterized by randomness that can be measured precisely while uncertainty relates to randomness that cannot be expressed by specific probability distributions , are not considered (CHANG, 1996).

in this model both minor and major illnesses affect health capital in the sense of extraordinary short-term and long-term depreciation of the health stock, respectively. Now consider the probability space $(\Theta, \mathcal{F}, \mathrm{P})$, where Θ is the non-empty space of health outcomes, $\mathcal{F}$ denotes the σ-algebra (or σ-field) of subsets of Θ, and P is the probability measure defined on $\mathcal{F}$, i.e. $P: \mathcal{F} \rightarrow [0,1]$, which fulfills the axioms of KOLMOGOROV (1973). Health capital $H(t)$ develops by a stochastic process that shows a stochastic differential equation in the sense of Ito. The stochastic noise process *W* is a Wiener process caused by random shocks to the health capital. A Wiener process $\{W(t), t \in [0,T]\}$ is a continuous time-dependent stochastic process on the probability space $(\Theta, \mathcal{F}, \mathrm{P})$ with the following properties:

(i) $W(0) = 0$,
(ii) for $0 \leq t_1 \leq \cdots \leq t_n$, the increments $W(t_i) - W(t_{i-1})$ with $i = 1, \dots, n$ are independent random variables,
(iii) for $0 \leq s < t$, the increment $W(t) - W(s)$ has a normal distribution $N \sim (0, t - s)$,
(iv) W is continuous with respect to time $t \geq 0$, and
(v) the path $W(t)$ for $t \geq 0$ is nowhere differentiable.[73]

It follows from (iii) that the variance of $W(t) - W(s)$ increases linearly with the length of the time interval $[s, t]$. Furthermore, with the Wiener process $\{W(t), t \geq 0\}$ defined on the probability space $(\Theta, \mathcal{F}, \mathrm{P})$, the random variable $\{W(s), 0 \leq s \leq t\}$ produces the σ-algebra $\mathcal{F}_t$, where $\mathcal{F}_t \coloneqq \sigma\{W(s): 0 \leq s \leq t\}$. $\mathcal{F}_t$ contains all past realizations of the Wiener process. Hence, it is assumed that the consumer knows all the available past information generated by the Wiener process. As time goes on, consumer information increases because the consumer observes additional realizations of the random variable.

In the stochastic case, analogous to the functional form presented, for example, in the study of LILJAS (1998), health capital is assumed to develop as a Brownian motion with drift given by

$$dH(t) = [I(t) - \delta(t)H(t)]dt + \sigma(t, H(t), I(t))dW(t) \tag{41}$$

and wealth develops over time according to

$$dA(t) = [rA(t) + y(t) + w(t)h(t)) - \pi_H(t)\, I(t)^{\alpha} - \pi_Z(t)Z(t)]dt. \tag{42}$$

These stochastic differential equations are defined by the corresponding integral equations

[73] For more information on these properties, see, for example, MALLIARIS and BROCK (1982).

$$H(t) = H(0) + \int_0^t [I(\tau) - \delta(\tau)H(\tau)]d\tau + \int_0^t \sigma\big(\tau, H(\tau), I(\tau)\big)dW(\tau), \tag{43}$$

$$A(t) = A(0) + \int_0^t [rA(\tau) + y(\tau) + w(t)h(\tau)) - \pi_H(\tau)\, I(\tau)^\alpha - \pi_Z(\tau)Z(\tau)]d\tau \tag{44}$$

for all t with a probability of one, where the admissible controls are adapted processes so that the above integrals are defined. Therefore, the behavior of the continuous time stochastic process $H(t)$ is characterized by the sum of a Lebesgue integral and an Ito integral. Under the assumption that health capital develops in an Ito stochastic process, the expected value and variance of the health increment consecutive to any decision $I(t)$ are known. The expected value of $H(t)$ is given by

$$\mathbb{E}[H(t)] = \mathbb{E}[H(0)] + \mathbb{E}\int_0^t [I(\tau) - \delta(\tau)H(\tau)]d\tau \tag{45}$$

since $\mathbb{E}[dW] = 0$. The variance of $H(t)$ is given by $\mathbb{V}[dH] = \sigma^2 dt$ (see MALLIARIS and BROCK, 1982). Hence, the probability of health shocks increases with age t. For this application, $\mathbb{E}[I(t) - \delta(t)H(t)]$ is the expected instantaneous drift rate of the Ito process, and $\sigma\big(t, H(t), I(t)\big)$ is the instantaneous diffusion rate. In this inquiry, the linear structure of the drift rate is mirrored by a linear diffusion rate of the form $\sigma\big(t, H(t), I(t)\big) = \beta + \sigma_H H + \sigma_I I$.

5.2.4.2 Optimization conditions

The stochastic problem setting of the Grossman health investment model can be written as follows, where the system must continuously compensate for health shocks. For simplicity, GROSSMAN's general assumption of a fixed terminal time *T* is assumed in the stochastic case.[74] Following BISMUT's approach (BISMUT, 1973), suppose that $I^*(t)$, $Z^*(t)$, $H(t)$, and $A(t)$ solve for $t \in [0, T]$

$$\max_{I,Z} \mathbb{E} \int_0^T U[Z(t), h(t)]e^{-\rho t}\, dt \tag{46}$$

subject to

(i) $dH(t) = [I(t) - \delta(t)H(t)]dt + \sigma\big(t, H(t), I(t)\big)dW(t)$,

(ii) $dA(t) = [rA(t) + y(t) + wh(t) - \pi_H(t)\, I(t)^\alpha - \pi_Z(t)Z(t)]dt$,

---

[74] This assumption is widely used in the health investment literature; see, for example, BOLIN et al. (2002a), BOLIN et al. (2002b), EISENRING (1999), and LAPORTE and FERGUSON (2007). In this inquiry, it is necessary based on technical grounds regarding BISMUT's approach. However, the assumption of a fix T does not change the results of the model's flow and stock equilibriums.

(iii) $I(t) = f_I\big(M(t), m(t); E(t)\big)$,

(iv) $Z(t) = f_Z\big(Q(t), k(t); E(t)\big)$,

and

(v) $H(0) = H_0, T\ fix$,

(vi) $A(0) > 0, A(T) \geq 0$,

(vii) $I \in [0, \infty]$.

Then for the resulting Hamiltonian

$$\mathcal{H} \coloneqq U[Z(t), h(t)]e^{-\rho t} \tag{47}$$
$$+\varphi_A(t)[rA(t) + y(t) + wh(t)) - \pi_H(t)\, I(t)^\alpha - \pi_Z(t)Z(t)]$$
$$+\varphi_H(t)[I(t) - \delta(t)H(t)] + B(t)\sigma\big(t, H(t), I(t)\big),$$

given $\varphi_{HH}(t) \coloneqq \frac{\partial \varphi_H(t)}{\partial H(t)}$, the following relations hold for optimal values of $I(t)$ and $Z(t)$

$$dH(t) = [I(t) - \delta(t)H(t)]dt + \sigma\big(t, H(t), I(t)\big)dW(t), \tag{48}$$

$$dA(t) = [rA(t) + y(t) + wh(t) - \pi_H(t)\, I(t)^\alpha - \pi_Z(t)Z(t)]dt, \tag{49}$$

$$\frac{\partial \mathcal{H}}{\partial Z} = \frac{\partial U(t)}{\partial Z(t)} e^{-\rho t} - \varphi_A(t)\pi_Z(t) = 0, \tag{50}$$

$$\frac{\partial \mathcal{H}}{\partial I} = -\varphi_A\,(t)\alpha\pi_H I(t)^{\alpha-1} + \varphi_H(t) + B\sigma_I = 0, \tag{51}$$

$$d\varphi_A(t) = [-\varphi_A(t)r]dt, \tag{52}$$

$$d\varphi_H(t) = \Big[-e^{-\rho t}\frac{\partial U(t)}{\partial h(t)}\frac{\partial h(t)}{\partial H(t)} - \varphi_A(t)w\frac{\partial h(t)}{\partial H(t)} + \varphi_H(t)\delta(t) - B(t)\sigma_H\Big]\, dt + \qquad B(t)dW(t), \tag{53}$$

with the transversality conditions

$$\varphi_H(T) = 0, \varphi_{HH}(T) = 0, \frac{\partial \mathcal{H}(T)}{\partial T} < 0,$$
$$\varphi_A(T) = 0.$$

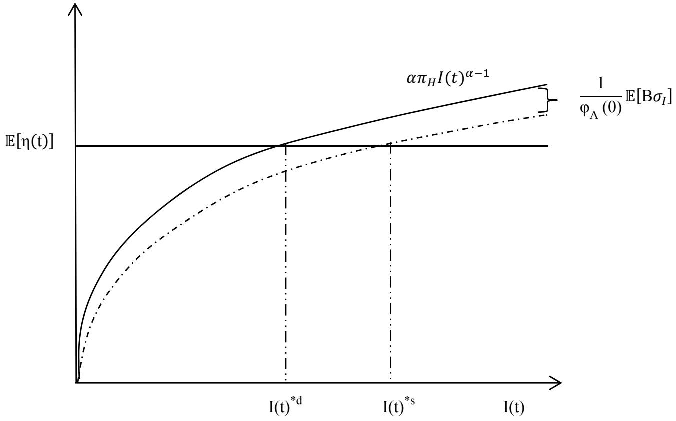
Again, wage rates and interest rates are assumed to be constant for simplicity. BISMUT's approach is based on Pontryagin's Maximum Principle (PONTRYAGIN et al., 1967). BISMUT's random variable $B(t)$ corresponds to $\frac{\partial \varphi_H(t)}{\partial H(t)}\sigma(t, H(t), I(t))$ and provides one's instantaneous attitude towards risk. This variable is positive if the individual is risk-seeking and negative if the individual is risk-averse. Furthermore, in the stochastic case the marginal value of health capital at time t is given by $\varphi_H(t) = \frac{\partial}{\partial H(t)}\mathbb{E}\left\{\int_t^T U[Z(\tau), h(\tau)]e^{-\rho\tau}\, d\tau \middle| \mathcal{F}_t\right\}$, which is the partial derivative of the conditional expectation of the utility function from time t to T with respect to $H(t)$ and with $I(t)$ being the optimal policy. The adjoint equation (53) shows that $-d\varphi_H(t)$ is the sum of the health capital's contribution to utility, plus health capital's contribution to enhancing the expected value of the increment of the health capital stock, plus health capital's contribution to enhancing the expected value of the increment of the wealth stock, plus its contribution to increasing the conditional standard deviation of the increment of the stock capital valued at the cost of risk, minus $B(t)dW(t)$. From equation (53) it follows that $B(t)dW(t) = \varphi_{HH}\left[dH - \left(I(t) - \delta(t)H(t)\right)dt\right]$. Therefore, in line with the general definitions of MALLIARIS and BROCK (1982), $B(t)dW(t)$ is a correction term in the evolution of the marginal value of health capital, which evaluates in terms of $\varphi_{HH}(t)$ the difference between dH and $\mathbb{E}[dH]$, where $\mathbb{E}[dH] = [I(t) - \delta(t)H(t)]dt$.

From the FOC (51) and $\eta(t) = \frac{\varphi_H(t)}{\varphi_A(t)}$, the flow equilibrium condition for health investments can be derived for all $t \in [0, T]$ as

$$\eta(t) = \alpha\pi_H I(t)^{\alpha-1} + \frac{1}{\varphi_A(0)} B(t)\sigma_I. \tag{54}$$

Then, if $B < 0$, i.e. assuming risk-averse consumers, condition (54) implies that consumers will invest in their health up to the point where the expected relative shadow price of health capital equals the marginal investment costs in health, minus the marginal risk of health investment valued at its costs. Because risk-averse consumers fear health capital losses, they will tend to invest more in their health with the same $\eta(t)$ as they would do, if no risk is involved. This result complies with the results of the static model setting of DARDANONI and WAGSTAFF (1987) and PICONE et al. (1998) for a simplified version of a dynamic Grossman household production model regarding the individual's precautionary behavior over time for the retirement period. These authors state that uncertainty surrounding the ex ante level of health modifies consumers' behavior in a way that they exhibit extra precautionary behavior by purchasing extra medical care. In Figure 13, the optimal investment in health in the stochastic case is achieved at $I(t)^{*s}$, which is higher than the optimal investment in the deterministic case $I(t)^{*d}$ at the same $\eta(t)$, i.e. $I(t)^{*s} > I(t)^{*d}$ and thus includes a cushion against the effects of a health shock.

Figure 13: Stochastic optimal investment for a flow equilibrium



Source: Own presentation based on EHRLICH and CHUMA (1990) for their deterministic case.
Note: For illustration purposes it is assumed that α=1.2 and B<0.

From $\eta(t) = \frac{\varphi_H(t)}{\varphi_A(t)}$, it follows that

$$d\varphi_H(t) = d\eta(t)\ \varphi_A(t) + \eta(t)\ \dot{\varphi}_A(t)dt, \tag{55}$$

$$\mathbb{E}[d\varphi_H(t)] = \mathbb{E}[d\eta(t)\ \varphi_A(t) + \eta(t)\ \dot{\varphi}_A(t)dt]. \tag{56}$$

Substituting (52), (54), …, (56) in (53) and taking the expected value, a continuous stock equilibrium condition for $H(t)$ can be derived for $t \in [0, T]$ as follows

$$\begin{aligned}\eta\mathbb{E}[d\eta(t)]\varphi_A(t) + \mathbb{E}[\eta(t)]\dot{\varphi}_A(t)dt \\ = -e^{-\rho t}\mathbb{E}\left[\frac{\partial U(t)}{\partial h(t)}\frac{\partial h(t)}{\partial H(t)}\right]dt - \varphi_A(t)w\mathbb{E}\left[\frac{\partial h(t)}{\partial H(t)}\right]dt \\ + \mathbb{E}[\varphi_H(t)]\delta(t)dt - \mathbb{E}[B(t)\sigma_H]dt.\end{aligned} \tag{57}$$

Divide by $\varphi_A(t)$ and subtract by $\mathbb{E}[\varphi_H(t)]\delta(t)dt$ such that

$$\begin{aligned}\mathbb{E}[\eta(t)]\left[\delta(t) + r - \frac{\mathbb{E}[d\eta(t)]}{\mathbb{E}(\eta(t))dt}\right] \\ = \frac{1}{\varphi_A(0)}\ e^{(r-\rho)t}\mathbb{E}\left[\frac{\partial U(t)}{\partial h(t)}\frac{\partial h(t)}{\partial H(t)}\right] + w\ \mathbb{E}\left[\frac{\partial h(t)}{\partial H(t)}\right] \\ + \frac{1}{\varphi_A(0)}\ e^{rt}\mathbb{E}[B(t)\sigma_H].\end{aligned} \tag{58}$$

According to equation (58) the stock of health capital is optimal in t if the expected marginal cost of health capital is equal to the expected marginal efficiency of health capital, minus the marginal risk of health, which is normalized with the initial shadow price of wealth.

5.2.4.3 Structural demand for medical care

Given the optimality conditions (54) and (58), the structural demand function for medical care can be derived to constitute the model's theoretical predictions. Again, since the majority of influencing effects on the demand for medical care remain ambiguous in sign (RIED, 1998), it is preferable to deal with the pure investment model. Applying the pure investment model, i.e. $\frac{\partial U}{\partial h} = 0$, the equilibrium condition for health capital (58) can be reduced to

$$\mathbb{E}[\eta(t)]\left[\delta(t) + r - \frac{\mathbb{E}[d\eta(t)]}{\mathbb{E}\big(\eta(t)\big)dt}\right] = w\mathbb{E}\left[\frac{\partial h(t)}{\partial H(t)}\right] + \frac{1}{\varphi_A(0)}\ e^{rt}\mathbb{E}[B(t)\sigma_H] \qquad (59)$$

or in logarithmic form

$$ln\,\mathbb{E}[\eta_i(t)] + ln\,\delta_i(t) - ln\,\mathbb{E}[\psi_{1i}(t)] = ln\,w_i(t) + ln\,\mathbb{E}\left(\frac{\partial h_i(t)}{\partial H_i(t)}\right) + ln\,\mathbb{E}(\psi_2(t)) \qquad (60)$$

with $\psi_1(t) = \frac{\delta(t)}{\delta(t)+r-\frac{\mathbb{E}(\dot{\eta}(t))}{\mathbb{E}(\eta(t))dt}}$ and $\psi_2(t) = 1 + \frac{\frac{1}{\varphi_A(0)}e^{rt}\mathbb{E}[B\sigma_H]}{w\,\mathbb{E}\left[\frac{\partial h(t)}{\partial H(t)}\right]}$.

Again, subscript *i* denotes reference to the *i*-th individual. The constructed variable $\psi_1(t)$ indicates the share of the depreciation rate in the adjustment factor of the marginal health capital costs. The constructed variable $\psi_2(t)$ is employed as a health risk indicator. With an infinitesimal increase of health capital, this variable indicates the share of the expected increase of wage income depressed by the marginal risk of health with respect to the expected increase of wage income considering zero risk.

Now, assume the health risk indicator to be of the form

$$\mathbb{E}\psi_2(t) = \beta_7\,\breve{B}_i(t)\sigma_H + \beta_8 t \qquad (61)$$

with $\beta_7 > 0$, $\beta_8 > 0$, and $\breve{B}_i(t)$ approximating the Bismut variable with $\breve{B}_i(t) < 0$ indicating a risk-averse consumer. Given the assumed approximations (30), …, (38), (61), and the stock equilibrium condition (58), the structural demand equations of the pure investment model can be derived. Hence, the optimal expected demand for health investments is given by

$$
\begin{aligned}
\ln \mathbb{E}[I_i^*(t)] = \beta_{02} - \frac{\beta_5\alpha}{\alpha-1} \ln p_M(t) + \frac{\beta_5\alpha}{\alpha-1} \ln w_i(t) + \frac{\beta_6\alpha}{\alpha-1} \check{E}_i(t) \\
+ \frac{(\beta_9 + \beta_8 - \beta_3)}{\alpha-1} t_i - \frac{1}{\alpha-1} \boldsymbol{\beta_4}'\mathbf{X}_{1,i}(t) \\
- \frac{(1+\beta_2)}{\alpha-1} \ln \mathbb{E}[H_i(t)] - \beta_7 \ln \mathbb{E}\left[\check{B}_i(t)\sigma_H\right] + u_{1i}
\end{aligned} \tag{62}
$$

with the constant $\beta_{02} = \frac{\ln \beta_1\beta_2 - \beta_{01} - \ln \alpha}{\alpha-1}$ and error term $u_{1i} = -\frac{1}{\alpha-1}\ln \delta_0$.

Substituting (62) in the cost minimizing factor input for medical services (34) yields the structural demand function for medical care with

$$
\begin{aligned}
\ln \mathbb{E}[M_i{}^*(t)] \\
= \beta_{02} - \left(1 + \frac{\beta_5\alpha}{\alpha-1}\right) \ln p_M(t) \\
+ \left(1 + \frac{\beta_5\alpha}{\alpha-1}\right) \ln w_i(t) + \frac{\beta_6\alpha}{\alpha-1} \check{E}_i(t) \\
+ (\beta_9 + \beta_8 - \beta_3) \frac{\alpha}{\alpha-1} t_i - \frac{\alpha}{\alpha-1} \boldsymbol{\beta_4}'\mathbf{X}_{1,i}(t) \\
- (1+\beta_2) \frac{\alpha}{\alpha-1} \ln \mathbb{E}[H_i(t)] - \beta_7 \ln \mathbb{E}\left[\check{B}_i(t)\sigma_H\right] + u_{2i},
\end{aligned} \tag{63}
$$

with the constant $\beta_{02} = (1-\beta_5\alpha)\ln\left(\frac{\beta_5}{\frac{1}{\alpha}-\beta_5}\right) + \alpha\beta_{02}$ and error term $u_{2i} = \alpha u_{1i}$.

According to the aforementioned parameter settings, comparative statics are presented in Table 15. This inquiry provides a demand function for medical care in which the expected medical care in t increases with an increasing wage rate and an increasing educational level, but it decreases with increasing prices of medical services. These results are in line with common results of general household production models and demand theory. Furthermore, $-(1+\beta_2)\frac{\alpha}{\alpha-1} < 0$ and $-\beta_7 < 0$ implies that the expected demand for medical care in *t* increases with an expected worsening health status in *t* and a higher expected health associated risk for that *t*, respectively. Thus, a health investment function with decreasing returns to scale leads to a demand function for medical care that predicts, *inter alia*, an expected increasing demand for medical care by those with a lower expected health status.

Table 15: Comparative statics stochastic case

	Expected demand for medical care [$\boldsymbol{ln\ M(t)}$]	
	Magnitude	**Sign**
$ln\ p_M\uparrow$	$-\left(1+\frac{\beta_5\alpha}{\alpha-1}\right)<0$	-
$ln\ w\uparrow$	$\left(1+\frac{\beta_5\alpha}{\alpha-1}\right)>0$	+
$E\uparrow$	$\frac{\beta_6\alpha}{\alpha-1}>0$	+
$t\uparrow$	$(\beta_9+\beta_8-\beta_3)\frac{\alpha}{\alpha-1}=:\begin{cases}>0\ iff\ \beta_9+\beta_8>\beta_3\\<0\ iff\ \beta_9+\beta_8<\beta_3\end{cases}$	+/-
$X_1\uparrow^*$	$-\frac{\beta_4\alpha}{\alpha-1}=:\begin{cases}>0\ iff\ \beta_4<0\\<0\ iff\ \beta_4>0\end{cases}$	+/-
$ln\ \mathbb{E}[H(t)]\uparrow$	$-\frac{(1-\beta_2)\alpha}{\alpha-1}<0$	-
$ln\ \mathbb{E}[\breve{B}_i(t)\sigma_H]\uparrow$	$-\beta_7>0$	+

Source: Own presentation.

Note: Upward arrow ↑ indicates a monotonic increase of the independent variables, while + and - indicate monotonic increasing and decreasing functions, respectively. * This holds for each element of $\mathbf{X_1}$ and the respective elements of $\boldsymbol{\beta_4}$.

To conclude, the theoretically-implied negative effect of health on the demand for medical care also holds in the stochastic model setting, with higher optimal health investments in the stochastic case in order to provide a cushion against the effects of health shocks.[75]

5.2.5 Empirical application of the deterministic health investment model

5.2.5.1 Variable description

In order to test the derived theoretical implications in an empirical model, the focus is set here on the deterministic model since the relevant effect directions do not vary between the deterministic and the stochastic model setting. For the empirical analysis of the demand for medical care, the model's endogenous medical care variable needs to be constructed since the RLMS-HSE data source does not provide information about medical care consumption in one given data variable. Therefore, a variety of health care utilization information is used to empirically measure the level of the individuals' medical care in the form of an a priori index as a counterpart to the theoretical model's endogenous variable. Information considered when constructing the demand for medical care includes medical care for disease treatments as well as prevention, since both can be considered as health investments. The dependent health care variable is constructed by ranking various dichotomous indicators beginning with a score of zero for no demand for medical care and ending up with a score of six indicating a hospital stay and further prescribed medicine. This ranking is shown in Table 16. The

[75] The analysis of chapter 5.2.4 is based on BURGGRAF et al. (2015d).

constructed ranked demand for medical care is assumed to indicate the underlying continuous and unlimited latent variable of the true demand for medical care $M(t)$.[76] Additionally, in order to control for potential validity problems of this constructed measure, out-of-pocket expenditures as well as nights spent in a hospital are also considered to indicate the dependent variable (see e.g., GALAMA et al., 2012). Using out-of-pocket expenditures rather than expenditure shares in such a demand analysis (see e.g., DEATON and MUELLBAUER, 1989) is often done due to data restrictions on total household expenditures. Furthermore, considering the Russian health care system, only out-of-pocket expenditures for prescribed medicine are applied.[77]

Table 16: Constructed medical care consumption

	Demand for medical services
1	Zero medical care consumption
2	Doctor visits
3	Doctor visits and demand for prescribed medicine
4	Doctor visits with further procedures
5	Hospital stay
6	Hospital stay with further prescribed medicine

Source: Own presentation.

Considering the explanatory variables of the health investment model, the theoretical construct knowledge is approximated here by educational achievement. For the education-level variable, the lowest value of zero indicates the educational level of a person without any sort of diploma. A value of one indicates ordinary vocational training without secondary education. A value of two indicates a high school diploma. A value of three indicates secondary education from advanced technical, medical, music, pedagogical, or art school or secondary education with vocational training in the form of technical or manufacturing trade schools. A value of four specifies a university degree. The highest possible value of five indicates a person within or after *aspirantura*, i.e. a PhD graduate school, internship, or residency program that leads to becoming a Russian candidate of science or doctor of science.

[76] The RLMS-HSE data set includes only variables exploring the question of whether individuals demand several types of medical care but not by how much they demand it. However, even if this information would be provided, such data fail to capture the intensity of services by duration of visits or the number of diagnostic tests performed; this is a general problem of studies on the demand for medical care (WAGSTAFF, 2002).

[77] In Russia, the public provision of health care predominates private financing. In this line, only 0.5 % of the observed Russians in the RLMS-HSE data set made direct payments for their hospital stay. Nevertheless, 17.54 % of all RLMS-HSE participants paid for their prescribed medicine (including informal payments).

Regarding the measurement of health capital, the categorical information of the self-reported health status is preferred over other measures such as a health capital index, quality-adjusted life years (QALYs), or the rating scale method (see GERDTHAM et al., 1999). Information on self-reported health is directly provided by the RLMS-HSE data set. Additionally, to control for potential endogeneity problems, the categorical measure of health is replaced with the binary RLMS-HSE variable on health problems in the previous 30 days.[78] This variable indicates an individual's health status prior to the demand for medical care because only respondents with health problems within the last 30 days are asked to indicate their demand for medical care to solve their health problems (e.g., by visiting a doctor). Finally, following GALAMA et al., (2012), both health indicators are considered by taking the first available lag $(t-1)$ to ensure that health investments are subsequent to the reported health status.

Household income $Y(t)$ is generally thought to be a good indicator of demand responses to changes in wages $w(t)$ and non-labor income $y(t)$. The household income variable used in this analysis reports the real household income generated by RLMS-HSE, in which both labor and non-labor income are accounted for.[79] Price indices for medical services and medicine for the observed time period are taken from the RUSSIAN FEDERAL STATES STATISTICS SERVICE (2014). Considering these official price indices, it has to be noted that a potential problem might arise from unofficial out-of-pocket payments in Russia (see e.g., DENISOVA, 2010). Nevertheless, it might be assumed that the amount of unofficial out-of-pocket payments tends to change according to the overall price developments of medical care. Although this problem cannot be controlled for in this analysis, exploring potential price effects of medical care consumption with the given price indices is still a useful task.[80] Finally, in her study of Russians' adult mortality, DENISOVA (2010) highlights the significant impact of variables such as access to medical care, family size, individual's satisfaction with life, social power, and the paid social respect for this person. Therefore, these variables are considered in the estimation procedure as well. All variables applied in the econometric model are summarized in Appendix 3 Table A 3.

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[78] Endogeneity problems arise from the interdependence of health capital and demand for medical care: demand for medical care depends on the actual health status and actual health is likely to be partly determined by prior demand for medical care.

[79] It has to be noticed that RLMS-HSE reported wage rate data are less informative due to wage arrears and delayed wage payment (DESAI and IDSON, 2000). Therefore, the RLMS-HSE constructed real household income variable considers different wage variables and imputes missing values according to regional, gender, and age-specific relations.

[80] Due to a mainly publicly financed hospitalization system in Russia, medical prices are not considered when estimating nights spent in a hospital.

5.2.5.2 Estimation procedure and empirical results

The employed estimation strategies consider the data structure of the three different dependent variables, which are as follows: constructed demand for medical care; out-of-pocket expenditures for prescribed medicine; and nights spent in a hospital. For the constructed ordinal medical care measure, an ordered probit panel model with the random effects estimator is estimated. In the ordered probit model, the underlying continuous latent variable defines an ordered response for the demand for medical care with the above-mentioned six ordered categories. In this estimation model, only the random effects estimator is considered because the ordered probit fixed effects estimates are expected to suffer from the incidental parameters problem (NEYMAN and SCOTT, 1948), resulting in substantially biased and inconsistent estimates. Regarding the dependent variable out-of-pocket expenditures for prescribed medicine, a Heckman-type two-step estimation model is applied because this empirical specification of the dependent variable has a high frequency of zero expenditure in its data and a right-skewed distribution (HECKMAN, 1979). The participation decision in the Heckman two-step estimation procedure is estimated by a probit random effects panel estimator, while the log-expenditure model is specified by both random and fixed effects linear estimators considering the inverse Mills' ratio.[81] Finally, regarding the number of nights spent in a hospital as a third dependent variable, both the random-effects and the conditional fixed-effects Poisson models are applied.[82] Generally, fixed-effects models allow causality to be inferred because they control for the time-invariant component of the error term while the random effects model is inconsistent for this form of endogeneity.

Under consideration of the two actual health indicators, the parameter estimates for all estimation models are presented in Table 17. Additionally, the parameter estimates considering the lagged health indicators are presented in Appendix 3, Table A 4. The estimated signs of the coefficients are consistent with the theoretical predictions derived in this inquiry. The Wald test of overall significance of the regression output indicates for both estimation models that all coefficients are joint statistically significant. The goodness of fit values (pseudo R^2)

[81] Because the expenditure data have many zero observations, the Poisson and Poisson pseudo-maximum-likelihood estimators have been additionally employed (see SANTOS SILVA and TENREYRO, 2006). The estimated coefficients are comparable to those presented here with a negative coefficient of health on the out-of-pocket expenditures in logs.

[82] The Vuong test between the Poisson and a zero-inflated Poisson model regarding the amount of hospital nights indicates that the zero-inflated model is not better than an ordinary Poisson regression model. Yet the efficiency of the fixed effects Poisson model is assumed to be relatively low since this estimation model considers only individuals with observations in all waves and additionally loses information from observations that have zero hospital nights in all waves.

mirror the improvement from the null model to the fitted model and indicate the total variability explained by the model (LONG, 1997; LONG and FREESE, 2014). The presented R^2 and pseudo R^2 values are in line with those obtained by WAGSTAFF (1986, 1993), GERDTHAM et al., (1999), and ERBSLAND et al. (1995).

The results in Table 17 imply that, for all three dependent variables, higher incomes $Y(t)$ tend to increase the demand for medical care. This is because increasing incomes raise expenditure budgets and increase the value of healthy lifetime, thus increasing the demand for health investments. In line with the results of other empirical studies (see e.g., WAGSTAFF, 1986; GALAMA et al., 2012), estimation results also indicate a significant negative effect of health $H(t)$ on the demand for medical care because a worsening health status raises the relative shadow price of health. Therefore, it is optimal for the individual to increase the amount of health investments if the health status is actually decreasing. In most of the estimated panel models, this result also holds if lagged health indicators are applied, especially considering the lagged binary health problem variable.[83] In absolute values, the coefficients of health tend to be higher in the model with actual health than in the model with lagged health; a result that is reasonable because actual health problems possibly dominate customers' decisions more strongly. Moreover, estimation results show that higher educational levels are significantly associated with an increased demand for health investments. This result can be explained by the fact that the efficiency of health investments is determined by the level of knowledge, which is approximated here by an individual's educational achievement $\check{E}_i(t)$.[84] Finally, according to the law of demand, the demand for medical care tends to increase with decreasing prices for medical care, while out-of-pocket expenditures are surely a positive function of prices.

Table 17 also presents the coefficients for several control variables. Depending on the estimation model, females are often significantly associated with a higher consumption of medical care than males. For the considered lifestyle factors, it can be stated that individuals who engage in sports and avoid smoking tend to have a higher constructed demand for medical care, possibly preventive care. Such lifestyle variables can be interpreted as proxies for the ability to anticipate future health outcomes from today's discretionary choices. Furthermore, these measures indicate an individual's subjective discount rate, whereby the

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83 By contrast, GALAMA et al. (2012) note that exploiting the panel nature of their data with fixed effects estimators would result in insignificant coefficients of lagged health. Additionally, their instrumental variable approach also shows insignificant results. Nevertheless, these authors argue that contemporaneously rather than lagged health variables may be more appropriate since medical treatment likely responds quickly to changes in health.

84 Furthermore, higher levels of education are often associated with lower subjective discount rates and hence a higher subjective value of longevity (EHRLICH and CHUMA, 1990).

more they care about their anticipated future health situation, the more they engage in sports, avoid smoking, or demand (preventive) medical care. Yet, considering the amount of nights spent in a hospital, the association with doing sports becomes significantly negative, probably due to acute health problems. Regarding the reported individual status-oriented ratings, the respect rank variable implies a significant positive association with the constructed demand for medical care. Along these lines, DENISOVA (2010) finds that a higher self-perceived respect status significantly improves the probability of increased longevity. Nevertheless, this association becomes negative considering the amount of nights spent in a hospital. Finally, the results of the regional control variables show that while urban settlement type is significantly linked with a higher consumption of medical care, the estimated coefficient regarding the distance to a private doctor is often statistically insignificant. Possibly, the settlement type coefficients, as well as our regional coefficients, might pick up parts of the distance effects. Furthermore, ROZENFELD (1996) points out that hospitals and medical doctors exist in large quantity in Russia, while the quality of health care services remains quite low.

Table 17: Estimation results of the demand for medical care

	Estimation models with self-reported health					Estimation models with health problems in last 30 days				
Consumption of	**Medical care**	**Out-of-pocket expenditures[a]**		**Nights spent in a hospital**		**Medical care**	**Out-of-pocket expenditures[a]**		**Nights spent in a hospital**	
Panel estimation models	**Ordered probit**	**Heckman two-part**		**Poisson**		**Ordered probit**	**Heckman two-part**		**Poisson**	
With random/fixed effects	**Random**	**Random**	**Fixed**	**Random**	**Fixed**	**Random**	**Random**	**Fixed**	**Random**	**Fixed**
Explanatory variables:										
Log of price index [ln p_M]	-0.259***	1.292***	2.652***			-0.278***	1.638***	3.402***		
	(0.048)	(0.134)	(0.214)			(0.048)	(0.223)	(0.346)		
Log of income [w]	0.035***	0.238***	0.148***	0.238**	0.220**	0.031***	0.237***	0.158***	0.176*	0.172*
	(0.007)	(0.018)	(0.032)	(0.080)	(0.085)	(0.007)	(0.018)	(0.032)	(0.077)	(0.080)
Age [t]	-0.005***	-0.001	0.040***	0.018	0.035*	-0.004***	0.002*	0.045***	0.014	0.020
	(0.000)	(0.001)	(0.007)	(0.012)	(0.015)	(0.000)	(0.001)	(0.007)	(0.009)	(0.012)
Health [H] (0 very bad, 5 very good)	-0.487***	-0.180***	-0.127***	-0.647***	-0.631***					
	(0.009)	(0.021)	(0.036)	(0.089)	(0.091)					
Health problems last 30d [H] (0 yes, 1 no)						-1.162***	-0.335***	-0.452**	-1.568***	-1.570***
						(0.012)	(0.086)	(0.138)	(0.120)	(0.123)
Education [E] (0 lowest, 5 highest)	0.029***	0.092***	0.105**	0.185*	0.210*	0.028***	0.085***	0.109**	0.181**	0.194**
	(0.005)	(0.010)	(0.035)	(0.074)	(0.083)	(0.005)	(0.010)	(0.035)	(0.068)	(0.075)
Other demographic control variables:										
Gender (1 female, 0 male)	0.191***	0.066*		-0.379		0.151***	0.085**	0.443	-0.258	
	(0.014)	(0.030)		(0.428)		(0.014)	(0.031)	(0.354)	(0.322)	
Household size	-0.036***	0.028**	0.034	-0.004	-0.009	-0.024***	0.025**	0.031	-0.039	-0.044
	(0.004)	(0.009)	(0.027)	(0.063)	(0.068)	(0.004)	(0.009)	(0.027)	(0.064)	(0.068)
Lifestyle control variables:										
Sports activities (1 yes, 0 no)	0.168***	-0.042	-0.030	-0.544**	-0.511*	0.094***	-0.055	-0.010	-0.572**	-0.542*
	(0.016)	(0.040)	(0.072)	(0.208)	(0.217)	(0.016)	(0.040)	(0.072)	(0.207)	(0.214)
Smoker (1 yes, 0 no)	-0.055***	0.063	-0.094	-0.490*	-0.480	-0.052***	0.051	-0.106	-0.745***	-0.771**
	(0.014)	(0.033)	(0.104)	(0.229)	(0.252)	(0.014)	(0.034)	(0.105)	(0.224)	(0.236)

	Estimation models with self-reported health					Estimation models with health problems in last 30 days				
Consumption of	**Medical care**	**Out-of-pocket expenditures[a]**		**Nights spent in a hospital**		**Medical care**	**Out-of-pocket expend-itures[a]**		**Nights spent in a hospital**	
Panel estimation models	**Ordered probit**	**Heckman two-part**		**Poisson**		**Ordered probit**	**Heckman two-part**		**Poisson**	
With random/fixed effects	**Random**	**Random**	**Fixed**	**Random**	**Fixed**	**Random**	**Random**	**Fixed**	**Random**	**Fixed**
Satisfaction with life? (1 not, 5 fully)	0.008	0.042^{***}	0.023	0.028	0.025	-0.001	0.024^{*}	0.010	-0.127^{*}	-0.135^{**}
	(0.005)	(0.011)	(0.018)	(0.049)	(0.051)	(0.005)	(0.011)	(0.018)	(0.050)	(0.051)
Power rank (1 lowest, 9 highest)	-0.002	0.002	0.023	0.024	0.026	-0.003	0.001	0.023	0.004	0.008
	(0.003)	(0.008)	(0.013)	(0.034)	(0.035)	(0.003)	(0.008)	(0.013)	(0.036)	(0.036)
Respect rank (1 lowest, 9 highest)	0.015^{***}	0.011	-0.001	-0.072^{*}	-0.073^{*}	0.010^{**}	0.010	-0.001	-0.061	-0.060
	(0.003)	(0.007)	(0.011)	(0.030)	(0.031)	(0.003)	(0.007)	(0.011)	(0.032)	(0.032)
Regional control variables:										
Settlement type (0 rural, 1 urban)	0.077^{***}	0.142^{***}	1.423^{**}	0.304	2.395^{*}	0.064^{**}	0.149^{***}	1.470^{**}	0.338	2.632^{**}
	(0.020)	(0.041)	(0.462)	(0.402)	(1.042)	(0.021)	(0.041)	(0.461)	(0.408)	(1.017)
Distance to doctor (in km)	0.000	-0.001^{***}	-0.001^{***}	0.000	0.001	0.000	-0.001^{***}	-0.001^{***}	0.001	0.001
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Observations	88,344	67,324 (11,933)	67,324 (11.933)	88,203	6,462	88,466	67,324 (11,933)	67,324 (11,933)	88,436	6,522
R^2 (o overall, w within)		0.059 (o)	0.072 (w)				0.054 (o)	0.072 (w)		
McFadden's Adjusted R^2:	0.192			0.352	0.516	0.231			0.312	0.474

Source: RLMS-HSE for the time period 1996-2008 with individuals aged 18 years or older.

Note: Estimates of the constants as well as the coefficients of the Russian economic regions are mostly significant but not presented here due to low explanatory power. It has been tested against a significance level of 5%. Nevertheless, for comparison reasons, $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$ are presented. Robust standard errors are in parentheses.

[a] Estimation of the selection equation predicts a negative health coefficient.

5.2.6 Interim conclusions

Considering recent trends in Russians' health care expenditures, it is important to understand the causal pathways and mechanisms behind the demand for medical care. While GROSSMAN's health investment model is a standard economic theory used to explain the demand for medical care, it has been argued that the model would fail in practical applications. This is because the model implies that the demand for medical care increases with a higher health status. Yet this theoretical implication cannot be confirmed by empirical results. Therefore, the aim of chapter 5.2 is to demonstrate that the theoretical predictions of GROSSMAN's model are in line with the empirical results if the health investment production function is assumed to be of decreasing returns to scale. Based on the standard theoretical model with the reworked specification of the health investment production function, the following can be concluded. First, if a health investment production function with decreasing returns to scale is applied, the model generates a demand function for medical care that is in line with empirical evidence. This means that the analytically derived empirical demand function for medical care of the reworked model setting finally indicates a negative health coefficient in the demand function for medical care. Hence, the hitherto criticized inconsistency of the health investment model is no longer valid even if GROSSMAN's standard model setting is applied. Second, the criticized assumption of instantaneous health adjustments from the current to the desired health stock is no longer necessary. Third, introducing uncertainty surrounding the health status does not change the theoretically implied negative effect of health on the demand for medical care. In fact, the behavioral predictions under uncertainty corroborate the analogous predicted effect directions under the assumption of certainty. Fourth, the presented empirical results reinforce the derived theoretical predictions for the demand for medical care. While confirming the implications of the theoretical model, the empirical analysis is also the first that analyzes Russians' demand for medical care and thus provides novel empirical results. It has been shown that besides income and health status, settlement type and lifestyle factors are also significantly associated with the demand for medical care. In conclusion, GROSSMAN's model offers reasonable predictions, provided that the functional forms are properly specified.

Nevertheless, theoretical and empirical applications of the Grossman health investment model are limited by the assumption of a fixed input ratio between healthcare and time investments. Therefore, for future research, the assumed Cobb-Douglas production function for health investments should be substituted by a more flexible production function to overcome this rather restrictive assumption. Additionally, more elaborate data on Russians' demand for medical care are necessary. Finally, to increase the relevance of the model to the real world, the Grossman health investment model ought to be enhanced by incorporating the concept of dietary quality.

5.3 DIETARY HEALTH INVESTMENT MODEL

5.3.1 Theoretical considerations

In chapter 5.2, it has been shown that GROSSMAN's model offers reasonable predictions of health investment behavior. In chapter 5.3, the focus is now set on the development of a theoretical model that is able to describe the effects of the manifold diet-quality specific explanatory factors. As mentioned in the chapter introduction (chapter 5.1), besides food prices, wage rates, and common sociodemographic or socioeconomic variables (e.g., knowledge, age, or gender), it is necessary to consider further influencing factors typically involved in dietary choices. Thereby, taste as well as health issues of vitamin and mineral intakes have been found to be major determinants of individuals' dietary quality (EERTMANS, 2001; BRUG, 2008; BLANCK et al., 2009; HONKANEN and FREWER, 2009). In an intertemporal context, the adequate intake of vitamins and minerals can be considered as a long-term investment in an individual's health, in addition to healthy lifestyles and good healthcare. Furthermore, healthy dietary behavior often means sacrificing the pleasure of palatable yet risky nutrients in return for an increased probability of future healthiness (BLAYLOCK et al., 1999). Hence, the concept of dietary quality remains considerably complex when considering its multidimensional character and varying influencing factors across these dimensions.

Consequently, in order to appropriately explain dietary behaviors with relevance for the development of public health prevention programs – but at the same time keeping it as simple as possible – the concept of dietary quality is modeled here by focusing on two dimensions of dietary quality: adequacy and moderation.[85] As explained in chapter 4.2.3.1, adequacy refers to the sufficient intake of nutrients beneficial to health, while moderation means avoiding the excessive intake of nutrients that may be detrimental to health, i.e. nutrients that increase the risk of chronic diseases if consumed in excess. Both dimensions sufficiently fulfill the two aforementioned aspects of dietary quality choices: health investments by vitamins and minerals but also the commonly known health-taste trade-off of nutrients to be moderated. With an adequate consumption of vitamins, minerals, trace elements, and phytochemicals, consumers invest in a better future health status. For example, the consumption of vitamin C today will support the immune system to defend itself against infections in the future, which in turn raises utility directly or indirectly through an extended healthy time that

[85] See footnote 21.

can be spent on either labor or household activities such as leisure time. In the following, micronutrients of the adequacy dimension of dietary quality are specified as *healthy nutrients*.[86] Thus, an investment in health can be produced, amongst others, through the adequate consumption of these healthy nutrients.

Nutrients considered to be subject to moderate intakes are mainly fatty acids, especially saturated fatty acids, saccharose, and sodium chloride (WAIJERS et al., 2007). The consumption of (saturated) fatty acids, saccharose, and sodium chloride creates direct utility by providing their preferred tastes of fattiness, sweetness, and saltiness, respectively. However, besides these direct utility effects in the period of consumption, an intake of these nutrients beyond their critical intake value increases the risk of diabetes, obesity, hypertension, and other chronic diseases in future periods (BINKLEY and GOLUP, 2011). In the following, nutrients related to the risk of chronic diseases are specified as *risky nutrients* because an excessive intake of these risky nutrients with its negative effect on health is of major concern in most industrialized environments. Accordingly, the utility-generating consumption of these risky nutrients has a negative effect on individuals' future health when consumed in excess (ARNADE and GOPINATH, 2006). The resulting worsened future health status will inevitably lower utility inflows of future periods.

Given these two basic diet-health relationships, GROSSMAN's standard health investment model has to be enhanced in order to incorporate the role of dietary quality into the health investment model. However, in contrast to the respective model formulations of, for example, CHERN (2003), VARIYAM (2003), and ZHAO et al. (2013), the health investment model should not retain its original structure if the primary health input is not medical care but dietary quality. This is because dietary quality is a theoretical construct comprising both adequate healthy nutrient consumption and moderate risky nutrient consumption. Furthermore, the construct dietary quality cannot be purchased on the market itself and thus does not have an observable market price. Even if an implicit price of dietary quality is considered, for example, by estimating hedonic pricing models, expenses for dietary quality will not necessarily increase with growing demands for dietary quality (see e.g., RAYNOR et al., 2002; CARLSON et al., 2014).

Based on the above discussion, the aim of this inquiry is to provide a comprehensive theoretical framework, which considers the above discussed aspects of dietary quality. Thereby, this inquiry contributes to the literature by providing a

[86] Although even some vitamins and minerals have a negative effect on health when consumed in excess, they are generally stated here as healthy nutrients. This is because by adhering to a diet solely based on foods without any supplements it is very unlikely to achieve an excessive intake of them.

rational utility-maximizing model of dietary behavior that is the first to account for each of the following three aspects at the same time: (i) health is improved by dynamic health investments; (ii) adequate healthy nutrient intake is an input factor of health investments; and (iii) the intake of risky nutrients raises today's utility but deteriorates future health if consumed in excess.[87] This model of dietary behavior, called the dietary health investment model, is based upon GROSSMAN's health investment model, which is enhanced by basic aspects of LANCASTER's goods characteristics approach (BURGGRAF et al., 2014; BURGGRAF et al., 2014b; BURGGRAF et al., 2016b).

5.3.2 Model assumptions

The model assumptions of the dietary health investment model are based on GROSSMAN's health investment model (GROSSMAN, 1972a, 1972b, 2000), but also consider aspects of dietary quality as discussed in chapter 5.3.1.[88] In the dietary health investment model, utility is created by the available amount of healthy time and the consumption of risky yet tasty nutrients, implying a movement of this modified Grossman model towards the goods characteristics approach (see BURGGRAF, 2014; BURGGRAF et al., 2015b, 2015f).[89] Other utility generating elements remain unconsidered in this model setting, which implies the additive separability of preferences. Furthermore, for analytical convenience, the individual's lifetime utility function J is specified as being separable over time. Thus, under conditions of certainty, the individual's objective functional can be expressed as

$$J = \int_0^T U[\mathbf{b}(t), h(t)]e^{-\rho t}\, dt. \tag{64}$$

[87] These specifications are in line with TRAILL's request that demand models for dietary quality need to recognize effects on utility by taste and future health consequences (see TRAILL, 2012).

[88] Modifications to the original Grossman model are the following. First, in the original Grossman model utility is created by the available amount of healthy time and the consumption of household commodities instead of the consumption of risky nutrients. Second, in the original model health investments are produced by medical care and time instead of the newly introduced consumption of healthy nutrients (combination with LANCASTER's goods characteristics approach) and time invested in health. Third, since the focus is on the demand for dietary quality, the consumption of non-food products is considered here by the exogenously given outside good.

[89] According to the goods characteristics approach, it is the characteristics of goods from which utility is derived. This assumption is tested, *inter alia*, by LADD and SUVANNUNT (1976) and MORSE and EASTWOOD (1989). Each of these studies supports the goods characteristics approach as being appropriate for the study of food consumption. There is a broad variety of empirical studies applying the goods characteristics approach to the demand analysis of nutrients (for an overview see, e.g., NAYGA, 1994).

In line with equation (6) of the standard health investment model, the utility function $U(\cdot)$ is assumed to be increasing, strictly concave, and continuously differentiable in its arguments. Again, parameter ρ of equation (64) denotes the subjective discount rate, which is a measure of the individual's impatience. However, adapted to the more detailed nutrient level of dietary quality, equation (64) now considers the consumption vector of tasty yet risky nutrients $\mathbf{b}(t)$ instead of general household commodities $Z(t)$.[90] Vector $\mathbf{b}$ with $\mathbf{b} = (b_1, b_2, \dots, b_n)'$ represents the average daily consumed amount of each risky nutrient b_f with $f = 1, \dots, n$, which are considered relative to their respective recommended daily upper intake values. Nutrient intakes are measured in relative rather than absolute terms to make the intakes of different nutrients comparable by accounting for the respective reference intake values.[91] Furthermore, it is assumed that consumers care about the accumulated levels of their risky nutrient intakes rather than about their sources. That means individuals value the intakes of, for example, saturated fatty acids in butter equal to those in meat. This assumption allows for substitutability among risky nutrients from different foods (ARNADE and GOPINATH, 2006). Let vector $\mathbf{x} = (x_1, x_2, \dots, x_d)'$ represent the consumed amounts of food items k with $k = 1, \dots, d$. Accordingly, considering constant input-output coefficients, the linear production function of risky nutrients is assumed to be

$$\mathbf{b}(t) = \mathbf{B}\mathbf{x}(t) \qquad (65)$$

where $\mathbf{B} = [b_{fk}]$ is a $(n \times d)$ matrix (see e.g., LANCASTER, 1966, 1971). This matrix defines for the f-th risky nutrient the amount of this risky nutrient contained in one unit of the k-th food product, x_k, relative to the daily recommended upper intake value of this f-th nutrient. The lifetime utility function (64) considering the consumption of risky nutrients and healthy time is maximized with respect to the health and wealth paths, as well as the production technology of the investment in health capital. These restrictions are defined in detail in the following.

As in the standard Grossman model, the amount of utility-yielding healthy time is a function of the individual's health capital $H(t)$, such that $h(t) = \phi(H(t))$, where $h(\cdot)$ is assumed to be increasing, strictly concave and continuously differentiable (GROSSMAN, 2000). The stock of health capital $H(t)$ depreciates on a progressive depreciation rate but can be revalued upwards by investments in health

[90] The studies of FORSTER (2001) and KOKA et al. (2014) modify GROSSMAN's health investment model by considering the consumption of utility yielding yet unhealthy goods (e.g., smoking) in their lifetime utility function.

[91] It has to be noted that reference intake values have changed over time with increasing scientific efforts and may vary across different geographical regions. Hence, for empirical analysis, researchers need to apply current reference values considering the observed geographical region.

capital (CHERN, 2003). Furthermore, the consumption of risky nutrients affects a consumer's health status by increasing the risk of chronic diseases if consumed in excess. This deteriorating effect of the vector of the consumption of the n risky nutrients on health status is valued in this inquiry by the vector of the proportional health impact rates $\boldsymbol{\gamma}$ with $\boldsymbol{\gamma} = (\gamma_1, \gamma_2, \ldots, \gamma_n)'$. As long as the average daily consumed amount of a risky nutrient is less than its respective daily reference intake level, i.e. $b_f(t) < 1$, then health is positively affected. However, if the average daily consumed amount of a risky nutrient exceeds its respective daily reference intake level, i.e. $b_f(t) > 1$, then health is negatively affected. The more excessive the relative intake of the risky nutrient is, the stronger this negative effect will be. Therefore, the equation of motion in health is expressed here as a modification of equation (7) by

$$\dot{H}(t) = I(t) - \boldsymbol{\gamma}'(\mathbf{b}(t) - \mathbf{c}) - \delta(t)H(t) \tag{66}$$

$$\text{with} \quad H(0) = H_0, H(0) > H_{min} > 0, H(T) \leq H_{min}, H(t) > H_{min} \; \forall \; t \neq T,$$

$$\gamma_f > 0, \delta(t) > 0, \dot{\delta}(t) > 0 \;\; \forall \; t \in [0, T],$$

where $I(t)$ is the investment in health capital, $\boldsymbol{\gamma}$ is the vector of the health impact rate, $\mathbf{c}$ is a $(n \times 1)$ vector with each element set to one, and $\delta(t)$ is the depreciation rate of health capital (BURGGRAF, 2014; BURGGRAF et al., 2016b).[92] The parameters γ_f for all $f = 1, \ldots, n$ and δ depend on individual-specific health endowments (e.g., from genetic traits), which cannot be controlled for. The stock of health capital at $t = 0$ is indicated by H_0. The end of the lifetime T is assumed to occur automatically once $H(t)$ drops to its critical minimum level H_{min} (EHRLICH and CHUMA, 1990).

Recent studies have started to differentiate between investment and disinvestment effects on health capital considering the consumption of healthy goods such as medical care and unhealthy goods such as smoking (see, e.g., JONES et al., 2014; KOKA et al., 2014). The innovation of the dietary health investment model lies in considering nutrients rather than goods within the theoretical framework of the health investment model to explicitly account for the health effects of dietary quality. Therefore, in this modified version of the Grossman model, investments in health are produced by the adequate consumption of a bundle of

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92 Studies, for example, of FORSTER (2001), JONES et al. (2014), and KOKA et al. (2014) provide in their health capital simulation analyses regarding the consumption of healthy goods (e.g., medical care) and unhealthy goods (e.g., smoking) an equation of motion for health that is a positive function of the consumption of healthy goods, but a negative function of the consumption of unhealthy goods and health capital depreciation. Yet this model's innovation lies in considering the health investment character of healthy nutrients and the health deteriorating effect of risky nutrients to explicitly account for health effects of dietary quality.

healthy nutrients g_j represented by the vector $\mathbf{g}(t)$ with $\mathbf{g} = (g_1, g_2, \ldots, g_o)'$, which is subject to the individual's nutrition knowledge $E(t)$. Similar to risky nutrients, vector $\mathbf{g}$ represents the average daily consumed amount of each healthy nutrient g_j with $= 1, \ldots, o$, which is measured relative to its respective daily adequate intake values. Therefore, considering constant input-output coefficients healthy nutrient intakes are given by

$$\mathbf{g}(t) = \mathbf{Gx}(t) \tag{67}$$

with $\mathbf{G} = [\mathrm{g}_{jk}]$ being an $(o \times d)$ matrix (see e.g., LANCASTER, 1966, 1971). The matrix **G** defines for each *j*-th healthy nutrient the contained amount of this healthy nutrient provided by one unit of the *k*-th food product, x_k, relative to the daily reference intake value of the *j*-th healthy nutrient. Hence, subject to nutritional knowledge $\tilde{E}(t)$, the individual produces health investments with healthy nutrients $\mathbf{g}(t)$.[94] Furthermore, an individual may choose to invest in health by time invested in health $m(t)$ such as doing sports.[95] By substituting the medical care with healthy nutrient intakes, the modified health investment production function is given by

$$\check{I}(t) = \check{I}\left(\mathbf{g}\,(t), m(t); \tilde{E}(t)\right) \tag{68}$$

with $\check{I}(t) \geq 0 \;\forall\; t \in [0, T]$.

Beginning with the intra-temporal cost minimization problem, the individual determines those input bundles that minimize short run costs of attaining health investment $\check{I}(t)$ subject to the constraints imposed by the respective production function and the given level of nutrition knowledge. Following EHRLICH and CHUMA (1990), a Cobb-Douglas health investment production function with decreasing returns to scale is assumed, which yields a cost function of health investments of the form

$$\check{C}_I(t) = \pi_H(t)\, \check{I}(t)^{\breve{\alpha}} \tag{69}$$

where $\pi_H(t) = \pi_H\left(\mathbf{p_g}(t), w(t), \tilde{E}(t)\right),\ \breve{\alpha} > 1$.

Parameter $\breve{\alpha}$ represents the inverse scale elasticity of health investments of a Cobb-Douglas production function with the two variable factor inputs healthy nutrients and time. The unit price $\pi_H(t)$ of health investment $\check{I}(t)^{\breve{\alpha}}$ is a function of the vector of the implicit prices for healthy nutrients $\mathbf{p_g}(t)$ with $\mathbf{p_g} = (p_{g_1}, p_{g_2}, \ldots, p_{g_o})'$, the opportunity costs of time by wage rate $w(t)$, and

94 CHERN (2003) considers overall dietary quality instead of healthy nutrients. JONES et al. (2014) and KOKA et al. (2014) substituted medical care by generally healthy goods.

95 Despite the importance of knowledge regarding recreational health investment activities, the focus is set here on nutrition knowledge.

the given dietary knowledge $\tilde{E}(t)$. Due to health investments with decreasing returns to scale, the dual cost function of producing health investment is monotonic increasing and convex in $\check{I}(t)$, meaning that $\frac{\partial \check{C}_I(t)}{\partial \check{I}(t)} > 0$ and $\frac{d^2 \check{C}_I(t)}{d(\check{I}(t))^2} > 0$. Therefore, the full-wealth constraint (see, e.g., BECKER, 1965) develops over a lifetime according to the following modified equation of motion

$$\dot{A}(t) = r(t)A(t) + w(t)h(t) + y(t) - \pi_H(t)\check{I}(t)^{\check{\alpha}} - \mathbf{p_b}(t)'\mathbf{b}(t) \\ - q(t)p_q(t) \tag{70}$$

with $A(0) = A_0, A(0) > 0, A(T) \geq 0$.

According to the full-wealth equation of motion (70), consumers receive interest revenues on their financial assets $A(t)$ with interest rate $r(t)$. Available healthy time $h(t)$ is valued at the wage rate $w(t)$. Non-labor income is represented by y(t). From these full-wealth inflows in t, the following flows of costs in t are deducted: the costs of health investments with the two factor inputs invested time (valued at the wage rate w(t)) and healthy nutrient intakes (valued at the implicit price vector $\mathbf{p_g}(t)$); the costs for the utility-yielding consumption of the relative amounts of risky nutrients $\mathbf{b}(t)$ (valued at the implicit price vector $\mathbf{p_b}(t)$ for risky nutrients with $\mathbf{p_b} = (p_{b_1}, p_{b_1}, \ldots, p_{b_n})'$); and the costs of the exogenously-given representative non-food market good $q(t)$ valued at its price $p_q(t)$.[96] Considering the above full-wealth constraint, an individual's time per period is constrained by

$$\Omega(t) = l(t) + m(t) + s(t) \tag{71}$$

with $\Omega(t) - s(t) = h(t)$.

Therefore, total time $\Omega(t)$ available in t has to be fully divided into labor time $l(t)$, time invested in gross health investments $m(t)$, and sick time $s(t)$. Sick time is lost for labor and non-market activities.

5.3.3 Demand for dietary quality

5.3.3.1 Optimization problem

According to the assumptions of the dietary health investment model, the respective optimal control problem is to maximize the individual's lifetime utility function (64) subject to the constraints for health (66), health investments (68), and wealth (70). Here, the dynamic optimization problem of the dietary health investment model is tackled by the optimal control theory with the maximum principle by PONTRYAGIN et al. (1967). In this version of the Grossman model, the consumed amount of risky nutrients $\mathbf{b}(\cdot)$ and the amount of health investments

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96 The implicit prices of healthy and risky nutrients reflect market equilibrium prices of the relative nutrient supply and demand.

$\check{I}(\cdot)$ qualify as control variables. The consumption of risky nutrients and the gross investment in health by healthy nutrients are subject to the individual's discretionary choice and affect the stocks of health capital $H(\cdot)$ and wealth capital $A(\cdot)$, which both indicate the state variables of the model. Thus, the task is to choose the optimal control paths that determine the associated state paths over a given health interval $[H_0, H_{min}]$, with H_{min} being the fixed terminal point. Based on the optimal values of risky and healthy nutrients, individuals specify their optimal basket of food. In this context, it is assumed that the requested combination of healthy and risky nutrients is always realizable by an according basket of infinitely divisible foods.[96] Hence, the decision for a certain food basket composition is equal to the decision for a certain dietary quality, taking into account the adequate intake of healthy nutrients and the moderate intake of risky nutrients.

Based upon the presented dietary health investment model, the intertemporal utility maximization problem of the dietary health investment model can be expressed for all $h: [0, T] \to \mathbb{R}_+$, $\mathbf{b}(t): [0, T] \to \mathbb{R}_+^n$ and all $t \in [0, T]$ as

$$\max_{\check{I},\mathbf{b},T} J = \int_0^T U[\mathbf{b}(t), h(t)]e^{-\rho t}\, dt \tag{72}$$

subject to

(i) $\dot{H}(t) = \check{I}(t) - \boldsymbol{\gamma}'(\mathbf{b}(t) - \mathbf{c}) - \delta(t)H(t)$,

(ii) $\dot{A}(t) = rA(t) + wh(t) + y(t) - \pi_H(t)\check{I}(t)^{\check{\alpha}} - \mathbf{p_b}(t)'\mathbf{b}(t) - p_q(t)q(t)$,

(iii) $\check{I}(t) = \check{I}\left(\mathbf{g}(t), m(t);\ \tilde{E}(t)\right)$,

with

(iv) $H(0) = H_0, H(0) > H_{min} > 0, H(T) \leq H_{min}, H(t) > H_{min}\ \forall\ t \neq T$,

(v) $A(0) = A_0, A(0) > 0, A(T) \geq 0, \check{\alpha} > 1$,

(vi) $\check{I} \in [0, \infty]$

Again, wage rate and interest rate are assumed to remain constant over time. The task is to choose the optimal control paths of risky nutrients $\mathbf{b}(\cdot)$ and health investments $\check{I}(\cdot)$ that determine the associated state paths over a given health interval $[H_0, H_{min}]$, with H_{min} being the fixed terminal point. Applying the maximum principle by PONTRYAGIN (see PONTRYAGIN et al., 1967), the aforementioned control problem can be rewritten as the following Hamiltonian function denoted by $\mathcal{H}$ with $A(\cdot)$ and $H(\cdot)$ being the state variables and $\check{I}(\cdot)$ and vector $\mathbf{b}(\cdot)$ being the control variables as

96 LANCASTER assumes infinite divisibility, which is appropriate for highly divisible and frequently purchased goods such as foods (see e.g., RATCHFORD, 1975).

$$\mathcal{H}\big(t,H,A,\check{I},\mathbf{b},\varphi_A,\varphi_H\big) \coloneqq U[\mathbf{b}(t),h(t)]e^{-\rho t} \qquad (73)$$
$$+\varphi_A(t)\big[rA(t)+wh(t)+y(t)-\pi_H(t)\check{I}(t)^{\breve{\alpha}}-\mathbf{p_b}(t)'\mathbf{b}(t)$$
$$-\,p_q(t)q(t)\big]$$
$$+\varphi_H(t)\big[\check{I}(t)-\boldsymbol{\gamma}'(\mathbf{b}(t)-\mathbf{c})-\delta(t)H(t)\big].$$

The Hamiltonian is jointly concave in both the state and control variables due to the strict concavity of the utility function, production of health, and the generation of healthy time (EHRLICH and CHUMA, 1990).[97] The adjoint variables $\varphi_H(t)$ and $\varphi_A(t)$ are in the nature of Lagrange multipliers of the states $H(t)$ and $A(t)$, respectively. As such, they show the extent to which lifetime utility will increase if health capital or full-wealth is increased by one unit in *t*. Therefore, these variables measure the shadow prices of the associated state variables at a particular point in time (CHIANG, 1992). For the above-stated problem and with the Hamiltonian (73), the optimality conditions of the Hamiltonian system can be derived by

$$\dot{H}(t)=\check{I}(t)-\boldsymbol{\gamma}'(\mathbf{b}(\mathrm{t})-\mathbf{c})-\delta(t)H(t), \qquad (74)$$

$$\dot{A}(t)=rA(t)+wh(t)+y(t)-\pi_H\check{I}(t)^{\breve{\alpha}}-\mathbf{p_b}(\mathrm{t})'\mathbf{b}(t)-p_q(t)q(t), \qquad (75)$$

$$\nabla_{\mathbf{b}}\mathcal{H}(t)=\nabla_{\mathbf{b}}U(t)e^{-\rho t}-\varphi_A(t)\mathbf{p_b}(t)-\varphi_H(t)\boldsymbol{\gamma}=0, \qquad (76)$$

$$\frac{\partial\mathcal{H}(\mathrm{t})}{\partial\check{I}(t)}=-\varphi_A(t)\,\pi_H(t)\,\breve{\alpha}\,\check{I}\,(t)^{\breve{\alpha}-1}+\varphi_H(t)=0, \qquad (77)$$

$$\dot{\varphi}_A(t)=\frac{\partial\varphi_A}{\partial t}=-\frac{\partial\mathcal{H}}{\partial A}=-\varphi_A(t)r, \qquad (78)$$

$$\dot{\varphi}_H(t)=\frac{\partial\varphi_H}{\partial t}=-\frac{\partial\mathcal{H}}{\partial H}$$
$$=-e^{-\rho t}\frac{\partial U(t)}{\partial h(t)}\frac{\partial h(t)}{\partial H(t)}-\varphi_A(t)w\frac{\partial h(t)}{\partial H(t)} \qquad (79)$$
$$+\,\varphi_H(t)\delta(t),$$

$$\mathcal{H}(T)=U[\mathbf{b}(T),h(T)]e^{-\rho T}+\varphi_A(T)\dot{A}(T)+\varphi_H(T)\dot{H}(T)=0, \qquad (80)$$

with

$$\varphi_H(T)=\varphi_H\geq 0, H(T)\leq H_{min}, \frac{\partial\mathcal{H}(T)}{\partial T}<0,$$

[97] Due to $\frac{\partial^2\check{C}_I(t)}{\partial\check{I}(t)^2}>0$ and $\frac{\partial^2U}{\partial {b_f}^2}<0\ \forall f=1,\dots,n$ we have $\frac{\partial^2\mathcal{H}(t)}{\partial\check{I}(t)^2}<0$ and $\nabla_{\mathbf{b}}(\nabla_{\mathbf{b}}\mathcal{H})<0$ under the assumption of additive separability of preferences of the assumed additive utility function. Furthermore, considering ARROW's theorem (see, e.g., KAMIEN and SCHWARTZ, 1991), the quadratic form of the involved maximized Hamiltonian, which is evaluated at the maximized controls, is semi-definite. Therefore, the Hamiltonian is concave for every $t\in[0,T]$. For comparison see also Appendix 2.

$\varphi_A(T) = \varphi_A \geq 0\,, A(T) \geq 0.$

Equations (74), …, (79) of the Hamiltonian system represent the equations of motion, the standard first-order conditions (FOC), and the adjoint equations for the intertemporal optimization problem (KAMIEN and SCHWARTZ, 1991). Because the terminal time is not fixed but rather defined by H_{min}, the problem is not only solved by the optimal control variables $\check{I}(t)$ and $\mathbf{b}(t)$, but also by the optimal lifetime time interval $[0, T]$. Hence, the necessary optimality conditions given in equations (74), …., (79) are complemented by the transversality condition (80).

Solving FOC (77), a flow equilibrium condition of optimal health investment $\check{I}(t)$ can be derived for all $t \in [0, T]$ as[98]

$$\pi_H(t)\ \ \check{\alpha}\ \check{I}(t)^{\check{\alpha}-1} = \eta(t) \tag{81}$$

with $\eta(t) = \frac{\varphi_H(t)}{\varphi_A(t)}$.

Just as in GROSSMAN's standard model setting, this function is equivalent to EHRLICH and CHUMA's flow equilibrium equation (8′) (see EHRLICH and CHUMA, 1990). The left-hand side of equation (81) represents the marginal cost of health investments. By the definition of $\frac{\varphi_H(t)}{\varphi_A(t)}$ as the relative shadow price of health capital $\eta(t)$, a flow equilibrium at optimal investment $\check{I}(t)$ exists if the marginal cost of health investment equals the relative shadow price of health capital $\eta(t)$ (EHRLICH and CHUMA, 1990).

Besides health investments by healthy nutrient intakes, the concept of dietary quality also calls to control for the moderate intake of risky nutrients. From FOC (76) and by solving (78), the flow equilibrium condition of the optimal demand for risky nutrients can be derived for all $t \in [0, T]$ as

$$\nabla_{\mathbf{b}} U(t)\,\frac{1}{\varphi_A(0)}\,e^{(r-\rho)t} = \mathbf{p_b}(t) + \eta(t)\boldsymbol{\gamma}. \tag{82}$$

The economic interpretation of the optimality condition given in equation (82) is that the intake of a risky nutrient is optimal if the marginal utility of the intake of this risky nutrient, subjectively discounted and normalized with $\varphi_A(0)$, is equal

[98] Again, the assumption $\frac{\partial \check{C}_I(t)}{\partial \check{I}(t)} > 0$ is sufficient to make $\eta(t) > 0$. Furthermore, due to $\dot{\varphi}_A(t) = -\varphi_A(t)r$, it follows that $\varphi_A(t) > 0$ for all $t \in [0, T]$ under the reasonable assumption that $\varphi_A(0) > 0$ with $A_0 > 0$. With the dual cost function of producing $\check{I}(t)$ being a monotonic increasing and convex function in $\check{I}(t)$, it follows from optimality condition (81) that optimal $\check{I}(t) = \left(\frac{\eta(t)}{\pi_H(t)\,\check{\alpha}}\right)^{\frac{1}{\check{\alpha}-1}}$ with $\check{I}(t) > 0$ if all factor prices are positive, $\check{\alpha} > 1$, and $\eta(t) > 0$.

to the implicit price of the risky nutrient plus the health impact valued with the relative shadow price of health capital.

Finally, given the adjoint equations (78) and (79), and by considering the definition of the relative shadow price of health, a continuous stock equilibrium condition for the optimal stock of health capital $H(t)$ can be derived for all $t \in [0, T]$ as

$$\eta(t)\left[\delta(t) + r - \frac{\dot{\eta}(t)}{\eta(t)}\right] = \frac{1}{\varphi_A(0)}\; e^{(r-\rho)t}\,\frac{\partial U(t)}{\partial h(t)}\frac{\partial h(t)}{\partial H(t)} + w\,\frac{\partial h(t)}{\partial H(t)}. \qquad (83)$$

Just as in GROSSMAN's standard model setting, this function is equivalent with EHRLICH and CHUMA's stock equilibrium equation, which equals equation (28) of this thesis (see EHRLICH and CHUMA, 1990). According to equation (83), the stock of health capital is optimal as soon as the marginal cost of holding an additional unit of health capital is equal to the instantaneous marginal benefit from the last unit of health capital acquired (EHRLICH and CHUMA, 1990). On the left-hand side of equation (83), the marginal costs of holding an additional unit of health capital in t consists again of three parts: (i) the interest earnings forgone by holding an additional unit of health capital; (ii) the health capital depreciation costs from holding an additional unit of health capital; and (iii) the offsetting capital gain from buying the investment good at time t instead of waiting until time $t + dt$. On the right-hand side of equation (83), the marginal efficiency of health capital consists of two parts: the additional wage income from an infinitesimal increase of health capital and the direct marginal utility of health capital, discounted and normalized with the initial shadow price of wealth.

5.3.3.2 Demand for healthy nutrients

Just as in chapters 5.2.3.2 and 5.2.4.3, the pure investment model with the restriction $\frac{dU(t)}{dh(t)} = 0$ is imposed in order to constitute the model's theoretical predictions (see GROSSMAN, 2000). Hence, the empirical specification of the optimal condition (83) can be rewritten in logarithmic form as

$$ln\,\eta_i(t) + ln\,\delta_i(t) - ln\,\psi_i(t) = ln\,w_i(t) + ln\frac{\partial h_i(t)}{\partial H_i(t)} \qquad (84)$$

with $\psi_{1i}(t) = \frac{\delta_i(t)}{\delta_i(t) + r - \frac{\dot{\eta}_i(t)}{\eta_i(t)}}$ indicating the relative importance of the depreciation rate in the marginal cost of health.[99] Again, subscript i indicates reference to the i-th individual.

[99] For comparison see equation (29).

To derive more precise model implications for the demand of healthy nutrient g_j, analogous to the previous process of deriving the structural demand function for medical care, it is necessary to make specific assumptions and approximations regarding the functional forms of $h(\cdot), \delta(\cdot), \check{C}_I, \varphi_H(\cdot)$ and $\varphi_A(\cdot)$. Regarding the functional forms of $h(\cdot)$ and $\delta(\cdot)$, again GROSSMAN's (2000) and WAGSTAFF's (1986) specifications (30) and (31), presented in chapter 5.2.3.2, are employed.

According to GROSSMAN (2000), the production function of healthy days is approximated by

$$h_i(t) = \Omega - \beta_1 \, H_i(t)^{-\beta_2} \tag{85}$$

with $\beta_1 > 0$ and $\beta_2 > 0$.

According to GROSSMAN (2000) and WAGSTAFF (1986) the depreciation rate is approximated by the functional form

$$ln\, \delta_i(t) = ln\, \delta_0 + \beta_3 t_i + \boldsymbol{\beta_4}'\mathbf{X}_{2,i}(t) \tag{86}$$

with $\beta_3 > 0$ indicating an increasing depreciation rate as the individual ages. The vector $\mathbf{X_2}(t)$ represents socio-economic, socio-demographic, and psychological characteristics such as subjective beliefs (LUSK et al., 2014), which are assumed to change the evaluation of health states in future periods. Accordingly, the elements of vector $\boldsymbol{\beta_4}$ will be positive if the respective individual characteristics of $\mathbf{X_2}$ are damaging to health.

Just as was done in chapter 5.2.3.2 and chapter 5.2.4.3, following EHRLICH and CHUMA (1990), health investments are assumed to be produced according to a Cobb-Douglas production function with decreasing returns to scale in order to provide an internal optimum. Therefore, based on the revised health investment production function $\check{I}(t) = \tilde{E}(t)m(t)^{\check{\mu}} \prod_{j=1}^{o} g_j(t)^{\check{\kappa}}$, with $o\check{\kappa} + \check{\mu} < 1$ and the inverse scale elasticity $\check{\alpha} = \frac{1}{o\check{\kappa}+\check{\mu}}$, the flow equilibrium (81) can be rewritten in logarithmic form as

$$\begin{aligned} ln\, \eta_i(t) = \check{\beta}_{01} + \check{\beta}_5 \check{\alpha}\, ln\, p_g + \left(1 - \check{\beta}_5 \check{\alpha}\right) ln\, w_i(t) - \check{\beta}_6 \check{\alpha}\, \check{E}_i(t) + ln\, \check{\alpha} \\ + (\check{\alpha} - 1)\, ln\, \check{I}_i(t) \end{aligned} \tag{87}$$

with $\check{\alpha} > 1$, $\check{\beta}_{01} = \ln\left(\left(\frac{\check{\kappa}}{\check{\mu}}\right)^{\frac{\check{\mu}}{o\check{\kappa}+\check{\mu}}} + o\left(\frac{\kappa}{\mu}\right)^{-\frac{o\check{\kappa}}{o\check{\kappa}+\check{\mu}}}\right)$, and $o\check{\kappa} = \check{\beta}_5$.[100]

Again, nutritional knowledge $\tilde{E}(t)$ is measured by an approximated measurement variable $\check{E}_i(t)$. For simplicity, consider the reasonable assumption of one price index p_g for healthy nutrients and one price index p_b for risky nutrients

[100] For simplicity it is assumed that $\check{\kappa}$ is valid for each healthy nutrient g_j as well as equal healthy nutrient prices (see also footnote 101).

rather than one price for each healthy and risky nutrient.[101] Furthermore, parameter subscripts with leading zeros indicate constants. Accordingly, the logarithmic cost-minimal factor input function for healthy nutrients $g_{\tilde{j}}(t)$ where $g_{\tilde{j}}(t)$ stands generally for every g_j with $j = 1,2, \dots, o$ is

$$ln\, g_{\tilde{j},i}\,(t) = \check{\beta}_{02} - \left(1 - \check{\beta}_5 \check{\alpha}\right) ln\, p_g + \left(1 - \check{\beta}_5 \check{\alpha}\right) ln\, w_i(t) - \check{\beta}_6 \check{\alpha}\, \check{E}_i(t) + \check{\alpha} \ln \check{I}_i(t) \tag{88}$$

with $\check{\beta}_{02} = \left(1 - \check{\beta}_5 \check{\alpha}\right) \ln\left(\frac{\check{\beta}_5}{\frac{1}{\check{\alpha}} - \check{\beta}_5}\right)$.

Finally, $\ln\, \psi_1(\cdot)$ has to be approximated.[102] Following EHRLICH and CHUMA (1990), $\varphi_H(t)$ and $\eta(t)$ are assumed to be progressively increasing with age since health is decreasing with age. While this assumption regarding $\varphi_H(t)$ has already been subsumed by $\ln \psi_{1i}(t) = \beta_9\, t_i$ (WAGSTAFF, 1986), $\varphi_A(t)$ does not necessarily follow such a strict time path but rather depends on $\varphi_A(0)$ with the associated wealth path. In line with MACURDY (1981), $\varphi_A(0)$ is assumed to be a function of the personal characteristics $\mathbf{X_2}(t)$, lifetime income represented here by $\sum_{t=t^*}^{T^*} ln\, w_i(t)$, and initial wealth $A(0)$. Furthermore, in this study it is controlled for income and prices effects of p_b and p_g. Since the task in chapter 5.3 regarding the dietary health investment model is different from that in chapter 5.2, $\psi_1(t)$ is approximated here by

$$ln\, \psi_{1,i}(t) = \check{\beta}_9\, t_i + \sum_{t=t^*}^{T^*} \beta_{10}\, ln\, w_i(t) + \beta_{11} A_i(0) + \beta_{12} \ln w_i(t) - \beta_{13}\, ln\, p_g(t) - \beta_{14}\, ln\, p_b(t) + \boldsymbol{\beta_{15}}' \mathbf{X}_{\mathbf{2},i}(t). \tag{89}$$

with $\check{\beta}_9, \beta_{10}, \beta_{11}, \dots, \beta_{13} > 0$.[103] Regarding permanent income, age t^* indicates the assumed age at earning first wages and age T^* indicates the average age at

[101] Due to consumers' weak understanding and memory of implicit nutrient prices, consumers probably relate food prices to implicit prices of such broader nutrient groups rather than single nutrient prices (MORSE and EASTWOOD, 1989). Yet, the general structure of the demand functions will not change if the nutrient price vectors are considered.

[102] GROSSMAN (2000) assumes $r(t) - \frac{\dot{\pi}(t)}{\pi(t)} = 0$ and hence $\psi_1 = 1$. WAGSTAFF (1986) assumes $r(t)$ and $\frac{\dot{\pi}(t)}{\pi(t)}$ to be constant and therefore $\dot{\psi}(t) > 0$ with $\ln \psi_{1i}(t) = \beta_9\, t_i$ because $\dot{\delta}(t) > 0$. While this assumption has been suitable for the standard Grossman model in chapter 5.2, it is more appropriate to enhance this assumption for the dietary health investment model.

[103] EHRLICH and CHUMA (1990) argue for a generally declining health-age profile dictated by the interior solution for longevity and $\dot{\delta}(t) > 0$ requiring negative net investments as one ages, i.e. $\varphi_H(\cdot)$ is assumed to be progressively increasing with age. While this assumption can be addressed by $\ln \psi_{1,i}(t) = \beta_9\, t_i$ (see e.g., WAGSTAFF, 1986), $\eta(\cdot)$ depends

retirement. Finally, the sign of β_{14} depends on the balance of income and price effects, considering substitutional or complementary price effects of healthy and risky nutrients.

Substituting (85), (86), (87), (89) after some rearrangements into (84), solving it for optimal $\breve{I}_i(t)$, and substituting optimal $\breve{I}_i(t)$ in the cost-minimal factor input function equation (88), the resulting demand function for healthy nutrients $g_{\breve{j},i}(t)$ reads

$$\begin{aligned} ln\, g_{\breve{j},i}\,(t) = \breve{\beta}_{03} &- \left(1 + \frac{\breve{\beta}_5\breve{\alpha} + \beta_{13}\breve{\alpha}}{\breve{\alpha} - 1}\right) \ln p_g(t) - \frac{\beta_{14}}{\breve{\alpha} - 1} ln\, p_b\,(t) \\ &+ \left(1 + \frac{\breve{\beta}_5\breve{\alpha} + \beta_{12}\breve{\alpha}}{\breve{\alpha} - 1}\right) \ln w_i(t) + \frac{\beta_{10}}{\breve{\alpha} - 1} \sum_{t=t^*}^{T^*} ln\, w_i(t) \\ &+ \frac{\beta_{11}}{\breve{\alpha} - 1} A_i(0) + \frac{\breve{\beta}_6\breve{\alpha}}{\breve{\alpha} - 1} \breve{E}_i(t) - \frac{\breve{\alpha}}{\breve{\alpha} - 1} (\boldsymbol{\beta_{15}} - \boldsymbol{\beta_4})'\mathbf{X}_{\mathbf{2},i}(t) \\ &+ \frac{(\breve{\beta}_9 - \beta_3)\breve{\alpha}}{\breve{\alpha} - 1} t_i - \frac{(1 + \beta_2)\breve{\alpha}}{\breve{\alpha} - 1} ln\, H_i(t) + \breve{u}_{1i}, \end{aligned} \tag{90}$$

with $\breve{\beta}_{03} = \breve{\beta}_{02} + \breve{\alpha} \left(\frac{\ln \beta_1\beta_2 - \ln \breve{\alpha} - \breve{\beta}_{01}}{\breve{\alpha} - 1}\right)$ and $\breve{u}_{1i} = -\frac{\breve{\alpha}}{\breve{\alpha} - 1}\, ln\, \sigma_0$.

Hence, in its reduced functional form, the derived empirical demand function for healthy nutrients $g_f(t)$ with $j = 1,2, \dots, o$ can be estimated by

$$\begin{aligned} ln\, g_{j,i}(t) = \breve{\beta}_{03} &+ \beta_{16}\, ln\, w_i(t) + \beta_{17} \sum_{t=t^*}^{T^*} ln\, w_i(t) + \beta_{18} A_i(0) \\ &+ \beta_{19}\, ln\, p_g(t) + \beta_{20}\, ln\, p_b(t) + \beta_{21}\, ln\, H_i(t) + \beta_{22}\breve{E}_i(t) \\ &+ \beta_{23} t_i + \boldsymbol{\beta_{24}}'\mathbf{X}_{\mathbf{2},i}(t) + \breve{u}_{1i}. \end{aligned} \tag{91}$$

The coefficients $\beta_{16}, \dots, \boldsymbol{\beta_{24}}$ in equation (91) are functions of the beta-parameters of the derived structural equation (90). According to the aforementioned parameter settings, comparative statics of the dietary health investment model imply the following marginal effects on the demand for healthy nutrients. The demand for healthy nutrients increases with an increasing wage rate $\left(1 + \frac{\breve{\beta}_5\breve{\alpha} + \beta_{12}\breve{\alpha}}{\breve{\alpha} - 1} > 0\right)$. Since increasing wage rates increase the expenditure budgets and the value of healthy lifetime, they also increase the demand for health investments by healthy nutrients. Additionally, initial financial assets $A(0)$ as well as lifetime income

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also on initial wealth endowments, income, and price changes because they affect lifetime wealth. A higher lifetime wealth level raises optimal longevity and the shadow price of health. This effect on the shadow price of health is assumed to be the higher as one ages because the influence of the value of life extension should dominate in the last phase of life (EHRLICH and CHUMA, 1990).

represented by $\sum_{t=t^*}^{T^*} ln\, \mathrm{w}(t)$ increase the demand for healthy nutrients by higher household budgets and an increased demand for health and longevity (EHRLICH and CHUMA, 1990). Furthermore, given the assumption of decreasing returns to scale in health investments, the model implies a rising demand for healthy nutrients with a worsening health status $\left(-\frac{(1+\beta_2)\breve{\alpha}}{\breve{\alpha}-1} < 0\right)$. Considering the demand for healthy nutrients, a worsening health status raises the relative shadow price of health capital, which has to equal the marginal costs of health investments under conditions of optimality. Assuming decreasing returns to scale and hence a convex dual cost function of health investments, higher marginal costs of health investments are associated with increased investment levels. To conclude, a worsening health status results in an increased demand for health investments and thus an increased demand for healthy nutrients. Moreover, the efficiency of the health investment production process is determined by the level of dietary knowledge. Higher nutritional knowledge increases the efficiency of producing health investments by healthy diets and thus reduces the marginal costs of health investments. For an optimal level of health investments in t, the individual has to increase the amount of health investments until the marginal investment costs again equal the current relative shadow price of health. Therefore, better nutritional knowledge raises the demand for health investments and healthy nutrients $\left(\frac{\breve{\beta}_6\breve{\alpha}}{\breve{\alpha}-1} > 0\right)$.

According to the law of demand, the relative intake of healthy nutrients decreeses with increasing implicit prices of healthy nutrients (represented here by index $p_g(t)$), *ceteris paribus*. This negative effect is replicated by $-\left(1+\frac{\breve{\beta}_5\breve{\alpha}+\beta_{13}\breve{\alpha}}{\breve{\alpha}-1}\right) < 0$. The impact of risky nutrient prices (represented here by index $p_b(t)$) on healthy nutrient demand is determined by the interplay of income effects and the respective cross-price effects. If there exists a complementary price effect or if the income effect is larger than the substitutional price effect, then $\frac{\partial\, ln\, g_i(t)}{\partial\, ln\, p_b(t)} < 0$. If the substitutional price effect is larger than the income effect, then $\frac{\partial\, ln\, g_i(t)}{\partial\, ln\, p_b(t)} > 0$.

Furthermore, dietary choices are assumed to be affected by the effects of the control variables of vector $\mathbf{X_2}(t)$, which account for consumers' different preferences and beliefs. Thereby, most empirical studies control for influencing effects of gender, race, household size, number of children, and settlement type (see e.g., THIELE et al., 2004; BINKLEY and GOLUP, 2011). Regarding the subjective discount rate it is assumed that the more individuals care about future anticipated health situations by lower rates of time preference, the more they engage in sports, avoid smoking, or demand adequate healthy nutrient intakes (see e.g., ROSIN, 2008; LAWLESS et al., 2013; CAVALIERE et al., 2014). Hence, this trade-off between current and future utility explains why consumers often choose rather unhealthy dietary patterns despite being sufficiently knowledgeable about healthy eating patterns (BISOGNI et al., 2012). The degree of urbanization may indicate the potential for home food production, food accessibility, and distinctions in the social, cultural, and economic environment (ADRIAN and DANIEL, 1976). For an overview of the comparative statics see Table 18.

Table 18: Comparative statics for the demand of healthy nutrients

Explanatory variables	Demand for good nutrients $\ln g_{j,i}(t)$	
	Magnitude	Sign
$ln\, w_i(t) \uparrow$	$\beta_{16} = 1 + \frac{\breve{\beta}_5\breve{\alpha} + \beta_{12}\breve{\alpha}}{\breve{\alpha} - 1}$	$1 + \frac{\breve{\beta}_5\breve{\alpha} + \beta_{12}\breve{\alpha}}{\breve{\alpha} - 1} > 0$
$\sum_{t=t^*}^{T^*} ln\, w_i(t) \uparrow$	$\beta_{17} = \frac{\beta_{10}}{\breve{\alpha} - 1}$	$\frac{\beta_{10}}{\breve{\alpha} - 1} > 0$
$A_i(0) \uparrow$	$\beta_{18} = \frac{\beta_{11}}{\breve{\alpha} - 1}$	$\frac{\beta_{11}}{\breve{\alpha} - 1} > 0$
$ln\, p_g(t) \uparrow$	$\beta_{19} = -\left(1 + \frac{\breve{\beta}_5\breve{\alpha} + \beta_{13}\breve{\alpha}}{\breve{\alpha} - 1}\right)$	$-\left(1 + \frac{\breve{\beta}_5\breve{\alpha} + \beta_{13}\breve{\alpha}}{\breve{\alpha} - 1}\right) < 0$
$ln\, p_b(t) \uparrow$	$\beta_{20} = -\frac{\beta_{14}}{\breve{\alpha} - 1}$	$\frac{-\beta_{14}}{\breve{\alpha} - 1} =: \begin{cases} < 0 \; iff \; \beta_{14} > 0 \\ \geq 0 \; iff \; \beta_{14} \leq 0 \end{cases}$
$ln\, H_i(t) \uparrow$	$\beta_{21} = -\frac{(1 + \beta_2)\breve{\alpha}}{\breve{\alpha} - 1}$	$-\frac{(1 + \beta_2)\breve{\alpha}}{\breve{\alpha} - 1} < 0$
$\breve{E}_i(t) \uparrow$	$\beta_{22} = \frac{\breve{\beta}_6\breve{\alpha}}{\breve{\alpha} - 1}$	$\frac{\breve{\beta}_6\breve{\alpha}}{\breve{\alpha} - 1} > 0$
$t_i \uparrow$	$\beta_{23} = \frac{(\breve{\beta}_9 - \beta_3)\breve{\alpha}}{\breve{\alpha} - 1}$	?
$X_{2,i}(t) \uparrow^*$	$\beta_{24} = -\frac{\breve{\alpha}}{\breve{\alpha} - 1}(\beta_{15} - \beta_4)$	?

Note: Upward arrows ↑ indicate a monotonic increase of the independent variables, while + and – indicate monotonic increasing and decreasing functions, respectively.
* This holds for each element of $\mathbf{X_2}$ and the respective elements of $\boldsymbol{\beta_{15}}$ and $\boldsymbol{\beta_4}$.

The theoretical implications of equation (91) are in line with similar findings of empirical studies, which show that dietary quality by healthy nutrient intakes tend to enhance with increasing wage rates. Several studies estimate positive income elasticities for their selected healthy nutrients (AGUIAR and HURST, 2005; TIAN and YU, 2013). Furthermore, healthy nutrient intake is found to increase with higher nutritional knowledge (see, e.g., IRALA-ESTEVEZ et al., 2000; CHERN, 2003; KIM et al., 2003b). Considering the marginal effect of nutrient prices, ALLAIS et al. (2010) show for France that vitamin C intakes decrease with increasing healthy nutrient prices. For cross-price effects, ABDULAI and AUBERT (2004) show that healthy nutrient intakes decrease with increasing risky nutrient prices. In addition, after compensating for the respective income effects, NICHÈLE (2003) shows negative cross-price effects between vitamin- and mineral-dense vegetables and animal fats, a food group high in saturated fats.

Furthermore, previous empirical studies found a positive association between age and dietary quality (SCHROETER et al., 2010; BINKLEY and GOLLUP, 2011). This might be attributable to two factors. First, aging means more time to enhance nutrition knowledge by new information gathered and more experience. Second, aging comes along with a generally lowering health status since health stock depreciates at an increasing rate (EHRLICH and CHUMA, 1990; VARIYAM, 2003). Both factors increase the demand for healthy nutrients and thus dietary quality. Yet controlling for nutrition knowledge or other influencing variables (such as the health stock variable), the effect that aging has on a healthier diet is often not significantly positive or even negative. For example, THIELE et al. (2004) do not find a significant association between age and adequate nutrient intakes for women. Furthermore, CHERN (2003) does not find a significant marginal effect of age on the consumption of fresh fruits and vegetables. With the dietary health investment model, healthy nutrient intakes are now separately explained by nutrition knowledge, health stock, and aging.[104] Thereby, the marginal effect of age on the demand for healthy nutrients may be positive or negative, depending on the different effect sizes of age on health stock depreciation and on the relative shadow price of health during aging.

5.3.3.3 Demand for risky nutrients

Besides the demand for healthy nutrients, the concept of dietary quality also calls for moderating the intake of risky nutrients. For this purpose, the equilibrium condition (82) for risky nutrient consumption $b_f(t)$ can be rewritten in logarithmic form by

$$ln\frac{\partial U_i}{\partial b_{\tilde{f},i}} - ln\,\varphi_{A_i}(0) + (r-\rho_i)t_i = ln\,\eta_i(t) + ln\,\gamma_f + ln\,\psi_{3_i}(t) \qquad (92)$$

with $\psi_{3,i}(t) = \frac{p_b}{\eta_i(t)\gamma_f} + 1$,

where ψ_3 points to the market price health cost ratio of risky nutrient $b_j(t)$, i.e. one plus the cost ratio of the implicit market price of risky nutrients relative to the corresponding health impact valued at the relative shadow price of health capital. Here, $b_{\tilde{f}}$ generally stands for every risky nutrient b_f with $f = 1,2,\dots,n$.

The following specifications are needed to derive a demand function for risky nutrients. Based on WAGSTAFF's (1986) utility function for healthy days, the marginal utility of risky yet tasty nutrients is approximated here by

[104] When estimating the health capital coefficient it is important to take care of possible endogeneity problems in the way that people who eat healthy are supposed to be generally healthier (see footnote 107).

$$\frac{\partial U_i}{\partial b_{\tilde{f},i}} = \beta_{25}\, \beta_{26}\, b_{\tilde{f},i}(t)^{\beta_{26}-1}, \tag{93}$$

with $\beta_{25} > 0$ and $0 < \beta_{26} < 1$.

Similar to the parameterization of MACURDY (1981), $ln\, \varphi_A(0)$ is approximated as a linear function of characteristics $\mathbf{X_2}(t)$, the natural log of wages $w_i(t)$, and initial wealth $A_i(0)$. Concavity of preferences implies that $\frac{\partial \varphi_A(t)}{\partial A(0)} < 0$ and $\frac{\partial \varphi_A(t)}{\partial w(t)} \leq 0$. Therefore, $ln\, \varphi_{A_i}(0)$ is assumed to be estimated according to

$$ln\, \varphi_{A_i}(0) = \boldsymbol{\beta_{27}}'\mathbf{X}_{2,i}(t) - \sum_{t=t^*}^{T^*} \beta_{28}\, ln\, w_i(t) - \beta_{29} A_i(0) \tag{94}$$

with $\beta_{28} > 0$, and $\beta_{29} > 0$. Again, the age t^* is the average age of leaving school or vocational training, i.e. the age of individuals earning their first wages. Age T^* is the average age at retirement.

The health impact rate only matters in the individual's decision process if the individual has complete knowledge about the negative health impact. Hence, in this empirical model $ln\, \gamma_f$ is approximated by

$$ln\, \gamma_{\tilde{f}} = \beta_{30}\, \check{E}_i(t). \tag{95}$$

For constant $\gamma_{\tilde{f}}$, the logarithmic market price health cost ratio $\psi_{3_i}(t)$ is approximated by

$$\begin{aligned} ln\, \psi_{3,i}(t) = {} & \beta_{32}\, ln\, p_b(t) - \beta_{33}\, t_i + \boldsymbol{\beta_{34}}'\mathbf{X}_{2,i}(t) + \beta_{35}\, ln\, p_g(t) \\ & - \sum_{t=t^*}^{T^*} \beta_{36}\, ln\, w_i(t) - \beta_{37}\, ln\, w_i(t) - \beta_{38} A_i(0) \end{aligned} \tag{96}$$

with $\beta_{32}, \beta_{33}, \beta_{35}, \ldots, \beta_{38} > 0$. The parameters of vector $\boldsymbol{\beta_{34}}$ are expected to have the same sign as those of $\boldsymbol{\beta_{27}}$. According to equation (96), the vector of the market price-health cost ratio is approximated as a linear function of initial wealth, lifetime income, personal characteristics, the implicit market prices of risky nutrients but also the implicit market prices of healthy nutrients as well as time and wage rate effects on the relative shadow price of health. This is because, dictated by a declining age-health profile (EHRLICH and CHUMA, 1990), the relative shadow price of health capital tends to increase and the market price-health cost ratio tends to decrease with aging. Furthermore, higher wage rates raise the marginal efficiency of health capital. Therefore, for an optimal stock of health capital, the shadow price of health capital has to increase, thus causing a decreasing market price-health cost ratio, *ceteris paribus*. Also, healthy and risky nutrient prices affect the relative shadow price of health $\eta(t)$ through $\varphi_A(t)$ and, hence, the market price-health cost ratio. Additionally, an increase of the risky nutrient prices directly increases the market price health cost ratio $\frac{p_b}{\eta(t)\gamma}$. Therefore, it is assumed here that $\beta_{32} > \beta_{14}$ because β_{32} is supposed to be mainly driven by the direct effect of $ln\, p_b$ on $ln\, \psi_{3i}(t)$, while β_{14} mirrors mainly the indirect effect of $ln\, p_b$ on the relative shadow price of health (see equation (89)), considering the possible effect sizes of income and substitutional or complementary price effects.

Substituting condition (87) considering optimal health investments $\check{I}_i(t)$ as well as the functional approximations (93), …, (96) in the optimality condition (92), the demand function for risky nutrients $b_{\tilde{f},i}$ reads

$$\begin{aligned}\ln b_{\tilde{f},i}(t) = {} & \beta_{04} + \frac{\beta_{37} - \beta_{12} - 1}{1 - \beta_{26}} \ln w_i(t) \\ & + \frac{\beta_{28} + \beta_{36} - \beta_{10}}{1 - \beta_{26}} \sum_{t=t^*}^{T^*} ln\, w_i(t) + \frac{\beta_{29} + \beta_{38} - \beta_{11}}{1 - \beta_{26}} \mathrm{A_i}(0) \\ & - \frac{\beta_{32} - \beta_{14}}{1 - \beta_{26}} ln\, p_b(t) - \frac{\beta_{35} - \beta_{13}}{1 - \beta_{26}} ln\, p_g(t) \\ & + \frac{1 + \beta_2}{1 - \beta_{26}} ln\, H_i\,(t) - \frac{\beta_{30}}{1 - \beta_{26}} \check{E}_i(t) \\ & + \frac{\beta_3 + \beta_{33} + r - \check{\beta}_9 - \rho}{1 - \beta_{26}} t_i \\ & + \frac{1}{1 - \beta_{26}} (\boldsymbol{\beta_4} - \boldsymbol{\beta_{15}} - \boldsymbol{\beta_{27}} - \boldsymbol{\beta_{34}})' \mathbf{X}_{\mathbf{2},i}(t) + \check{u}_{2i}\end{aligned} \tag{97}$$

with $\beta_{04} = \frac{ln\, \beta_1\, \beta_2 - ln\, \beta_{26}\, \beta_{27}}{1 - \beta_{26}}$ and $\check{u}_{2i} = \frac{ln\, \delta_0}{\beta_{26} - 1}$.

Therefore, framed within the context of the dietary health investment model, the empirical demand function for risky nutrients $b_f(t)$ with $f = 1,2, \dots, n$ can be estimated by

$$\begin{aligned}ln\, b_{f,i}(t) = {} & \beta_{04} + \beta_{39}\, ln\, w_i(t) + \beta_{40} \sum_{t=t^*}^{T^*} ln\, w_i(t) + \beta_{41} A_i(0) \\ & + \beta_{42}\, ln\, p_b(t) + \beta_{43}\, ln\, p_g(t) + \beta_{44}\, ln\, H_i\,(t) + \beta_{45} \check{E}_i(t) \\ & + \beta_{46} t_i + \boldsymbol{\beta_{47}}' \mathbf{X}_{\mathbf{2},i}(t) + \check{u}_{2i}.\end{aligned} \tag{98}$$

As with the demand function for healthy nutrients, the coefficients $\beta_{39}, \dots, \boldsymbol{\beta_{47}}$ in equation (98) are functions of the beta-parameters of the derived structural equation (97). According to the assumed parameter specifications, the higher the wage rate, the higher the relative shadow price of health, *ceteris paribus*. With a higher relative shadow price of health, the marginal effect of a wage rate increase on the demand for risky nutrients works through two different channels. The first one draws on health capital efficiency because risky nutrient intakes reduce future productivity. Therefore, given the optimality condition (92), the higher the relative shadow price of health is, the higher the optimal marginal utility of risky nutrients will be, *ceteris paribus*. Implying concavity of preferences, a higher marginal utility of risky nutrients is linked with a lower optimal demand for risky nutrients. The second effect addresses the market price health cost ratio with the term $\left(\frac{p_b}{\eta_i(t)\gamma_f}\right)$, which is reduced by an increased relative shadow price of health. Given optimality, this effect reduces the optimal marginal utility of risky nutrient consumption, *ceteris paribus*. Therefore, assuming concavity of preferences, the demand for risky nutrients will increase. To conclude, if the income effect on $ln\,\psi_{3,i}(t)$ is considerably large with respect to the income effect on the marginal relative costs of health, then $\frac{\partial\, ln\, b_{f,i}(t)}{\partial\, ln\, w_i(t)} \geq 0$. Otherwise, it tends to be negative with $\frac{\partial\, ln\, b_{f,i}(t)}{\partial\, ln\, w_i(t)} < 0$ for a well-informed consumer because risky nutrient consumption reduces future productivity. Therefore, the specific effect of increasing wage rates depends on the relative magnitude of both effects, an interaction that may explain varying empirical findings regarding income effects on the healthiness of diets (see e.g., THIELE et al., 2004; AGUIAR and HURST, 2005; BEATTY and LAFRANCE, 2005). In addition, if the effects of lifetime income and initial financial assets on the cost ratio $(\frac{p_b}{\eta(t)\gamma_f})$ and the shadow price of wealth are stronger than on the shadow price of health (by increasing the demand for health and longevity), then lifetime income and financial assets will have a positive effect on the demand for risky nutrients. This phenomenon has been extensively discussed in the nutrition transition literature on western diets (e.g., POPKIN and NG, 2007).

Furthermore, in line with demand theory, increasing implicit risky nutrient prices negatively influences the demand for risky nutrients. The marginal effect of implicit healthy nutrient prices on the demand for risky nutrients depends on the interplay of income effects and the respective complementary or substitutional cross-price effects. Another interesting result is that the higher the stock of health capital, i.e. the better the health status, the higher the demand for risky nutrients $\left(\frac{1+\beta_2}{1-\beta_{26}}\right)$. Argumentum e contrario, the lower the health status and the sicker the individual, the more the individual tries to avoid consuming risky nutrients. Hence, the more valuable health, the greater the individual's emphasis on healthy nutrient consumption and the lower the individual's risky nutrient consumption. Furthermore, the demand for risky nutrients decreases with higher nutrition knowledge $\left(-\frac{\beta_{30}}{1-\beta_{26}}\right)$. Again, other important explanatory variables of dietary choices are captured by vector $\mathbf{X_2}(t)$. Regarding the subjective discount rate, it is assumed that the higher the individuals' time preference, i.e. the more emphasis placed upon immediate gratification, the more unhealthy diets are consumed, even if nutrition knowledge might be high (see e.g., KOMLOS et al., 2004; LAWLESS et al., 2013; CAVALIERE et al., 2014). For an overview of the discussed comparative statics see Table 19.

Table 19: Comparative statics for the demand of risky nutrients

Explanatory variables	Demand for risky nutrients $\boldsymbol{ln\, b_{\tilde{f},i}(t)}$	
	Magnitude	**Sign**
$ln\, w_i(t)\uparrow$	$\beta_{39}=\frac{\beta_{37}-\beta_{12}-1}{1-\beta_{26}}$	$\frac{\beta_{37}-\beta_{12}-1}{1-\beta_{26}} =: \begin{cases} > 0\ iff\ \beta_{37}-\beta_{12}>1 \\ \leq 0\ iff\ \beta_{37}-\beta_{12}\leq 1 \end{cases}$
$\sum_{t=t^*}^{T^*} ln\, w_i(t)\ \uparrow$	$\beta_{40}=\frac{\beta_{28}+\beta_{36}-\beta_{10}}{1-\beta_{26}}$	$\frac{\beta_{28}+\beta_{36}-\beta_{10}}{1-\beta_{26}} =: \begin{cases} > 0\ iff\ \beta_{28}+\beta_{36}>\beta_{10} \\ \leq 0\ iff\ \beta_{28}+\beta_{36}\leq \beta_{10} \end{cases}$
$A_i(0)\uparrow$	$\beta_{41}=\frac{\beta_{29}+\beta_{38}-\beta_{11}}{1-\beta_{26}}$	$\frac{\beta_{29}+\beta_{38}-\beta_{11}}{1-\beta_{26}} =: \begin{cases} > 0\ iff\ \beta_{29}+\beta_{38}>\beta_{11} \\ \leq 0\ iff\ \beta_{29}+\beta_{38}\leq \beta_{11} \end{cases}$
$ln\, p_g(t)\uparrow$	$\beta_{42}=-\frac{\beta_{35}-\beta_{13}}{1-\beta_{26}}$	$-\frac{\beta_{35}-\beta_{13}}{1-\beta_{26}} =: \begin{cases} > 0\ iff\ \beta_{35}<\beta_{13} \\ \leq 0\ iff\ \beta_{35}\geq \beta_{13} \end{cases}$
$ln\, p_b(t)\uparrow^*$	$\beta_{43}=-\frac{\beta_{32}-\beta_{14}}{1-\beta_{26}}$	$-\frac{\beta_{32}-\beta_{14}}{1-\beta_{26}}<0$
$ln\, H_i(t)\uparrow$	$\beta_{44}=\frac{1+\beta_2}{1-\beta_{26}}$	$\frac{1+\beta_2}{1-\beta_{26}}>0$
$\check{E}_i(t)\uparrow$	$\beta_{45}=-\frac{\beta_{30}}{1-\beta_{26}}$	$-\frac{\beta_{30}}{1-\beta_{26}}<0$
$t_i\uparrow$	$\beta_{46}=\frac{\beta_3+\beta_{33}+r-\check{\beta}_9-\rho}{1-\beta_{26}}$	?
$X_{2,i}(t)\uparrow$	$\beta_{47}=\frac{(\beta_4-\beta_{15}-\beta_{27}-\beta_{34})}{1-\beta_{26}}$	?

Note: Upward arrows ↑ indicate a monotonic increase of the independent variables, while + and – indicate monotonic increasing and decreasing functions, respectively. * This holds for each element of $\mathbf{X_2}$ and the respective elements of $\boldsymbol{\beta_4}$, $\boldsymbol{\beta_{15}}$, $\boldsymbol{\beta_{27}}$ and $\boldsymbol{\beta_{34}}$.

Just as for healthy nutrients, the implications of the structural demand function for risky nutrients reflect general findings of empirical studies. Regarding the marginal effects of wage rates, empirical studies indicate different or not significant effects of increasing wage rates on the demand for risky nutrients, especially for fatty acids in a western context (e.g., THIELE et al., 2004; AGUIAR and HURST, 2005; BEATTY and LAFRANCE, 2005; TIAN and YU, 2013). Conflicting effects of increasing wage rates can be explained by the varying importance between individuals concerning their health capital efficiency and market price to health cost ratio. Approximating nutrition knowledge by educational achievement, the studies of VARIYAM (2003) and ABDULAI and AUBERT (2004) show that total fat, saturated fat, and cholesterol intake decrease with more years of education.

Regarding the implied effect of health on the demand for risky nutrients, KAN and YEN (2003) show that the better the health status of individuals, the more eggs they consume, considering the health risk information of cholesterol and controlling for age and education. ZHAO et al. (2013) find for Chinese consumers that upon being informed of having hypertension, consumers significantly reduce their fat intakes. Approximating nutrition knowledge by educational achievement, VARIYAM (2003) and ABDULAI and AUBERT (2004) show that total fat, saturated fat, and cholesterol intakes decrease with more years of education. For own price effects of fats, TIFFIN and ARNOULT (2010) for the U.K. as well as NICHÈLE (2003) for France report negative own-price elasticities for fats and oils. Furthermore, as the above mentioned theoretical derivations show, cross-price effects depend on the balance of income effects and substitutional or complementary price effects. Along these lines, NICHÈLE (2003) shows positive cross price effects between animal fats and fruits, but negative cross-price effects between animal fats and vegetables or grain products. TIFFIN and ARNOULT (2010) show all cross-price effects to be negative, indicating complementary relationships. Furthermore, empirical studies often find a reduced intake of risky nutrients with increasing age (e.g., GERMAN NUTRITION SOCIETY, 2012). This can be explained by higher nutritional knowledge, less income (pensions), lower health stocks, or generally less physical activities and hence reduced energy expenditures. With the dietary health investment model, it can be separately controlled for these effects in order to show the responsible causal pathways.[105]

5.3.4 Graphical description of the dietary health investment model

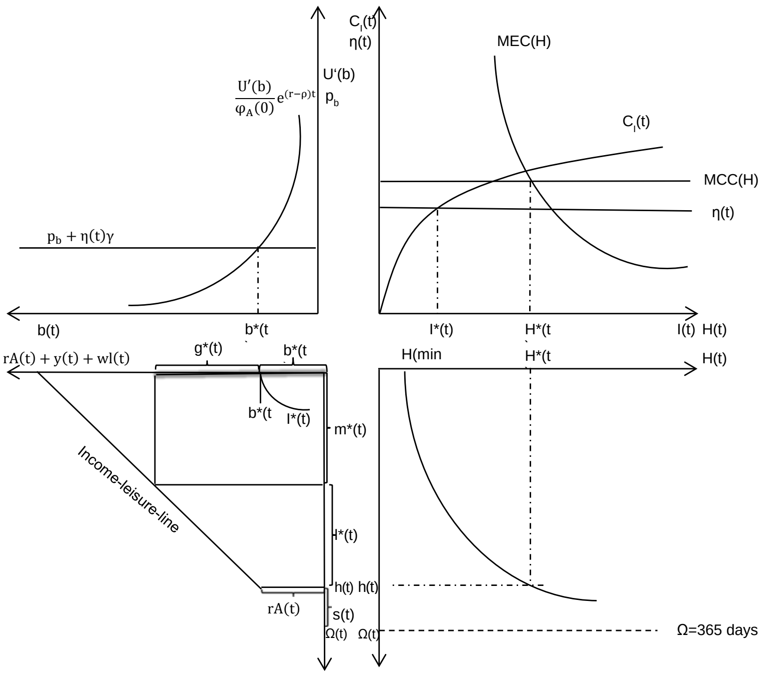
A geometric description of the model's dynamic optimization process is provided in Figure 14 by a four-quadrant approach. With its focus on dietary quality, the figure includes central features of the presented dietary health investment model. Thereby, for graphical clarity, the model assumes here only one healthy nutrient $g(t)$ and one risky nutrient $b(t)$. Nevertheless, the implications of Figure 14 do not change in the case of more than one nutrient each.

Starting with the inter-temporal utility maximization problem presented in quadrant I and II, the individual chooses the system dynamic optimal values of investment in health $\check{I}(t)$ and the consumption of $b(t)$ that maximize the present value of utility. Optimal investment in health $\check{I}^*(t)$ is achieved at the point at which the increasing function of marginal costs of health investments intersects the horizontal curve of the relative shadow price of health capital in t. This is shown in quadrant I, together with the optimal health stock $H^*(t)$. The optimal health stock is determined at the point where the horizontal curve of marginal cost of health capital (MCC) intersects with the curve of the marginal efficiency

[105] Parts of chapter 5.3.2 and 5.3.3 are based on BURGGRAF et al. (2016b).

of health capital (MEC; see Ehrlich and Chuma, 1990). Having $H^*(t)$ and $\check{I}^*(t)$ specified, the focus now turns toward quadrant II, in which the optimal demand for risky nutrients is determined. For this, the decreasing function of marginal utility of consumption of $b(t)$, subjectively discounted and normalized with $\varphi_A(0)$, has to intersect the marginal cost function of the consumption of risky nutrients. These marginal costs of the consumption of risky nutrients comprise the implicit price of the risky nutrient and the corresponding health deterioration by $\gamma(t)$ valued at the relative shadow price of health $\eta(t)$.

Figure 14: Four-quadrant framework



Source: Own presentation.

Note: The quadrants are numbered counter-clockwise starting from the upper-right quadrant. MCC indicates the marginal costs of health capital and MEC indicates the marginal efficiency of health capital. For illustration purposes, it is assumed that $\dot{A}(t) = 0$, $q(t) = 0$. Additionally, for simplicity, it is assumed that $\eta(t)$ and MCC would follow a horizontal line, see, for example, the MCC illustration of Ehrlich and Chuma (1990).

In quadrant III the intra-temporal cost minimization problem is displayed. Given the utility maximizing level of health investments $I^*(t)$, consumers specify the optimal input bundle of good nutrients $g^*(t)$ and time $m^*(t)$ that minimizes short-run costs, subject to the constraints imposed by the according production function and resources. In order to keep Figure 14 as simple as possible, it is assumed that the consumption of non-food products equals zero. Furthermore, wealth cannot be withdrawn to following periods in this illustration. Hence, the y-axis of quadrant III reflects the available amount of healthy time after reducing sick time from total time per period. Likewise, the x-axis of quadrant III reflects the expenditures for nutrient inputs, either healthy or risky nutrients. In this illustration, implicit prices of healthy and risky nutrients are normalized to one. Hence, the displayed quantities directly reflect expenditures. Healthy time available for health investments or labor work is determined by the concave functional relationship between health capital and healthy time, which is illustrated in quadrant IV. The resulting conceivable allocation of time to wage-earning activities is illustrated by the income-leisure line of quadrant III. Non-wage income from interest and other earnings results in a shift of this income-leisure line at the maximum level of healthy time. The income-leisure line displays the standard labor-leisure trade-off (GOODMAN et al., 1999).

In the optimum, the consumer chooses how many hours to work, how much time to invest in health activities, and how much income to spend either on healthy or risky nutrients. Therefore, quadrant III indicates how the optimal amounts of health investments $\check{I}^*(t)$ and risky nutrients $b^*(t)$ are produced. Each efficiently produced combination of $\check{I}(t)$ and $b(t)$ corresponds to a single Edgeworth box; with bad nutrient production in the northeast corner and health investment production in the southwest corner. The box's height indicates the amount of time used for health investment. The box's width indicates the amount of income that is allocated between the expenditures for healthy nutrients and the expenditures for the consumption of bad nutrients. The contract curve of the Edgeworth box, which shows all pareto optimal combinations of time and income for the production of $\check{I}(t)$ and $b(t)$, lies for this problem on the x-axis since the production of bad nutrients is 100 % capital intensive. This contract curve, displayed by the shaded line, entails a point that indicates the optimal combination of healthy nutrients $g^*(t)$ and time $m^*(t)$ to produce the optimal health investment $\check{I}^*(t)$ (see quadrant I) and the optimal amount of the risky nutrient $b^*(t)$ (see quadrant II). This optimal combination is displayed at the point where the production isoquants for $\check{I}^*(t)$ and $b^*(t)$ intersect on the contract curve.

Because of the motion in an individual's health and wealth, for example, by income, health depreciation, or the optimal amounts of health investments and risky nutrients in t, the shadow prices φ_A and φ_H and therefore η will be revalued in $t + dt$. Hence, the optimal stock and flow values have to be recalculated for the time $t + dt$ in order to best proceed to the terminal time T by a systematic interactive procedure.

5.3.5 Empirical application of the dietary health investment model

5.3.5.1 Variable description

To empirically estimate both the demand function for healthy nutrients (91) and the demand for risky nutrients (98), the variables of the theoretical model have to be operationalized in order to appropriately employ information presented in the RLMS-HSE data set. To measure the adequate intake of healthy nutrients, the assortment of vitamins and minerals is manifold. Again, the selection of analyzed nutrients in this panel analysis draws upon actual deficiency problems in Russia: fiber, vitamin A, vitamin B1, vitamin B2, vitamin B12, vitamin C, vitamin E, as well as calcium. For problems of excessive intakes, the intakes of fatty acids and saturated fatty acids are analyzed.[106] Again, intake recommendations are taken from official Russian recommendations provided by TUTELJAN et al. (2008).

The income and health variables of the theoretical model are operationalized according to the discussion presented in chapter 5.2.5.2. This means that the household income variable used in this analysis is the real household income generated by RLMS-HSE, which accounts for both labor and non-labor income. Regarding GROSSMAN's explanatory health stock variable in the sense of overall health status, a single reported health problem cannot appropriately measure the latent variable overall health. Nevertheless, an overall health index could be constructed based on the occurrence of various health problems. The incidence of these health problems can be objectively measured (e.g., by the question "Have you ever been diagnosed with diabetes?"). However, the selection of necessary health problems and the determination of their weights for index construction are rather subjective (GERDTHAM et al., 1999). Furthermore, a dichotomous variable such as being diagnosed with diabetes does not provide a rank concerning how strongly health is affected. Alternatively, a self-reported health status variable provides a categorical measure of overall health and is most often used in empirical studies (see, e.g., GROSSMAN, 2000). Nonetheless, as with the constructed health index, self-reported health is not an objective measure. However, according to GERDTHAM et al. (1999), an objective measure of overall health status does not exist. The authors show in their study that self-reported health should be preferred because it works best in their empirical analysis and is more practicable. Thereby, information on self-reported health is directly provided

[106] See the according discussion in chapter 4.2.3.2 and footnote 28.

by the RLMS-HSE data set. Furthermore, because the RLMS-HSE data set does not provide information on nutrition knowledge $\tilde{E}(t)$, this variable is approximated here by the maximal educational achievement $\breve{E}(t)$, as is commonly done in diet quality studies (see, e.g., ADRIAN and DANIEL, 1976; KANT et al., 2000; VARIYAM 2003). Again, the maximal educational achievement variable is categorized in a way that the lowest value of zero indicates the education of a person without any diploma from a high school, technical trade school, manufacturing trade school, or manufacturing department training program. The highest possible value of five indicates the educational achievement of a person with a diploma either from a graduate school or residency program.

Although the implicit prices of risky as well as healthy nutrients are not directly observable, they can be estimated by hedonic price equations. Here, the approach of MORSE and EASTWOOD (1989) is followed by aggregating nutrients to different nutrient groups. The authors' aggregation procedure reduces correlations among nutrients when estimating implicit prices. Furthermore, attributed to the consumers' weak understanding and memory of implicit nutrient prices, it is more reasonable to assume that consumers untangle food prices to implicit prices of broader nutrient groups rather than single nutrient prices. Consequently, nutrients are aggregated by the following two categories: a healthy nutrient category comprising vitamins and minerals and a risky nutrient category comprising total fatty acids and saturated fatty acids. The estimation procedure of the yearly Russian implicit price indices $p_g(t)$ and $p_b(t)$ for these two categories is based on the food prices of the RLMS-HSE community price data. Such a calculation of implicit nutrient prices considering information of more than one food group is appropriate since the selected vitamins, minerals, and fats are general characteristics of all applied food groups. The results of the hedonic price regressions per survey year are presented in Appendix 3 Table A5, and a full summary table of variables employed in the empirical model is provided in Appendix 3 Table A 6.

5.3.5.2 Estimation procedure and empirical results

The demand functions for healthy nutrients (91) and risky nutrients(98) are estimated with the maximum likelihood estimator using a mixed effects random intercept model. The mixed effects random intercept model is a more elaborate version of the basic random effects model because it also allows the intercept to vary across individuals to account for individual effects and to lead to more efficient estimates (CAMERON and TRIVEDI, 2010). The fixed effects model would allow causality to be inferred because it permits the time-variant regressors to be correlated with the time-invariant component of the error term, while the random effects model is inconsistent in case of this form of endogeneity. Nevertheless, the use of a random effects model is more appropriate for this study due to the following reasons. First, the random effects model allows one to include model-specific but time-invariant regressors such as education level, initial wealth, and permanent income into the estimation model. Coefficients of time-invariant regressors cannot be estimated with the fixed effects model. Second, the random effects model considers both between-variation (across individuals) and within-variation (over time for each individual), while the fixed effects model uses only within-variation. Given low within-variations yet considerably high between-variations of the above described independent variables within the RLMS-HSE data set, within-estimates of a fixed effects estimator would entail a great loss of efficiency. Especially the inefficiency regarding slowly-moving variables such as health leads to highly sample-dependent, unreliable and imprecise point estimates with little explanatory power since the influence of the error on the estimated coefficients becomes larger as the inefficiency of the estimator increases (PLUMPER and TROEGER, 2007; CHRISTEN and GATIGNON, 2009; BREUSCH et al., 2011; CLARK and LINZER, 2014; BELL and JONES, 2015). Third, endogeneity resulting from uncontrolled confounding variables is considered to be reduced by implementing a number of additional socioeconomic, socio-demographic, lifestyle, and regional variables. Furthermore, the estimation of a random intercept model is a possible approach to model unobserved heterogeneity resulting from unconsidered unobservable variables such as attitudes or ability (CAMERON and TRIVEDI, 2005). This is because the random intercept model assumes that the regression intercept varies across individuals.[107]

Based on the above discussion of the theoretical dietary health investment model, it is assumed here that the true estimation model is correctly specified. Normality of residuals has been checked by a visual inspection of the produced kerned density plots compared to an overlaid normal density plot. Thereby, it has to be noted that the estimation procedure is based on a data set with a considerably large number of observations. Considering the problem of unusual and influencing data, all observations with a studentized residual larger than |3| have been individually checked and removed as necessary. Furthermore, correlation coefficients of the explanatory variables as well as the results of the variance inflation factor (VIF) with a mean VIF equal to 2.29 do not indicate severe problems of

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[107] Endogeneity problems regarding dietary intakes and overall contemporaneous health states might arise because nutrient intakes are expected to change subsequent health by health investments or detrimental health effects. Therefore, a fixed effects model has also been estimated. The resulting R^2 of the fixed effects estimates are on average about 0.04 (see also STILLMAN and THOMAS, 2008). Nonetheless, the fixed effects income coefficients show the same patterns of significance and deviate only slightly from the presented random effects results. While some of the healthy nutrient price elasticities become insignificant, the fixed effects (saturated) fat price elasticities tend to be even higher (in absolute terms) than those of the random effects model.

multicollinearity, i.e. the variance of the considered coefficients is not severely inflated by multicollinearity. Additionally, robust standard errors of the random intercept model are estimated to obtain standard errors that are robust to the presence of heteroskedasticity and cluster effects. Robust standard errors are thereby clustered at the individual level. The estimated coefficients of the demand functions for healthy and risky nutrient intakes are presented in Table 20. These results are presented both separately for each nutrient and as aggregated measures for healthy and risky nutrients. The aggregated nutrient intakes are presented as scores that are calculated as equally-weighted means of separate nutrient intakes.

Table 20: Empirical results of the dietary health investment model

Log of relative nutrient intake	Fiber	Vitamin A	Vitamin B1	Vitamin B2	Vitamin B12	Vitamin C	Vitamin E	Cal-cium	Total healthy nut-rients	Risky nutrients: Total fat	Risky nutrients: Satura-ted fat	Total Risky nut-rients
	Healthy nutrients											
Log of real income Y(t)	-0.070***	0.137***	0.011***	0.098***	0.116***	0.154***	-0.004	0.138***	0.051***	0.054***	0.127***	0.073***
	(0.003)	(0.006)	(0.003)	(0.004)	(0.006)	(0.007)	(0.005)	(0.004)	(0.003)	(0.002)	(0.005)	(0.002)
Log of cum. income Σ w(t)	0.001	0.002*	0.001*	-0.000	0.001	0.001	0.001*	0.000	0.000	0.003***	0.004***	0.003***
	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)
Log of initial wealth A(0)	0.04	0.093*	0.036*	0.038*	0.113***	0.036	-0.019	-0.002	0.027*	0.039**	0.131***	0.062***
	(0.012)	(0.025)	(0.011)	(0.019)	(0.029)	(0.023)	(0.019)	(0.021)	(0.011)	(0.009)	(0.019)	(0.010)
Health status H(t)	-0.245***	-0.441***	-0.291***	-0.230***	-0.163***	-0.503***	-0.388***	-0.335***	-0.266***	-0.233***	-0.440***	-0.278***
	(0.022)	(0.041)	(0.018)	(0.028)	(0.043)	(0.045)	(0.036)	(0.029)	(0.019)	(0.014)	(0.029)	(0.016)
Age t	-0.004***	-0.003***	-0.005***	-0.004***	-0.004***	-0.003***	-0.002***	-0.004***	-0.003***	-0.003***	-0.002***	-0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Max. educational level Ě(t)	0.000	0.058***	0.010***	0.024***	0.037***	0.054***	0.003	0.032***	0.019***	0.024***	0.043***	0.030***
	(0.003)	(0.005)	(0.002)	(0.004)	(0.005)	(0.006)	(0.004)	(0.004)	(0.002)	(0.002)	(0.004)	(0.002)
Log price healthy nutrients	-0.491***	-0.193	-0.324***	-0.371***	-0.710***	-0.921***	1.091***	0.046	-0.392***	-0.067*	0.308***	0.003
	(0.057)	(0.108)	(0.050)	(0.073)	(0.119)	(0.123)	(0.095)	(0.075)	(0.054)	(0.031)	(0.078)	(0.037)
Log price risky nutrients	2.586***	0.352	0.365	1.970***	-0.329	0.642	-3.511***	-0.871*	1.377***	-1.728***	-5.846***	-2.973***
	(0.254)	(0.482)	(0.225)	(0.341)	(0.533)	(0.542)	(0.445)	(0.353)	(0.232)	(0.159)	(0.323)	(0.166)
Gender [1 female, 0 male]	-0.235***	-0.213***	-0.243***	-0.245***	-0.233***	-0.217***	-0.207***	-0.251***	-0.228***	-0.068***	-0.054***	-0.060***
	(0.007)	(0.012)	(0.006)	(0.008)	(0.013)	(0.014)	(0.011)	(0.009)	(0.006)	(0.004)	(0.009)	(0.005)
Sports [1 yes, 0 no]	-0.003	0.088***	-0.011	0.001	0.006	0.089***	0.021	0.038***	0.012	0.013**	0.047***	0.024***
	(0.007)	(0.013)	(0.006)	(0.009)	(0.014)	(0.015)	(0.012)	(0.009)	(0.006)	(0.004)	(0.008)	(0.005)
Smokes [1 yes, 0 no]	-0.016*	-0.048***	-0.005	-0.048***	-0.004	-0.049***	0.023*	-0.076***	-0.030***	-0.014**	-0.041***	-0.031***
	(0.006)	(0.012)	(0.006)	(0.008)	(0.013)	(0.014)	(0.011)	(0.009)	(0.006)	(0.004)	(0.008)	(0.005)
Household size	0.012***	-0.018***	0.000	0.018***	0.006	-0.008	0.028***	0.009**	0.001	-0.001	-0.022***	-0.008***
	(0.002)	(0.004)	(0.002)	(0.003)	(0.004)	(0.004)	(0.003)	(0.003)	(0.002)	(0.001)	(0.003)	(0.002)
Share of children	-0.133***	0.085**	-0.059***	0.082***	-0.155***	0.050	-0.299***	0.220***	-0.057***	0.008	0.152***	0.066***
	(0.017)	(0.031)	(0.015)	(0.022)	(0.033)	(0.035)	(0.028)	(0.023)	(0.015)	(0.011)	(0.023)	(0.012)
Settlement type [1 urban, 0 rural]	0.074***	0.346***	0.121***	0.016	0.349***	0.171***	0.233***	-0.085**	0.102***	0.018	0.348***	0.152***
	(0.014)	(0.028)	(0.012)	(0.022)	(0.029)	(0.027)	(0.023)	(0.024)	(0.013)	(0.010)	(0.021)	(0.011)
Farming [1 yes, 0 no]	0.022***	0.181***	0.018***	0.013	-0.040***	0.285***	0.010	0.024***	0.021***	-0.008*	-0.017*	-0.007
	(0.006)	(0.012)	(0.005)	(0.007)	(0.011)	(0.014)	(0.010)	(0.007)	(0.005)	(0.004)	(0.008)	(0.004)

Log of relative nutrient intake	Fiber	Vitamin A	Vitamin B1	Vitamin B2 (Healthy nutrients)	Vitamin B12	Vitamin C	Vitamin E	Calcium	Total healthy nutrients	Total fat (Risky nutrients)	Saturated fat	Total Risky nutrients
Observations	65,803	65,945	65,791	65,684	61,073	65,025	66,062	65,560	66,098	65,824	65,744	66,205
McFadden's Adjusted R^2:	0.17	0.14	0.19	0.14	0.12	0.11	0.11	0.15	0.17	0.33	0.18	0.35
Cox-Snell´s R^2	0.28	0.37	0.27	0.30	0.33	0.33	0.27	0.32	0.25	0.28	0.39	0.35
Cragg-Uhler (Nagelkerke) R^2:	0.33	0.38	0.33	0.33	0.34	0.34	0.29	0.35	0.31	0.44	0.41	0.50

Source: Own calculations, RLMS-HSE, 1996-2005.

Note: Results of the mixed effects random-intercept model are presented without constants and coefficients on regional dummies due to their low informative power. The null hypothesis that all of the estimated coefficients of the explanatory variables in any specification are jointly zero is rejected in all cases. In the estimation procedure, only individuals aged at least 18 years are considered. Cluster robust standard errors are reported in parentheses. It has been tested against a significance level of 5 %. Nevertheless, for comparison reasons, * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$ are presented.

The results in Table 20 suggest that the adequate consumption of vitamins and minerals tends to increase with increasing incomes $Y(t)$. The estimated income elasticity for the demand of healthy nutrients suggests that if income increases by 1 %, the consumption of vitamins and minerals tends to increase by 0.051 %. According to the Grossman model, increasing incomes raise expenditure budgets and increase the value of a healthy lifetime, thereby increasing the demand for health investments. Since the healthiness of fruits and vegetables is a generally well-known fact among Russian consumers (HONKANEN and VOLDNESS, 2006), Russians invest in their health with higher intakes of vitamins and minerals. However, as indicated by the definition of nutrition transition, results show that fiber intakes tend to decrease with increasing incomes. Therefore, the importance of fiber-rich whole grain products as health investments seems to be rather disregarded in nutritional awareness during nutrition transition. Furthermore, in line with the results of TIAN and YU (2013) for Chinese nutrient income elasticities, vitamin E is not significantly affected by income. With respect to initial wealth $A_i(0)$ and cumulated lifetime income $\sum_{t=t^*}^{T^*} ln\, w_i(t)$, the empirical results imply only a small positive association with healthy nutrient intakes in few cases.

Furthermore, the results imply a negative association between the health status $H(t)$ and the consumption of healthy nutrients, because a worsening health status raises the marginal utility of health. Therefore, it is optimal for the individual to increase the amount of health investments through healthy nutrients if health status is decreasing. Moreover, the estimation results imply that higher educational levels tend to raise the demand for health investments and healthy nutrients; again except for fiber and vitamin E. This result can be explained by the fact that the efficiency of health investments is determined by the level of dietary knowledge, which is proxied here by the maximal educational level $\check{E}_i(t)$. Greater nutritional knowledge increases the efficiency of producing health investments by healthy diets and reduces the marginal cost of health investments. Finally, according to the law of demand, the consumption of healthy nutrients tends to increase with decreasing implicit prices for healthy nutrients $p_g(t)$, except for vitamin E.[108]

Several control variables show significant associations with healthy nutrient consumption. For the lifestyle variables, the presented results suggest a significantly negative association between smoking and healthy nutrient intakes and a

[108] Two reasons might possibly explain this finding. First, the content of vitamin E is significantly correlated with fat content (correlation coefficient r=0.61) such that the implicit price of risky nutrients possibly covers the price effect of healthy nutrients. Second, one anonymous reviewer noted that the own-price elasticity of vitamin E might be biased due to informal freshwater fishing, especially by poor households; some fish species contain a considerable amount of vitamin E (LALL and PARAZO, 1995).

significant positive association between doing sports and the intake of the most well-known healthy micronutrients, namely vitamin A, vitamin C, and calcium. Such lifestyle variables can be interpreted as proxies for the ability to anticipate future health outcomes of today's discretionary choices and how future benefits are discounted considering an individual's rate of time preference. The better individuals are able to anticipate future health outcomes and the more they care about their anticipated outcomes by lower rates of time preference, the more they generally engage in sports, avoid smoking, or ensure adequate vitamin and mineral intake (see, e.g., ROSIN, 2008; LAWLESS et al., 2013; CAVALIERE et al., 2014).

Other socioeconomic variables controlled for include age, gender, household size, share of children in the household, settlement type, and the use of a garden to grow fruits and vegetables. Results suggest that the higher the share of children per household, the lower the consumption of fiber (see also, NORDSTRÖM and THUNSTRÖM, 2011) and vitamin E, while the consumption of calcium tends to increase. In line with THIELE et al. (2004), the estimation results of this study also show that men tend to have higher vitamin and mineral intakes than women. Furthermore, the intakes of vitamins and minerals are possibly more deficient with increasing age. Both results can be explained by the fact that women and older people generally eat less, which has a negative effect on the adequate intake of vitamins and minerals (THIELE et al., 2004). Moreover, in contrast to most other national dietary guidelines, Russian nutrient intake recommendations of the analyzed vitamins and minerals do not vary across gender and different age groups. Therefore, the relative vitamin and mineral intakes of women and older people with respect to the Russian recommended intake values tend to be lower than those of young men, who usually have higher overall intakes. However, with a higher daily food intake, not only does the intake of vitamins and nutrients tend to increase, but so does the intake of risky nutrients, which needs to be moderated considering the risk of chronic diseases.

Regarding risky nutrient intakes, Russians' tend to increase their consumption with increasing household incomes, initial wealth and lifetime wage. The income elasticity results imply that if income increases by 1 %, the consumption of unhealthy nutrients increases by 0.073 %, with a particularly higher income elasticity for saturated fat of 0.127. Compared to the lower income elasticity of healthy nutrients, this higher income elasticity of risky nutrients may be explained by the common health-taste trade-off. Russians value today's direct utility of tasty yet risky nutrient consumption more highly than the according indirect positive effect that healthy nutrients have on long-term utility via an increased future healthy time. Moreover, with an increasing implicit price index of risky nutrients $p_b(t)$ the consumption of risky nutrients tends to decrease. Thereby, the risky nutrient own-price elasticity above one (in absolute values) indicates that risky nutrient intakes (especially for saturated fat) are relatively price elastic. By contrast, price elasticity results of healthy nutrients imply that the aggregated healthy nutrient intake is relatively price inelastic. Considering cross-price elasticities, increasing risky nutrient prices tend to increase aggregated healthy nutrient consumption, thus indicating a substitutional association between risky and healthy nutrients. Hence, increasing risky nutrient prices are linked to two positive effects on Russian's dietary quality: reduced risky nutrient intakes and increased intakes of many healthy nutrients.

Furthermore, the empirical results imply that the higher the educational level, the higher the consumption of risky nutrients. This result does not fit the generally positive relationship found in western countries between the level of education and healthier behaviors such as avoiding smoking, drinking or unhealthy diets (CUTLER and LLERAS-MUNEY, 2010). However, such an unexpected positive association between the level of education and the consumption of risky nutrients can be explained by the low nutritional knowledge in Russia (MAZZOCCHI et al., 2014). Although the healthiness of fruits and vegetables is generally well-known by Russians, empirical studies show they have a dramatically low level of dietary knowledge regarding the negative effects of excessive intakes of fatty foods (HONKANEN and VOLDNESS, 2006; DELLAVA et al., 2010).[109] For Russia, as well as other countries of the former Soviet Union, a lack of governmental efforts to provide recent nutritional knowledge on the causes of nutrition-related chronic diseases is observed. Hence, many health professionals in the former Soviet Union countries still seem to recommend diets high in calories and animal protein without providing sufficient counter-education about the negative health effects of saturated fats (BILOUKHA and UTERMOHLEN, 2001; DELLAVA et al., 2010). Therefore, the maximal educational level might not serve as a good indicator of proper nutritional knowledge regarding fat intakes. Combined with the fact that Russians have a traditional preference for meat and dairy items, which are generally high in (saturated) fat contents, this inappropriate nutritional knowledge possibly explains the observed growth of obesity and nutrition-related chronic diseases. The aforementioned low level of nutritional knowledge is further mirrored in the effects of those lifestyle variables that can be interpreted as proxies for the ability to anticipate the future health outcomes of today's discretionary choices. A greater ability to anticipate negative future health outcomes does not work in a society where the risks of (saturated) fat intakes are fairly unnoticed. While the

[109] HONKANEN and VOLDNES (2006) show that between 70-80 % of their interviewed Russian women link a healthy diet with the adequate intake of fish, fruits, and vegetables, but they generally lack sophisticated knowledge about risky nutrients. Only 20 % of them link unhealthy diets with the consumption of fatty foods and fast food, and even less than 20 % of them with a moderate intake of meat products, sweets, and soda.

presented results regarding the consumption of healthy nutrients suggest that Russians actively invest in their health by the well-known association between healthy nutrients and positive health outcomes, Russians possibly disregard the deteriorating health effects of risky nutrients, even if their health is already at a lower level. More importantly, people who experience a worsening in their health status probably eat more dairy and meat products, which are considered important to stay healthy in the Russian climate, and thus tend to have an increasing intake of risky nutrients (BILOUKHA and UTERMOHLEN, 2001). In this context, higher risky nutrient intakes are positively associated with engaging in sport activities and negatively associated with being a smoker. If both measures are considered as time preference proxies, then these results are not in line with the general findings regarding health behavior and obesity in western societies (see e.g., KOMLOS et al., 2004; LAWLESS et al., 2013; CAVALIERE et al., 2014). Furthermore, the estimated associations may be influenced by other unobservable effects. For example, smoking is hypothesized to lower an individual's body weight basis point, which tends to result in lower calorie intake (e.g., KIMOKOTI et al., 2010).

Nonetheless, the estimation results of Table 20 provide only a partial view of the important relationships regarding dietary choices. Since it is beneficial to also describe the diet-health relationship at crucial points in the conditional distributions of the healthy and risky nutrient intakes, estimation results of the quantile regressions at the 25th, 50th, and 75th percentiles are provided in Table 21, Table 22, and Table 23, respectively. These quantile regression models express the quantiles of the conditional nutrient distributions as linear functions of the independent variables. Some of the estimated coefficients differ considerably. Therefore, by employing a simultaneous-quantile regression with the bootstrapping method, the full covariance matrix of coefficients is used to also perform a Wald test on the hypothesis that the coefficients are the same for the estimated quantiles.

Table 21: Demand for healthy and risky nutrients at the 25th percentile

Dependent variable:	Healthy nutrient intakes			Total			Risky nutrient intakes				Total	
Log of relative nutrient intake	Fiber	Vitamin A	Vitamin B1	Vitamin B2	Vitamin B12	Vitamin C	Vitamin E	Calcium	healthy nutrients	Total fat	Saturated fat	Risky nutrients
Log of real income Y(t)	**-0.071*****	**0.191*****	**0.018*****	**0.096*****	**0.187*****	**0.239*****	**0.020*****	**0.178*****	**0.073*****	**0.086*****	**0.185*****	**0.121*****
	(0.003)	**(0.008)**	**(0.003)**	**(0.004)**	**(0.009)**	**(0.007)**	**(0.005)**	**(0.004)**	**(0.002)**	**(0.003)**	**(0.008)**	**(0.003)**
Log of cum. income Σ w(t)	0.001	**0.003*****	0.001*	**0.002****	0.003*	0.001	0.002**	0.001**	0.001	**0.003*****	0.004***	0.003***
	(0.000)	**(0.001)**	(0.000)	**(0.001)**	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	**(0.000)**	(0.001)	(0.000)
Log of initial wealth A(0)	0.013	**0.146*****	**0.057*****	**0.050****	0.153***	0.091***	**-0.023**	**0.021**	**0.037****	0.041***	**0.191*****	0.060***
	(0.014)	**(0.029)**	**(0.008)**	**(0.016)**	(0.028)	(0.026)	**(0.020)**	**(0.028)**	**(0.013)**	(0.009)	**(0.023)**	(0.013)
Health status H(t)	-0.353***	**-0.597*****	-0.363***	-0.336***	-0.182**	**-0.646*****	**-0.516*****	**-0.539*****	-0.356***	**-0.289*****	**-0.498*****	-0.378***
	(0.030)	**(0.034)**	(0.019)	(0.023)	(0.063)	**(0.055)**	**(0.030)**	**(0.028)**	(0.022)	**(0.015)**	**(0.028)**	(0.018)
Age t	-0.005***	**-0.005*****	**-0.006*****	**-0.005*****	-0.004***	**-0.006*****	**-0.003*****	**-0.004*****	-0.004***	**-0.003*****	**-0.003*****	**-0.003*****
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**
Max. educational level Ĕ(t)	0.003	**0.069*****	**0.014*****	**0.035*****	**0.058*****	**0.076*****	**0.014*****	0.045***	**0.026*****	**0.031*****	**0.051*****	**0.040*****
	(0.003)	**(0.005)**	**(0.002)**	**(0.003)**	**(0.005)**	**(0.008)**	**(0.004)**	(0.004)	**(0.003)**	**(0.002)**	**(0.003)**	**(0.003)**
Log price healthy nutrients	**-0.271*****	**0.002**	**-0.202****	**-0.327*****	**-0.732*****	**-0.145**	**0.464*****	**0.408*****	**-0.309*****	**-0.317*****	**0.556*****	**0.006**
	(0.063)	**(0.177)**	**(0.077)**	**(0.076)**	**(0.161)**	**(0.181)**	**(0.095)**	**(0.099)**	**(0.055)**	**(0.040)**	**(0.116)**	**(0.060)**
Log price risky nutrients	**1.871*****	**-0.709**	**-0.862***	**0.912****	**-0.808**	**-0.290**	**-1.355****	**-3.050*****	**0.768****	-1.426***	**-7.747*****	**-3.434*****
	(0.302)	**(0.714)**	**(0.357)**	**(0.309)**	**(0.895)**	**(0.913)**	**(0.460)**	**(0.360)**	**(0.243)**	(0.169)	**(0.564)**	**(0.334)**
Gender [1 female, 0 male]	-0.243***	-0.241***	-0.236***	-0.249***	-0.241***	-0.233***	-0.221***	**-0.241*****	-0.232***	-0.076***	**-0.048*****	**-0.062*****
	(0.006)	(0.012)	(0.006)	(0.007)	(0.015)	(0.014)	(0.009)	**(0.007)**	(0.004)	(0.003)	**(0.007)**	**(0.006)**
Sports [1 yes, 0 no]	**-0.009**	**0.130*****	-0.013	**0.023****	**0.014**	0.090***	**0.040*****	**0.099*****	**0.023*****	0.015**	0.061***	0.036***
	(0.009)	**(0.014)**	(0.009)	**(0.008)**	**(0.013)**	(0.019)	**(0.011)**	**(0.010)**	**(0.005)**	(0.005)	(0.012)	(0.008)
Smokes [1 yes, 0 no]	-0.024***	**-0.074*****	0.000	-0.049***	-0.012	-0.058***	**0.028***	-0.075***	-0.035***	**-0.029*****	-0.037***	-0.034***
	(0.006)	**(0.011)**	(0.006)	(0.007)	(0.012)	(0.013)	**(0.014)**	(0.008)	(0.003)	**(0.005)**	(0.011)	(0.005)
Household size	**0.029*****	-0.021***	**0.009****	**0.015*****	**0.009**	**-0.011***	**0.064*****	**0.005**	0.008***	0.001	-0.030***	**-0.008*****
	(0.002)	(0.004)	**(0.003)**	**(0.004)**	**(0.005)**	**(0.005)**	**(0.004)**	**(0.003)**	(0.002)	(0.002)	(0.003)	**(0.002)**
Share of children	-0.137***	**0.139*****	**-0.102*****	0.103***	**-0.214*****	**0.104****	**-0.396*****	0.242***	**-0.069*****	0.025*	**0.236*****	**0.121*****
	(0.018)	**(0.025)**	**(0.011)**	(0.023)	**(0.035)**	**(0.040)**	**(0.028)**	(0.024)	**(0.014)**	(0.012)	**(0.027)**	**(0.020)**
Settlement type [1 urban, 0 rural]	**0.040****	0.326***	0.105***	**0.152*****	**0.371*****	0.074*	**0.318*****	0.164***	**0.109*****	0.019	**0.442*****	**0.167*****
	(0.014)	(0.030)	(0.010)	**(0.014)**	**(0.032)**	(0.031)	**(0.022)**	(0.026)	**(0.014)**	(0.010)	**(0.028)**	(0.015)
Farming [1 yes, 0 no]	**0.020****	**0.276*****	**0.017*****	**0.024****	-0.038**	**0.321*****	**0.058*****	0.004	**0.036*****	**-0.008***	-0.008	-0.011**
	(0.006)	**(0.009)**	**(0.004)**	**(0.007)**	(0.012)	**(0.014)**	**(0.007)**	(0.009)	**(0.004)**	**(0.003)**	(0.011)	(0.004)
Observations	65803	65945	65791	65684	61073	65025	66062	66044	66098	65824	65744	66205

Source: Own estimations, RLMS-HSE 1996-2005. // Note: Results of the quantile regression model are presented without constants and coefficients on regional dummies due to their low informative power. Robust standard errors according to the Huber-White sandwich against heteroskedasticity are used. Standard errors are given in parentheses. Bold figures indicate that the hypothesis of equality of the estimated coefficients for the three quartiles is rejected at the 5 % level after performing simultaneous-quantile regression with bootstrapped standard errors. It has been tested against a significance level of 5 %. Nevertheless, for comparison reasons, $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$ are presented.

Table 22: Demand for healthy and risky nutrients at the 50th percentile

Dependent variable: Log of relative nutrient intake	Healthy nutrient intakes Fiber	Vitamin A	Vitamin B1	Vitamin B2	Total Vitamin B12	Vitamin C	Risky nutrient intakes Vitamin E	Calcium	healthy nutrients	Total fat	Total Saturated fat	Risky nutrients
Log of real income Y(t)	**-0.078*****	**0.127*****	**0.024*****	**0.101*****	**0.141*****	**0.155*****	**0.010**	**0.169*****	**0.066*****	**0.067*****	**0.121*****	**0.091*****
	(0.003)	**(0.007)**	**(0.003)**	**(0.004)**	**(0.008)**	**(0.006)**	**(0.008)**	**(0.005)**	**(0.002)**	**(0.003)**	**(0.004)**	**(0.002)**
Log of cum. income Σ w(t)	0.000	**0.001**	0.001**	**0.000**	0.001	-0.000	0.001	0.001**	0.000	**0.002*****	0.004***	0.003***
	(0.000)	**(0.001)**	(0.000)	**(0.000)**	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	**(0.000)**	(0.000)	(0.000)
Log of initial wealth A(0)	0.003	**0.055***	**0.045*****	**0.019**	0.139***	0.033	**-0.052***	**-0.016**	**0.005**	0.022***	**0.124*****	0.058***
	(0.008)	**(0.026)**	(0.010)	**(0.014)**	(0.025)	(0.024)	**(0.023)**	**(0.020)**	**(0.009)**	(0.006)	**(0.016)**	(0.008)
Health status H(t)	-0.332***	**-0.492*****	-0.346***	-0.325***	-0.193***	**-0.520*****	**-0.609*****	**-0.452*****	-0.352***	**-0.354*****	**-0.444*****	-0.386***
	(0.022)	**(0.040)**	(0.017)	(0.021)	(0.046)	**(0.052)**	**(0.058)**	**(0.028)**	(0.016)	**(0.015)**	**(0.028)**	(0.014)
Age t	-0.004***	**-0.004*****	**-0.006*****	**-0.004*****	-0.004***	**-0.003*****	**-0.002*****	**-0.004*****	-0.003***	**-0.003*****	**-0.002*****	**-0.002*****
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**
Max. educational level Ě(t)	-0.000	**0.061*****	**0.010*****	**0.025*****	**0.035*****	**0.054*****	**-0.004**	0.039***	**0.021*****	**0.026*****	**0.042*****	**0.032*****
	(0.002)	**(0.005)**	**(0.003)**	**(0.003)**	**(0.005)**	**(0.006)**	**(0.006)**	(0.003)	**(0.002)**	**(0.002)**	**(0.002)**	**(0.002)**
Log price healthy nutrients	**-0.603*****	**-0.569*****	**-0.334*****	**-0.403*****	**-1.057*****	**-1.015*****	**1.975*****	-0.015	**-0.504*****	**-0.019**	**-0.164***	**-0.118***
	(0.055)	**(0.126)**	**(0.067)**	**(0.073)**	**(0.117)**	**(0.137)**	**(0.227)**	**(0.093)**	**(0.045)**	**(0.033)**	**(0.072)**	**(0.051)**
Log price risky nutrients	**3.496*****	**2.883*****	**0.237**	**1.837*****	**1.033**	**2.676*****	**-7.483*****	**-1.157****	**2.194*****	-1.544***	**-3.535*****	**-2.348*****
	(0.228)	**(0.692)**	**(0.214)**	**(0.354)**	**(0.602)**	**(0.486)**	**(1.049)**	**(0.389)**	**(0.249)**	(0.165)	**(0.289)**	**(0.261)**
Gender [1 female, 0 male]	-0.247***	-0.240***	-0.243***	-0.259***	-0.239***	-0.236***	-0.193***	**-0.255*****	-0.242***	-0.074***	**-0.060*****	**-0.071*****
	(0.007)	(0.013)	(0.006)	(0.005)	(0.010)	(0.014)	(0.019)	**(0.008)**	(0.004)	(0.005)	**(0.008)**	**(0.003)**
Sports [1 yes, 0 no]	**-0.005**	**0.081*****	-0.020***	**0.009**	**0.022**	0.062***	**0.020**	**0.063*****	**0.010**	0.009	0.051***	0.027***
	(0.007)	**(0.012)**	(0.006)	**(0.008)**	**(0.015)**	(0.017)	**(0.026)**	**(0.009)**	**(0.006)**	(0.005)	(0.009)	(0.005)
Smokes [1 yes, 0 no]	-0.023***	**-0.048*****	-0.009*	-0.057***	-0.002	-0.065***	**0.076*****	-0.084***	-0.029***	**-0.013***	-0.042***	-0.029***
	(0.005)	**(0.012)**	(0.004)	(0.006)	(0.011)	(0.010)	**(0.022)**	(0.009)	(0.004)	**(0.005)**	(0.009)	(0.004)
Household size	**0.019*****	-0.017***	**-0.000**	**0.017*****	**0.026*****	**-0.016*****	**0.066*****	**0.001**	0.011***	0.002	-0.030***	**-0.015*****
	(0.002)	(0.003)	**(0.002)**	**(0.003)**	**(0.004)**	**(0.004)**	**(0.004)**	**(0.003)**	(0.001)	(0.001)	(0.003)	**(0.001)**
Share of children	-0.147***	**-0.000**	**-0.061*****	**0.097*****	**-0.289*****	**0.023**	**-0.615*****	0.253***	**-0.097*****	0.009	**0.175*****	**0.096*****
	(0.017)	**(0.026)**	**(0.014)**	(0.018)	**(0.029)**	**(0.039)**	**(0.042)**	(0.019)	**(0.010)**	(0.010)	**(0.018)**	**(0.015)**
Settlement type [1 urban, 0 rural]	**0.034****	0.308***	0.095***	0.066***	**0.248*****	0.132***	**0.393*****	-0.007	**0.086*****	0.019*	**0.347*****	**0.169*****
	(0.011)	(0.024)	(0.011)	**(0.013)**	**(0.027)**	(0.025)	**(0.029)**	(0.021)	**(0.011)**	(0.009)	**(0.016)**	**(0.010)**
Farming [1 yes, 0 no]	**0.015****	**0.125*****	**-0.003**	**0.027*****	-0.042***	**-0.005**	**0.002**	0.004	**0.012*****	**-0.020*****	-0.010	-0.010***
	(0.006)	**(0.009)**	**(0.004)**	**(0.006)**	(0.011)	**(0.011)**	**(0.012)**	(0.007)	**(0.003)**	**(0.003)**	(0.007)	(0.003)
Observations	65803	65945	65791	65684	61073	65025	66062	66044	66098	65824	65744	66205

Source: Own estimations, RLMS-HSE 1996-2005. // Note: Results of the quantile regression model are presented without constants and coefficients on regional dummies due to their low informative power. Robust standard errors according to the Huber-White sandwich against heteroskedasticity are used. Standard errors are given in parentheses. Bold figures indicate that the hypothesis of equality of the estimated coefficients for the three quartiles is rejected at the 5 % level after performing simultaneous-quantile regression with bootstrapped standard errors. It has been tested against a significance level of 5 %. Nevertheless, for comparison reasons, $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$ are presented.

Table 23: Demand for healthy and risky nutrients at the 75th percentile

Dependent variable:				**Healthy nutrient intakes**					**Total**	**Risky nutrient intakes**		**Total**
Log of relative nutrient intake	**Fiber**	**Vitamin A**	**Vitamin B1**	**Vitamin B2**	**Vitamin B12**	**Vitamin C**	**Vitamin E**	**Calcium**	**healthy nutrients**	**Total fat**	**Saturated fat**	**Risky nutrients**
Log of real income Y(t)	**-0.085*****	**0.086*****	**0.015*****	**0.111*****	**0.084*****	**0.098*****	**-0.037*****	**0.143*****	**0.053*****	**0.052*****	**0.075*****	**0.063*****
	(0.004)	**(0.009)**	**(0.003)**	**(0.004)**	**(0.007)**	**(0.008)**	**(0.006)**	**(0.004)**	**(0.003)**	**(0.002)**	**(0.003)**	**(0.002)**
Log of cum. income Σ w(t)	0.001	**0.000**	0.001**	**-0.001**	-0.000	0.001	0.001***	0.001	0.000	**0.002*****	0.003***	0.002***
	(0.000)	**(0.001)**	(0.000)	**(0.001)**	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	**(0.000)**	(0.000)	(0.000)
Log of initial wealth A(0)	-0.011	**0.041**	**0.021***	**-0.028**	0.125***	0.023	**-0.019**	**-0.106*****	**-0.021**	0.019***	**0.060****	0.048***
	(0.010)	**(0.025)**	**(0.009)**	**(0.023)**	(0.032)	(0.032)	**(0.021)**	**(0.030)**	**(0.012)**	(0.005)	**(0.020)**	(0.010)
Health status H(t)	-0.334***	**-0.425*****	-0.378***	-0.309***	-0.182***	**-0.470*****	**-0.360*****	**-0.374*****	-0.336***	**-0.372*****	**-0.414*****	-0.400***
	(0.028)	**(0.047)**	(0.023)	(0.034)	(0.050)	**(0.051)**	**(0.029)**	**(0.023)**	(0.025)	**(0.011)**	**(0.016)**	(0.017)
Age t	-0.004***	**-0.003*****	**-0.005*****	**-0.004*****	-0.003***	**-0.002*****	**-0.004*****	**-0.004*****	-0.003***	**-0.003*****	**-0.001*****	**-0.002*****
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**
Max. educational level Ě(t)	-0.004	**0.044*****	**0.009*****	**0.020*****	**0.023*****	**0.030*****	**-0.006**	0.036***	**0.019*****	**0.019*****	**0.032*****	**0.027*****
	(0.003)	**(0.006)**	**(0.002)**	**(0.004)**	**(0.006)**	**(0.004)**	**(0.004)**	(0.005)	**(0.003)**	**(0.002)**	**(0.003)**	**(0.002)**
Log price healthy nutrients	**-0.837*****	**-0.759*****	**-0.494*****	**-0.588*****	**-0.900*****	**-1.663*****	**0.955*****	**-0.363*****	**-0.793*****	**0.187*****	**-0.416*****	**-0.143****
	(0.055)	**(0.213)**	**(0.058)**	**(0.109)**	**(0.144)**	**(0.153)**	**(0.137)**	**(0.087)**	**(0.080)**	**(0.041)**	**(0.077)**	**(0.051)**
Log price risky nutrients	**4.450*****	**4.484*****	**1.189*****	**3.626*****	**1.149**	**5.460*****	**-1.575****	**1.257****	**3.621*****	-1.430***	**-1.107*****	**-1.441*****
	(0.249)	**(0.722)**	**(0.184)**	**(0.451)**	**(0.688)**	**(0.623)**	**(0.559)**	**(0.458)**	**(0.311)**	(0.182)	**(0.326)**	**(0.307)**
Gender [1 female, 0 male]	-0.254***	-0.217***	-0.250***	-0.259***	-0.234***	-0.229***	-0.216***	**-0.269*****	-0.243***	-0.079***	**-0.070*****	**-0.077*****
	(0.006)	(0.012)	(0.005)	(0.009)	(0.012)	(0.014)	(0.010)	**(0.008)**	(0.005)	(0.004)	**(0.006)**	**(0.004)**
Sports [1 yes, 0 no]	**-0.022****	**0.075*****	-0.015*	**-0.020***	**-0.022**	0.062***	**-0.011**	**0.021****	**-0.008**	0.004	0.042***	0.022***
	(0.008)	**(0.015)**	(0.007)	**(0.010)**	**(0.015)**	(0.013)	**(0.012)**	**(0.008)**	**(0.007)**	(0.005)	(0.007)	(0.005)
Smokes [1 yes, 0 no]	-0.026***	**-0.023**	-0.010	-0.048***	0.002	-0.051***	**-0.005**	-0.086***	-0.030***	**-0.003**	-0.037***	-0.022***
	(0.007)	**(0.015)**	(0.006)	(0.008)	(0.011)	(0.010)	**(0.009)**	(0.009)	(0.007)	**(0.004)**	(0.006)	(0.004)
Household size	**0.005****	-0.018***	**-0.008*****	**0.026*****	**0.008**	**-0.022*****	**-0.033*****	**-0.003**	0.007***	-0.000	-0.030***	**-0.017*****
	(0.002)	(0.004)	**(0.002)**	**(0.004)**	**(0.005)**	**(0.004)**	**(0.003)**	**(0.003)**	(0.002)	(0.001)	(0.002)	**(0.002)**
Share of children	-0.150***	**-0.140*****	**-0.058****	0.056*	**-0.260*****	**-0.067****	**-0.127*****	0.247***	**-0.143*****	0.021*	**0.079*****	**0.068*****
	(0.019)	**(0.031)**	**(0.020)**	(0.024)	**(0.040)**	**(0.025)**	**(0.016)**	(0.021)	**(0.015)**	(0.009)	**(0.014)**	**(0.011)**
Settlement type [1 urban, 0 rural]	**0.070*****	0.342***	0.083***	**-0.109*****	**0.218*****	0.115**	**0.108*****	-0.205***	**0.073*****	0.014	**0.292*****	**0.150*****
	(0.011)	(0.030)	(0.010)	**(0.022)**	**(0.032)**	(0.035)	**(0.022)**	(0.026)	**(0.013)**	(0.008)	**(0.020)**	**(0.010)**
Farming [1 yes, 0 no]	**0.004**	**-0.059*****	**-0.006**	**0.012***	-0.019	**-0.095*****	**-0.023*****	0.004	**-0.015***	**-0.016*****	-0.005	-0.015**
	(0.006)	**(0.013)**	**(0.005)**	**(0.006)**	(0.014)	**(0.010)**	**(0.007)**	(0.008)	**(0.006)**	**(0.003)**	(0.006)	(0.004)
Observations	65803	65945	65791	65684	61073	65025	66062	66044	66098	65824	65744	66205

Source: Own estimations, RLMS-HSE 1996-2005. // Note: Results of the quantile regression model are presented without constants and coefficients on regional dummies due to their low informative power. Robust standard errors according to the Huber-White sandwich against heteroskedasticity are used. Standard errors are given in parentheses. Bold figures indicate that the hypothesis of equality of the estimated coefficients for the three quartiles is rejected at the 5 % level after performing simultaneous-quantile regression with bootstrapped standard errors. It has been tested against a significance level of 5 %. Nevertheless, for comparison reasons, $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$ are presented.

As can be seen, the income elasticity of the relative intake of common vitamins and minerals such as calcium and vitamin A, B1, B12, and C tends to be higher at the more problematic 25th percentile of the relative nutrient intake than at the 75th percentile. These results suggest that Russians with unfavorably low intakes of these healthy nutrients would react to increasing incomes with potentially stronger intake growth than Russians who have already more adequate intakes of these healthy nutrients. On the contrary, the negative effect of an income increase on fiber and vitamin E intakes is stronger at the 75th percentile than at the 25th percentile. Furthermore, at the lower quartiles of relative nutrient intakes, the effect of a worsening health status possibly increases the intake of healthy nutrients such as calcium, vitamin A, and vitamin C stronger than at the upper quartile. The same is true for the effect of the educational knowledge on the relative intakes of calcium and vitamins A, B1, B2, B12, and C. Also, the results imply that vitamin intakes at the 25th percentile are more positively correlated with household farming. For calcium, the empirical results do not imply such an association, which is possibly explained by the fact that milk is not produced at a typical Russian datcha. Price elasticities of calcium and most vitamins are lower (in absolute values) at the 25th percentile of relatively healthy nutrient intakes, i.e. decreasing healthy nutrient prices would possibly lead to less effective intake increases of vitamins and minerals at the first consumption quartile rather than at the third consumption quartile. Considering the consumption of risky nutrients, the estimated income elasticities of fat and saturated fat are higher at the 25th percentile than at the 75th percentile, which implies that an increase of income would possibly result in greater increases of the (saturated) fat intakes at the first quartile than at the third quartile. Also, in absolute values the price elasticity of saturated fatty acids is lower at the 75th percentile than at the 25th percentile of the fat intake distributions. This result implies that increasing risky nutrient prices tend to reduce the consumption of saturated fat less effectively at the unhealthier upper intake quartile.

5.3.6 Policy implications

The empirical results of chapter 5.3.5.2 are vital for national intervention programs designed to slow down the pandemic of obesity and nutrition-related chronic diseases (POPKIN, 2007). Generally, there are three possible types of official intervention strategies that aim to improve private food consumption behavior: product-based, market-based, and consumer-based (FRAZAO und ALLSHOUSE, 2003; ROOSEN et al. 2009). Within the product-based strategies, measures such as the state subsidized bio-fortification of staple foods may be an obvious option. This could be supplemented with banning certain products or legally-regulated product standards. Market-based strategies rely on changes in food prices by either implementing higher taxes on food products with a higher density of calorie-intensive risky nutrients (e.g., fat taxes) or subsidizing foods with a higher density of healthy nutrients (e.g., thin subsidies) to discourage the consumption of risky nutrients and promote alternative healthier diets, respectively (e.g., DREWNOWSKI and DARMON, 2005; BROWNELL and FRIEDEN, 2009; POPKIN, 2011). Furthermore, governments could provide incentives for the production of predominantly healthy foods such as fruits and vegetables while removing existing subsidies for the production of predominantly unhealthy foods such as sugar-sweetened beverages (DREWNOWSKI and DARMON, 2005). Consumer-based strategies are based on information campaigns such as the implementation of labeling policies, which aim to raise consumers' awareness of the nutritional value of foods consumed, or public nutritional education programs, which target either the whole population or different population strata such as children at school or people suffering from chronic diseases (ROOSEN et al., 2009).

The success or failure of these intervention strategies has been assessed in various publications (e.g., KIM et al., 2003b; FRAZAO and ALLSHOUSE, 2003; VARIYAM, 2003; SMED et al., 2007). For example, it can be shown that labeling approaches have a significantly positive effect on consumer's dietary quality (KIM et al., 2003b). However, a remarkable heterogeneity of the effectiveness of food labeling on consumption behavior is observed. Consumers with a higher educational level often benefit from nutrition education and labeling approaches more strongly than less-educated individuals (VARIYAM, 2003). Regarding the implementation of higher taxes or subsidies on certain foods, ANDREYEVA et al. (2010) and POWELL and CHALOUPKA (2009) provide evidence suggesting that non-trivial pricing interventions have the potential to improve dietary quality and lower obesity rates. Nevertheless, it is important to note that taxation of certain foods can have unwanted effects on the consumption of other food products by substitution and complementary associations (FRAZAO und ALLSHOUSE, 2003; SMED et al., 2007). Additionally, the implementation of fat taxes alone is often considered as relatively ineffective because wealthier consumers are not very responsive to food prices. Moreover, fat taxes are thought to be regressive because poorer consumers generally spend the largest share of their incomes on food. Therefore, instruments such as fat taxes should be ideally complemented with a thin subsidy in order to encourage fruit and vegetable consumption (TIFFIN and SALOIS, 2014).

Based upon the presented empirical results of the Russian demand for healthy and risky nutrients, Russian policy makers may slow down the accelerating prevalence of nutrition-related chronic diseases by the discussed elements of price regulations. That means Russian policy makers might levy higher taxes on foods with a relatively high density of risky nutrients ("fat tax"), such as fatty meats and snack products, and subsidize foods with a relatively high density of healthy nutrients such as fruits and vegetables. Nevertheless, according to the quantile regression results, adequacy improvements by thin subsidies are probably less effective at the unhealthier lower-healthy-nutrient-intake quartile, while moderation improvements by fat taxes are probably less effective at the unhealthier upper-risky-nutrient-intake quartile. Furthermore, the estimated cross price elasticities of the empirical analysis show that a higher taxation of fatty products would not only improve dietary quality by the reduced consumption of energy-rich fatty foods but also by the increased consumption of foods rich in healthy nutrients, except for calcium and vitamin E. Yet calcium is responsible for countering the development of osteoporosis. Hence, a reduction of the already highly deficient Russians' calcium intakes, mainly due to low cheese intakes, is not desirable. Therefore, if fat taxes are introduced, the complementary association between fat and calcium intakes accentuates the need for subsidies of low-fat but calcium-rich food products, such as low-fat cheese.

Furthermore, households may receive some financial aid in order to increase the consumption of healthier foods and fight micronutrient deficiencies in poorer households. This is because relatively costly vitamin- and mineral-dense foods such as fresh fruits and vegetables are less affordable if household budgets are limited. Moreover, as the empirical results of the Russian demand for healthy and risky nutrients suggest, providing financial aid and hence increasing household budgets is not only linked with an increased intake of most vitamins and minerals, but also with an increased fat intake. Additionally, the estimated income elasticities imply that fiber intakes would further decline with increasing household budgets, as long as no counter education is provided.

Finally, a consumer-based intervention strategy aiming to improve the Russian population's dietary knowledge should utilize officially-promoted intake recommendations, labeling approaches, and/or nutritional education programs. In particular, information regarding health risks of excessive (saturated) fat intakes and the importance of fiber intakes for the human body seems to be essential in order to pave the way for Russians to adopt a behavioral change pattern with lower fat yet higher fiber intakes, as has already been observed in many western countries (POPKIN and DU, 2003). This is fully in line with the recommendations of MAZZOCCHI et al. (2014), who state that the level of nutrition education is poor in Russia, and thus consumer policies targeting increasing nutritional knowledge and awareness are highly relevant in Russia. Since it has been shown that individuals are more strongly influenced by information about risk compared to information about benefits (KAHNEMAN and TVERSKY, 1979; TVERSKY and KAHNEMAN, 2008), health information campaigns should more strongly focus on information about the risks of unhealthy diets rather than their benefits. Furthermore, it has to be considered that the effectiveness of taxes, incentives, and government information policies within the Russian environment depends, *inter alia*, on the country's macroeconomic and political stability as well as its quality of governance considering political accountability and trust in governmental institutions (ZAGHA and NANKANI, 2005).[110]

5.4 CHAPTER CONCLUSIONS

Chapter 5 provides a theoretical framework for modeling the demand for dietary quality and applies this framework to the empirical analysis of Russian dietary quality. This chapter starts with the introduction of GROSSMAN's health investment model and a slight modification of the specification of the health investment production function. Afterwards, the specifications of the demand choices for dietary quality are incorporated into the health investment model in order to derive the dietary health investment model.

Thus, this chapter addresses research question 3.1 of whether GROSSMAN's health investment model is of practical relevance for health economists. In this regard, previous studies have criticized an existing inconsistency between the model's theoretical implications and respective empirical results considering the effect of health on the demand for medical care. To analyze this research question, GROSSMAN's standard model assumptions remain unchanged in this inquiry but the functional specification of the model's inherent health investment production function has been slightly modified by employing a health investment production function with decreasing returns to scale rather than constant returns to scale. To the best of the author's knowledge, this is the first study following this approach. It has been shown that if a health investment production function with decreasing returns to scale is applied, i.e. a more realistic assumption of increasing marginal cost of health investments, the model generates a demand function for medical care that is in line with empirical findings. The analytically derived structural demand function for medical care implies that the demand for medical care increases if the individual's stock of health capital decreases. This implication, amongst others, has been approved by the empirical analysis of the Russian demand for medical care. Hence, GROSSMAN's health investment model is of practical relevance for health economists, provided that the health investment function is properly specified.

Furthermore, in order to apply GROSSMAN's model to the analysis of dietary quality, this chapter addresses research question 3.2, i.e. whether the health investment model is able to guide the selection and effects of the influencing factors of dietary quality. In this regard, the modified health investment model has been enhanced by aspects of the goods characteristics approach in order to integrate two dimensions of dietary quality: the adequate intake of healthy nutrients as well

[110] Parts of chapter 5.3 are based on BURGGRAF et al. (2015b) and BURGGRAF et al. (2016b).

as the moderate intake of risky nutrients. The respective newly developed dietary health investment model meets the dynamic character of health investments. Utility-generating health states are produced by adequate intake levels of healthy nutrients as well as by time invested in health. Furthermore, the model explains the problematic health-taste trade-off by considering the intake of risky nutrients, which increase utility by preferred tastes today but increase the risk of chronic diseases in the future if consumed in excess. Based upon this dietary health investment model and considering additional assumptions and approximations, demand functions for healthy and risky nutrients are derived whose theoretical implications are in line with the general findings of other empirical studies. Therefore, the dietary health investment model contributes to the literature by constituting a comprehensive theoretical framework describing the effects of diet-specific explanatory factors.

Finally, this chapter answers research question 3.3, i.e. how Russian dietary quality is influenced by socio-economic, socio-demographic, and lifestyle factors. Amongst others, the empirical results of the Russian demand for dietary quality imply, on the one hand, that with higher household incomes the intakes of healthy nutrients tend to increase, except for fiber. This development would reduce many micronutrient deficiencies in Russia. On the other hand, higher household incomes tend to lead to an increasing consumption of fats, which generally causes a growing prevalence of nutrition-related chronic diseases. These effects of increasing incomes on vitamin, mineral, fiber, and fat intakes are in line with an ongoing nutrition transition in Russia. The estimated price elasticities underline the fact that lower implicit prices of vitamins and minerals would increase their consumption, especially of vitamin C. Furthermore, the estimated price elasticities of fats indicate that increased prices of fats would possibly reduce their excessive intakes. Yet, unlike what is usually found for diet quality choices in western economies, the presented estimates for the Russian demand for risky nutrients do not show a positive relationship between the level of education as an indicator of dietary knowledge and the avoidance of excessive fat intakes. This result can be explained by the fact that higher education levels in Russia do not necessarily accompany higher nutritional knowledge, especially concerning the importance of a moderate fat intake (DELLAVA et al., 2010).

In summary, this chapter provides new theoretical and empirical aspects on the demand for dietary quality in Russia, which can aid nutrition policy more effectively and efficiently. Nevertheless, the inquiry has some limitations. Besides the fact that the RLMS-HSE data set is a remarkable source of information, unequaled by any other dataset for the Russian Federation in terms of its breadth and depth, the RLMS-HSE provides only limited information on individual nutrient intakes. Furthermore, the use of educational levels as proxies for the respective levels of nutrition knowledge seems to be inappropriate when analyzing the Russian demand for dietary quality. Therefore, future research needs to more deeply account for the effects of nutrition knowledge on the demand for dietary quality in Russia, especially considering Russians' nutrition knowledge regarding fatty acids. Therefore, it is necessary to not only collect more elaborated food intake data but also data on nutritional knowledge in Russia. Moreover, due to the random effects estimation procedure, estimation results and policy recommendations need to be interpreted with care due to potential endogeneity problems. Further research attempting to control for the potential bias of time-invariant fixed effects is clearly required. Furthermore, the assumed specifications of the health investment production function and the functional form of the health impacts of risky nutrients could be improved by even more elaborate and flexible functional forms. Finally, for future research it might be beneficial to enhance the dietary health investment model by the variety and balance dimensions of dietary quality.

6 SUMMARY AND CONCLUSIONS

6.1 SUMMARY

The increasing prevalence of diet-related chronic diseases in Russia accentuates the need for an analysis of the Russian demand for dietary quality. Furthermore, as Russia has been subject to severe political, social, and economic changes during the last two decades, it is interesting to analyze to what extent such changes have modified Russians' demand for dietary quality. More knowledge about the influencing factors of dietary quality, with their respective effect directions and effect sizes, should aid nutrition policy by compiling more effective and more efficient intervention strategies. Therefore, this thesis aims to provide more information on Russians' diet quality patterns during nutrition transition and the effects that socio-economic, socio-demographic, and lifestyle factors have on Russian demand for dietary quality. Furthermore, this thesis aims to contribute to the methodological tools of operationalizing the latent construct dietary quality and to the theoretical framework of analyzing the demand for dietary quality.

To meet these research objectives, the following tasks have been performed within this thesis. Based upon household micro data for the time period 1996-2008 of Phase II of the RLMS-HSE data set, this thesis starts by elaborating whether there have been major changes in Russians' nutrition patterns during economic transition in the sense of a nutrition transition. The term nutrition transition describes the commonly-observed pattern that improvements in per-capita incomes are generally linked with increased and more varied consumption of fruits and vegetables, as well as animal products, fats, and sugar, while at the same time fiber intakes decrease (POPKIN and DU, 2003). Considering this definition of a nutrition transition, it has been investigated for the Russian case whether increasing household incomes are accompanied by a nutrition transition and whether declining household incomes, during periods of economic crisis, lead to a reversed profile of a nutrition transition (see chapter 3).

Furthermore, in order to analyze overall Russian dietary quality, basic theoretical issues of the construction of dietary quality indices are compiled. Afterwards, existing a priori dietary indices are reviewed and discussed in relation to the appropriateness of their construction criteria considering theoretical considerations or recent knowledge about diet-health relationships. According to this discussion, preferable features of dietary indices are elaborated. After the selection of the DQI-I-2003 as the most suitable index construction for transition countries, the DQI-I-2003 has been modified to meet the specifications of Russian nutrition patterns, as well as the restrictions of the RLMS-HSE data set. With this modified DQI-I-2003, overall Russian dietary quality has been analyzed (see chapter 4).

Given the operationalization of the diet quality construct, a comprehensive theoretical model explaining the demand for dietary quality has been developed. Therefore, the analysis starts with the standard Grossman health investment model. The basic assumptions of GROSSMAN's health investment model as well as the model's limitations are outlined. Then, a systematic English-language literature review of theoretical studies on GROSSMAN's health investment model, which discusses these limitations, is provided. To solve the often criticized inconsistency between the model's theoretical implications and empirical results, the specification of the health investment production function was modified while the standard model assumptions remained unchanged. Considering a Cobb-Douglas production function with decreasing returns to scale rather than constant returns to scale, a structural demand function for medical care has been derived in the deterministic and stochastic model setting. Afterwards, the newly derived model implications were tested for the Russian demand for medical care. Then the focus of this thesis is set on health investments by healthy dietary patterns. To accomplish this, the concept of dietary quality is discussed with respect to rational utility-maximizing theoretical models. Based upon this discussion the dynamic dietary health investment model was developed and solved by the maximum principle of optimal control. Given the derived optimality conditions, the structural demand functions for two different aspects of dietary quality have been derived. As the main task of this thesis, the dietary health investment model was empirically employed to analyze Russian dietary quality. Finally, policy implications were drawn in order to provide more effective and efficient intervention strategies (see chapter 5).

Performing these tasks in order to answer the theoretical and empirical research questions of this thesis, the presented results are manifold. Descriptive results regarding Russian food and nutrient consumption during 1996-2008 time period confirm the assumption that Russians' dietary patterns follow the experienced rules of an ongoing nutrition transition in periods of economic growth. This means that with economic growth and higher household incomes, Russians' consumption of fruits and vegetables, as well as meat products and fats have increased. Furthermore, as expected by the definition of nutrition transition, the intake of dietary fiber has decreased with increasing household incomes. These changing dietary patterns lowered several evidenced vitamin and mineral deficiencies but also increased energy intakes per day, raising the incidence of overweight and obesity as well as the risk of nutrition-related chronic diseases (see research question 1.1).

Additionally, the descriptive analysis of Russian nutrition patterns answers the research question of whether declining household incomes during periods of economic crisis lead to a reversed profile of a nutrition transition in Russia. Considering the definition of a nutrition transition, a reversed profile of a nutrition transition can be shown during periods of economic crises such as in the year of the Russian financial crisis in 1998. From 1996 to 1998 the consumption of fruits and vegetables, as well as meat products, fats, and oils, decreased. By contrast, fiber intakes are at their highest levels in 1998. This reversed profile of a nutrition transition is mirrored in the decreasing rates of overweight and obesity prevalence from 1996 to 2000 (see research question 1.2).

For a more detailed analysis of Russian dietary quality, it is important to know how the dietary quality of the Russian population can be most appropriately measured. Therefore, existing a priori dietary indices have been discussed in relation to their construction criteria, i.e. theoretical framework, indicator selection, normalization and valuation methods, as well as aggregation techniques. It has been shown that the observance of the adequacy, moderation, and balance dimensions of dietary quality is valued as being necessary to provide an overall picture of a population's dietary quality. The observance of the variety dimension of dietary quality depends on the considered number of relevant adequacy indicators in the index construction as well as inter-correlation problems of the variety sub-index with other index components. Furthermore, a nested index structure is favored, with indicators based upon nutrients or a combination of nutrients and food groups. In order to increase discriminatory power, metric or a combination of metric and ordinal indicator scales are considered as being beneficial, with their feasibility depending on the nutrition intake data type at hand. Finally, a weighting system has to take into account variations in nutrient intake levels with respect to variations in health outcomes as well as correlations between index components. Based upon these objective criteria, the DQI-I-2003 was selected for the analysis of Russian dietary quality. The DQI-I-2003 comprises a range of most favorable construction criteria. For example, the theoretical framework of the DQI-I-2003 coincides particularly well with an analysis of transition countries such as Russia. Furthermore, the relatively high degree of elaborateness and its nested structure contribute significantly to the informative value of diet quality analysis (see research question 2.1).

After a modification of the DQI-I-2003, taking into account improvements in methodology as well as regional specifics of the Russian diet and restrictions based upon the RLMS-HSE data set, the Russian DQI-I_{mod} was empirically assessed. The calculated scores of the DQI-I_{mod} as well as its sub-scores underline the basic results regarding an ongoing nutrition transition in Russia. Again, it can be shown that with economic growth and with higher household incomes, food variety and the adequate intakes of vitamins and minerals improve while the moderate intakes of (saturated) fats, empty-calorie products, and total energy worsen. Furthermore, as noted by the definition of a nutrition transition, the intakes of dietary fiber decrease with increasing household incomes. Finally, the nested structure of the DQI-I_{mod} highlights in an excellent manner that Russians' of different income groups as well as different economic regions have their distinct problematic areas of dietary quality (see research question 2.2).

After the operationalization of the diet quality construct, this thesis provides new theoretical and empirical aspects on the demand for dietary quality in Russia, which aid nutrition policy more effectively and efficiently. To properly consider the aspect of dynamic health investments, it has been analyzed whether GROSSMAN's health investment model is of practical relevance for health economists by providing a structural demand function for health investments that is in line with empirical findings. It has been shown that if a health investment production function with decreasing returns to scale is applied, the model generates a demand function for health investments by medical care that is in line with empirical findings. The analytically derived empirical demand function for medical care implies that the demand for medical care increases if the individual's stock of health capital decreases. This implication, amongst others, has been approved by the empirical analysis of the Russian demand for medical care. Hence, GROSSMAN's health investment model is of practical relevance for health economists, provided that the health investment function is properly specified (see research question 3.1).

Furthermore, to adjust the relevance of the Grossman model to the demand for dietary quality, the health investment model was enhanced to integrate aspects of the adequate intake of healthy nutrients as well as the moderate intake of risky nutrients. The resulting dietary health investment model meets the dynamic character of health investments. Utility-generating health states are produced by adequate intake levels of healthy nutrients, as well as by time invested in health. Furthermore, the model explains the problematic health-taste trade-off by considering the intake of nutrients that are tasty and hence utility-generating, but increase the risk of chronic diseases in future periods if consumed in excess. The theoretical implications of the derived demand functions for healthy and risky nutrients are in line with the general findings of existing empirical studies. Therefore, the dietary health investment model constitutes a comprehensive theoretical framework describing the effects of diet-specific explanatory factors (see research question 3.2).

Finally, the empirical analysis of the Russian demand for dietary quality provides insights into the influencing effects of various socio-economic, socio-demographic, and lifestyle factors. For example, the estimated income elasticities imply, on the one hand, that with higher household incomes healthy nutrient intakes tend to increase, except for fiber. But on the other hand, the estimated income elasticities imply that higher household incomes tend to increase the consumption of fats, which is associated with a growing prevalence of nutrition-related chronic diseases in Russia. Again, these associations between income increases and the consumption of vitamins, minerals, fiber, and fat are in line with an ongoing nutrition transition in Russia. The estimated price elasticities highlight the fact that lower implicit prices of vitamins and minerals would possibly increase most of their respective intakes, especially of vitamin C. Furthermore, the estimated price elasticities of fats indicate that increased prices of fats would possibly reduce their excessive intakes. Yet, unlike what is usually found for diet quality choices in western economies, the presented estimates for the Russian risky nutrient consumption do not show a positive relationship between the level of education as an indicator of dietary knowledge and the avoidance of risky behaviors such as excessive fat intakes. This result can be explained by the fact that higher education levels in Russia do not necessarily correspond with higher nutritional knowledge (see research question 3.3).

6.2 Research contributions

By answering the research questions of this thesis, the theoretical and empirical contributions to the existing literature are manifold. Beginning with the theoretical contributions, this study first offers a discussion of preferable features of dietary indices and provides an elaborated summarizing toolbox for nutritionists, which helps them to identify those indices whose construction is most appropriate, considering their respective study aim as well as restrictions given by the study target-region and available dietary intake data. Second, the thesis offers a methodological contribution by aligning the DQI-I-2003 to the country-specific needs of Russia and to technical requirements of a statistically sound composite index. Third, this inquiry solves the often criticized inconsistency between the Grossman model's theoretical implications and empirical results, emphasizing its practical relevance. Specifying the model's inherent health investment production function to be of decreasing rather than constant returns to scale, it has been shown that the standard Grossman model generates a reasonable demand function for medical care, which now implies that sick people use more medical care. Fourth, the health investment model has been enhanced to the newly developed dietary health investment model, which (i) incorporates basic aspects of Lancaster's goods characteristics approach, (ii) explains the intertemporal health investment character of vitamin and mineral intakes, (iii) considers the health-taste trade-offs of palatable yet risky nutrients, and (iv) generates a structural demand function for health investments by healthy nutrients that implies sick people demand more health investments. The dietary health investment model constitutes a comprehensive theoretical framework guiding the selection of diet-specific explanatory factors and describing their effects. Hence, with this inquiry, a reasonable theoretical basis for future empirical work on dietary behavior is provided, which aids nutrition policy.

Based upon the aforementioned methodological tools, the following empirical findings have been provided by this thesis. First, given the tremendous changes in economic, political, and social conditions during the last two decades in Russia, as well as the fact that diet-related diseases are of major concern to Russian authorities, a analysis of the Russian nutrition transition is provided. Thereby, this study presents a hitherto missing analysis of the Russian nutrition transition and its reversed patterns, considering the manifold aspects of the term nutrition transition. The provided empirical results on Russian food and nutrient consumption during the 1996-2008 time period confirm the assumption that Russians' dietary patterns follow the experienced rules of an ongoing nutrition transition during periods of economic growth. Thereby, it has to be noted that the observed 1998-2008 time period covers a considerably long period of an ongoing economic and nutritional transition, interrupted by the economic crisis in 1998. Second, based upon the empirical application of the modified DQI-I-2003 to the Russian nutrition transition, a more thorough picture of Russian's overall diet quality is provided by identifying those aspects of dietary quality that are in need of improvements. Third, based upon the empirical application of the modified DQI-I-2003, this thesis contributes to the very limited literature on longitudinal studies regarding diet quality index constructions. Fourth, the theoretically derived implications of the dietary health investment model have been affirmed in an empirical analysis on Russians' demand for dietary quality. Thereby, the empirical analysis provides important insights into the influencing factors of the Russian demand for dietary quality. Finally, based upon the empirical results of the dietary health investment model, implications of more effective and more efficient intervention strategies for healthier diets in Russia are provided.

6.3 Limitations

This thesis presents new theoretical and empirical aspects of the demand for dietary quality in Russia, which can aid nutrition policies. Nevertheless, the theoretical and empirical analyses are subject to several limitations.

Besides the fact that the RLMS-HSE data set is a remarkable source of information, unequaled by any other dataset for the Russian Federation in terms of its breadth and depth, the RLMS-HSE provides only limited information about individual nutrient intakes. A major limitation of the RLMS-HSE data is the changing structure of the panel data, which limits the descriptive analysis of Russian household food and nutrient consumption to the time period 1996-2008 and the panel regression of the individual nutrient intakes to the time period 1996-2005. Furthermore, the provided 24-hour recall data is restricted by the RLMS-HSE officials to the information on total kcal per day as well as fat and protein intakes in energy percentage for only one day per survey wave. However, single 24-hour recalls do not appropriately measure habitual intakes and they suffer from random measurement errors and day-to-day intake variations. Finally, it has been shown that the 24-hour recalls pose the problem of systematic underreporting of energy intakes, which makes it necessary to additionally employ household food consumption data.

Considering the commonly performed approximation of nutritional knowledge by educational achievement, this approximation procedure seems to be inappropriate for the analysis of the Russian demand for dietary quality. Therefore, future research needs to more deeply take into account the effects of dietary knowledge on the demand for dietary quality in Russia. Thereby, it is necessary to not only collect more elaborated food intake data but also data on nutritional knowledge in Russia. Moreover, due to the random effects estimation, the presented estimation results and derived policy recommendations need to be interpretted with care due to potential endogeneity problems. Further research attempting to control for the potential bias of time-invariant fixed effects is clearly required.

In terms of theoretical considerations, the derivation of intersubjective, comprehensible and verifiable valuation functions as well as a weighting system for diet quality index constructions remains unsolved. Furthermore, besides the measurement problem of sugar intakes, future research needs to address, which kind of sugar (free sugar, added sugar, for example, in beverages, disaccharide, or fructose) is most associated with the incidence of chronic diseases, and what the appropriate upper intake levels for sugar intakes might be. Considering the theoretical model, it might be beneficial for future research to enhance the dietary health investment model to further include the variety and balance dimension. Last but not least, nutritionists have to pay more attention to the assumed specification of the health investment production function and other functional specifications assumed in this inquiry, which could be improved by even more elaborated and flexible functional forms. In future research, the production function for health investments as well as the other employed functional approximations might require more flexible and more elaborated specifications to account, for example, for the potential complex interactions between nutrients. This is especially true if the assumption of an infinite divisibility of foods is relaxed and if interactions between nutrient supplies are considered.

In conclusion, the analyzed Russian nutrition transition with its associated growing prevalence of nutrition-related chronic diseases should be of major interest for health economists, nutritionists, and Russian policy-makers.

APPENDIX 1: DEVELOPMENT OF PER CAPITA FOOD CONSUMPTION

Table A 1: Development of average annual per capita food aggregate consumption

	1996	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008
Households with incomes above or equal to yearly median income											
Carbohydrates	240.30	230.61	226.16	231.92	218.12	204.25	200.91	191.87	187.87	179.61	172.50
Milk and dairy	89.69	97.87	90.51	93.58	97.57	96.99	91.09	91.54	91.57	89.40	90.28
Meat	69.87	54.90	53.34	57.11	62.51	63.40	63.35	63.23	67.77	70.79	68.20
Other proteins	28.44	23.76	24.60	26.11	24.98	24.94	25.38	25.31	26.41	26.36	26.95
Fruits	49.25	29.56	51.38	49.30	50.25	56.67	55.76	50.26	52.57	53.50	52.80
Vegetables	77.55	65.42	67.46	68.63	62.84	60.74	58.45	58.27	59.00	52.72	53.30
Fats and oils	16.05	13.48	14.27	14.77	14.55	13.08	12.45	12.59	11.79	12.12	11.51
Other foods	14.45	13.93	17.54	22.75	23.06	25.21	24.39	23.43	27.70	24.54	23.70
Households with incomes below yearly median income											
Carbohydrates	243.44	225.12	248.53	259.23	242.85	234.61	249.96	231.47	223.66	216.68	210.98
Milk and dairy	76.24	70.49	81.79	85.60	86.87	89.16	89.72	90.44	93.53	87.71	92.29
Meat	50.29	39.34	40.02	44.90	53.92	55.93	57.27	57.68	61.13	65.76	68.26
Other proteins	21.57	18.46	22.82	24.36	25.08	26.50	25.77	27.88	27.09	28.42	30.02
Fruits	30.19	14.99	34.23	34.67	37.67	41.41	40.52	40.40	40.99	43.74	43.73
Vegetables	64.03	47.97	63.27	67.98	61.23	63.53	68.23	66.20	63.42	58.38	62.59
Fats and oils	17.25	14.79	19.00	19.67	18.61	17.98	18.21	18.06	16.72	17.78	16.52
Other foods	9.90	9.64	16.98	18.70	18.12	19.48	18.93	19.65	19.56	19.15	18.65

Source: Own calculations, RLMS-HSE 1996-2008.

Note: Average per capita consumption is presented in kg/year.

Table A 2: Development of average annual per capita meat aggregate consumption

Year	1996	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008
Households with incomes above or equal to median incomes											
Beef	20.23	16.76	11.11	10.87	11.57	12.74	11.20	11.06	10.99	13.38	13.22
Pork	26.26	20.65	19.63	19.77	24.91	24.68	23.69	23.63	25.82	28.40	25.12
Poultry	14.21	7.33	9.78	13.35	14.17	13.47	15.88	14.61	18.29	18.36	18.59
Other meat	4.69	4.59	3.55	4.33	4.29	4.84	4.05	3.96	4.46	3.57	6.34
Processed meat	5.88	4.05	4.86	6.17	5.64	6.54	7.44	7.58	7.96	7.74	7.23
Households with incomes below median											
Beef	11.92	15.06	6.93	7.60	9.77	10.33	9.48	9.29	8.40	10.63	9.67
Pork	17.12	16.34	16.09	15.56	21.60	24.11	18.42	20.97	20.21	23.24	24.12
Poultry	12.13	6.58	8.20	12.21	13.57	12.71	16.52	16.80	20.25	20.37	23.38
Other meat	4.67	4.12	3.89	4.84	5.03	5.64	4.89	4.10	4.06	4.56	5.27
Processed meat	4.16	2.96	3.55	4.23	5.78	6.43	7.70	7.41	8.23	8.27	9.28

Source: Own calculations, RLMS-HSE 1996-2008.

Note: Average per capita consumption is presented in kg/year.

APPENDIX 2: SUFFICIENT CONDITION FOR THE MAXIMUM PRINCIPLE

With $\frac{\partial^2\mathcal{H}(\mathrm{t})}{\partial(\mathrm{Z(t)})^2} < 0, \frac{\partial^2\mathcal{H}(\mathrm{t})}{\partial(\mathrm{I(t)})^2} < 0$ and using ARROW's theorem, the necessary conditions of the maximum principle are also sufficient for a global maximum. To check the Arrow sufficiency condition, some definitions are needed. Let the maximized Hamiltonian function be the value of the Hamiltonian when evaluated at the maximizing controls

$$\mathcal{H}^0(t, H, A, \varphi_A, \varphi_H) \\ := F(t, H, A, I^*, Z^*) + \varphi_A f_A(t, H, A, I^*, Z^*) + \varphi_H f_H(t, H, A, I^*, Z^*).$$

If $\mathcal{H}^0(t, H, A, \varphi_A, \varphi_H)$ is a concave function of H and A, then I^*, Z^*, H^*, and A^* will maximize (16) subject to (i) - (vii).[111] If $\frac{\partial C_I{}^*(t)}{\partial I(t)} > 0$ and $\frac{\partial^2 C_I{}^*(t)}{\partial (I(t))^2} > 0$, it follows that the dual cost function of health investments $C_I{}^*(t) = \pi_H I^\alpha$ with $\alpha > 1$ is a monotonic increasing function of health investments. Therefore, with the general function $\frac{\partial C_I{}^*(t)}{\partial I(t)} = \frac{\varphi_H}{\varphi_A}$ one obtains $I(t)^* = \left[\frac{1}{\alpha\,\pi_H}\frac{\varphi_H(t)}{\varphi_A(t)}\right]^{\frac{1}{\alpha-1}}$. Thus, since marginal utilities $\varphi_H(t) \geq 0, \varphi_A(t) \geq 0$, the production parameter $\alpha > 0$, and the cost parameter $\pi_H \geq 0$, it follows that $I(t)^* \geq 0$.

If $\frac{\partial C_Z{}^*(t)}{\partial Z(t)} > 0$ and $\frac{\partial^2 C_Z{}^*(t)}{\partial (Z(t))^2} = 0$, it follows that the cost function of commodities $C_Z{}^*(I) = \pi_Z Z$ is also a monotonic increasing function of commodities Z. From $\frac{\partial U}{\partial Z} e^{-\rho t} - \varphi_A \frac{dC_Z{}^*(t)}{dZ(t)} = 0$ and the assumptions that $U_Z > 0$ and $U_{ZZ} < 0$, an inverse function of $U_Z(t)$ exists of the form $Z(t)^* = U_Z(t)'^{-1}(e^{\rho t}, \varphi_A(t), \pi_Z(t))$.

Hence, the maximized Hamiltonian according to Arrow's Theorem can be written as

$$\mathcal{H}^0 = U\left[U_Z(t)'^{-1}\left(e^{\rho t}, \varphi_A(t), \pi_Z(t)\right), h(t)\right]e^{-\rho t} \\ + \varphi_A \left[rA(t) + y(t) + wh(t) - \pi_H \left(\left[\frac{1}{\alpha\,\pi_H}\frac{\varphi_H(t)}{\varphi_A(t)}\right]^{\frac{1}{\alpha-1}} \right)^{\alpha} \\ - \pi_Z U_Z(t)'^{-1}\left(e^{\rho t}, \varphi_A(t), \pi_Z(t)\right) \right] \\ + \varphi_H \left[\left[\frac{1}{\alpha\,\pi_H}\frac{\varphi_H(t)}{\varphi_A(t)}\right]^{\frac{1}{\alpha-1}} - \delta(t)H(t) \right],$$

[111] Arrow's theorem has been proven on the assumption of a fixed time problem, but is also valid for fixed terminal state problems (CHIANG, 1992).

with $|D| = \begin{bmatrix} \mathcal{H}_{AA}^0 & \mathcal{H}_{AH}^0 \\ \mathcal{H}_{HA}^0 & \mathcal{H}_{HH}^0 \end{bmatrix}$ and $|D^0| = \begin{bmatrix} \mathcal{H}_{HH}^0 & \mathcal{H}_{HA}^0 \\ \mathcal{H}_{AH}^0 & \mathcal{H}_{AA}^0 \end{bmatrix}$, whose principal minors are $|D_1| = 0$, $|D_2| = 0$, $|D^0{}_1| < 0$, $|D^0{}_2| = 0$. If $|D_1|$ and $|D^0{}_1|$ are referred to $|\breve{D}_1|$ and $|D_2|$ and $|D^0{}_2|$ are referred to $|\breve{D}_2|$ then the test for semi-definiteness is as follows: $|\breve{D}_1| \leq 0$ and $|\breve{D}_2| = 0$. In conclusion, the quadratic form is negative semi-definite, meaning that the maximized Hamiltonian $\mathcal{H}$ is concave for every t. For T it is known that $\mathcal{H}(T) = \left[U\big(Z(T), h(T)\big)e^{-\rho T}\right] + \varphi_A(T)\,\dot{A}(T) + \varphi_H(T)\,\dot{H}(T) = 0$. Hence, I^*, Z^*, H^*, and A^* maximize problem (16) subject to (i)-(vii).

Considering the stochastic model setting, the Hamiltonian (47) is maximized with respect to the admissible controls for any t from $[0, T]$ and regarding any trajectory of the introduced stochastic process, i.e. for every t the given trajectories evolve into a deterministic optimization problem with probability 1. Using ARROW's theorem the necessary conditions (48), …., (53) are also sufficient for a global maximum, i.e. the maximized Hamiltonian $\mathcal{H}$ is concave for every t and with probability 1 also within the stochastic model setting. Therefore, $I^*(t)$, $Z^*(t)$, $H^*(t)$, and $A^*(t)$ maximize problem (47) subject to (i) - (vii).

APPENDIX 3: DEMAND ANALYSIS

Table A 3: Data description for the analysis of the demand for medical care

Variable	Observa-tions	Mean	Standard Deviation	Mini-mum	Maxi-mum
Endogenous variable [M]					
Demand for medical care	106,456	1.65	1.24	1	6
Out-of-pocket expenditure	80,191	71.37	356.03	0	22,421.53
Nights in hospital	106,418	0.26	2.80	0	90
Explanatory variables:					
Log price index for medical care [p_M]	106,520	0.06	0.11	-0.01	0.42
Log of real household income, per capita [w]	100,531	7.74	0.89	0.07	13.64
Age in years (≥18) [t]	106,459	45.35	17.75	18.00	102.61
Self-reported health (1 very bad, 5 very good) [H]	106,107	3.11	0.75	1	5
Health problems in last 30 d (0 yes, 1 no) [H]	106,274	0.59	0.49	0	1
Maximal education level (0 lowest, 5 highest) [E]	100,536	2.47	1.24	0	5
Other demographic control variables:					
Gender (1 female, 0 male)	106,342	0.58	0.49	0	1
Household size	106,520	3.31	1.60	0	13
Lifestyle control variables:					
Sport activities (1 yes, 0 no)	106,520	0.10	0.29	0	1
Smoker (1 yes, 0 no)	106,520	0.35	0.48	0	1
Satisfaction with life at present (1 not, 5 fully)	105,852	2.72	1.15	1	5
Power rank (1 not respected, 9 very respected)	103,296	3.38	1.68	1	9
Respect rank (1 without rights, 9 with great power)	101,514	5.96	1.72	1	9
Regional control variables					
Settlement type (1 urban, 0 rural)	106,520	0.74	0.44	0	1
Distance to private doctor (in km)	106,207	294.34	155.56	0	400.00
North and Northwest	106,520	0.06	0.24	0	1
Central Black and Central Black Earth	106,520	0.18	0.38	0	1
Volga-Vaitsky and Volga Basin	106,520	0.18	0.38	0	1
North Caucasian	106,520	0.14	0.34	0	1
Ural	106,520	0.14	0.35	0	1
West Siberian	106,520	0.09	0.29	0	1
East Siberian	106,520	0.09	0.29	0	1

Source: Own calculations, RLMS-HSE 1996-2008.

Note: For practical reasons it is assumed that all ordinal data behave more like interval-level measures.

Table A 4: Empirical results with lagged health

	Estimation models with self-reported health					Estimation models with health problems in last 30 days				
Demand for	**Medical care**	**Out-of-pocket expenditures**		**Nights spent in a hospital**		**Medical care**	**Out-of-pocket expenditures**		**Nights spent in a hospital**	
Panel estimation models	**Ordered probit**	**Heckman two-part[a]**		**Poisson**		**Ordered probit**	**Heckman two-part[a]**		**Poisson**	
With random/fixed effects	**Random**	**Random**	**Fixed**	**Random**	**Fixed**	**Random**	**Random**	**Fixed**	**Random**	**Fixed**
Explanatory variables:										
Log of price index [ln p_M]	-0.319^{***}	2.747^{***}	3.601^{***}			-0.324^{***}	2.813^{***}	4.549^{***}		
	(0.054)	(0.333)	(0.515)			(0.054)	(0.309)	(0.491)		
Log of income [w]	0.034^{***}	0.220^{***}	0.117^{**}	0.328^{***}	0.321^{***}	0.030^{***}	0.220^{***}	0.136^{***}	0.337^{***}	0.331^{***}
	(0.008)	(0.020)	(0.036)	(0.086)	(0.090)	(0.008)	(0.020)	(0.036)	(0.086)	(0.091)
Age [t]	0.001^{**}	0.004^{**}	0.023^{***}	0.038^{**}	0.046^{**}	0.004^{***}	0.004^{**}	0.026^{***}	0.035^{**}	0.041^{*}
	(0.000)	(0.001)	(0.007)	(0.012)	(0.018)	(0.000)	(0.001)	(0.007)	(0.012)	(0.017)
Health [H] (0 very bad, 5 very good)	-0.219^{***}	-0.068^{*}	-0.012	0.026	0.048					
	(0.010)	(0.031)	(0.047)	(0.089)	(0.091)					
Health problems in last 30d [H] (0 yes, 1 no)						-0.232^{***}	-0.110^{**}	-0.186^{***}	-0.020	-0.004
						(0.012)	(0.038)	(0.056)	(0.114)	(0.114)
Education [E] (0 lowest, 5 highest)	0.022^{***}	0.079^{***}	0.048	0.119	0.116	0.018^{**}	0.078^{***}	0.052	0.120	0.116
	(0.006)	(0.011)	(0.032)	(0.088)	(0.094)	(0.006)	(0.010)	(0.032)	(0.088)	(0.095)
Other demographic control variables:										
Gender (1 female, 0 male)	0.210^{***}	0.155^{***}		-0.058		0.222^{***}	0.156^{***}		-0.060	
	(0.016)	(0.038)		(0.377)		(0.016)	(0.037)		(0.368)	
Household size	-0.037^{***}	0.019	0.016	0.043	0.046	-0.038^{***}	0.019	0.003	0.041	0.045
	(0.005)	(0.011)	(0.028)	(0.080)	(0.086)	(0.005)	(0.010)	(0.028)	(0.081)	(0.086)
Lifestyle control variables:										
Sports activities (1 yes, 0 no)	0.167^{***}	-0.043	-0.039	-0.550^{*}	-0.514	0.152^{***}	-0.049	-0.001	-0.571^{*}	-0.537^{*}
	(0.019)	(0.046)	(0.078)	(0.259)	(0.267)	(0.019)	(0.045)	(0.076)	(0.258)	(0.266)
Smoker (1 yes, 0 no)	-0.054^{***}	0.012	-0.164	-0.869^{***}	-0.941^{***}	-0.048^{**}	0.008	-0.208	-0.845^{***}	-0.916^{***}
	(0.016)	(0.037)	(0.112)	(0.246)	(0.255)	(0.016)	(0.038)	(0.113)	(0.246)	(0.255)
Satisfaction with life? (1 not, 5 fully)	-0.032^{***}	-0.023	-0.036	-0.215^{***}	-0.220^{***}	-0.038^{***}	-0.026^{*}	-0.047^{*}	-0.220^{***}	-0.226^{***}
	(0.006)	(0.013)	(0.020)	(0.062)	(0.062)	(0.006)	(0.013)	(0.019)	(0.062)	(0.063)
Power rank (1 lowest, 9 highest)	-0.007	-0.005	-0.001	0.032	0.032	-0.009^{*}	-0.006	-0.001	0.024	0.025
	(0.004)	(0.008)	(0.013)	(0.039)	(0.040)	(0.004)	(0.008)	(0.013)	(0.039)	(0.040)
Respect rank (1 lowest, 9 highest)	0.009^{**}	0.010	0.004	-0.058	-0.056	0.008^{*}	0.010	0.006	-0.067	-0.065
	(0.004)	(0.007)	(0.011)	(0.036)	(0.036)	(0.004)	(0.007)	(0.011)	(0.037)	(0.037)
Regional control variables:										
Settlement type (0 rural, 1 urban)	0.039	0.084	1.453^{**}	0.477	1.810^{**}	0.029	0.080	1.456^{**}	0.495	1.805^{**}
	(0.024)	(0.045)	(0.522)	(0.315)	(0.653)	(0.024)	(0.045)	(0.530)	(0.310)	(0.656)

	Estimation models with self-reported health					Estimation models with health problems in last 30 days				
Demand for	**Medical care**	**Out-of-pocket expenditures**		**Nights spent in a hospital**		**Medical care**	**Out-of-pocket expenditures**		**Nights spent in a hospital**	
Panel estimation models	**Ordered probit**	**Heckman two-part[a]**		**Poisson**		**Ordered probit**	**Heckman two-part[a]**		**Poisson**	
With random/fixed effects	**Random**	**Random**	**Fixed**	**Random**	**Fixed**	**Random**	**Random**	**Fixed**	**Random**	**Fixed**
Distance to doctor (in km)	0.000*	-0.000*	-0.001	0.001	0.001	0.000**	-0.000*	-0.001	0.001	0.001
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Observations	70,656	57,294	57,294	70,637	4,959	70,753	57,294	57,294	70,733	4,982
		(9,483)	(9,483)				(9,483)	(9,483)		
R^2 (o overall, w within)		0.055(o)	0.054(w)				0.055 (o)	0.057 (w)		
McFadden's Adjusted R2:	0.348			0.482	0.603	0.347			0.477	0.598

Source: RLMS-HSE for the time period 1996-2008 with individuals aged 18 years or older.

Note: Estimates of the constants as well as the coefficients of the Russian economic regions are mostly significant but not presented here due to low explanatory power. Robust standard errors are in parentheses. It has been tested against a significance level of 5 %. Nevertheless, for comparison reasons, * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$ are provided.

Table A 5: Results of the hedonic price function

Log of food prices	1996	1998	2000	2001	2002	2003	2004	2005
Healthy nutrients	0.847***	1.033***	1.026***	0.998***	0.986***	0.939***	0.964***	0.972***
	(0.078)	(0.080)	(0.082)	(0.083)	(0.081)	(0.080)	(0.083)	(0.081)
Risky nutrients	0.293***	0.322***	0.311***	0.320***	0.312***	0.299***	0.293***	0.292***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)
Sweets[a]	0.842***	0.923***	0.920***	0.925***	0.913***	0.938***	0.922***	0.910***
	(0.020)	(0.019)	(0.020)	(0.021)	(0.021)	(0.020)	(0.021)	(0.022)
Meat products[a]	0.819***	0.903***	0.955***	0.984***	0.973***	0.998***	0.990***	1.014***
	(0.014)	(0.015)	(0.015)	(0.016)	(0.016)	(0.015)	(0.016)	(0.016)
Dairy products[a]	-0.021	-0.077**	-0.024	0.014	0.011	0.046	0.045	0.071**
	(0.022)	(0.023)	(0.024)	(0.024)	(0.024)	(0.024)	(0.026)	(0.025)
Premium products[a]	0.771***	0.746***	0.791***	0.788***	0.815***	0.872***	0.819***	0.864***
	(0.015)	(0.021)	(0.017)	(0.017)	(0.019)	(0.021)	(0.018)	(0.021)
Northern and Northwest	-0.062	-0.045	-0.055	-0.085*	-0.121**	-0.068	-0.114**	-0.215***
	(0.037)	(0.040)	(0.041)	(0.041)	(0.038)	(0.039)	(0.041)	(0.041)
Central and Central Black-Earth	-0.131***	-0.099**	-0.100**	-0.134***	-0.174***	-0.166***	-0.192***	-0.295***
	(0.032)	(0.034)	(0.035)	(0.035)	(0.032)	(0.032)	(0.035)	(0.035)
Volga-Vaytski and Volga Basin	-0.210***	-0.179***	-0.179***	-0.209***	-0.269***	-0.230***	-0.276***	-0.374***
	(0.034)	(0.036)	(0.037)	(0.037)	(0.034)	(0.034)	(0.036)	(0.037)
North Caucasus	-0.232***	-0.205***	-0.160***	-0.230***	-0.276***	-0.223***	-0.301***	-0.399***
	(0.036)	(0.038)	(0.038)	(0.038)	(0.038)	(0.035)	(0.038)	(0.039)
Ural	-0.162***	-0.163***	-0.160***	-0.200***	-0.239***	-0.238***	-0.275***	-0.377***
	(0.037)	(0.040)	(0.040)	(0.040)	(0.038)	(0.038)	(0.040)	(0.041)
West Siberia	-0.137***	-0.117**	-0.119**	-0.183***	-0.218***	-0.251***	-0.289***	-0.365***
	(0.038)	(0.041)	(0.041)	(0.044)	(0.039)	(0.040)	(0.041)	(0.041)
East Siberia	-0.082*	-0.070	-0.071	-0.147***	-0.201***	-0.160***	-0.186***	-0.269***
	(0.037)	(0.040)	(0.040)	(0.041)	(0.039)	(0.038)	(0.040)	(0.041)
Constant	1.299***	1.148***	1.135***	1.140***	1.166***	1.140***	1.176***	1.256***
	(0.031)	(0.033)	(0.034)	(0.033)	(0.030)	(0.030)	(0.033)	(0.033)
Observations	8,476	8,320	8,216	8,112	7,800	8,164	8,164	8,216
Adjusted R^2	0.430	0.419	0.422	0.431	0.422	0.425	0.424	0.426

Source: Own estimations, RLMS-HSE 1996-2008.

Note: [a] These variables are binary variables taking the value 1 if the product belongs to the product category and 0 otherwise. Standard errors are presented in parentheses. It has been tested against a significance level of 5 %. Nevertheless, for comparison reasons, * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$ are provided.

Table A 6: Data description for the analysis of the demand for dietary quality

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Socioeconomic and health variables					
Log of real income	68,013.00	7.54	0.90	0.07	13.64
Log of cum. income	71,436.00	13.15	7.10	-16.54	18.89
Log of initial wealth	71,233.00	12.47	0.63	8.64	13.52
Health status (normalized on scale 0,…,1)	71,908.00	0.74	0.14	0.10	1.00
Individual characteristics					
Age	72,114.00	45.42	17.71	18.00	102.61
Maximal education level (0 lowest, 5 highest)	71,999.00	2.31	1.32	0.00	5.00
Gender (1 female, 0 male)	72,141.00	0.58	0.49	0.00	1.00
Sports (1 yes, 0 no)	72,191.00	0.12	0.32	0.00	1.00
Smokes (1 yes, 0 no)	72,191.00	0.34	0.47	0.00	1.00
Household characteristics					
Log of household size	72,191.00	3.31	1.59	0.00	13.00
Share of children in household	72,182.00	0.13	0.17	0.00	0.75
Settlement type (1 urban, 0 rural)	72,186.00	0.74	0.44	0.00	1.00
Farming (1 yes, 0 no)	72,115.00	0.63	0.48	0.00	1.00
Implicit prices					
Log price healthy nutrients	72,191.00	0.97	0.05	0.85	1.03
Log price risky nutrients	72,191.00	0.31	0.01	0.29	0.32
Regional dummies					
Metropolitan areas: Moscow and # St. Petersburg	71,878.00	0.12	0.32	0.00	1.00
Northern and North Western area	71,878.00	0.06	0.24	0.00	1.00
Central and Central Black-Earth	71,878.00	0.18	0.38	0.00	1.00
Volga-Vaytski and Volga Basin	71,878.00	0.18	0.38	0.00	1.00
North Caucasus	71,878.00	0.13	0.34	0.00	1.00
Ural	71,878.00	0.14	0.35	0.00	1.00
West Siberia	71,878.00	0.09	0.29	0.00	1.00
East Siberia and Far East	71,878.00	0.10	0.29	0.00	1.00

Source: Own calculations, RLMS-HSE 1996-2005.

Note: For practical reasons it is assumed that all ordinal data behave more like interval-level measures.

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