The Obesity Epidemic in Turkey: A System Dynamics and Behavioral Economics Approach in the context of an Obesogenic System

by

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Abstract

Obesity is an increasing problem across the world, and it has risen dramatically in the last decades. It is a major risk factor for noncommunicable diseases which are the world's leading cause of death. In Turkey, the obesity epidemic is becoming a growing concern. Policies against obesity have had minimal success thus far. Given this issue, the aim of this study is to analyze the underlying structure of the obesity problem from a system's perspective since the obesogenic system is a complex adaptive system. Therefore, this study uncovers the dynamic interactions within this system and resulting behavior patterns by developing a system dynamics simulation model. Furthermore, behavioral economics and reinforcement pathology frameworks are integrated into the model to provide policymakers with more robust insights.

This thesis employs a system dynamics methodology to analyze aggregated level interactions between system components to understand complex systems. Combining system dynamics with behavioral economics and reinforcement pathology frameworks provides a guide to this complex adaptive system to understand how the obesogenic environment shapes individual decision-making. A theoretical model developed to show how reinforcement pathology occurs within the obesogenic environment, as well as the feedback loop analysis to identify important feedbacks within the system. Thereafter, the theoretical model quantified into a system dynamics simulation model that generates the behavior pattern and trend from endogenous interactions for further analysis of the system.

According to the findings, the obesogenic environment is a complex adaptive system where ingestive behavior is shaped by the environment as well as the environment is influenced by the ingestive behavior. It was found that this system is dominated by many uncontrolled powerful reinforcing feedback loops at various levels interacting with each other. In addition, the study found that reinforcement pathology framework integrated to system dynamics methodology shows how environmental factors are making food consumption more valuable, more reinforcing within this adaptive system, hence affecting individual behavior. Additionally, the study also identified several leverage points to intervene obesogenic system namely intervening reinforcement pathology feedback loop by creating substitutes for food, the weak balancing feedback loop that fails to balance the relative reinforcing value of food and lack of rules within the system especially mechanisms that reward individuals with healthier lifestyle.

In conclusion, the study showed that without a clear understanding feedback mechanisms working within an obesogenic environment and interventions that aim to address those feedback processes may result in less effective policies. This research sheds some light into understanding the obesity problem as a complex adaptive system and how the system can be leveraged to help reduce obesity rates.

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1. Introduction

1.1. Problem Background

Obesity is an increasing problem across the world, and it has risen dramatically especially in the last decades. In the United States, obesity prevalence increased more than 10% and became almost 43%. More recently, about half of the population in the US is obese (Hales, 2020) while it was only 13% between 1960 and 1962 (*National Center for Health Statistics - Health, United States*, 2006). In the United Kingdom, it has estimated that by 2050, over half of the adult population could be obese (Butland et al., 2007).

Simply defined, the obesity is excess bodyweight, especially fat tissue, caused by an imbalance between caloric intake and caloric burn (Haslam & James, 2005). And it is not an acute condition, it takes time for a person to gain body weight and lose it (Apovian, 2010; Rippe et al., 1998). Furthermore, its etiology includes multilevel factors such as genetics, material environment, psychology, metabolism, lifestyle, and social environment (Coulston, 1998; Eisenberg & Burgess, 2015).

Initially, it was assumed that it was an issue only developed countries faced. However, with recent technological breakthroughs , it is no longer a problem of developed countries (Bleich et al., 2008). According to the United Nations' World Health Organization (WHO), worldwide obesity has nearly tripled since 1975 and in 2016, more than 21% of the world population was overweight (*World Health Statistics*, 2021). Obesity appears to be a global epidemic, posing several challenges for governments and citizens alike.

Turkey is not an exception to this epidemic trend in the world. It is also a growing concern in Turkey. According to studies carried out by the Ministry of Health and the Statistical Institute of Turkey (TurkStat), and researches by the scholars, nearly every 1 in 2 people in Turkey is obese (either obese or pre-obese) and the numbers are rising (Erem, 2015; Erem et al., 2004; İşeri & Arslan, 2008; Santas & Santas, 2018; *Turkey Health Research (Türkiye Sağlık Araştırması)*, 2019; Yumuk, 2005).

Despite the efforts by health authorities to slow down the increase of obesity rates via several awareness raising campaigns, the number of overweight and obese people in Turkey continues to rise. Below graph on Figure 1 shows the data from eleven different studies conducted in Turkey between 1990-2010 (Erem, 2015). The sample size of these studies is relatively limited, and the initial age of sample size varies between 18 to 30. They do, however, reveal an increase in obesity over the years.

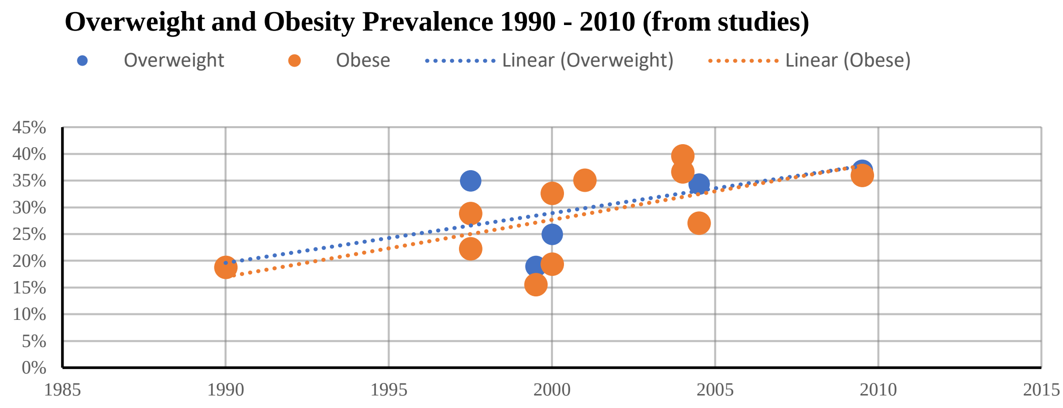

Figure 1 – Overweight and Obesity Prevalence in Turkey 1990-2010 (from different studies)

In 2008, the Ministry of Health and TurkStat began to conduct studies to measure overweight and obesity prevalence with two to three years intervals with larger sample size with the initial age of 15. On Figure 2, the data points show the overweight and obesity prevalence in Turkey (Turkey Diet and Health Research 2010, 2014; Turkey Diet and Health Research 2019, 2019). Unfortunately, there is no single longitudinal data regarding obesity exists in Turkey. However, the figures reveal that the prevalence of obesity is rising.

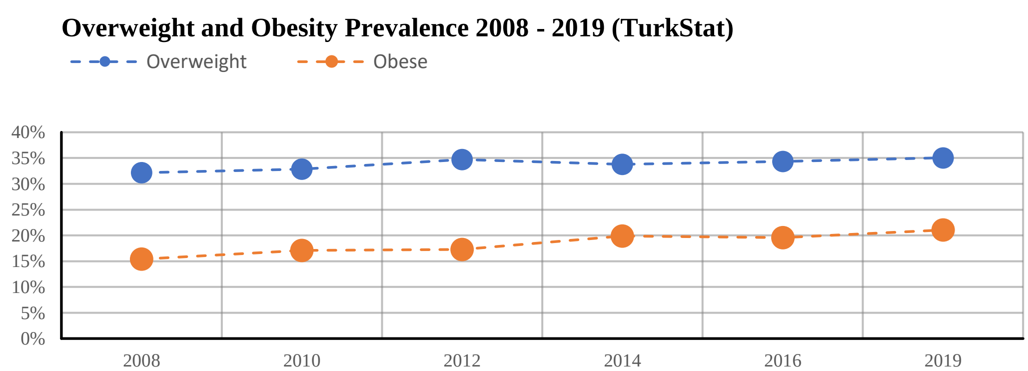

Figure 2 - TurkStat Overweight and Obesity Prevalence

In addition, there is model data from NCD Risk Factor Collaboration (NCD-RisC) based on obesity studies (Abarca-Gómez, 2017; Rodriguez-Martinez, 2020). On the Figure 3, shows the obesity prevalence data collected from the modeled data. It shows the overweight and obesity prevalence trend between 1975 – 2016.

According to an OECD report, Turkey is the third country in the world with the highest obesity rates with 32.1% obesity and 34.7% pre-obesity prevalence (*The Heavy Burden of Obesity: The Economics of Prevention*, 2019).

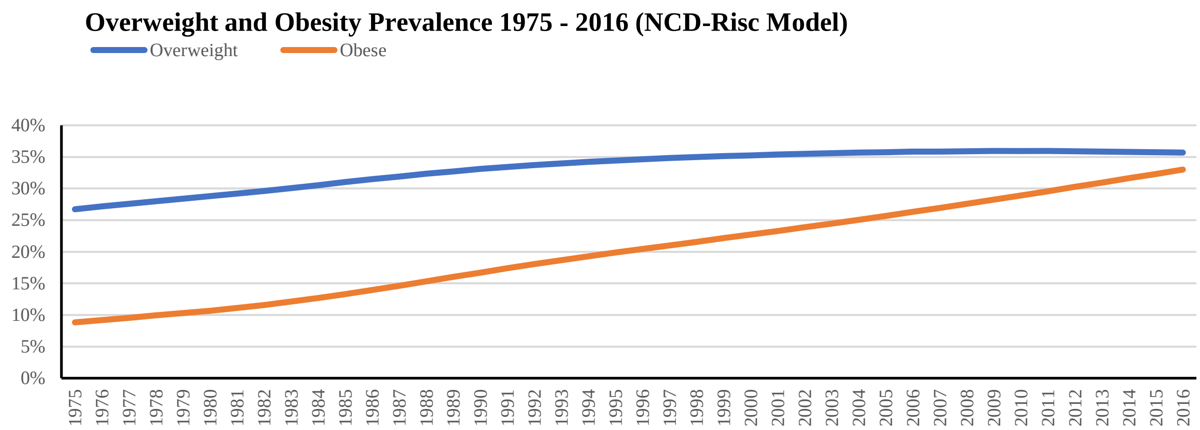

Figure 3 - Obesity Prevalence in Turkey, NCD-RisC Model

Obesity is associated with the leading cause of death in worldwide via causing serious chronic diseases such as diabetes, osteoarthritis, cardiovascular diseases, and some type of cancers. It is one of the key risk factors in terms of noncommunicable diseases as the world's leading cause of death (Abdelaal et al., 2017; *World Health Statistics*, 2021). It is estimated that almost 90% of the deaths in Turkey is caused by noncommunicable diseases (dietary habits related chronic diseases) (*Turkey Diet and Health Research 2019*, 2019).

In addition to the health risks of obesity, obesity also comes with economic burden. OECD expects that Turkey will have to spent at least 12% of its healthcare budget to treatment of obesity and associated diseases (*The Heavy Burden of Obesity: The Economics of Prevention*, 2019). Also, obesity causes not just excess healthcare expenditures, but also leads to loss of productivity through poorer productivity at work, missed workdays, permanent incapacity and other factors (Borak, 2011).

1.2. Problem Formulation

Following the drastic changes in obesity prevalence globally, it started to attract more attention to obesity research in Turkey during the early 2000s. With the year 2010, obesity prevalence became more prominent (*Turkey Diet and Health Research 2010*, 2014). In 2012, obesity became one of the top health priorities of Turkish authorities (*Strategic Plan 2013 - 2017*, 2012). Based on these policy documents, the government-initiated campaigns to reduce the obesity prevalence through a series of possible policy interventions. However, only several awareness campaigns took place. In addition, according to one of the WHO's report for NCDs, there is no ongoing policy intervention against obesity except awareness raising for physical activity (Kontsevaya, 2018). Given the fact that the obesity prevalence is still rising, it is reasonable to conclude that current interventions are ineffective.

Some policies which are planned to be implemented are mentioned in the policy documents: *(1) promoting physical activity in all age groups through healthcare workers, advertisements on TV and websites, (2) increasing the number obesity treatment facilities.* In addition, more policies are also being discussed in the official strategic document of the Ministry of Health such as *(1) additional taxes or import limitations on unhealthy foods (2) providing incentives and supports to minimize the effects of inflation (3) increase incentives on production of fresh products to decrease their prices (4) promoting healthy food consumption (5) promoting reduction of meal portions*

These policy alternatives that are planned to be implemented are common and well-known obesity prevention and reduction policies since they are similar and/or same with the policies which are being implemented or have been implemented in other countries. There are many studies states that current strategies against obesity have only limited or no effects on reducing and/or preventing the obesity (Chan & Woo, 2010; Cory et al., 2021; Jebb et al., 2013; Theis, 2021; Tseng et al., 2018).

Some problems with these strategies have been highlighted in the literature. One of them is their reliance on individuals to change their behavior rather than changing the environment that shapes the behavior (Novak & Brownell, 2012; Swinburn et al., 2011; Theis, 2021). Another one is related to the previous one and it is the lack of holistic view of the problem (Finegood, 2012; Gortmaker et al., 2011; Lee et al., 2017).

Applications of systems thinking and system science approaches seems to be delivering limited but promising results in several intervention programs such as *Be Active Eat Well (BAEW)* and *Romp and Chomp* in Australia, *Change 4 Life* in the UK, *"Shape up Somerville", the Central California Regional Obesity Prevention Program (CCROPP)* in the USA (Allender et al., 2019; Bagnall et al., 2019; Coffield et al., 2015; de Silva-Sanigorski et al., 2010; Johnson et al., 2012; Pronk & Boucher, 1999).

As a part of system science method, system dynamics (SD), is a useful method to analyze aggerate level interactions between system components to understand a complex system such as obesogenic system where obesity problem arises (Frood et al., 2013; Homer et al., 2006; Madahian et al., 2012; Meisel et al., 2018; Meisel et al., 2016).

Most of system dynamics research has focused on the environmental factors leading to overweight and obesity. Evidently, it is expected those studies do not emphasize too much on individual behaviors. However, it seems that how these environmental factors influence people's behavior and shape behavior patterns is important in determining the leverage points for policy interventions (Chan & Woo, 2010). To that end, SD is a useful method to understand a complex system with top-down approach, however, it provides limited insights from individual level (Hammond, 2009).

In that regard, agent-based method provides strong individual level insights since it is a kind of microscale approach (Gustafsson & Sternad, 2010). It is a powerful methodology to analyze interactions between autonomous agents whether they are individuals or organizations. This approach offers unique insights at the micro level (Auchincloss et al., 2011; Chen et al., 2017; Zhang et al., 2014). Disaggregation about individual level dynamics from agent-based provides complementary insights for SD because obesity epidemic occurs as a result of complex adaptive system where multi scale level interactions happen at the aggregate level and it makes individuals to adapt the changes arises from these interactions (Hammond, 2009; MacLennan, 2007).

At the individual level, and also at the clinical level, reinforcing pathology and behavioral economics frameworks also provide limited (Ross et al., 2020) but promising results especially in terms of our understating of how and why overconsumption and inactivity occurs (Epstein et al., 2014; Epstein & Saelens, 2000; Epstein et al., 2010; Jacques-Tiura & Greenwald, 2016; Murphy et al., 2007; *Reframing health behavior change with behavioral economics*, 2000; Ruhm, 2012; Temple, 2014). Yet, environmental factors in complex socio-economic systems are missing from these frameworks.

Therefore, a different approach under the systems science umbrella might be helpful to understand how and why obesity is a very persistent problem and why existing policies are not being effective. Thus, understanding the key components of the system that contribute to obesogenic environment, how this environment affects human behavior patterns, which feedback loops are governing the problem and how the system can be leveraged, may be useful for policymakers in Turkey in shaping their policies to achieve more effective results.

1.3. Research Objective

Objective of this study is to understand the underlying structure of the obesity problem in Turkey and uncover the dynamic interactions within this structure and resulting behavior patterns over time by developing a system dynamics simulation model. Additionally, behavioral economics and reinforcement pathology theory frameworks are integrated into the model to give more robust insights to decision-makers.

1.4. Research Questions

Research questions of this study are: *(1) What are the physiological and socio-economic concepts/theoretical frameworks, related key variables, and their relations for obesity? (2) Which feedback loops are important to understand to tackle obesity? (3) How the concepts/theoretical frameworks about obesity and key variables can be represented and analyzed with an SD model? (4) What leverage points can be identified for better policy formulations?*

2. Literature Review

2.1. Obesity and the Environment

Obesity, by definition, is the excessive adipose tissue commonly known as body fat that causes health problems. Like all mammals and some non-mammal animals, humans also accumulate fat tissue which has many functions as well as being energy storage (Cohen & Spiegelman, 2016). The reason of existence of such tissue and its accumulation lies within our evolutionary history (Bellisari, 2008; Speakman, 2013; Speakman, 2016; Wells, 2012). Whatever the reason is, excess energy due to negative energy balance is stored as fat tissue and excessive amount of this fat tissue may lead to obesity. The energy imbalance is the result of interaction between behavior, biology, and the environment regardless of the species but the exact dynamics are still disputed (Edward Archer et al., 2018). Nonetheless, human behavior plays a key role since it is the gateway for the energy balance or imbalance. Therefore, to understand the obesity better, one must focus on interaction of human and environment (social, economic, and natural) since the human decision arouses from this interaction (An, 2012; Fox et al., 2013; Johnson, 2021).

Yet, the exact dynamics between environment and humans which causes the obesity epidemic and which structures are more responsible is still a topic of heated debate. It is mainly because the interaction between environment and human is extremely complex (Frood et al., 2013; Hammond, 2009; Speakman, 2013). Some scholars suggest that the rise in the consumption of food outside resulted from the decrease of food prices and increased opportunity cost of time is more responsible (Gomis-Porqueras, 2005). Some argues that the technological development and change in division of labor is to blame (Cutler et al., 2003). Others speculate that the increase sugar consumption is the cause (Faruque et al., 2019). Some thinks that the decreased PA and fitness levels causes obesity (Edward Archer et al., 2018; Archer, Lavie, et al., 2013). And some argue that the increased food supply led to overconsumption and obesity epidemic (Swinburn et al., 2009). It can be said that the combination of these different theories and many others is more likely to be true to explain increase in obesity prevalence across to globe. But still, a framework is necessary which all these explanations can fit into.

All these theories and many others have one thing in common: changes in the environment caused changes in human behavior (overconsumption and/or physical inactivity). Global and local economic growth generated an obesogenic environment in most of the countries resulting in a shift in human behavior patterns. As a result, understanding what structures are responsible for human behavior pattern change driven by environmental change would be beneficial.

2.2. Obesity and Behavioral Economics

Behavioral economics seems to be a suitable framework to explain behavior patterns which are shaped by the environmental factors that leads to obesity epidemic (Epstein & Saelens, 2000; Epstein et al., 2010; Jacques-Tiura & Greenwald, 2016; Ruhm, 2012). It is a robust approach to explain human decision-making especially in terms of how and why individuals allocate their limited resources to access goods or service or any other things (Matjasko et al., 2016; Thaler, 2018). These resources can either be time, budget or well-being/health, and the goods or services can be physical activity (PA) or food. While using most of the concepts from classical and neoclassical economic theory, it differs from them by including the effects of neurological, psychological, and social factors on human behavior (Lea, 2006; Matjasko et al., 2016). Hence, behavioral economic framework can provide us to understand human behavior associated with the obesity whether it is physical activity or ingestive behavior (Epstein et al., 2018; Temple, 2014).

Human decision-making can be described as selection of most valued thing (either an action or an object) among different alternatives (Epstein et al., 2007). Thus, it can be conceptualized by reinforcement value, relative reinforcement and delay discounting paradigms based on behavioral economics (Bickel et al., 2000; Carr et al., 2011; Epstein et al., 2010). Reinforcements affect the value or utility of actions, behaviors, commodities, or objects. Individuals choose things or behaviors that are more reinforcing among the alternatives since their reinforcing value would be higher (Epstein & Leddy, 2006). And delay discounting explains the valuation of different options when there is a time difference when achieving these options (Frederick et al., 2002). Therefore, this framework could be used to study what environment changed in human behavior in terms of food consumption.

Because obesity epidemic is a result of a human-environment interaction, whether the effect of this interaction is on a biological level or on a social level, behavioral and environmental factors are needed to be investigated. Human and environment interaction occurs on a systemic level, therefore, a holistic view of the problem seems to be necessary to analyze the dynamics between these factors which lead to obesity epidemic phenomenon and understand how the environment shape human behaviors, and how these interactions make them irrational (Gortmaker et al., 2011; Sent, 2018; Swinburn et al., 2011). A systems approach is a suitable methodology for this job and provides promising insights to tackle this problem since it helps us to understand the complexity of the obesogenic system and the underlying structure (Abdel-Hamid, 2003; Roberts et al., 2018; Wang et al., 2015; Zainal-Abidin et al., 2014).

2.3. Theoretical Background

The section below provides a summary theoretical background in the obesity research literature via having a special focus on modeling and simulation approaches in obesity problem.

a. Etiology of Obesity

Classified as a medical condition and a disease, obesity is now an interest of multiple disciplines such as endocrinology, epidemiology, biology, social sciences, medicine, physiology, psychology, psychiatry, economics and many more (CDC, 2021; WHO, 2021b). This is mainly due to the complex nature of obesity (Authority, 2013; Butland et al., 2007; Chiolero, 2018; Tomer, 2014).

Even though the obesity and being overweight is not a new thing for humanity (Haslam, 2007), it was not a significant problem until the early 1950’s since the most countries, even developed ones, were still struggling with malnutrition, child deaths and poverty (Caballero, 2007; Haslam, 2007). WHO formally recognized obesity as a global epidemic in 1997 following the alarming rise of obesity prevalence in the world (*Obesity: Preventing and Managing the Global Epidemic*, 2000).

In the obesity research literature, etiology of obesity is still disputed (Hall et al., 2022). Though, it is widely accepted that the rapid increase in obesity is a result of sustained positive energy balance over time due to the changes in our environment both in terms of food and psychical (Hall et al., 2012; Hill, 2006; Schwartz et al., 2017b). However, how exactly these changes affect the body weight and what are the underlying mechanisms is still a topic of hot debate in the literature (Hall et al., 2022).

There are complex pathophysiological processes take place for obesity (Goodman, 2003; Schwartz et al., 2017b). After the discovery of the gene that produces leptin in 1994, and thereafter the gene that regulates leptin receptors in 1995, obesity research in genetics and molecular science has been accelerated (Tartaglia et al., 1995; Zhang et al., 1994). But genetics, which drives the molecular processes, is not enough to explain the global obesity epidemic (Romieu et al., 2017). Though, they are crucial for the obesity treatment and therapy (Flier, 2004).

There are two main conceptual models for obesity: energy balance model (EBM) and carbohydrate-insulin model (CIM). EBM proposes that the weight dynamics are controlled by the brain through complex neurological, and endocrinal and metabolically processes which reacts to body’s energy needs and environmental changes (Blundell et al., 2020; Hall et al., 2022). Due to change in their environment, humans started to gain weight since their total energy balance was positive (Hill et al., 2012).

On the other hand, CIM proposes that the increased dietary carbohydrates consumption leads to excess insulin secretion which causes fat tissue to accumulate and trap the fat thereby causes non-fat tissue to be used as the main fuel of energy (Taubes, 2011). CIM gained popularity with the works of Gary Taubes which are primarily based on studies of David S. Ludwig and Robert H. Lustig (Taubes, 2007).

However, CIM received many criticisms from the academia and remains controversial (Hall et al., 2022; Schwartz et al., 2017a). Studies did not provide convincing evidence of any advantage to low-carbohydrate diets (Hall, 2019; Hall et al., 2016; Taubes, 2021). Also, the model itself has been criticized extensively (Hall, 2017; Hu et al., 2020). Hence, according to Hall, the EBM is still the best conceptual model for obesity research and models (Hall et al., 2022).

b. Approach in Obesity Research

Models are widely used in obesity research to understand and investigate the mechanisms that causes obesity in human populations. Mainly, there are two models in the literature: animal-based models and mathematical models.

Animal-based models are used the conduct experiments on animals to replicate the obesity in humans. One of the most popular models in this field is the diet-induced obesity (DIO) model which is used to study obesity caused by nutritional intake via high-fat or high-density diet (Wang & Liao, 2012). Even though DIO models are very effective in the explanation of obesity caused by food intake, it has major limitations since the obesity has no single determinant (Hariri & Thibault, 2010; Lai et al., 2014).

With mathematical modeling, some of these limitations aroused from the complex nature of obesity can be overcome through inclusion of economics, social, environmental, public policy, and other relevant aspects to observe their effects on obesity prevalence both in individual and population level. With the mathematical models, it is possible to investigate the relationship between variables (or determinants of a phenomenon) and make predictions to analyze possible trends (Levy et al., 2011). As one type of mathematical technique, systems helps to deconstruct underlying structure of a complex system such as obesity through non-linearities and feedback loops which explains interactions of one system component to another (Xue et al., 2018). Deconstructing a complex system makes it easy to understand for decision and policy makers.

c. System Dynamics Modeling Applications in Obesity Research

System dynamics modeling is one of the main mathematical simulation techniques in the field. It is a robust methodology to understand systems, uncover and propose solutions to complex problems originated from the endogenous mechanisms of systems (Forrester, 1961; Sterman, 2000). This methodology also helps us to frame, understand and tackle the complex problems (Forrester, 1968; Sterman, 2000).

In the last two decades, many studies with SD approach in obesity has been published (Morshed et al., 2019; Xue et al., 2018). The SD methodology is increasingly used in public health research since it can capture the relations of different determinants of health issues and provide a top-down approach (Homer & Hirsch, 2006; Wang et al., 2015). In addition, systems thinking in general could provide a holistic view to policy makers which could provide them a different angle to intervene to the system through not overlooking some feedback mechanisms and set reasonable goals using policies (Frood et al., 2013; Johnston et al., 2014).

Currently, there few examples of SD simulation models where they are being used by large scale government projects to provide insight about obesity and other chronic diseases and to test possible policy options along with their possible consequences. The most notables are UK Government's *Foresight Programme*, Centers for Disease Control and Prevention (CDC) and National Heart, Lung, and Blood Institute (NHLBI)'s *Prevention Impacts Simulation Model (PRISM)*, and The Australian Prevention Partnership Centre's *The Compelling Case for Prevention* (Butland et al., 2007; Institute, 2019; McPherson et al., 2007; Yarnoff et al., 2021). Foresight Programme provides a conceptual framework through system mapping, whereas PRISM and the Australian Prevention Partnership Centre's project provides simulation models where economic and social impacts of different policies can be investigated.

SD models of obesity can either be individual level, population level or sometimes both based on their main outputs. One of the first SD model in obesity research is Abdel-Hamid's studies first in 2002 and then in 2003 (Abdel-Hamid, 2002, 2003). In these studies, he explored the human energy dynamics through using EBM method at the individual level. The ultimate focus of the studies was to provide insights about treatment of obesity. He suggests that since the physical activity in an essential part of weight loss, the dynamic relations between diet composition and physical activity should also be taking into consideration.

Like Abdel-Hamid's approach, Flatt modeled the metabolization of fat and carbohydrates on the individual level to capture what is disturbing the steady-state of the human energy balance and causing obesity via focusing on the role of glycogen levels (Flatt, 2004). Flatt highlights the role of glycogen levels on body weight via explaining under which conditions fat mass in the body can be maintained. In addition, this model follows the CIM approach which is unusual among the SD obesity models in the literature.

In a similar fashion, but using EBM approach, Goldbeter proposed a model to explore the weight cycling in humans through an individual level model (Goldbeter, 2006). In conclusion of the study, Goldbeter proposes that keeping the body weight under a critical value could provide a steady state for the body system since the cycles in the body weight appears of disappears based on the control parameter. Therefore, the model provides important insights about "yo-yo" dieting in humans and its dynamics.

Like studies of Abdel-Hamid, Madahian and colleagues developed an SD model to explore possible prevention strategies in obesity through individual approach (Madahian et al., 2012). Unlike the studies of Abdel-Hamid, they focused upon childhood obesity based on collected data from the subjects. They tested a couple of policy intervention options with using the model and suggested that SD modeling might be useful for obesity research.

Sabounchi and colleagues developed an explanatory model where they focused upon the pregnancy obesity that tracks the body weight increase throughout the phases in the pregnancy (Sabounchi et al., 2014). In the study, a special emphasize put upon the effect of obesity on pregnant women's health and probability of cesarean section operation requirement.

In 2006, unlike the previous studies, Homer, Milstein, Dietz, Buchner, and Majestic developed one of the first population level SD obesity model (Homer et al., 2006). In this model, Homer et al. proposes an SD model to simulate obesity trend in United States. In addition, they provide insights about possible trends in the future. They suggest that targeting only children obesity is not a solution for obesity epidemic though it decreases the risk of adult obesity if not prevents it.

In a unique way, Fallah-Fini, Rahmanadad, Chen, Xue and Wang developed an SD model where they captured individual level of obesity through physiological obesity mechanisms for multiple individuals to calculate the distribution of a population in US setting (Fallah-Fini et al., 2013). In 2014 Fallah-Fini and colleagues published another study which was a follow-up to their original study in 2013 but an elaborated version which includes disaggregation of the US population into racial subpopulations (Fallah-Fini et al., 2014).

As another population level model, the work of Dangerfield and Zainal-Abidin in 2010 was focused upon English children population via the child population average weight and body mass index to ultimately explore options for the prevention of childhood obesity (Dangerfield & Zainal-Abidin, 2010).

Later, Zainal-Abidin and colleagues developed a population level SD obesity model in 2014 to model childhood obesity in UK (Zainal-Abidin et al., 2014). Their focus was the eating behavior of the children. Hence, they considered physical activity as an exogenous variable to deconstruct how children's BMI is influenced by their eating behavior. Also, they assessed whether the target set by UK Government can be achieved by 2020 which they concluded that it is not possible until 2026.

Lan and colleagues developed another population level SD obesity model in a US school system setting to explore the determinant factors of increasing BMI values of students (Lan et al., 2014). In this study, a special emphasis has been put on the nutritional education and students' health concept which are significant aspects of obesity. They represented both dependent variables via stocks to capture the accumulative behavior in education and health concept.

In 2014, Struben, Chan and Dubé developed a population level obesity policy simulation model in Canadian context for the first time in an SD obesity model (Struben et al., 2014). They approached the obesity system in a macro level where they assessed not only the obesity prevalence but also the possible outcomes of several policies on country wide. Specifically, they analyzed how market conditions are affecting the food quality and consumption habits (portion size, taste, food availability etc.).

Meisel and colleagues developed the first SD obesity model in the middle-income countries via tracking the BMI categories of the Colombian population and analyzing different socioeconomic categories of the population (Meisel et al., 2016). In the conclusion of the study, they stated that the model predicts the trend of the obesity prevalence until 2030 which is an increasing trend. In a following study in 2018, they developed another model to investigate the obesity prevalence ratio based on the socioeconomic status of the age groups via using the same population dynamics structure from their previous study (Meisel et al., 2018). The model proposes scenarios for the probable future trends of the population until 2030. They propose that the most vulnerable and poorest socioeconomic groups have the highest rate of BMI transition rate whereas obesity prevalence is the highest among high-income group.

d. Obesity Research in Turkey

In Turkey, obesity research is relatively a new concept despite the rapid increase in obesity prevalence in all age groups. Other than official diet and nutrition guidelines, the main body of the government responsible for the obesity policies and treatment, the Ministry of Health, has no research on obesity in Turkey. Therefore, the researchers use the findings from studies conducted by international organizations such as WHO (*Turkey Nutrition and Health Survey*, 2019). Currently, only surveys are being conducted by the Ministry with 5 years intervals(*Turkey Healthy*

Nutrition and Active Life Program, 2019; *Turkey Nutrition and Health Survey*, 2019). Though, recently, the Grand National Assembly of Turkey declared that they have completed a study to assess the current situation of obesity in Turkey and provided possible policy intervention options (Uslu, 2021).

Other than studies funded by the government, many of the studies in Turkish obesity literature are in fields of medical research and medicine. There are very few studies on socio-economic aspects and determinants of obesity. Though, in recent years, the number of studies has increased.

The studies of Erem, Hatemi and Yumuk in early 2000s are the pioneer studies in socio-economic analyses of obesity in Turkey (Erem et al., 2004; Hatemi et al., 2003; Yumuk, 2005). However, these studies cover only some parts of Turkey. The first study that focuses on national level is the study of Tansel and Karaoglan (Tansel & Karaoğlan, 2014). Following this, they have also conducted another study using quantile regression analysis in national level (Karaoğlan & Tansel, 2019). Another national level study has been published by Sipahi in 2021 (Sipahi, 2021).

There are even less studies focusing on the momentous policies and possible policy options in context of Turkey. The study of Beyaz and Koç is one of the first study which discusses the possible obesity policies for Turkey (Beyaz & Koç, 2011). No study has been found by the researcher about the evaluation or assessment of momentous policies in nationwide. However, Kılıç et. al conducted an experimental study with 20 individuals to measure the effectiveness of two strategies planned to be implemented by the government against obesity (Kılıç et al., 2017). They suggest that the possible obesity taxes may not have effect on consumers decisions. Therefore, policies should focus on the labeling with detailed nutritional information and restriction of unhealthy food promotions (Kılıç et al., 2017).

2.4. Key Concepts and Discussions

This section introduces some of the key concepts that will be used throughout the research is introduced and explained briefly.

a. Body Mass Index (BMI)

In the literature, the definition of obesity is generally defined by the BMI value, *which calculates mass and height of a person following the body mass divided by the square of* the body height. For classification of overweight and obesity, following BMI, or Quetelet, index will be used for this study. The index and the calculation method were first proposed by Adolphe Quetelet (Eknoyan, 2008; Quetelet, 1842). This index is an accepted classification in the literature and by the reputable national and international organizations (Services, 1998; WHO, 2021a).

- Underweight: BMI < 18,50
- Normal weight: 18.50 ≤ BMI < 25,00
- Pre-obese: 25,00 ≤ BMI < 30,00

- Obese: BMI ≥ 30,00
- Morbid-obese: BMI ≥ 40,00

Since pre-obese or overweight people is also in high-risk group, in this research, the term overweight & obese (OWOB) includes pre-obese, obese, and morbid-obese populations. Therefore, obese or OWOB will describe the same phenomena for the rest of the thesis.

b. Obesity vs. Obesity Epidemic

As discussed above, obesity is a medical condition caused by the excessive amount of body fat. So, obesity etiology lies in the evolution of adipose tissue in mammals and some other non-mammal animals because it is a result of a survival mechanism which is to preserve energy (Sellayah et al., 2014). Genes that are allowed species to store energy as fat provided them survival advantage throughout the history. Hence, those genes have favored through natural selection (Speakman, 2013; Speakman, 2016; Wells, 2012). But obesity epidemic is different than just obesity as a disease.

Obesity epidemic, originated from the definition of epidemic, is an unexpected rapid spread of obesity to a population (Green et al., 2002; James et al., 2001). Obesity as an epidemic requires more socio-economic explanation than just a genetic explanation (Edward Archer et al., 2018; Romieu et al., 2017). Therefore, this research will differentiate between obesity and obesity epidemic as two different phenomena and focus on the obesity epidemic even though they are interrelated.

c. Utility and Reinforcing Value

Every action or object has a utility to a consumer (or an individual) which is used to model the value or worth of that thing or behavior (Broome, 1991; Robinson, 2021). The utility is a subjective concept, same things might be valued differently for each individual (Fishburn, 1990).

Reinforcing value on the other hand defines the amount of behavior a subject will show to gain a reward, for instance food (Bickel et al., 2000; Epstein et al., 2010). Therefore, the reinforcing value of food describes the amount of behavior that a subject is willing to spend or will work or to achieve food (Temple, 2014). In that sense, the relative reinforcing value of food is going to be used in the following chapters as almost a synonym for utility of food for the purpose of simplification. Though it is clear that utility is the consequence of an action that indicates a realization, reinforcing value denotes the willingness of an individual to gain that potential utility. However, it can also be argued that this potential utility is what motivates an individual to work more. As a result, the researcher thinks that the reinforcing value and utility are synchronized to some extent.

d. Relative Reinforcing Value

Relative reinforcing value indicates the reinforcing value of a behavior or an object relative to another one to measure the strength of the behavior or object. The generic equation is as follows (Carr & Epstein, 2020; Epstein et al., 2014; Epstein et al., 2007; Kong et al., 2015):

$$Relative\ Reinforcing\ Value_X = \frac{Reinforcing\ Value_X}{(Reinforcing\ Value_X + Reinforcing\ Value_Y)} \quad (1)$$

According to the equation, X's Relative Reinforcing Value increases as the X's Reinforcing Value increases or Y's Reinforcing Value decreases and the result approaches to 1. Conversely, when it decreases or if reinforcing value of Y increases, Relative Reinforcing Value of X decreases, and the result approaches to 0.

In an empirical study, reinforcing value of things is measured via completing certain tasks given to the subjects or via a questionnaire for quantification purposes and then relative reinforcing values are calculated via aforementioned equation (Epstein et al., 2007; Hill et al., 2009; Kong et al., 2015; Stojek & MacKillop, 2017). Due to the limitations of this research and available data, initial reinforcing value of food is estimated based on these empirical studies.

e. Delay Discounting

Delay discounting is an economics term to describe the present value of a thing based on the time that thing received (Doyle, 2013). It derives from discounted utility approach of intertemporal choice. It indicates a decline in the present value of a thing when there is a delay to achieve that thing (Odum, 2011). In other words, smaller but immediate rewards are valued more by consumers than higher but delayed rewards. Hence, the value or utility of the future reward is being discounted by consumers. This phenomenon can be called "present-bias." It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). But every individual discounts differently as it is showed by the empirical studies (Epstein et al., 2014; Ross et al., 2020; Stojek & MacKillop, 2017).

There are different ways to model delay discounting in the literature such as Irving Fisher's intertemporal choice model (Thaler, 1997), exponential discounting or discounted utility (Samuelson, 1937) hyperbolic discounting (Green & Myerson, 2004; Hampton et al., 2017; Ohmura et al., 2006), quasi-hyperbolic discounting (Ida, 2014; Laibson, 1997; Loewenstein & Prelec, 1992).

For this research, the researcher will use hyperbolic discounting approach due to its extensive use in the empirical studies (Epstein et al., 2014; Epstein et al., 2010; Hampton et al., 2017; O'Brien et al., 2011) and the model that developed for this research is not focusing on the individual differences rather focuses on the population level analyses through distribution of traits of reference individuals. In the literature, the model developed by Mazur (Mazur, 1987) is most cited version to explain hyperbolic discounting (Ainslie, 1975, 2010; Bickel et al., 1999; Mazur, 1987):

$$V = A / [1 + (kD)] \quad (2)$$

where V is the present value of an object or an action, A is the initial value, k is the degree of impatience and D is the delay time. As the delay time increases, the present value decreases. If we reformulate the model as:

$$V = A \times 1/(1 + kD) \quad (3)$$

we can describe the discount factor from this reformulation as:

$$g(D) = 1/(1 + kD) \quad (4)$$

This formulation used in the model in this study. The details of the model explained in upcoming chapters.

3. Research Methodology

3.1. Methodology and Research Approach

This research utilizes mixed methods approach as research strategy to answer the research questions. In this approach, both quantitative and qualitative data are processed and analyzed (Denscombe, 2008; Greene et al., 1989). A mixed methods approach is suitable because it helps to uncover relations among multilayered research questions (Shorten & Smith, 2017).

The mixed methods approach has been used to build a simulation model using SD methodology to provide insights about the complex obesity epidemic problem. SD is a robust methodology to understand systems, uncover and propose solutions to complex problems originated from the endogenous mechanisms of systems (Forrester, 1961; Sterman, 2000). SD methodology consists of applying a mathematical modeling technique to frame, understand and tackle the complex problems (Forrester, 1968; Sterman, 2000). The model is a continuous time model that includes dynamic stocks and flows consisting of various internal feedback loops and time delays. This method has been chosen to understand the non-linear behavior of the complex obesity epidemic in Turkey over time.

While the core methodology of this study is System Dynamics, a behavioral economics approach and the reinforcement pathology theory were integrated into the model as frameworks. Behavioral economic principles form the basis of reinforcer pathology (Bickel et al., 2014; Bickel et al., 2000). Reinforcement pathology is derived from the interaction between environment and individuals. It is mainly used to understand substance use disorders but recently this theory is being adapted to explain obesity (Epstein et al., 2010; Hill et al., 2009). This framework is useful to understand to how obesogenic environment shapes food consumption behavior.

Behavioral economics studies the decision-making strategies and processes which are affected by cognitive, social, cultural, and psychological factors (Thaler, 2018; Tversky & Kahneman, 1974). And it is heavily influenced by neuroscience, psychology, sociology, and other fields of science which makes it vary from the traditional economic theory. In that sense, it is closely related to system dynamics methodology specifically in terms of (Sterman, 2000) and it provides new perspectives in terms of public policy tools (Chetty, 2015).

Behavioral economics and interventions utilizing behavioral economics is considered as a promising approach in public health studies (Matjasko et al., 2016). It can also be said that is especially significant for obesity epidemic (Gundersen et al., 2012; Jacques-Tiura & Greenwald, 2016; Richards & Sindelar, 2013). However, traditional economic models are not sufficient to cover formulation of obesity and body weight and aspects of behavioral economics approach hence reinforcement pathology since they are lacking insights from psychology and cognitive aspects (Bertrand & Schanzenbach, 2009; Gundersen et al., 2012).

3.2. Overview of Research Process

Qualitative research used to conceptualize the model based on several frameworks from literature and documentary evidence to create a unique framework for this research. For the SD methodology, literature review as part of the qualitative research is one of the most important process since system dynamics is a structural theory (Lane, 1999).

The literature review was conducted by reading and analyzing scientific sources from scientific databases. Following terms have used to conduct the search on databases including Scopus, Web of Science, PubMed, ScienceDirect without any period limit: “obesity,” “obesity epidemic,” “system dynamics” AND “obesity,” “behavioral economics” AND “obesity”, “reinforcer pathology”, “reinforcer pathology” and “obesity”, “reinforcing value” AND “obesity”, “bodyweight model”.

The conceptual framework concerning the body weight dynamics, behavioral economics, reinforcer pathology theory was developed through literature review to define key variables and their relationships with each other to expose the structures of the obesity epidemic. This framework can be captured in a Causal Loop Diagram (CLD) in the next chapter, also known as dynamic hypothesis. Thereafter, the conceptual model was quantified in a mathematical model using Stella Architect software. The equations of the model are grounded on the literature and the data collected from the reputable and credible sources.

During the quantification of the conceptual frameworks used in the model, several prior studies has been adapted to this research. Firstly, body weight dynamics structures adapted from works of Hall (Hall et al., 2022; Hall et al., 2012) as well as works from Fallah-fini (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014). Hall’s body weight model which is energy balance model is a simplified yet a robust model to capture how body weight changes based on energy consumption and energy expenditure. The other adapted model is from Fallah-fini's work on how a treat in a population can be distributed among different categories of population (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014; Homer et al., 2006).

Following the development of the quantified model, several validation tests were conducted to increase confidence in the model which followed established validation standards in the SD field (Barlas, 1989, 1994, 1996).

3.3. Data Collection

The data required to develop the model, calibrate, and validate, has been collected from reputable and reliable sources such as empirical evidence in the literature and global and national documents publicly available. Following the collection of data, the data has been processed and cleaned to be used as input for the variable and parameter values. Table 1 summarizes the primary data sources, collection method and their contribution to the model:

Table 1 - Primary Data Sources

Data type	Primary Sources	Collection Method	Contribution
Numerical data	Obesity prevalence (Hatemi et al., 2003; *Turkey Diet and Health Research 2010*, 2014; *Turkey Diet and Health Research 2019*, 2019; Yumuk, 2005)	Literature review and downloading official data releases	Estimation of parameter values, validation, and calibration
Qualitative and quantitative data related to reinforcer pathology theory	(Epstein et al., 2014; Epstein & Leddy, 2006; Epstein et al., 2007; Epstein & Saelens, 2000; Epstein et al., 2010; Epstein et al., 2018; Hill et al., 2009; Kong et al., 2015; Ohmura et al., 2006; Ross et al., 2020; Stojek & MacKillop, 2017; Temple, 2014; Vanderveldt et al., 2016)	Literature review with the focus on reinforcing value of food, delay discounting and other factors derived from behavioral economics	Developing causal structures, parameter estimation, and equations related to reinforcer pathology theory
Qualitative and quantitative data related to behavioral economics	(Ainslie, 1975; Chetty, 2015; Cory et al., 2021; Jacques-Tiura & Greenwald, 2016; Loewenstein & Prelec, 1992; Mazur, 1987; Murphy et al., 2007; Richards & Sindelar, 2013; Thaler, 1997, 2018)	Literature review with focus of understanding the assumptions of behavioral economics and related terms with obesity	Developing causal structures, assumptions, parameter estimation and delay discounting equations
SD models of Obesity or Obesity Epidemic	(Dangerfield & Zainal-Abidin, 2010; Fallah-Fini et al., 2013; Fallah-Fini et al., 2014; Finegood, 2012; Homer et al.,	Reviewing existing models with the focus on obesity structures, and methods	Developing causal structures, modeling techniques, assumptions

	2006; Homer & Hirsch, 2006; Zainal-Abidin et al., 2014)	and equations related to population level dynamics

3.4. Research Ethics

Throughout this study, generally accepted research ethics has been followed to make a valuable contribution to the scientific community by abiding the rules manifested in guidelines of reputable institutions (komiteene", 2019; Smith, 2003). The researcher stands by the principles of research ethics, modeling ethics, and respect individuals, groups, and institutions (Saltelli et al., 2020; Walker, 2009; Wallace, 1994). Also, the researcher acknowledges that the plagiarism is an unacceptable act and lead to serious negative consequences for the researcher. In addition, to ensure transparency of the research, all research materials are available for other researchers including equations used in the model, model assumptions, data sources and other required model documentation in the Appendixes section. Since the research includes only anonymous data and non-sensitive data, it did not require ethics approval.

4. Dynamic Hypothesis and Feedback Analysis

This section describes the dynamic hypothesis of the research. The hypothesis is dynamic in the sense that it indicates how obesity epidemic in Turkey, as a problematic behavior, consist of a set of feedback mechanisms among obesity drivers that have the potential to generate the problematic behavior. It reflects the mental model of the researcher related to the system which might be capable of creating the problematic behavior after rigorously reviewing the literature and existing SD model regarding obesity.

The dynamic hypothesis is represented in a Causal Loop Diagram (CLD). CLDs are useful qualitative tools to capture the structure of the system and show how the components of the system interact with each other (Sterman, 2000, p. 137). Visualization of the system via CLDs helps us to identify feedback loop chains which are responsible for the behavior of the system (Ford & Ford, 1999, pp. 69-71).

Arrows with plus sign denotes a positive link while arrows with negative sign denotes as negative link. The links indicates causal relations. Positive links indicate that a change in variable A, causes a change in the same direction in variable B. For example, if a variable linked to another variable (cause) increases, the variable that is linked to this one (effect) will also increase. Negative links indicate that a change in variable A, causes a change in opposite directions in variable B. For example, if a variable linked to another variable (cause) increases, the variable that is linked to this one (effect) will decrease (Sterman, 2000, pp. 139-140). The label with the circular arrows indicates the feedback loops where R means reinforcing (positive) and B means balancing (negative). Reinforcing feedback loops amplify the system output from an initial state, whereas balancing feedback loops counteract the change in the system and seek equilibrium or a goal state (Sterman, 2000, pp. 12-14).

4.1. Dynamic Hypothesis of the Research

The primary hypothesis of this research is that a system dynamics model that incorporates reinforcement pathology theory based on behavioral economics can explain how obesogenic environment/system shapes the behavior patterns of individuals in a way that make them overconsume food and why the increase in obesity epidemic is so stubborn.

This hypothesis can be reflected by two vicious cycles that feeds each other accompanied by a weaker balancing feedback loop (Figure 4). It can be said that this structure is applicable to other reinforcement pathologies such as drug addiction, smoking, gambling, or other kinds of addictions. This might be the one of the most important causes of stubborn obesity epidemic today. The interaction between obesogenic environment, which has been created by the economic growth and technological advancements, and human nature is the main cause of inactivity and overconsumption.

Economic growth and technological advancements created almost a free-feeding environment for humans by:

- increasing the accessibility of food in terms of palatability, variety, and ease of access,
- and loosening the main constraints on food consumption via decreasing price of food and increasing purchasing power

which affects human ingestive behavior, which leads to obesity epidemic.

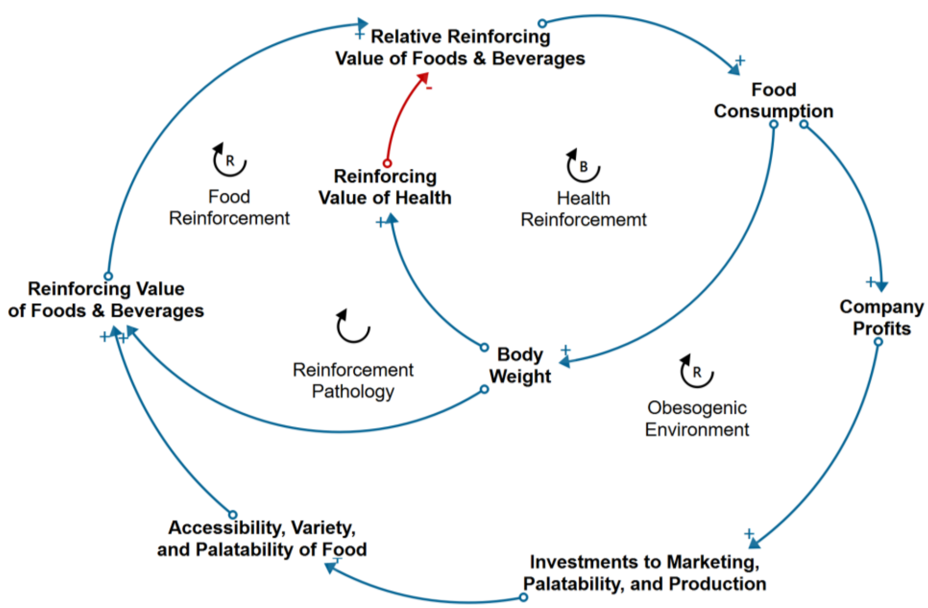

Figure 4 - Aggregated CLD of the dynamic hypothesis

Even though inactivity is a significant part of the obesity epidemic, overconsumption seems to contribute the most to this problem (Swinburn et al., 2009; Swinburn et al., 2011; Vandevijvere et al., 2015). Figure 4 shows the hypothesis of this research as an aggregate CLD. This CLD is a part of the larger CLD in the next section.

a) **Obesogenic Environment Loop:** Obesogenic environment increases food consumption via increasing accessibility of food & beverages by decreasing prices, increasing ease of access, variety, and palatability. The increased consumption boosts the company profits, which leads companies to invest in more to this environment

b) **Food Reinforcement Loop:** Reinforced by the obesogenic environment, reinforcing value of food is increased which leads to overconsumption of food which leads to increase in body weight which causes food to become even more valuable which leads to more food consumption. This feedback loop works as a reinforcer for the food consumption, and it is stronger than the Health Reinforcer loop which leads to Reinforcement pathology, which leads to overconsumption.

c) **Health Reinforcement Loop**: Increased body weight depreciates the health of the individual which increases the reinforcing value of health, which decreases the relative reinforcing value of food. This feedback loop works as the balancing mechanism for the food consumption but due to the obesogenic environment, this loop is weaker than the Food Reinforcer loop.

4.2. Dynamic Hypothesis Details

In almost all countries, interaction between economic growth and technological advancements allowed more food to be produced as well as decreased the production costs which led to decrease in food prices in real terms especially with the 1960s (Christian & Rashad, 2009; Jacks, 2019; Southgate, 2009). Consumption increased due to the increase in per capita income and the decrease in price levels. Hence companies started to invest more in food outlets, restaurants, and research & development activities. It made food easy to access, more palatable and as well as more energy dense.

On the individual level, these developments created like an ad libitum (free-feeding) environment for humans. Food is a strong reinforcer for individuals since food consumption is a part of survival instinct which is one of the fundamental motivations in humans. Ease of access to food, varied and more palatable food increased the reinforcing value of food which led to overconsumption of food. As the overconsumption continued, companies continued to invest in development of more palatable foods, more varied food, more food outlets, and newer delivery methods. At the same time, new transportation methods and work environments led to the decrease in physical activity levels. Altogether, obesity prevalence started to increase exponentially across the globe.

Figure 5 shows the dynamic hypothesis of this research as a simple CLD.

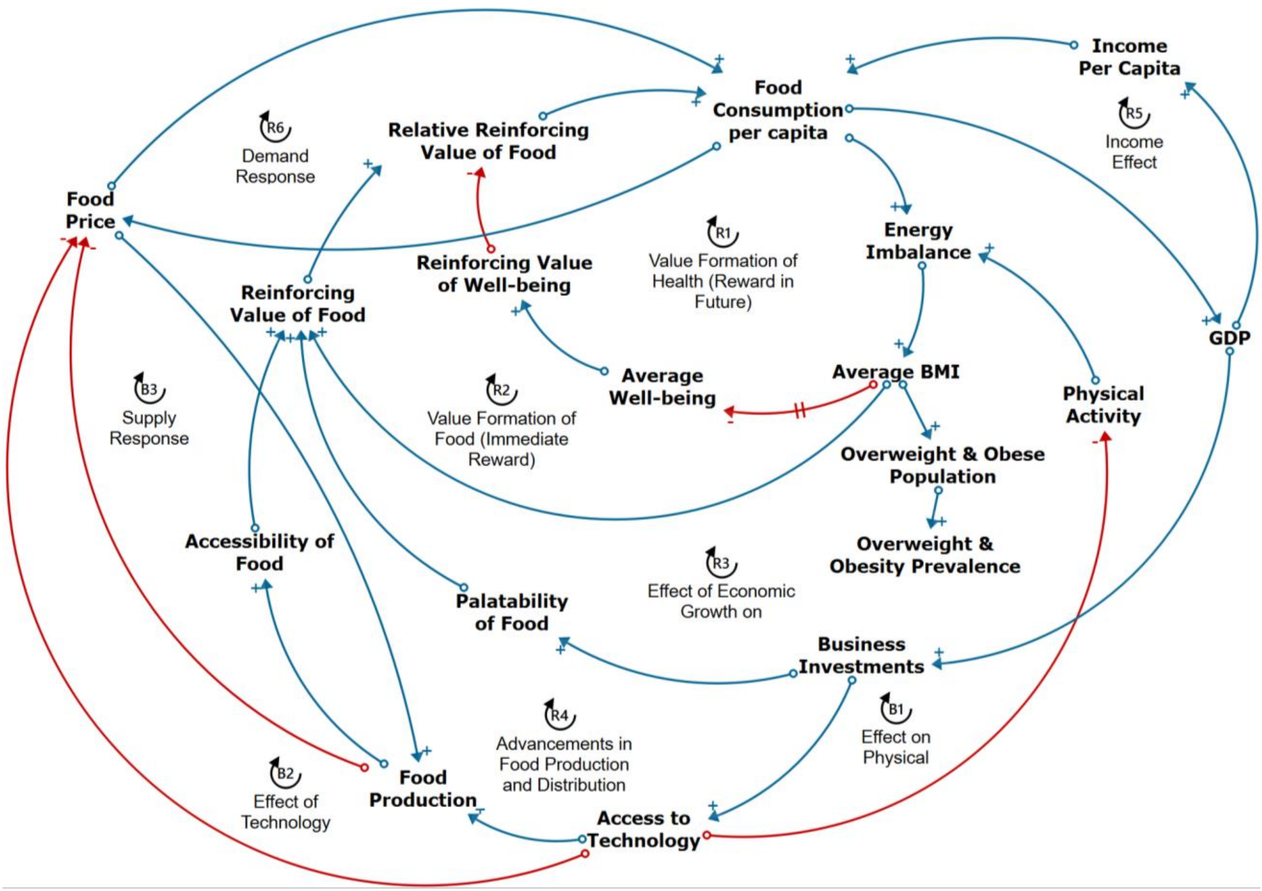

Figure 5 – Dynamic Hypothesis

As it can be seen on the Figure 5, there are nine major feedback loops which six of them are reinforcing and three of them are balancing. Together, these feedback loops generate the behavior of the system.

R1 Value Formation of Health

This reinforcing feedback loop represents the formation of value of health for individuals. It is hypothesized that the higher BMI values cause depreciation in health (Gregg & Shaw, 2017), so it leads individuals to care more about their health. In addition, health is hypothesized as a non-food reinforcement (Kong et al., 2015), the more value health has, the less the relative reinforcing value of food will be. This is due to the delay discounting because there is a time difference between gaining the reward of food and reward of health because value of health is in the future due to the delay in perceiving health (Epstein et al., 2014; Vanderveldt et al., 2016).

R2 Value Formation of Food

This reinforcing loop represents the formation of value of food for individuals. Together with reinforcing value of well-being, they determine the relative reinforcing value of food. In this research, the reinforcing value of food is compared to a non-food reinforcement which well-being

(Kong et al., 2015). Hence, higher the reinforcing value of food is, higher the relative reinforcing value of food will be due to the equation mentioned earlier.

It is hypothesized in this research that the higher the BMI of an individual is, the higher the reinforcing value of food will be for that individual due to addiction processes which are out of boundaries of this research (Volkow et al., 2012). Reinforcing value of food is different for each individual and it is not constant, it is influenced by many factors (Epstein et al., 2007; Temple, 2014). For the sake of simplification, this research includes accessibility of food and palatability of food as environmental factors and body weight as internal factor.

When the R1 loop is lower than R2 loop, the individual tends to eat more calories which is normal for organisms. But if the food is easy to access and palatable, the individual can consume more than what she/he needs because of higher reinforcing value. As the overconsumption persists, at some point, reinforcing value of food will be high enough to drive the consumption even though environmental impact will not change.

R3 Effect of Economic Growth on Palatability of Food

This reinforcing feedback loop represents the investments in research & development and as well as marketing activities to make foods and beverages more palatable. This investment is allowed by the increase in GDP. In addition to taste enhancers, it is well-known that foods with high sugar content is more palatable for humans due to our evolutionary history (Springer et al., 2014; Springer & Gagneux, 2016). Hence, companies use these techniques to make foods for palatable (Scanga et al., 2000). As one of the influencers of reinforcing value of food, more palatable foods increases the reinforcing value of food for individuals (Temple, 2014). Since more palatable food leads to more consumption, it increases companies' profits which make them invest more to this field.

R4 Advancements in Food Production and Distribution

This reinforcing feedback loop represents the investments in food outlets, food distribution channels, and production techniques. As explained earlier, increase in GDP, provides more investment opportunities to companies to invest in increase varied food supply, more restaurants, supermarkets, shops, and as well as more food. Altogether, these developments make food more accessible and varied. More accessible and varied food affects the reinforcing value of food and leads more consumption (Johnson & Wardle, 2014).

R5 Income Effect

This reinforcing feedback loop represents the budget constrain for individuals. Income is one of the most important constrain in terms of decision making for food consumption along with the price of food. It is conceptualized with the income elasticity of food demand. When income per capita increases, food demand also increases, and it increases consumption which increases GDP

(Talukdar et al., 2020). Though, this relation can be other way around too depending on the conditions of the country but on average income and obesity is positively related but this effect is limited (Ameye & Swinnen, 2019).

R6 Demand Response

This reinforcing feedback loop represents the demand decision making mechanism as a response to change in price. It is the other constraint for individuals along with the budget constraint conceptualized as R5 Income Effect. Individuals make their decisions about how much food they should consume through this feedback loop along with others. In this model, the price conceptualized as price level instead of the real price of a commodity due to model includes all kinds of food and beverages not a specific commodity. Therefore, as the price level increases, consumption decreases which leads to decrease in price level which leads to increase in consumption.

B1 Effect of Access to Technology on Physical Activity

This balancing feedback loop represents negative effects of technological advancements on physical activity levels of individuals. With economic growth, individuals gained access to technology such as cars, kitchen appliances, computers, etc. which led to decrease in physical activity levels on average (Pratt et al., 2012). It is not a one-time development since innovative technologies continue to emerge every year which leads to less energy consumption.

B2 Effect of Technology on Food Price

This balancing feedback loop represents the decrease in food price levels due to technological advancements which led to reduction of production, processing, and delivery costs (Gabre-Madhin, 2002; Harper & Jansen, 1985). Economic growth allowed Turkey to access these technologies with 1970s.

B3 Supply Response

This balancing feedback loop represents the supply response to changes in food prices. It operates as a supply-side decision-making mechanism. Companies make decisions on their production capacities and production levels based on food prices. If food prices decrease, companies will decrease their production capacity but if food prices increase, they will be more willing to produce more food to meet the demand. Together with R6 Demand Response feedback loop, both serves as a supply and demand feedback loop chain for food in Turkey.

5. Model Description

This chapter describes the simulation model with its boundaries, major assumptions and finally the model structure with its modules, variables, primary equations, and estimations of parameter values. For detailed description of the model structure please refer to Appendix chapter.

5.1. Model Boundary

Purpose of modeling in general is to understand a part of the world easier by focusing on a simplified but accurate version of it. Therefore, for all the models, it is inevitable to exclude some certain parts or features of the world that effects the system in focus. Hence, the model of this research also includes some boundaries (Richardson & Pugh, 1997). These boundaries can also be the limitations of this research which are explained in the eighth chapter.

Firstly, the model is bounded by the time horizon which is the period of time over which the problem develops. The time horizon of the model is from 1970 to 2050. The time horizon is long enough to capture how obesity epidemic became a problem for Turkey over time and how it will possibly be in the near future.

Secondly, due to time limitations, the model excludes some factors and risk regulators affects obesity. And it aggregates some of the risk regulators and factors for the same reason and because of the focus point of the research. Also, as stated extensively by so many scholars before (Bagnall et al., 2019; Feldman et al., 2019; Finegood, 2012; Flint, 2019; Frood et al., 2013), obesity is extremely complex due to its multilevel nature such as biological, genetic, social, psychological, and economic. Though, the model developed through the research incorporates the major levels of obesity epidemic. In that sense, it is still a system oriented multilevel model (Huang et al., 2009).

Thirdly, the model captures only obesity among adult population. Adolescent or childhood obesity is out of the boundaries of the research. Though, childhood obesity is also included in the model through a simple structure with assumptions to get more accurate results.

Following table summarizes the boundaries of the model through endogenous and exogenous components and excluded elements. Table 2 includes primary endogenous variable, all exogenous parameters except initial values, delay times and sensitivity/elasticity values for effect equations, and the main excluded elements.

Table 2 - Model Boundary Summary

Endogenous	Exogenous	Excluded
Body Weight	Total Population	Social Factors
Energy Intake	Fertility Rate	Genetic Factors
Energy Expenditure	Death Fractions of Each Body Weight Group	Psychosocial Factors
Food Price Level	Transition Fractions from Age Group 0 to Age Group 1 of Each Body Weight Category	Socio-economic status
Physical Activity	Physiological coefficients	Physical Environment
GDP	Labor Share and Tax Rate	Appetite
Food Demand	Propensity to Investment	Birth Weight
Reinforcing Value of Food	Food Export and Waste	Early Exposure

Reinforcing Value of Health	Energy Density of LED & HED Food
Relative Reinforcing Value of Food	

5.2. Assumptions

As discussed in the previous sub-section, a model should not incorporate all aspects or features of a system. Therefore, certain assumptions are necessary for the model's development to be feasible. Major assumptions are explained in this section.

a. Obesity Prevalence

It is assumed that obesity prevalence is an exogenous variable which is considered as a key indicator. Obesity prevalence affects mortality rates, productivity of individuals and increased costs of healthcare which have negative impacts on GDP and development of the country (Okunogbe et al., 2021; Tremmel et al., 2017). Then, it is assumed in the model that death rates of overweight and obese population are higher than the normal weight population, but it is not directly affected by the obesity prevalence. Furthermore, the effect of obesity on GDP can be omitted since it does not affect the behavior significantly given that it is not the focus of this study.

b. Transition from Age Group 0 to Age Group 1

Age Group 0 represents the childhood population. To calculate the obesity prevalence among the adult population, it is necessary to take the probability of childhood population to become obese or overweight when they reach adulthood which is age 15 in this research. Since childhood obesity is out of the boundaries of this research, it is assumed that the prevalence of obesity among adult population affects the fraction of transitions from Age Group 0 to Age Group 1 for each body weight category namely normal weight, overweight and obese. For instance, if the obesity prevalence increases, transition from overweight and obese categories of Age Group 0 to overweight and obese categories of Age Group 1 also increases. It is assumed that the parents affect their children's eating or dietary habits through promoting overeating which is also supported by the empirical research (Fuemmeler et al., 2013; Skouteris et al., 2011; Tzou & Chu, 2012).

c. Price Setting and Supply Response

The model includes a simplified version of commodity market model to represent the production of food (Meadows, 1969; Sterman, 2000). Since this research covers a long period of time and the focus is not on the commodity cycles, the commodity cycle model has been modified to fit the purpose of the model developed for this research.

Firstly, price in this model does not represent the price of a single item or commodity, instead, it represents the average level of prices of all foods and beverages in Turkey. This is due to the fact that commodity prices were on decline in real terms on average until 2000s (FAO, 2022). So, the model reflects these changes in a simplified manner. But the model does not consider that the food prices in real terms are on the rise after 2015 due to numerous reasons. Though this rise is not effective on obesity prevalence given the fact that numbers across the globe is still on the rise. Therefore, it is assumed that the food prices will continue to decrease slowly in the future.

Secondly, to prevent high amplitudes in price level due to commodity cycle model, since there are other factors that influences commodity prices (i.e., cost of production, government incentives, environmental effects etc.) and to simplify the price setting dynamics to fit the purpose of the model, it is assumed that the inventory coverage has minimal effect on price level.

Thirdly, it is assumed that supply side will always meet the demand, thus the demand perceived by the food producers is equal to production goal of these producers.

d. Body Weight and Age

The model calculates transition rates between body weight categories namely normal, overweight, and obese, based on change in BMI rates of representative individuals. These representative individuals represent only body weight categories but not age categories. This is mainly because distribution of obesity among age groups for adult population is close to each other except for early adulthood and later adulthood (İşeri & Arslan, 2008; *Turkey Health Research (Türkiye Sağlık Araştırması)*, 2019). This is true for the other countries as well, such as the UK and the US (Baker, 2022; Park, 2021). And given the fact that the trends in obesity in Turkey is similar to that in USA (Erem, 2015), it can be said that the distribution of obesity by age group might also be similar. It is important because as mentioned earlier, obesity data of Turkey is insufficient like many other countries. Though these exceptions can be disregarded due to the purpose of this research. Therefore, it is assumed that the age does not influence body weight for this research.

e. Physical Activity

As argued previously, physical inactivity is one of the most crucial factors in obesity epidemic along with the overconsumption. However, this research is only accounts physical activity to calculate obesity prevalence more accurately. Therefore, physical activity has been represented in a simple structure comparing to the structure for the consumption. Hence, it is assumed that physical activity is only affected by GDP. It is also assumed that as GDP grows, individuals will have less jobs that requires physical activity, have more access to modes of transportation etc. However, physical environment, body weight, socio-economic status are also drivers of physical activity levels. Therefore, the physical activity section of the model can be considered as a limitation for the research which will be described more in detail the upcoming chapters.

5.3. Model Overview

The model developed for this research is a mix of population dynamics and individual decision-making dynamics which follows the technique developed by Fallah-fini et al. as discussed previously. This technique will be detailed in the next sections.

Basically, the aim of the model is to analyze the dynamics of interaction between obesogenic environment and individuals, and to show how consumption decisions are shaped by this environment which leads to obesity. Hence, the model follows a population level approach. Generally, in the SD methodology, when focusing on population level dynamics, capturing the mean of the population elements (e.g., body weight, age, or sex) through stocks is sufficient where heterogeneity of population elements is not accounted.

Given the nature of this research, it is important to capture the heterogeneity of attributes within the stocks, namely, the population. So, the stocks in the model divided into different sub-stocks. In the model, population of Turkey divided into multiple attributes/dimensions: sex, age groups, and body weight. In addition, the food types are also divided into two categories to observe reinforcement effects of different food types. These dimensions can be seen in the following table:

Category	Attribute or Dimension
Sex	Male / Female
Age Group	Age Group 1 (15-49) / Age Group 2 (50-74) / Age Group 3 (75+)
Body Weight	Normal weight / Overweight / Obese
Food Type	Low Energy Dense (LED) Food / High Energy Dense (HED) Food

Though, the population level dynamics are based on individual behaviors. Because of that, the model also includes the individual level dynamics. But since the model is not an agent-based model, individual behaviors and characteristics are demonstrated simply with the single representatives of the most important attribute of the population which is body weight. Therefore, the individual decision-making is based on three sub-categories namely normal weight individual, overweight individual, and obese individual.

5.4. Model Structure

As mentioned previously, the hypothesis of the model is demonstrated and analyzed applying System Dynamics modeling methodology. To simplify the modeling process, computer software with graphical user interfaces is used extensively with SD modeling. The SD methodology uses stocks to represents accumulation and to indicate the state of the system at a point in time which gives the system the memory to quantify the system shown in the next chapter (Sterman, 2000, pp. 191-192). Stocks are corresponding to integral equations. Flows alter the stocks by increasing or depleting them with inflows and outflows, respectively. Since the change in stocks depend on the net change at any time, they are represented by differential equations. Flows are functions of stocks and other state variables and/or parameters (Sterman, 2000, p. 194). State variables and parameters are auxiliary variables of the SD models which consist functions of stocks such as constant values or exogenous inputs (Sterman, 2000, pp. 201-203).

This subsection presents the model with its modules, variables, equations, and estimations of some exogenous variables.

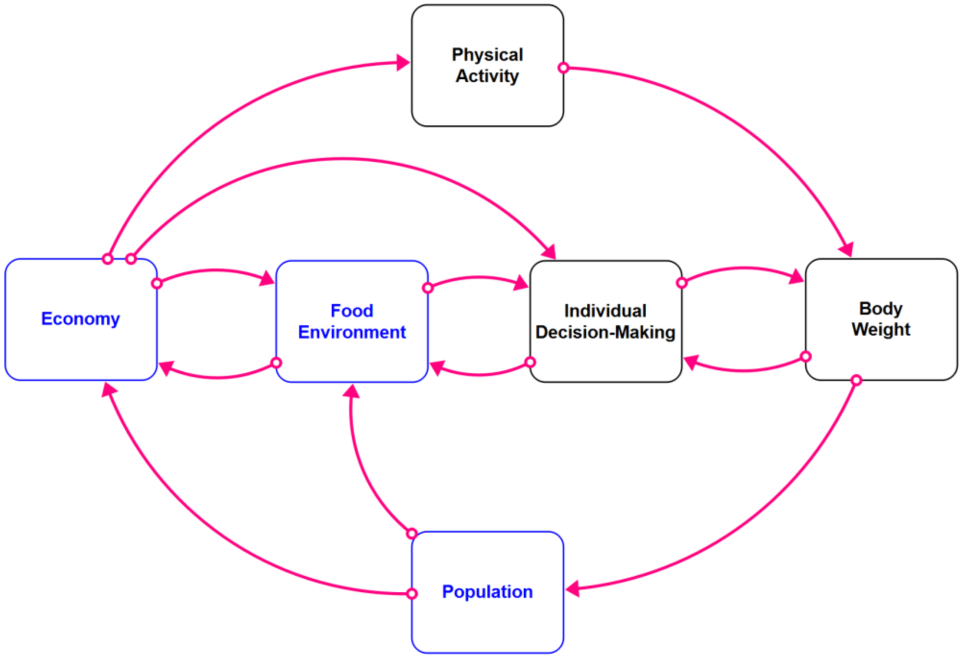

Figure 6 - Model Overview

The model consists of six modules which interacts each other. Figure 6 shows these modules and their relationship with each other in an overview. In this figure, blue colored modules represent environmental factors, and black colored modules represent individual factors related to obesity epidemic. The rest of the subsection explains each module briefly. For the detailed explanations of model equations, variables, and parameters, please refer to Appendix chapter.

a. Economy Module

This module represents the macroeconomic dynamics with a simplified fashion within the country. Figure 7 shows the structure of this module. Developments within this model allows generation of obesogenic environment that affects eating behaviors of individuals. Hence, economic development is represented by the Gross Domestic Product (GDP) in real terms. The module is connected to other models through GDP, Business Investments and Disposable Income Per Capita. And Food Environment module connected to this module through Total Food Consumption.

GDP is the main stock in this module. It is hypothesized that the GDP is a function of Aggregate Demand which consists of consumption, business investment and government purchases. It can be shown as:

$$GDP = Consumption + Business\ Investments + Government\ Purchases \quad (5)$$

Overall, this module is derived by three main reinforcement loops which increases GDP. These feedback loops are (1) from GDP to Household Revenues, from Household Revenues to Aggregate Demand (2) from GDP to Business Investments, from Business Investments to Aggregate Demand, (3) from GDP to Wages, from Wages to Taxes, from Taxes to Government Funds, from Government Funds to Aggregate Demand.

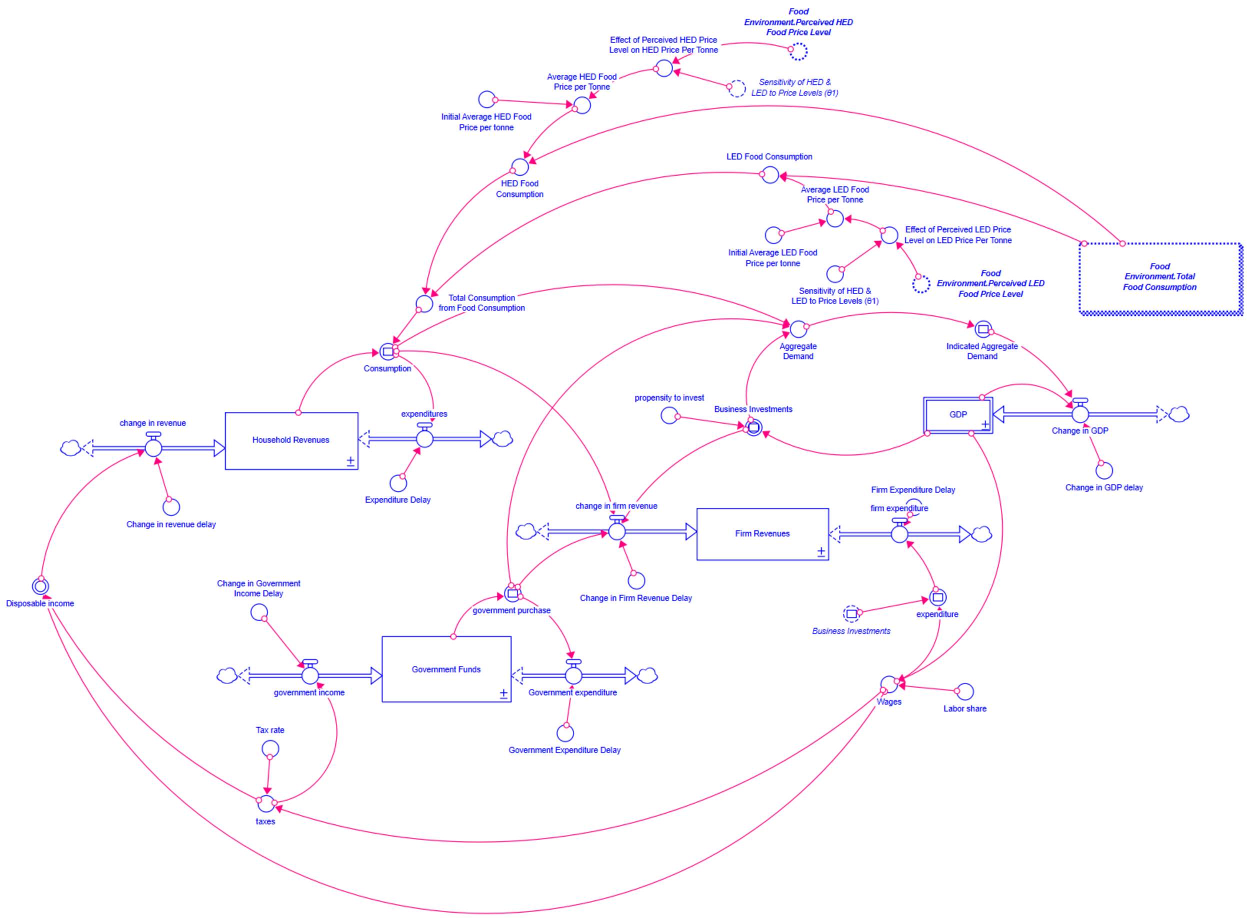

Figure 7 - Economy Module

b. Food Environment Module

This module represents the aggregate food environment that consists of three sub-modules namely food supply-demand, ease of access to food and food attributes. This module makes the ad libitum environment possible through continuously producing food. This module is connected to other modules through effect of price level for HED and LED food on food demand, effect of investments in food research and development activities, effect of investments in food stores and delivery services.

Food supply-demand sub-module is a simplified version of the commodity market model. This sub-module is shown in Figure 8 It has supply and demand mechanism through one balancing feedback loop operates as demand mechanism and one reinforcing feedback loop operates as supply mechanism.

As mentioned earlier, the price is measured as a level rather than an actual price of a commodity.

$$\begin{aligned} &\mathit{LED\ Food\ Price\ Level} \\ &\quad = \mathit{Effect\ of\ Inventory\ Coverage} \times \mathit{Effect\ of\ Liberalization\ Program} \\ &\quad \times \mathit{Initial\ LED\ Food\ Price\ Level} \end{aligned} \tag{6}$$

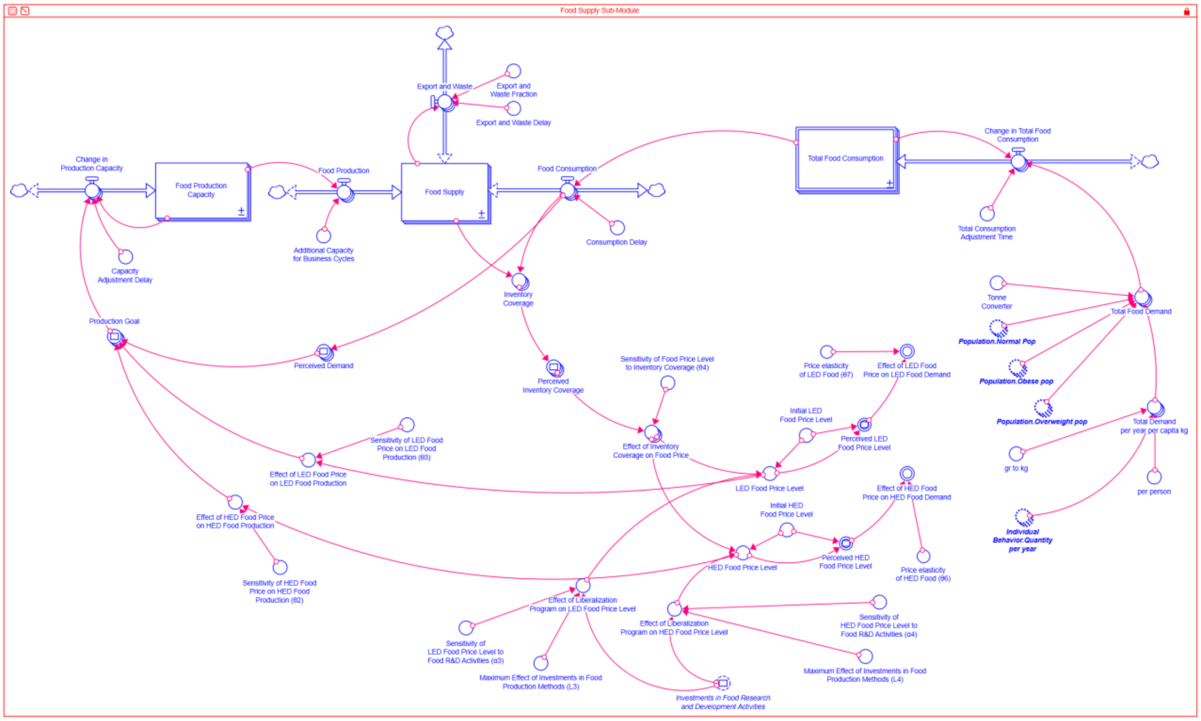

Figure 8 - Food Supply Sub-Module

With this equation, it is hypothesized that price level is affected only by the supply-demand ratio and the liberalization program of Turkish government in the beginning of 1980s (Cizre-Sakallioglu & Yeldan, 2000; Öniş, 2004; Utkulu & Özdemir, 2004). This program is important because it allowed Turkish companies to import food without any official approval and allowed foreign direct investments to Turkey along with imports of technology which led to decrease in food price level especially in HED foods. This equation is the same with both types of food.

Availability and accessibility of food is an important determinant for ingestive behavior (Duong et al., 2022; Gordon-Larsen, 2014). Therefore, it is hypothesized that the investments in food stores and delivery services have positive effect on reinforcing value of food through increasing ease of access to food and making varied food available. This relation represented in the model as an effect formulation. Figure 9 shows the structure of this relation.

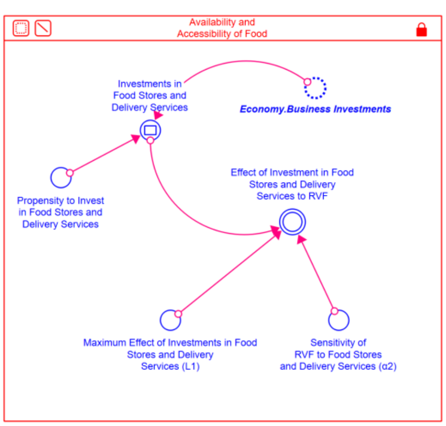

Figure 9 - Availability and Accessibility of Food

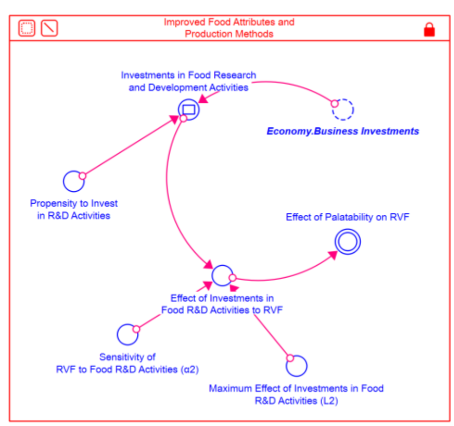

Figure 10 - Improved Food Attributes and Production Methods

It is hypothesized that the investment in food stores and delivery services has effect on reinforcing value of food.

Figure 10 shows the effect structure for improved food attributes and production methods through investments in food research and development activities like the previous effect structure. These investments have two different effects in the model. First one is the effect on food price level through decreasing the production cost. Second one is related to the reinforcing value of food as shown in Figure 10. It represents the improvements in food taste and marketing methods that makes food more palatable and attractive through investments in R&D activities. The attractiveness of food and palatability increases consumption (Johnson & Wardle, 2014). Hence, it is hypothesized that the improved food attributes increase the reinforcing value of food.

c. Population Module

This module represents the population dynamics of the country and calculates the obesity prevalence. The population dynamic is modeled through two aging chain structures. The first is the population aging chain by age categories and the second is the population aging chain by age and body weight categories. The first one is connected to the second one to model and distribute the population into body weight categories.

To make better calculations for the obesity prevalence, first aging chain needed to be modeled to make accurate estimates for the birth rate and death rate. For this reason, a simplified aging chain is used for the first population aging chain. Figure 11 shows this aging chain.

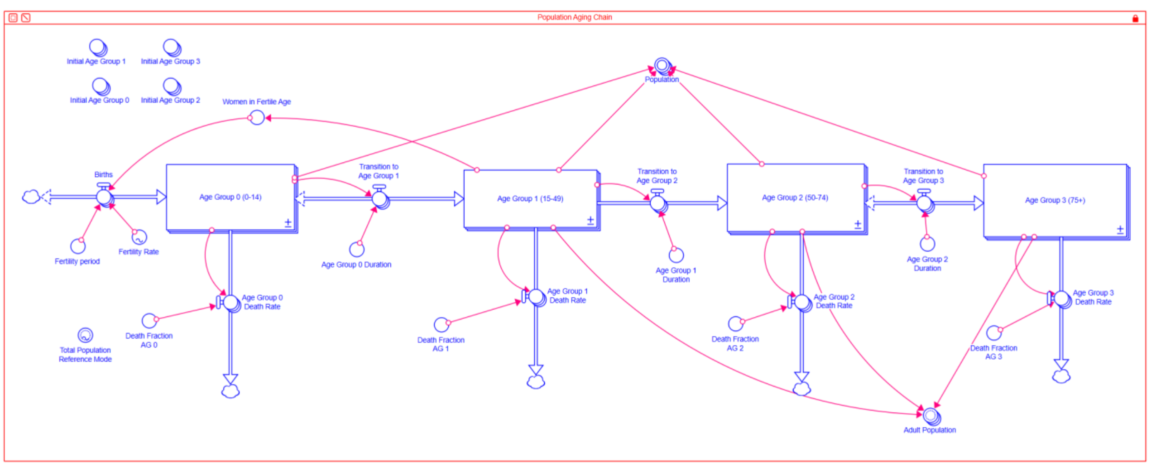

Figure 11 - Population Aging Chain by Age Categories

Based on first population aging chain, the population is distributed to body weight categories namely normal weight, overweight and obese. This adds body weight dimension into aging chain along with sex and age group.

Transition rates between age groups and death rates by age categories are based on the first population aging chain but the transition rates between body weight categories are calculated with a method developed by Fallah-fini et al. as mentioned previously. Figure 12 shows this aging chain.

Based on that, in each interval, the number of people belong to this interval can be calculated with a distribution equation as (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014):

$$Y_n = \frac{P_n}{X_f - X_i} \quad (7)$$

where Y_n is the number of individuals belong to this category in other words this is sub-population, P_n is the total population, and X_f and X_i are the final and initial values for the intervals to indicate the starting and ending point of that category.

After calculating the sub-population, transition rates can be calculated. Transition rates are based on two factors: frequency of the sub-population which is shown in Equation (*7*) as Y_n, and rate of change of the population attribute in this case is body weight. Rate of change of body weight is calculated with change in BMI in the model. Hence, the initial and final values of the intervals are the BMI rates.

Movement from one sub-population to another is based on the change in BMI. If BMI is decreasing, then the individuals should move to previous category but if BMI is increasing, then they should move to the next category.

The equation for the transition rates between body weight categories can be demonstrated with two equations. The first one is

$$Transition\ from\ Group_n\ to\ Group_{n+1} = MAX(\Delta BMI_n \times Y_n, 0) \quad (8)$$

where *MAX* function in Stella Architect denotes that the maximum value inside the parentheses is true. Therefore, the expression cannot take a value less than zero. Also, ΔBMI_n is the change rate of BMI, and Y_n is the frequency of the body weight group *n*. This equation is only possible when ΔBMI_n is positive meaning that the individuals gaining weight so they should be moving up to the next body weight category. Hence, $Group_{n+1}$ denotes the next body weight category.

When ΔBMI_n is negative, then it means that they are losing weight so they should be moving down from to the previous body weight category. This expression is formulated as:

$$Transition\ from\ Group_n\ to\ Group_{n-1} = ABS(\Delta BMI_n \times Y_n, 0) \quad (9)$$

In addition to transition rates, it is important to note that since the childhood obesity is out of the boundary of this model, transitions from Age Group 0 to Age Group 1 is included in the model to have more accurate results for the obesity prevalence. Because the number of stocks for the first adult population group is dependent on the transition rates from previous age group. Hence, in the model this transition rates are simply estimated and calibrated through a simple effect formulation. It assumed that the obesity prevalence will affect the society and the probability of obese parents to have obese children will be increased.

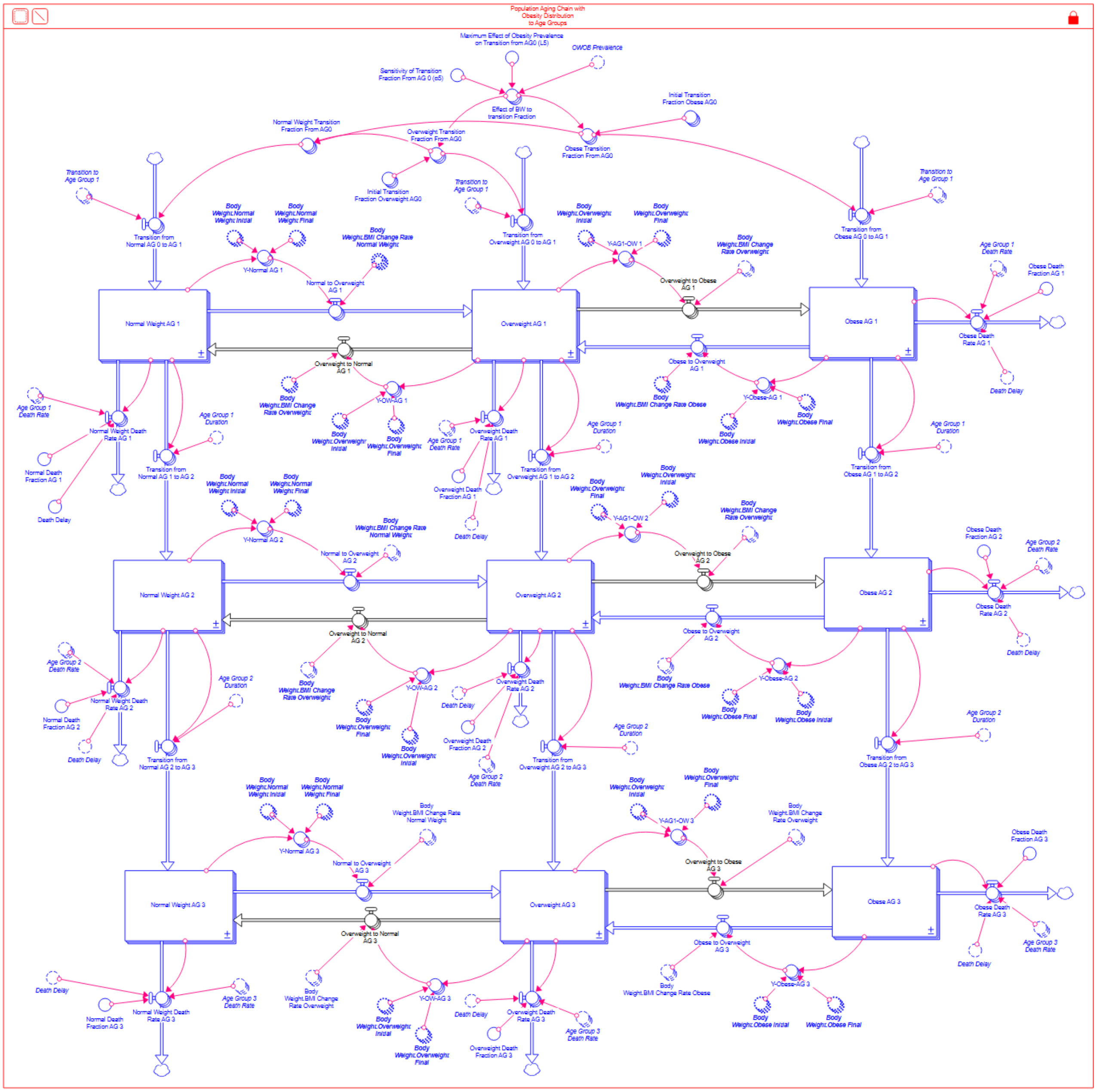

Figure 12 - Population Aging Chain by Age and Body Weight Categories

d. Body Weight Module

This module represents the body weight dynamics of individuals. The module consists of body weight model to capture the dynamics of body weight. This model is based on Kevin Hall's model developed for adults (Hall, 2010; Hall et al., 2022; Hall et al., 2012). This model is also used by Fallah-fini et al. when they applied their body weight distribution (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014). Following Fallah-fini et al.'s method, the dynamics of representative individuals is used to calculate BMI change rates which determines the transition rates between body weight categories. Figure 13 shows the overview of the body weight dynamics of normal weight individuals as representative. The model is the same for overweight and obese representative individuals except the initial values such as fat mass, fat free mass and BMI.

The module is connected to other modules through BMI change rate for representative individuals and takes input from physical activity module for physical energy expenditure, and individual behavior module for energy intake.

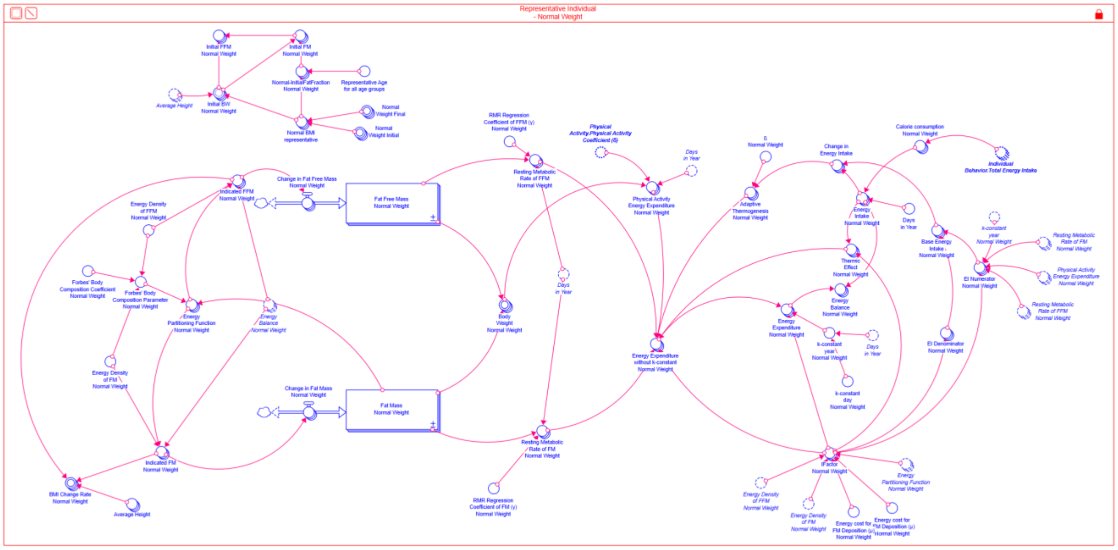

Figure 13 - Body Weight Dynamics Model

The model conceptualizes the body weight as the sum of fat mass (FM) and fat free mass (FFM) where fat mass represents adipose tissue and fat free mass represents the rest of the body mass includes muscle tissue, bone tissue and organ tissue. Energy balance model indicates that the change in FM and FFM depends on the balance of energy. If energy balance is negative, then it means that the change is also negative. And energy partitioning function only controls the relationship between FM and FFM (Hall, 2007). Energy balance is the most principal factor in this model:

$$Energy\ Balance = Energy\ Intake - Energy\ Expenditure \quad (10)$$

where energy intake is simply and input to it model from individual behavior module which regulates the ingestive behavior. Energy expenditure on the other hand is more complicated than energy expenditure due to its function:

$$\begin{aligned} Energy\ Expenditure \\ &= k + (\delta \times BW) + (\gamma_{FM} \times FM) + (\gamma_{FFM} \times FFM) + (\beta \times \Delta EI) \\ &+ \left(\mu_{FM} \times \frac{dFM}{dt}\right) + \left(\mu_{FFM} \times \frac{dFFM}{dt}\right) \end{aligned} \quad (11)$$

where k is a constant, δ is the physical activity constant proportional to the *BW* because heavier the body is the more energy it will burn, γ for FM and FFM are constants for resting metabolic rate regression coefficients which are proportional to FMM and FM weight respectively which indicates the required energy to sustain the FM and FFM, β is another constant which is the coefficient for adaptive thermogenesis based on energy intake change rate, μ for FM and FFM are also constants indicates the energy cost for fat and protein turnover which are proportional to change in body composition.

e. Individual Behavior Module

This module represents demand for food which is shaped by both environmental and individual factors. Like body weight dynamics module, this module also consists of representative individuals to calculate the food demand for each body weight category accordingly.

The module is connected to other modules through body weight from body weight dynamics module, LED and HED food price level, effect of price level to food demand from food environment module, and disposable income from economy module. Also, this module gives input to body weight module via total energy intake and food environment module via demand quantity.

It is assumed that the food demand is determined by the price food, reinforcing value of food, and disposable income. As mentioned previously, there are more factors that influence food demand/consumption, but they are out of the boundaries of this research.

Figure 14 shows the food demand structure. Each food type has different demand based on both their reinforcing values, price, cross-price, and income elasticities. Naturally, representative of each body weight category has different demand for food. Food demand of LED and HED foods are calculated in the same way. It is formulated as the multiplication of effect variables related to food demand.

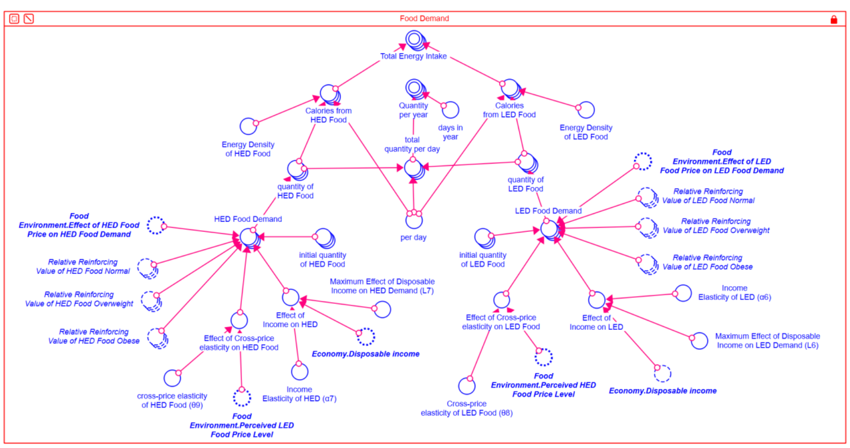

Figure 14 - Food Demand Structure

Effect of price level is explained in the food environment module. It is hypothesized that if price decreases, food demand increases. Disposable income is another important determinant as mentioned in the Introduction chapter. Income is directly proportional to food consumption, but this effect assumed to be limited because after reaching to a certain income level, priorities of consumers changes.

Another effect is cross-price elasticity. This indicates the sensitivity of demand of a good to change in price of a substitute. It is hypothesized that a decrease in price of HED food will decrease the demand of LED food and vice versa. So, it plays a counterbalancing role against own price elasticity of each food type (price elasticity of demand).

Other factor is individual relative reinforcing value of food for each body type. As mentioned earlier, both environmental and the individual factors affect reinforcing value of food. In this model, factors that influence reinforcing value of food has been aggregated to body weight as individual factor, and effect of palatability/attractiveness of the food and ease of access to food as environmental factors. Figure 15 shows this structure. This structure is hypothesized reinforcement pathology structure which is described in Introduction and Dynamic Hypothesis chapters.

Figure 15 shows the conceptualization of a choice structure which an individual makes a choice between two reinforcers: health, and food. The individual chooses the option that has highest reward relative to the other. But this reward is perceived, so it is biased because the reinforcing value of food is increased due to the environmental and individual factors which causes the increase in food consumption along with the disposable income and price factors. As noted, as the individual gains weight, the food becomes even more reinforcing for the individuals and the individual delay discounts more for health reinforcer (Stojek & MacKillop, 2017; Temple, 2014). This feedback loop leads individual to overeating which initiates a reinforcement pathology.

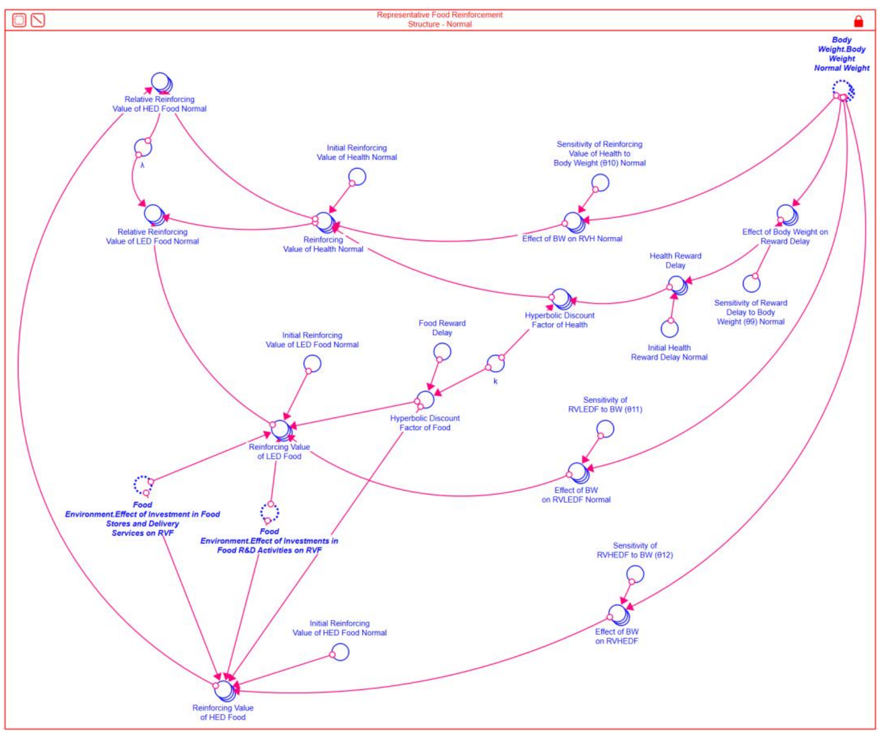

Figure 15 - Individual Food Reinforcement Structure

In the literature, reinforcement, which is conceptualized as relative reinforcement value, is used to describe choice among concurrent options that are substitutes or alternatives to each other, and delay discounting is used to conceptualize choice when there is time-inconsistency namely when receiving a reward takes longer than other reward where the reward of the former is discounted (Epstein & Leddy, 2006; Epstein et al., 2007; Epstein et al., 2010).

The model includes the relative reinforcement value as in the literature mentioned above to conceptualize concurrent choices but not between two immediate reward options but two time-inconsistent options namely being healthy and food consumption which is different from the other studies. In that sense, again different from the other studies, this study suggests and hypothesizes that the delay discounting and food reinforcement is connected (Carr et al., 2011). Because in behavioral economics, delay discounting is used to explain how the value of a reward changes with the delay of receiving that reward which ultimately causes a decrease in its value as the delay increases (Odum, 2011; Odum et al., 2020). Therefore, in the individual behavior module, delay discounting formulation and relative reinforcement is used to describe how immediate small reward, food consumption, has more value than larger delayed reward, staying healthy conceptualized simply as health reward.

Increase in body weight affects delay-discounting process, reinforcing value of health and reinforcing value of food. So, it is hypothesized on one hand that increase in body weight leads to increased delay discounting of the alternative against the food consumption via decreasing their reinforcing value or utility (Epstein et al., 2014; O'Brien et al., 2011; Temple, 2014; Vanderveldt et al., 2016). On the other hand, increase in body weight increases reinforcing value of food consumption due to almost creating an addiction (Carr et al., 2011; Stojek & MacKillop, 2017; Volkow et al., 2012). As it shown in the empirical studies, individuals with higher body weights delay discount more and find foods highly reinforcing which together, make them more impatient (Epstein et al., 2014; Ross et al., 2020; Vanderveldt et al., 2016).

However, increase in body weight does not only increase reinforcing value of food, but it also increases reinforcing value of health because it is assumed that the health is also a reinforcer that increases along with the body weight which makes them more aware of their health depreciation with increasing rates and may lead them to look for solutions such as dieting, eating less or bariatric surgery or etc. So, the relative reinforcing value of food is calculated relative to the reinforcing value of health.

To do quantify the influence of body weight on reinforcing value of health, reinforcing value of food, and delay discounting, effect formulations are used. These formulations are the same for each representative individuals though initial values and some sensitivity values are estimated to be different. This estimation is based on assumption of as individuals gain weight, they become more sensitive to food as a reinforcer and delay discount more.

Effect of body weight on reinforcing value of food is quantified with an effect formulation. Along with this effect, environmental effects from food environment module, and the delay discount for food, the reinforcing value of food is calculated based on its initial value for each food type:

$$\begin{aligned} &\textit{Reinforcing Value of Food} \\ &\quad = \textit{Initial Value of Food} \\ &\quad \times \textit{Effect of Body Weight on Reinforcing Value of Health} \\ &\quad \times \textit{Effect of Investments in Food Stores and Delivery Services} \\ &\quad \times \textit{Effect of Investments in Food R\&D Acitivities} \\ &\quad \times \textit{Hyperbolic Discount Factor of Food} \end{aligned} \tag{12}$$

where initial value of food is estimated for each body weight representative based on studies of Epstein et al. It is estimated that normal weight representative has the lowest and obese representative has the highest initial reinforcing value of food. This initial value is multiplied by multiple effects and then discounted by the discount factor. This discount function is explained in Delay Discounting under Key Concepts and Discussions section. This equation formulated as:

$$\textit{Hyperbolic Discount Factor}_{\textit{Food}} = \frac{1}{1 + \textit{Food Reward Delay} \times k} \tag{13}$$

where k, degree of impatience/discounting, estimated to be 1 because the impatience is modeled through effect of body weight on delay. So, the as the food reward delay increases, the discount on the reinforcing value of food will increase. However, in the model food reward delay estimated to be 0 which indicates an immediate reward because intemporal decision in this model is made comparing to the health. So, relative to receiving health reward, food reward is immediate; the individual will have the utility immediately after consumption. Therefore, hyperbolic discount factor for food is always 1 which means that food reward is not discounted unlike the health reward. Reinforcing value of food is calculated with the same equation for both HED and LED foods for every individual representative. Only initial values differ. These values can be seen on the table at the end of the subsection.

With similar equations, effect of body weight on reinforcing value of health is formulated with an effect formulation.

After calculating the effect, the reinforcing value of health is:

$$\begin{aligned} &\textit{Reinforcing Value of Health} \\ &\quad = \textit{Initial Value of Health} \\ &\quad \times \textit{Effect of Body Weight on Reinforcing Value of Health} \\ &\quad \times \textit{Hyperbolic Discount Factor} \end{aligned} \tag{14}$$

where the initial value of health is estimated to be the same for every body weight representative due to same assumption of sensitivity. Delay discount factor is quantified like food delay discount factor:

$$Hyperbolic\ Discount\ Factor_{Food} = \frac{1}{1 + Health\ Reward\ Delay \times k} \quad (15)$$

where *k*, degree of impatience/discounting, again estimated to be 1 because the impatience is modeled through effect of body weight on delay. But unlike the food reward delay, health reward delay depends on the body weight. So, the as the health reward delay increases, the discount on the reinforcing value of health also increases. This is because the health reward is distant in the future, so it is not immediate. Health reward delay is quantified as:

$$Health\ Reward\ Delay = Initial\ Health\ Reward\ Delay \times Effect\ of\ Body\ Weight\ on\ Health\ Reward\ Delay \quad (16)$$

where initial health reward delay is different for each individual because individuals with higher body weight delay discount more so in other words, for them the health reward is even farther in the future. And effect of body weight on health reward delay quantified with another effect formulation.

After calculating the reinforcing values, then as mentioned in Relative Reinforcing Value under Key Concepts and Discussions section, relative reinforcing values of LED food and HED food calculated differently but with similar equations. But the equation mentioned in Relative Reinforcing Value part, is modified with a coefficient to quantify how relative reinforcing value effects food demand:

$$Relative\ Reinforcing\ Value_{food} = \lambda + \frac{Reinforcing\ Value_{food}}{\left(Reinforcing\ Value_{food} + Reinforcing\ Value_{health}\right)} \quad (17)$$

where λ is a coefficient and estimated to be 0.25, and the division indicates the relative value of food reinforcement comparing to value of health. So, as the reinforcing value of health increases, the reinforcing value of food and eventually the relative reinforcing value of health decreases. The coefficient, λ, helps formula to effect food demand even in extreme conditions to make the equation more realistic. For instance, if reinforcing value of food is 0 which indicates that the food is not reinforcing, then equation results 0.25 which the demand will be increased but it will never be zero. Because even if the food is not reinforcing, individuals should eat to survive. Without the coefficient, the equation cannot go over 1 which means that it will always have a decreasing effect on food demand. To prevent that, the coefficient is added to the equation.

After calculating the demand of each food type, they multiplied with the initial quantity of food in grams per day per person. Then, this amount is converted to calories through densities of the LED food and HED food.

f. Physical Activity Module

This module represents physical activity as one of the main factors of energy expenditure. As mentioned earlier, physical activity is out of boundaries of this research, but it is included to calculate energy expenditure accurately. Figure 16 shows the structure for physical activity.

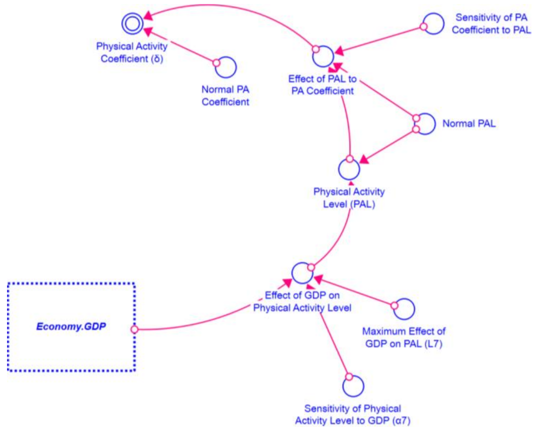

Figure 16 - Physical Activity Structure

This module receives input from economy module and give input to body weight dynamics module. Whole structure is based on a simplified effect structure that hypothesis that as the GDP increases, physical activity level (PAL) decreases due to increased access to modes of transportation, working in job that require less physical activity etc.

6. Model Validation and Testing

This chapter explains the validity of the model and gives details about the tests that conducted to assess internal and external validity of the model. As mentioned earlier, methods that is followed through the validation and testing are from the guidelines of Forrester and Senge (1980), Barlas (1989, 1994, 1996) and Sterman (2000). The aim of this model is to explain the causal relations for the obesity epidemic which makes this model an exploratory and explanatory model. So, it is a white-box model where descriptive causalities are more important comparing to a black-box model where correlational relations are more important (Barlas, 1996). Therefore, structural validity is more important for this model due to its purpose.

6.1. Structure Validity

Structural validity indicates robustness of relations between model parts and structures. Structural validity is the first thing that is assessed in validation process because without a valid structure, the behavior of the model will be less meaningful. Therefore, the structure of the model should be robust enough before comparing the result of the model behavior with the real-world counterpart.

a. Direct Structure Tests

These tests assess the validity of the model via comparing the model structure with the knowledge of the real-world counterpart of the system or parts of the system. At this stage, a simulation run is not required. Instead, relationships between variables are compared with the knowledge about the system from the literature or available sources.

- **Structure-confirmation Test:** This test verifies the structure of the model through comparing the equations and relations based on equations with the real-world knowledge. The knowledge about the system is collected from the literature as explained in Literature Review chapter. Therefore, the model passed this test successfully.
- **Parameter-confirmation Test:** This test verifies and confirms that each parameter in the model has a counterpart in the real-world. As explained in Model Structure section, each parameter and values that are used in the model are based on the available literature and observations. Though, some parameters and structure are excluded as mentioned in Model Boundary section. But it should be noted that one parameter mentioned in Individual Behavior Module subsection is not from the literature. This parameter is "λ" coefficient, added to the relative reinforcing equation. In the said subsection, it is mentioned why this coefficient is mathematically required. But still, it can be said that this is an artificial coefficient.
- **Direct Extreme-condition Test:** This test assesses whether each equation of the model is still coherent with the real-world knowledge even if its inputs are replaced with extreme yet meaningful values. This test is also conducted without simulating the whole model, instead, each equation is confirmed individually with extreme inputs.
- **Dimensional Consistency Test:** The purpose of the test is to make sure that all the dimensions that is used in the model are consisted with each other and all dimensions have real-world counterpart. Since the model is a result of iterative process through literature review, the model tested for dimensional consistency in each step of the modeling process. And for the consistency of dimensions, Stella software which is used to quantify the theoretical framework has an internal checking mechanism to make sure that the dimensions are always consistent.

b. Structure-oriented Behavior Tests

These tests assess the structure of the model indirectly, through observing the behavior that model generates. At this stage, the whole model or each module is simulated to conduct the tests for structure-oriented behavior tests to compare the generated behavior with the real-world knowledge and to see if the model generates any error.

- **Extreme-condition Test:** This test is conducted through setting the parameter values of selected variables to their extreme values to and running the simulation with these conditions. These tests are done for each variable. Purpose of the test is to check that the model does not generate any error and the generated behavior/results are consisted with the anticipated behavior of the model.

- **Integration Test:** This test verifies that the model is not sensitive to integration method that is used. The test is done by testing each of the integration method provided by the Stella software namely Euler method, Runge-Kutta 2nd order and Runge-Kutta 4th order methods. The test has done by testing each integration method and it has seen that the behavior of the system does not change by the change in integration method. Therefore, the system is not sensitive to the integration method.
- **Behavior Sensitivity Test:** These tests check if the parameters of the model are sensitive and if they are, are they also sensitive in real-world as well. These tests are conducted by changing the exogenous and calibrated parameters of the model between their -20% and +20% range and their effect on OWOB prevalence, overweight and obesity prevalence are observed. After the tests, the model found to be sensitive to some sensitivity and initial parameters as expected. In addition, sensitive parameters are expected to be sensitive in the real-world as well. Therefore, after the behavior sensitivity tests, no unexpected result was found. Details about the tested parameters, test values and the results can be seen in the Appendix chapter.

6.2. Behavior Pattern Tests

After making sure that the model is valid structurally, the next step is to test the behavior pattern of the model. It is important to note that, as Barlas indicates, the focus is not the point/event prediction but the prediction of the pattern (Barlas, 1996). The focus of the behavior pattern tests will be the pattern, trend, and the shape of the behavior. Though, the problem about available data is also limits these tests. Still, the test is conducted with the available data for the overweight and obesity prevalence in Turkey.

- **Model Pattern Test:** To see the pattern of the model, the whole model was simulated with business-as-usual conditions, then the generated behavior compared with the available data. Figure 17 shows the behavior of the model in comparison to the available data mentioned in the Introduction chapter. The behavior of the model is blue line for overweight and red line for obesity prevalence where the connected data points with yellow and brown are the results from NCDM-RisC model for Turkey. The separate data points (purple squares and green circles) show the data points from obesity research in Turkey where the points connected through grey lines are from TurkStat studies. The figure shows the model pattern and trend are like the result of the NCDM-RisC model. In addition, the model behavior is within the range of data points collected through the independent research.

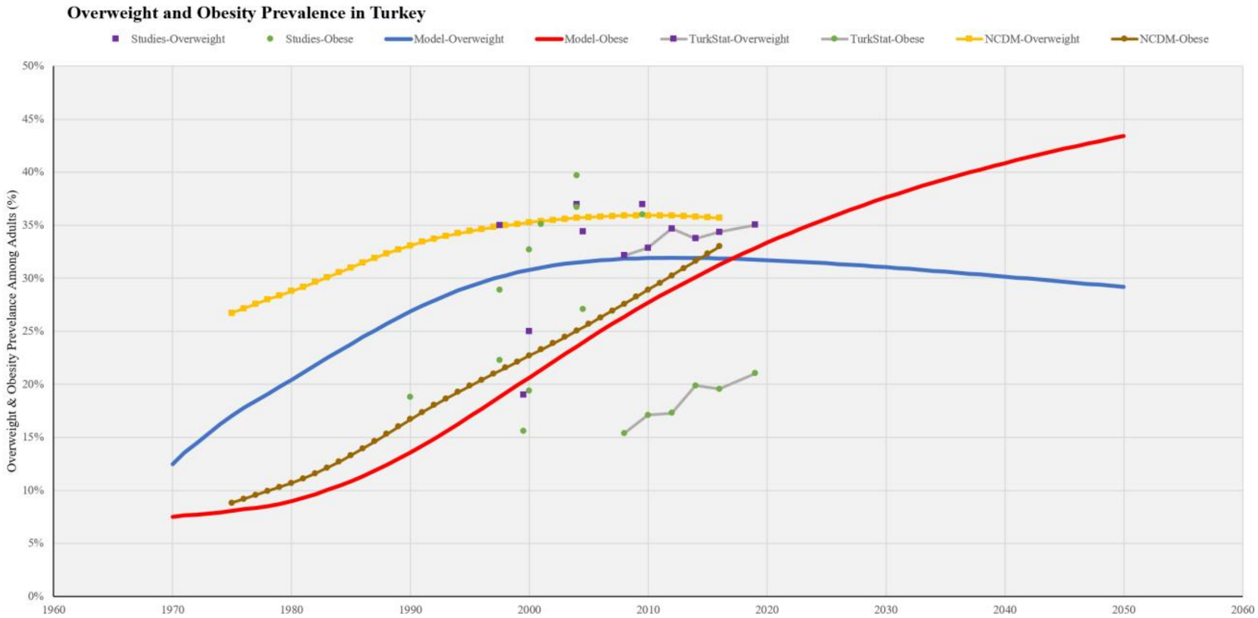

Figure 17 - Model Pattern

7. Model Behavior and Analysis

The model developed for the research is an attempt to approximate and mimic the real-world socioeconomic and physiological system that causes the obesity epidemic. When the model is simulated, it generates overtime data that describes this system not just in the past but also possible development into the future. Though, as mentioned earlier, the purpose of the model is not to predict future data points but the possible trend. Because the modeling technique that is used is a deterministic model which means that the model has no probability or randomness, and the result is determined by the initial conditions of the variables. Then, this technique provides a white-box model that allows to analyze how the behavior of the model occurs and to determine the key parameters that affect the system and the behavior.

How the system works endogenously is described in Chapter 4 and the theoretical framework is explained in Chapter 2.

7.1. Business-as-usual Simulation

Business-as-usual simulation describes the simulation run based on the default values and default condition of the system, without changing any parameter or value. The specification for simulation is as follows:

- Simulation software: Stella Architect, version 3.0.1
- Time horizon: 1970 - 2050
- Integration method: Runge-Kutta 4th order
- DT: 1/24

With default values, the behavior of the system can be observed with the main indicator which is obesity prevalence. These indicators can either be overweight and obese prevalence together comparing to rest of the population or separately as overweight and obese prevalence. Following graphs shows both indicator side by side.

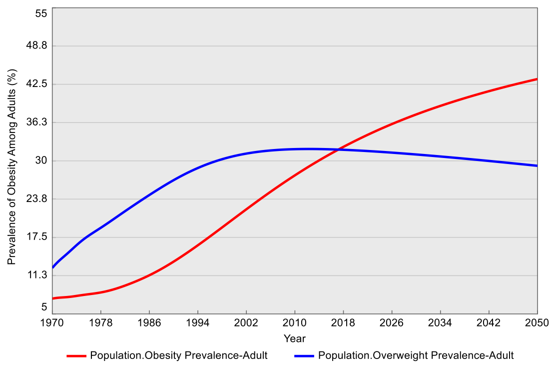

Figure 18 - Prevalence of Overweight and Obesity

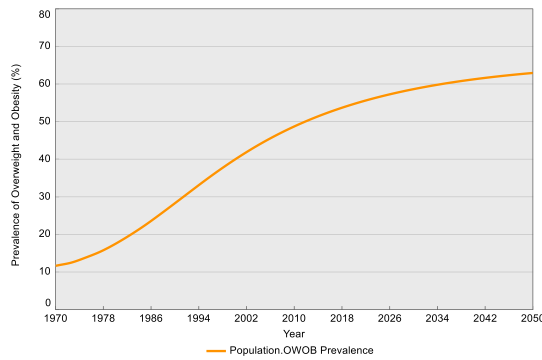

Figure 19 - OWOB Prevalence

As mentioned earlier, obesity prevalence includes overweight, obese, and morbid obese population. So, as it is seen in the graphs, both overweight and obesity is increasing among adult population. In 1970s, it is on the rise because as mentioned earlier, obesity started in 1950s. So, in the beginning it started slowly during the 1950s and continued to increase until this day. This trend in Turkey is coherent with other countries especially with the US but of course it is lagged due to Turkey's status of a developing country.

The shape of obesity and OWOB prevalence follows an s-shaped growth which is expected due to the internal weight gain mechanism of humans which puts a limit to weight gain hence the BMI change rate. Therefore, after some point, BMI change rate slows down and causes weight gain to slow down. And as the weight gain slows down, reinforcing value of food is also slows down, both due to slowing body weight change and the limits of the rest of factors that affect energy intake such as income and price level.

Overweight prevalence is also following an s-shaped behavior until it starts to decrease because overweight people become obese as they continue to gain weight. Even though the prevalence of OWOB slows down, it continues to increase because the obesogenic environment stays the same.

Figure 20 shows representative men and women's body weight overtime. Body weights are increasing almost linearly due to the increase in energy intake and decrease in energy expenditure.

It should be noted that these values represent average representatives, hence the aging is ignored. Another point is that representatives with normal weight gains weight much faster than overweight and obese individuals. This is also related to internal dynamics of body weight which indicates that it is easier to gain weight when there is not much fat tissue present.

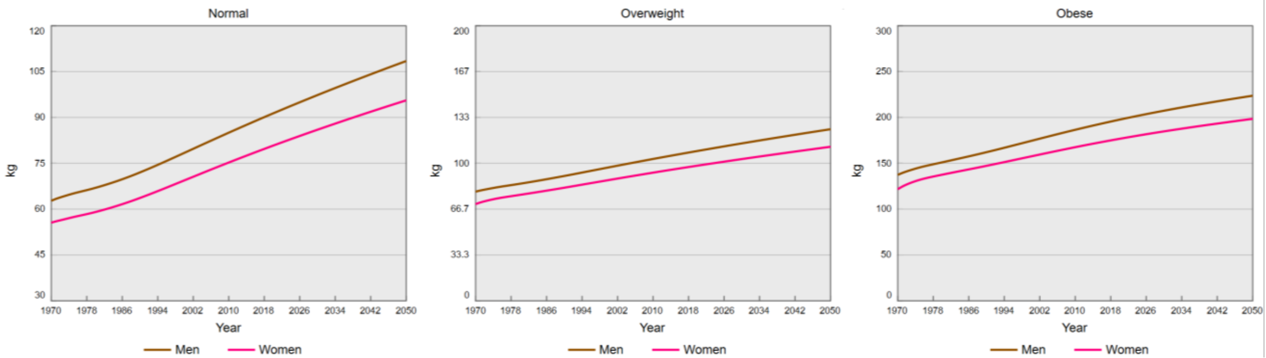

Figure 20 - Body Weight

Increase in body weight is only possible with increase in energy intake. The real-world data from UN FAO about available calories per day per person in Turkey can be seen below.

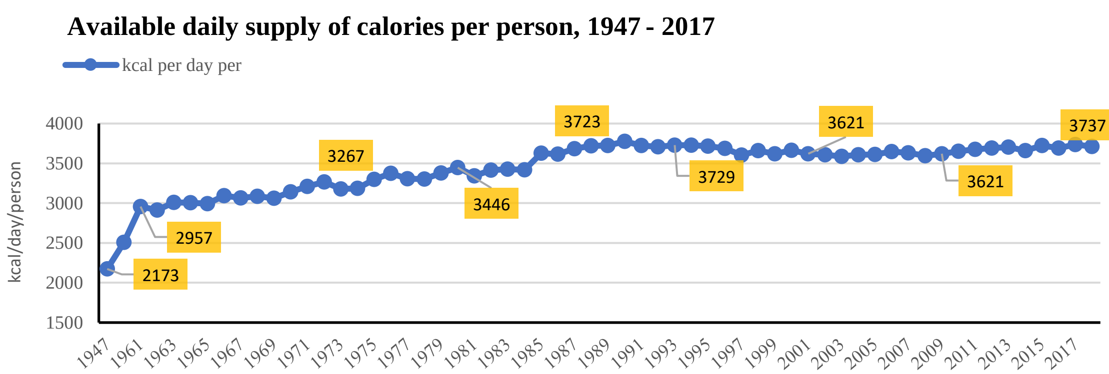

Figure 21 - UN FAO available calories per day per person in Turkey, 1947 - 2017

Figure 21 shows that the available calories per person after 1980's was around 3700 kcal. Figure 22 shows the average energy intake for men and women generated by the model.

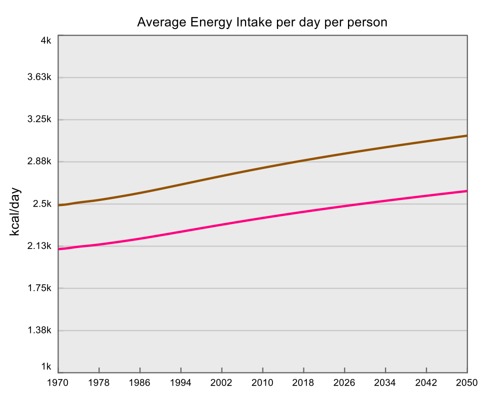

Figure 22 - Average Energy Intake

Since the data in Figure 21 is the available calories meaning that it is not necessarily the number of consumed calories, increase in energy intake generated by the model is possible. This increase in energy intake is the primary cause of weight gain. The factor for increase in energy intake is the decreased food price level, increased income and reinforcing value of food.

Liberalization policies in 1980s caused a rapid grow in Turkish economy. This development affected all parts of the socioeconomic life which led to a boost for weight gain as it can be seen in Figure 18 and Figure 19 for obesity prevalence. It has its reflection in food price levels.

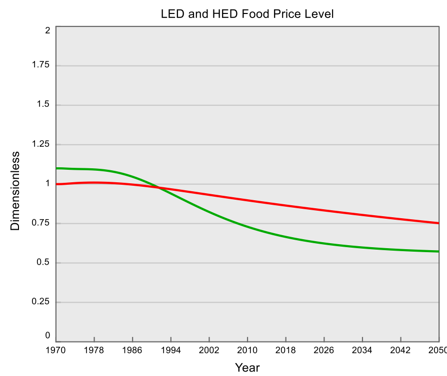

Figure 23 - Price Level of LED and HED Food

Figure 23 shows the change in price level. Already decreasing food prices starts to decrease faster after 1980. HED food price decreases faster because after 1980, Turkey received so many foreign direct investments from fast-food chains, all fast-moving consumer good (FMCG) brands entered Turkish market and Turkish factories were allowed to import raw materials and technologies to invest in food production. These developments led not only decrease in HED foods but also LED foods. Figure 24 and Figure 25 shows these investments generated by the model.

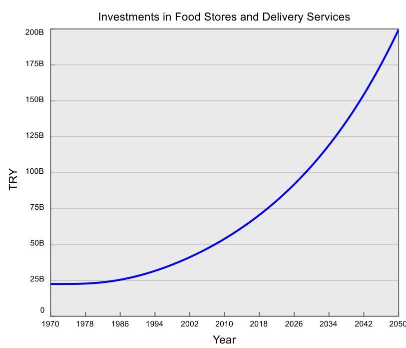

Figure 24 - Investments to Improve Food Availability and Accessibility

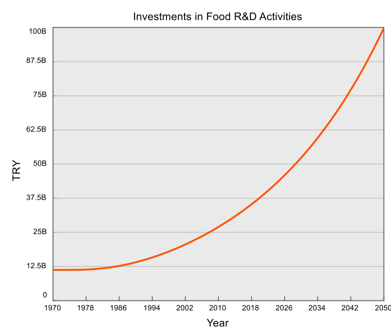

Figure 25 - Investments to Improve Food Attributes

These investments created the obesogenic food environment where the food is so easy to access, varied and cheap. This environment led to an increase in energy intake though at the same time, it shaped the perception of individuals towards the food through reinforcing food even more as it is explained previously. It is hypothesized that this almost free feeding environment is the primary cause for reinforcement pathology in varying degrees for growing number of people just as smoking.

Figure 26 and Figure 27 shows the relative reinforcing value of food for normal weight individual. The shape is similar for overweight and obese individuals, but the magnitude is larger due to initial conditions. Individual with normal weight is chosen to portray the behavior of important variables because the system is most sensitive to change in population with normal weight. It is because the population with normal weight is higher in the beginning, so their actions affect the system the most. So, observing the behavior overtime of variables related to representative individual with normal weight would be better to analyze the system.

Firstly, it is important to analyze how reinforcement pathology occurs in individuals with normal weight. The process and the paths are the same for overweight and obese individuals. Increase in RRV of food is the responsible factor for reinforcement pathology.

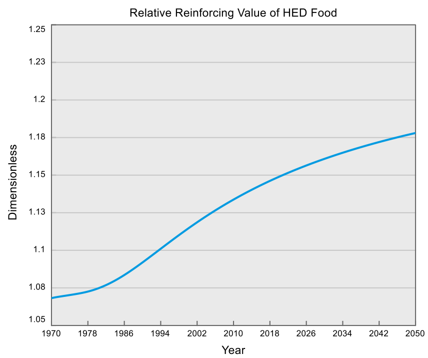

Figure 26 - Relative Reinforcing Value of HED Food

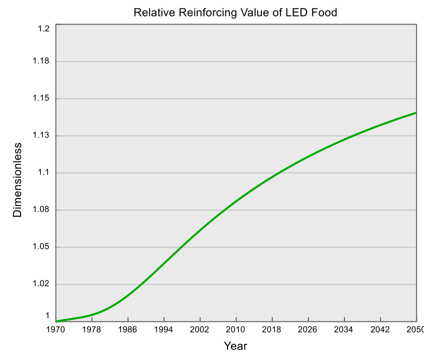

Figure 27 - Relative Reinforcing Value of LED Food

They start increasing slowly at first, then as the effects and body weight increases, they start to increase faster and faster until both weight gain, and environment effects from food environment starts to slow down, and as well as the reinforcing value of health increases. Following graph shows the increase in reinforcing value of food.

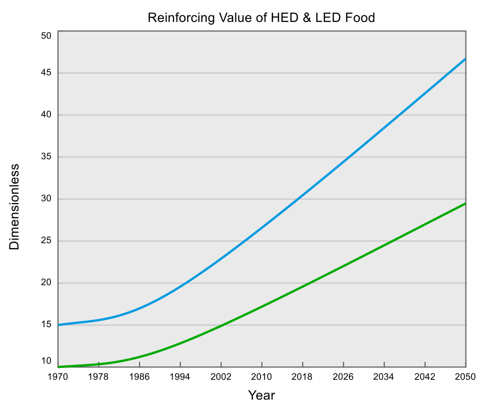

Figure 28 - Reinforcing Value of Food

Increase in reinforcing value of health limits the relative reinforcing value of food but as explained in dynamic hypothesis, relative to reinforcing value of food, it is lower. Hence, this situation gets worse and worse and leads to reinforcement pathology as shown with two reinforcing feedback loop feeds each other.

Reinforcing value of health is also slows down at some point because as the body weight increases, people delay discount more. Hence, it discounts the reinforcing value of health because health is a reward distant in the future.

As the reinforcement pathology persists due to environmental factors, individual will continue to consume more calories which will lead to increase in body weight.

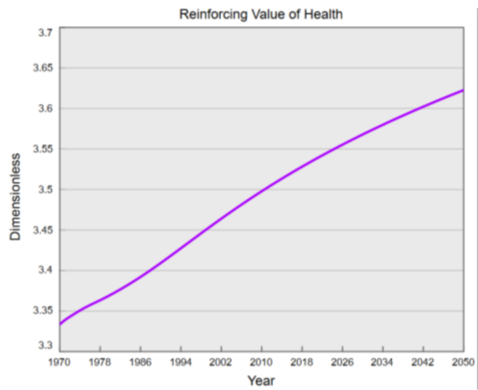

Figure 29 - Reinforcing Value of Health

Energy expenditure is the other determinant of body weight along with the energy intake. Energy expenditure can be divided into two as the energy being expended for the body functions and the energy for physical activity. The details are explained in Physical Activity Module subsection. Figure 30 shows the simulation result for how PAL changed overtime in average for all body weight categories.

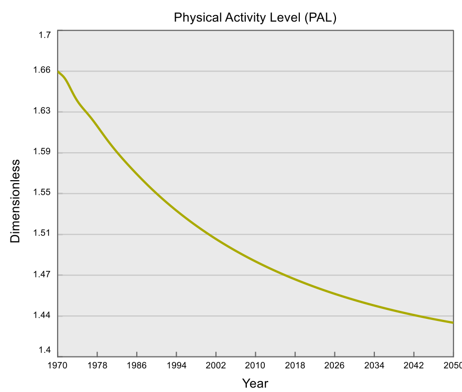

Figure 30 - Physical Activity Level

Decrease in PAL is the result of economic development which allowed most of the population to have access to kitchen appliances, public transportation, cars, computers, TVs, office works, and many others that leads to sedentary lifestyle. Thus, average energy expenditure from physical activity among the population has also decreased and it will continue to decrease as the technology advances. This situation causes the energy expenditure to stay below energy intake for all representative individuals since PAL directly influences the energy expenditure which leads to energy imbalance.

7.2. Scenario Analyses

This section will present some possible scenarios to analyze how system reacts to certain parameter changes with the aim of identifying the sensitive variables within the system that might help to identify the leverage points following the Donella Meadows' description of leverage points

(Meadows, 1998). Since policy structures and analyses are not the purpose of this research, the aim of this section is to experiment with parameter changes and provide some arguments that may provide insights to reader and policy makers.

For the experiments with the simulation model, no additional structures will be presented but instead, simple parameter changes and few additional parameters will be included to test some scenarios. Therefore, effect of the changes is immediate which is most likely not possible in real-world. Thus, these scenarios can be considered as hypothetical scenarios.

a. Scenario 1: Additional Taxes for Unhealthy Foods and Import Limitations

First, and most obvious solution for the obesity prevalence is to decrease energy intake since it is the primary cause of obesity. To do this, the food environment needs to be intervened. It is mostly suggested as additional taxes on unhealthy foods, most of the HED foods, are argued to deter individuals from calorie dense foods.

This policy recommendation is also mentioned in policy documents in Turkey against obesity and NCDs. To simulate this possible policy with the model a basic logic function added to Perceived HED Food Price Level to set the HED food price level to 1.1 with year 2023, to its initial level. However, this amount of increase would be so extreme in real-world, because usually these taxes are between 10% to 20% (Briggs et al., 2013; Falbe et al., 2016). Figure 31 shows the change in food demand with the scenario. Increase in price, can either be by additional taxes or other ways, causes decrease in HED food demand as intended but it also increases the substitute of HED foods which is LED food.

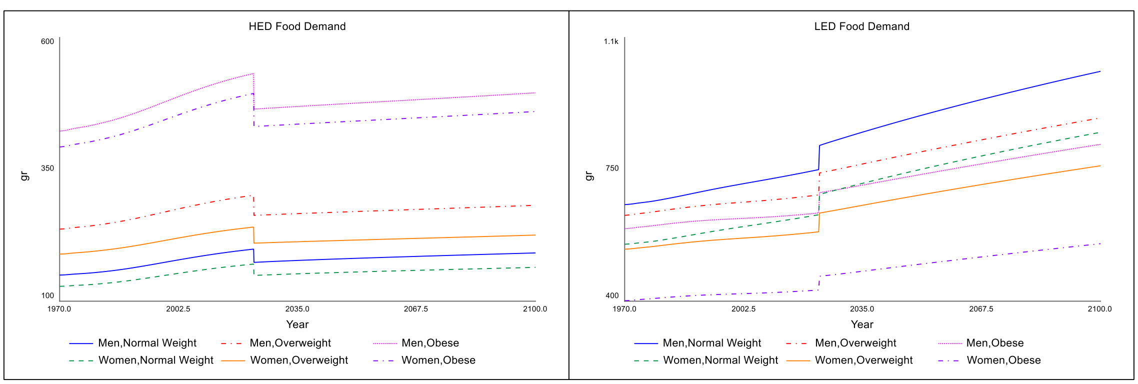

Figure 31 – Food Demand with Scenario 1

As expected, obesity prevalence decreased that increased overweight prevalence because obese people moved from obese to overweight category. This kind of effect is modelled and observed in other countries which a tax on sugar-sweetened beverages caused decrease in obesity by 1% to 3% (Briggs et al., 2013; Falbe et al., 2016; Veerman et al., 2016). This decrease might seem small, but it brings a lot of health benefits. Though, still, for reducing obesity, it might be said it is not enough.

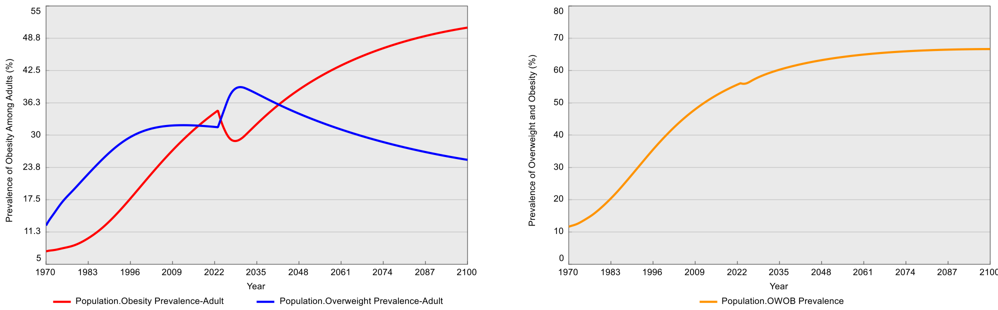

Figure 32 - Obesity Prevalence with Scenario 1

The decrease in obesity prevalence in the model does not last long. Of course, in the real-world situation things might be different though this kind of reaction has also pointed out by other studies (Cawley et al., 2019; Sacks et al., 2021). This behavior is mainly because of substitution effect, also the obesogenic environment is still in place. Therefore, energy intake is still increasing.

b. Scenario 2: Effective PAL Policy Scenario

Another test can be done for the outflow of the body weight, energy expenditure. For this test, increase in PAL tested which is a direct and controllable factor for energy expenditure. To test the effect of awareness raising campaigns and changing the environment to increase PAL of the population, again, a basic logic function is used to be effective with the year 2023. It is tested a hypothetical scenario where the PAL is increased from around 1.45, which is sedentary level, to moderately active level, 1.75. Figure 33 shows the PAL with the scenario.

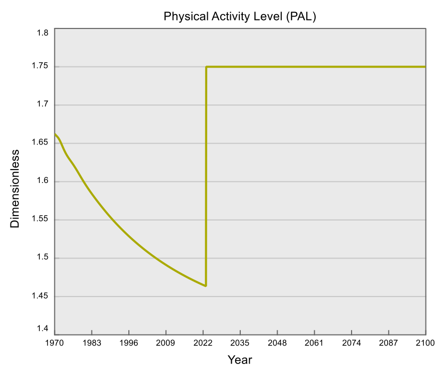

Figure 33 - PAL with Scenario 2

Figure *34* shows the effect of this policy on obesity prevalence. The model time horizon extended to 2100 to observe the long-term effects of this scenario.

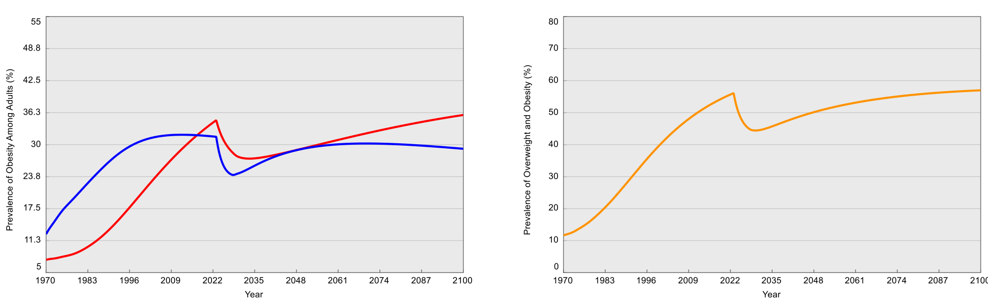

Figure 34 - Increase in PAL Scenario

As it is seen, obesity prevalence is decreasing initially but then it continues to increase because energy intake stays the same. The main reason for that is that the food environment is not affected, hence the reinforcing value of food is only affected a bit due to decrease in body weight.

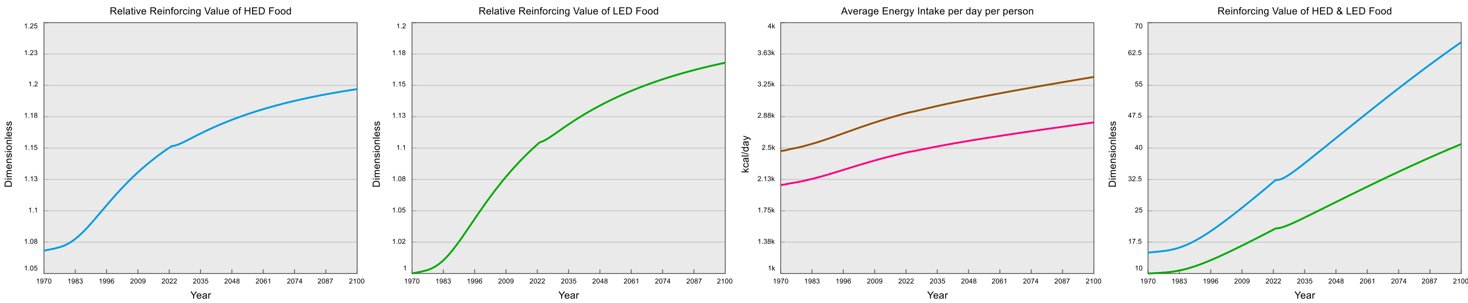

Figure 35 - RRV of Food with Scenario 2

a. Scenario 3: Combination of Scenarios

Then, two scenarios or policy options could be combined to see how it will affect the system. Figure 36 shows the effect of the combination.

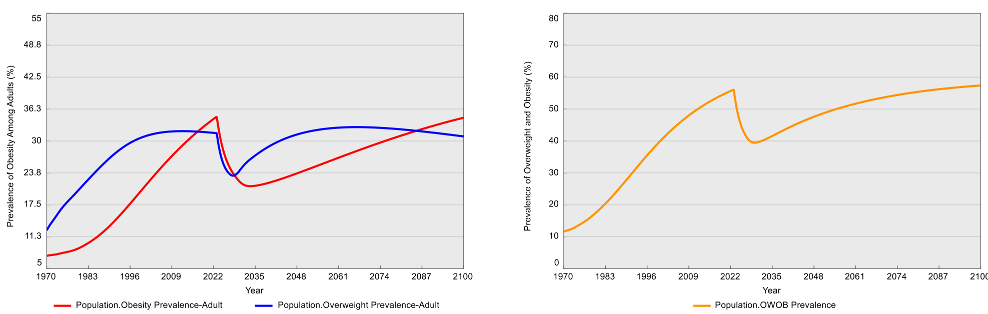

Figure 36 - Obesity Prevalence with Scenario 3

Again, obesity prevalence decreases at first but then, it begins to increase again due to reinforcing feedback loop that dominates food reinforcement still intact and obesogenic environment was not affected deeply.

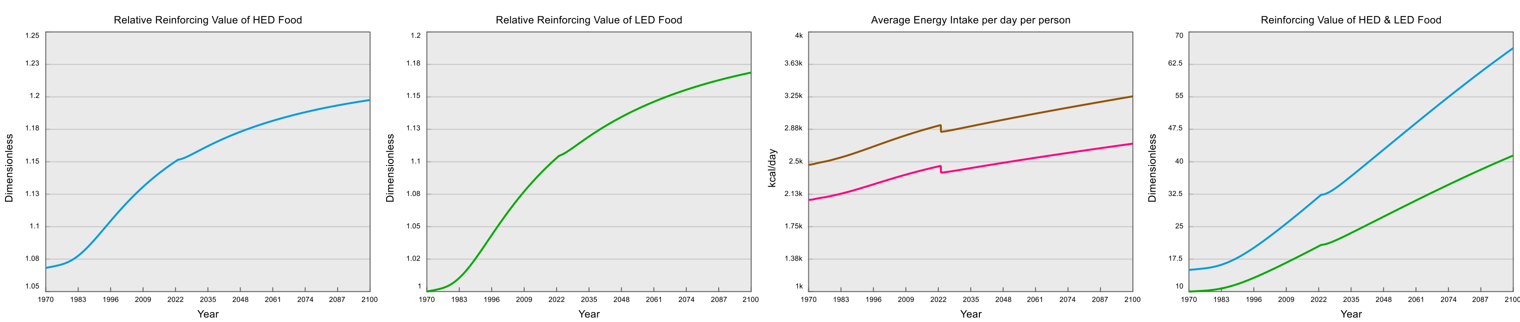

Figure 37 - RRV of Food with Scenario 3

More effective results can be observed if the parameters that are changed with the scenarios have increased even more aggressively. Though, as the environment that makes food an important reinforcer, it is not easy to achieve satisfactory results.

Even though these scenarios built extremely simplistically, as discussed in Introduction chapter, the real-world examples are not promising as well. Policies against obesity are useful in terms of improving overall health but they are not highly effective against reducing or preventing the obesity. In that sense, it seems to be the scenario results are coherent with the real-world.

c. Scenario 4: Influencing Individual Behavior through a Substitute

Scenarios explained above do not aim to change reinforcement pathology problem, even though they can affect reinforcement value of food slightly. This is mostly because it is extremely difficult to affect a reinforcer without limiting the access to this reinforcer or creating an alternative reinforcer, a substitute, or affecting the complements (Carr & Epstein, 2020; Epstein et al., 2004; Maas et al., 2012).

Therefore, this scenario aims to create a hypothetical situation where there is a policy to create a substitute for food, which is physical activity, as proposed by other scholars as well (Carr & Epstein, 2020; Epstein et al., 2004; Epstein et al., 1997; Epstein et al., 1995)

The last hypothetical scenario tests what if there is substitute for reinforcing value of food, for instance physical activity. In this scenario, it is assumed that there is a reward mechanism for increasing physical activity. Similar scheme is currently being evaluated in the UK by the Department of Health & Social Care which the pilot study has concluded and the results are yet to be published (*HeadUp Systems*, 2022; Throup, 2021).

It assumed that with 2023, substitute to food reinforcer is initiated. This reinforcer replaces the reinforcing value of health. Specifications for the scenario is as following:

Physical Activity Level	1.75 after 2023
Substitute Reinforcer initial value	30
Substitute Reinforcer initial reward delay	0.5

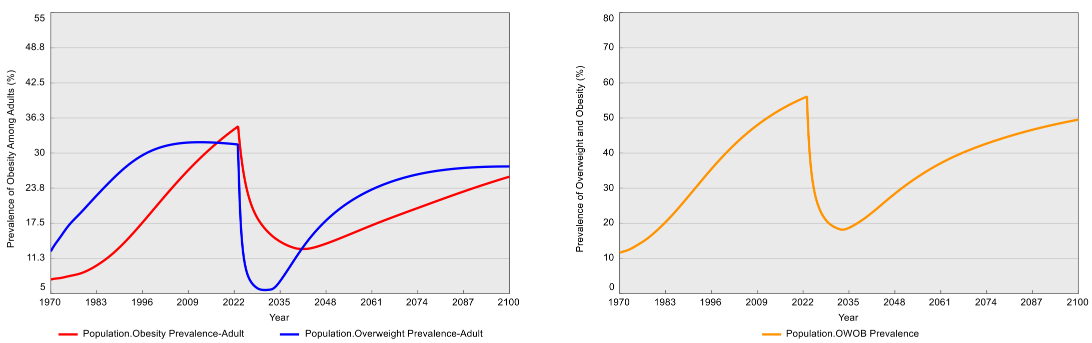

Figure 38 - Obesity Prevalence with Scenario 4

Figure 38 shows the result of the scenario 4. It seems to be more effective than the other changes since this parameter change affects relative reinforcing value of food directly via creating a substitute for it.

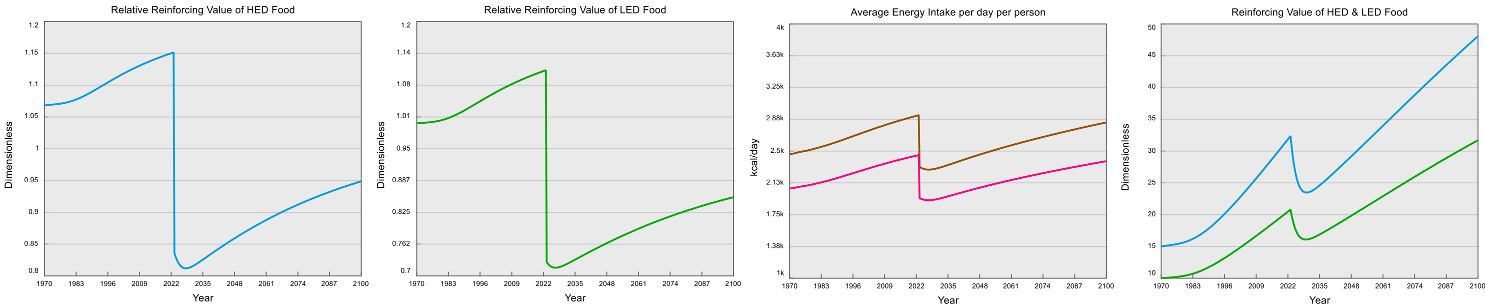

Figure 39 - Reinforcing value of Food with Scenario 4

But like other scenarios, prevalence of obesity begins to increase again after a certain point. The cause of this behavior is similar to others, what is affecting reinforcing value of food, which is food environment, is still not changed. In this scenario, individuals have still access to easy and cheap food and their budget allows them to purchase as much food as they need.

As discussed in the Introduction chapter, approaches that consider both part of the obesity problem: individual behavior and obesogenic environment. Without focusing both, the other reverses the gains that is achieved through policies affecting one part. Creating a substitute may not be the solution without policies to prevent increase in reinforcing value of food or reducing it.

7.3. Implications of Analyses and Discussions

It has seen that the obesity epidemic problem is extremely difficult to tackle due to characteristics of complex adaptive systems after analyzing the system through scenario analyses and experimenting with the model to observe behavior changes. Every scenario ended up with obesity epidemic persists at various levels. As emphasized earlier, these scenarios are not realistic due to their simplicity, but they provide an idea about how stubborn the obesity epidemic is.

Following the experiments and scenario analyses, some leverage points can be identified based on Donella Meadows’ framework (1998):

- **Weak negative feedback loops:** If negative feedback loops within a system are not strong enough relative to reinforcing feedback loops, the negative feedback loops cannot function properly to correct the unintended behavior. Within the obesogenic system following negative feedback loops are identified to be weak:
    - The main weak negative feedback loop is the physical activity negative feedback loop that should have been preventing the increase in body weight. Since this negative feedback loop is weakened by the environment, it cannot correct the overconsumption. Even though it seems to be the most obvious weak negative feedback loop, it is almost often underemphasized (Archer, 2018). Physical activity

requires more attention (Archer, Lavie, et al., 2013; Hand et al., 2015; Hill, 2006; Melby et al., 2019), especially in terms of reinforcement pathology (Carr & Epstein, 2020).

    - Another weak negative feedback loop is the substitute of the food reinforcer. In the model, it is represented by the health reinforcer, but it can be another reinforcer as well. Since food is a strong reinforcer, if there is a weak reinforcer present, the reinforcing feedback loop that increases the reinforcing value of food will be the dominant feedback loop.
- **Strong reinforcing feedback loops:** As explained earlier in the study, reinforcing feedback loops are the source of growth or decay. In this model, there are many reinforcing feedback loops that are dominant which leads to obesity epidemic.
    - Overall, the main reinforcing feedback loop is food consumption, as the body grows, more calories are needed. Origin of this feedback loop lies within our evolutionary heritage hence it may not be possible to intervene currently.
    - Reinforcing value of food is one of the important reinforcing feedback loops that increases the food consumption. Since there is no other reinforcer to balance this loop, reinforcing value of food is increasing almost uncontrolled.
    - Another reinforcing feedback loop is economic growth which might be the one root causes of obesity epidemic. With economic growth, disposable income per capita increases which allows individuals to purchase foods that they are willing to consume. Decrease in food prices can also be considered the part of this reinforcing feedback loop.
    - Increase in accessibility of food and improvements in variety and palatability of food are also other reinforcing feedback loops that originate from economic growth and influence reinforcing value of food.
- **Rules of the system:** As explained by Donella Meadows, rules of the system are the boundaries and degree of freedom within a system. For instance, the ban for marketing activities targeting children. Tough, there are some missing rules and regulations might help to tackle obesity epidemic.
    - Reward mechanisms regarding the physical activity and being lean might help to reduce reinforcing value of food by creating a substitute against food
    - Limiting the access to make it more difficult might reduce the consumption of food just like limiting the access to drugs, alcohol, and tobacco.

The main implication from the scenario analyses is that it is not easy to reduce or prevent obesity with focusing only one area of the problem which can either be the obesogenic environment or individual behavior. Focusing only one area to solve the problem would require extreme measures. Therefore, holistic, and synchronized approaches are required, focusing on changing the individual behavior through providing substitutes against food, such as physical activity, while changing the obesogenic environment to make it easy for individuals to access these substitutes and as well as reduce the strength of food as a reinforcer via identifying complements.

8. Conclusion

This study introduced a system dynamics approach to obesity problem arises from the dynamic interaction between the human and the environment via utilizing reinforcement pathology framework based on behavioral economics to explain how environment shapes ingestive behaviors of individuals, and how individuals shape the environment. To understand this dynamic interaction, firstly, the research provided a theoretical framework which combines behavioral economics and reinforcement pathology frameworks with the holistic view of systems thinking to understand underlying structure and interactions between different system parts of obesogenic environment and individual behavior. Secondly, in addition to the theoretical framework, the study presented an SD simulation model to analyze and demonstrate how obesity prevalence is increasing via endogenous dynamics of system parts and provided insights about the issues of current policies against obesity.

8.1. Summary of chapters and Answers to Research Questions

Chapter 1 explains the problem that this study addresses by providing background information about the current situation in Turkey as well as in other countries, and rationale for the policies against obesity. Also, this chapter briefly introduces the frameworks to be used in this study. In addition to formulation of the problem and the background, this chapter presents the research objective and research questions. In summary, the objective of this study was to investigate the underlying structure of obesity problem in Turkey and uncover the dynamic interactions through system dynamics approach via utilizing behavioral economics and reinforcement pathology frameworks. It has been found that the obesogenic system is an appropriate example of a complex adaptive system that indicates the multilevel interactions among system parts. This system requires system lens to analyze both individual and the environmental level interactions. This study developed a theoretical model and its mathematical simulation to analyze the obesogenic system and the resulting insights are described at end of the study.

Chapter 2 provides the review of relevant literature that answers the first research question of the study (*What are the physiological and socio-economic concepts/theoretical frameworks, related key variables, and their relations for obesity?*) in two parts. The first part of the literature review investigates theoretical background about obesity, human ingestive behavior and obesogenic environment and presents the main concepts and data from the literature which served as frameworks in the study. It was found that the reinforcement pathology framework which is based on behavioral economics provides crucial concepts to understanding human behavior aspects that shaped by the environment such as relative reinforcing value and delay discounting. These concepts are insightful to understand individual level decision-making in an obesogenic system. Based on these concepts, reinforcement pathology provides detailed insights about how exactly the obesogenic environment influences human behavior and provides a distinct perspective to direct attention on important feedback mechanisms responsible for obesity development. This part also provides explanations of these concepts of the study. The second part of the literature review presents available research focusing on existing system dynamics models about the study.

Chapter 3 explains the methodology followed through the study by giving details about the system dynamics approach and its process, data collection, and research ethics. As mentioned previously, the SD methodology is a powerful tool to analyze complex systems where the human and the environment interact. The methodological approach presented in this section resulted in describing the development of a theoretical model and its quantification through a computer simulation software.

Chapter 4 presents the dynamics hypothesis of the study through providing a theoretical model expressed as a CLD and analyzing the dynamic interactions within the system based on feedback loops identified. By explaining and identifying important feedback loops, this chapter answers the second research question (*Which dynamic interactions are important?*). It was found that there are significant feedback loops that require attention to understand the obesogenic system. In addition, feedback analysis also provided insights about where the obesogenic system originated and evolved over time. The influence of obesogenic system on individual behavior has also analyzed through feedback analysis. Overall, it has found that the system is dominated by multiple reinforcing feedback loops on both at the environmental and at the individual level. At the environmental level, economic growth, and resulting technological advancements is one of these feedback loops which caused obesity epidemic as an unforeseen consequence. This feedback loop allowed companies to invest in food stores and improving food attributes such as variety and palatability that created the free feeding environment where the individuals started adapting to this environment by overconsuming food. How this adoption occurred explained through analyses at the individual level. At this level, the underlying adaptation mechanism has explained through reinforcement pathology loop which has found that it is formed by two strong reinforcing feedback loops that feeds each other and one weak balancing feedback loop. Because of the environmental factors such as increasing purchasing power of consumers, decreasing food prices, varied and palatable food, food consumption became more reinforcing which led to increase in body weight and as body weight increased, strength of food consumption as a behavior reinforcer became even more reinforcing which in the end led to overconsumption. After this behavioral adaptation, individual behavior reinforced the environmental factor through increasing demand for energy dense, cheap, and varied food. Thus, it led to adaptation of the environment to the behavioral adaptation.

Chapter 5 introduces the quantified version of the theoretical model that answers the second research question *(How the concepts/theoretical frameworks about obesity and key variables can be represented and analyzed with an SD model?)*. Quantification of the theoretical model is presented through explaining each module, and structures within the modules via providing details about the main relations between system parts demonstrated in the form of equations. To quantify the model, data that has collected through literature review has used.

Chapter 6 provides details about model validation and various tests that conducted to verify that the model is valid both structurally and behaviorally. Then, data about obesity prevalence in Turkey collected from the literature is presented against the simulated behavior pattern produced by the model. Overall, the model produced a trend that is like other dynamic obesity models and projections from statistical models. After model validation, the behavior that the model generated was analyzed through several scenarios.

Chapter 7 presents the behavior of the model detail in two parts. First part explains the quantified model through simulating the model and presenting the generated behavior. This behavior showed that the overweight and obese population in Turkey is increasing as coherent with the data. As expected, the obesity boosted after liberalization policies after with 1980 due to increased free market conditions. Currently, overweight prevalence and obesity prevalence are close to each other. But in near future, obesity prevalence will go over overweight prevalence as average weight in the population increases. Even though the obesity prevalence is slowing down, prevalence will be high enough to become more of a burden on the society and economy. Second part provides some possible scenarios to analyze the model trough experimenting. Based on the observations after scenario analyses, leverage points for the system are presented which answers the fourth research question (*Which leverage points can be identified for better policy formulations based on the model?*). Donella Meadows' framework utilized to identify leverage points of the system. One of the key leverage points within the system is the uncontrolled reinforcing feedback loops especially the one that is active in reinforcement pathology. It might be helpful to intervene this feedback loop by adding a substitute, such as physical activity, which could act as a balancing feedback loop which might decrease the relative reinforcing value of food that will lead to decrease food consumption. Because other dominant reinforcing feedback loops at the environmental level such as economic growth, purchasing power of individuals or companies' investments are not easy to intervene and they require strong measurements which may end up creating inequalities among susceptible groups.

Chapter 8 presents the conclusion for the study, findings and reflections of the study, a summary for each chapter, and limitations as well as possible further work needed to be done. One of the important findings was the usefulness of holistic approaches due to nature of the obesity problem. Since there are multiple actors interacting with each other, it is crucial to see the system holistically to identify leverage points to intervene. As another important finding is to focus on all levels of the obesogenic system because without understanding the adaptive capabilities of the system at all levels, especially individual level, could cause policy resistance or unintended consequences when implementing policies to tackle the problem. This possible because behaviors of the agents/actors within the system co-evolve and reinforce each other and interact with the environment. The study also highlights some of these possible unintended consequences such as nutritional deficiencies among low-income groups by increasing unhealthy food prices, increasing inflation rate even further, and damaging the food security for middle- and low-income groups.

8.2. Findings and Reflections

The findings and reflections of this research are, without a doubt, highly related to the system dynamics methodology. Thus, it is inevitable to present findings and reflections of this research based on the insights and value-added of system dynamics in the context of the obesity epidemic. These findings and insights can be summarized as:

- Even though human beings have managed to slow down the natural selection process, they are still a part of the nature. Obesity was always a part of human nature, but it was not apparent until the technological developments allowed humans to produce excess amount of food. Holistic approaches of systems thinking, and system dynamics offer an opportunity to see obesity epidemic as a part of larger socio-economic system which is a result of human-nature interaction. This perspective allows us to understand how obesity as problem is developing overtime through endogenous causal feedback loops and which parts of this system can be influenced by us. Some feedback loops may be beyond humans' influence. For instance, with the current technology, it is not possible to stop excess energy to be stored as fat tissue.
- Obesity is an unforeseen consequence of the developments in modern history. Without thinking in feedback loops, it may not be possible to foresee effects of actions. Causal relation between economic development and technological advancements generated a socio-economic environment (obesogenic environment) that caused obesity epidemic. Understanding problems within a system can provide us opportunity to mind the consequences of our actions. Hence, it is important to consider the possible unintended consequences of the policies to be implemented against obesity. One of the unintended consequences might be the higher inflation rates due to increased prices of high energy dense foods especially for a country that has a fragile economy such as Turkey. Related to this consequence, another one might be damaging the food security of middle- and low-income groups.
- Developing a theoretical simulation model capturing causal feedback loops based on data about system components help us to understand the obesity as a system. Via quantifying this theoretical model, we can identify important feedback loops and assess their influence on the system. In this study, it is showed that the uncontrolled reinforcing feedback loop in RRV of food is an important feedback loop.
- Since obesity is tightly related to our socio-economic environment, which is almost a free-feeding environment, and food is a very strong reinforcer, it is not easy to alter this environment and lead individuals to consume less food. Any extreme measure may result

in inequalities among different socio-economic groups. For instance, high taxes in unhealthy food may lead to nutritional deficiencies among individuals who belong to low-income groups.

- There is a causal relation between individual behavior and environment. Hence, understanding this causal relation is crucial to tackle obesity problem. With focusing only one aspect of this relation will not be enough.
- Reinforcement pathology with behavioral economics is a useful theoretical framework to understand individual dietary behavior which is the individual behavior aspect of the obesity epidemic and how the obesogenic environment shapes this behavior. In that sense, policies planned to alter the obesogenic environment should also be providing alternative reinforcers against the value of the food consumption. Also, they need to consider the complements of increased food consumption such as inactivity or stress related problems.
- Since obesity system is a complex adaptive system, it is significant to identify the key actors within the system. On the top level, it is seen that the government, companies, and individuals are the important actors though most of the policies put emphasizes on either companies or individuals though due to system's adaptive capabilities, it is important for policies to cover all levels of the system.

8.3. Research Limitations and Further Work

Like any other research, this research has several limitations. This subsection presents these limitations and provides further work needed to be done to improve the insights of this research.

- Availability and validity of the existing data is a limitation for this research as well as for any other health related research. The data about obesity is relatively scarce outside of the US and the UK. In Turkey, only data points are available collected from different studies. Therefore, it is challenging to assess the trend of obesity (Lien et al., 2010). In addition, validity of this data is also debated (Archer, Hand, et al., 2013; E. Archer et al., 2018) The validity of the data collected by the US is important because health data is collected more or less the same way in other countries as well. Thus, with better surveillance and data collection, more accurate models can be developed.
- Some initial values of the model are based on estimations of the author due to lack of data. Especially the initial values in Individual Module are estimations based on studies conducted in the US. Hence, studies about reinforcing value of food in Turkey are necessary to have more accurate model. But it is possible that the values would be similar due to food is same as a reinforcer for humans.
- Another important limitation is the aggregated structure of physical activity. Physical activity is often neglected in obesity research (Edward Archer et al., 2018), except providing policy recommendation about physical environment and awareness raising to be

more active. Though, physical activity provides more opportunities than just an outflow for energy balance (Hand et al., 2015; Melby et al., 2019; Ostendorf et al., 2019).

- The study does not provide any detailed policy structure other than intervention entry points to better inform policy makers about possible effective policies. Therefore, the future work of this study requires a focus on policy structures and implementations.
- Related to policy structure, future work should also include structures to measure both the economic and social burden of obesity through healthcare expenditures, death rates and possible prevented NDCs.

Despite the above-mentioned limitations, this research sheds some light in to understanding the obesity problem as a complex adaptive system. Applying a system dynamics perspective that includes behavioral economics and reinforcement pathology frameworks, dynamic interactions between various levels of the obesogenic system can be revealed.

9. References

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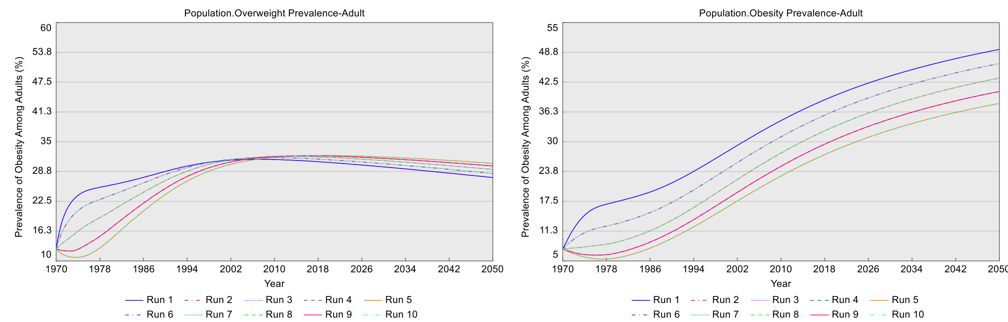
Appendix

I. Sensitivity Test Results

SENSITIVE VARIABLES

Physical Activity Module

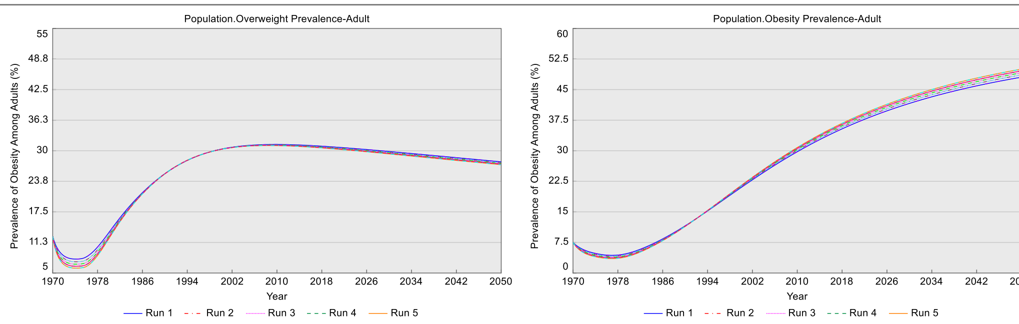
Normal PA Coefficient



Tested Range: 5.6 - 8.4

The behavior of the model is sensitive to change as expected since it determines the amount of energy expenditure based on PAL.

Sensitivity of Physical Activity Level to GDP (α7)

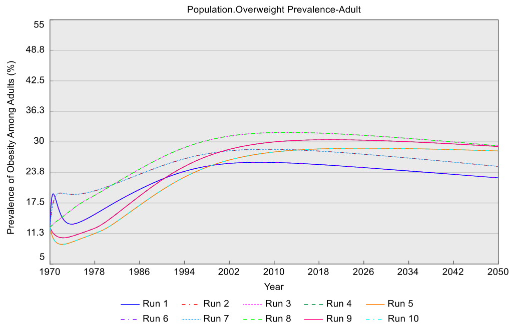


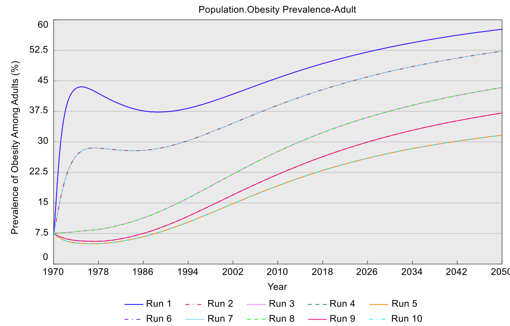
Tested Range: 0.96 - 0.64

The behaviors are sensitive with values change in between each tested value as expected since it determines the initial values of PAL. However, there is no meaningful change on behavior pattern except the initial.

Body Weight Module

Average Height, Men

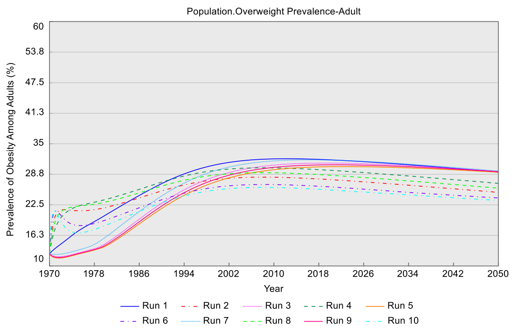


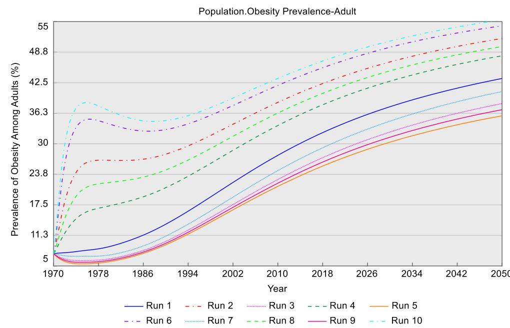


Tested Range: 1.36 - 2.04

The behavior of the model is sensitive to change as expected since it is a direct factor for BMI.

Average Height, Women

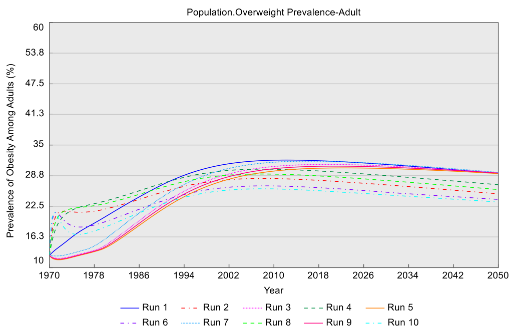


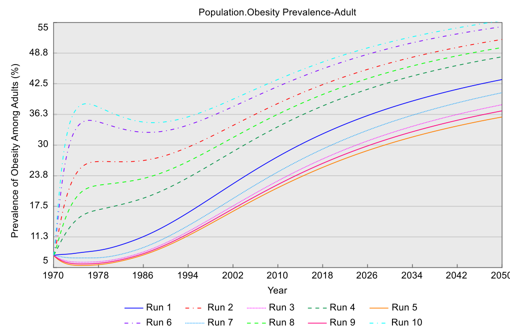


Tested Range: 1.28 - 1.92

The behavior of the model is sensitive to change as expected since it is a direct factor for BMI.

k-constant day Normal Weight, Overweight, Obese

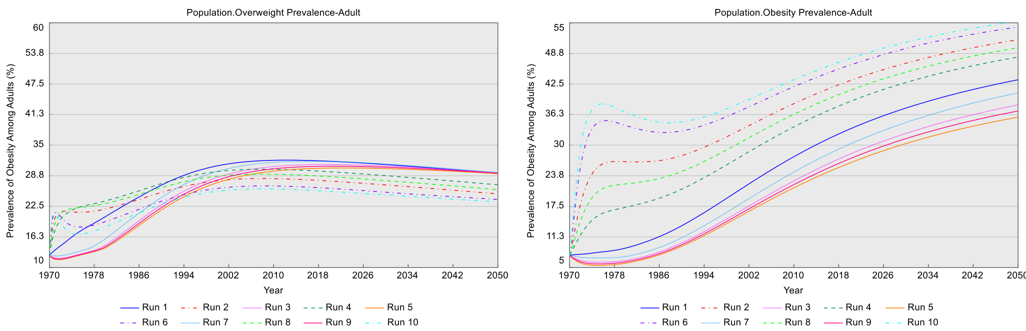




Tested Range: 1.28 - 1.92

The behavior of the model is sensitive to change as expected since the value directly affects the energy expenditure.

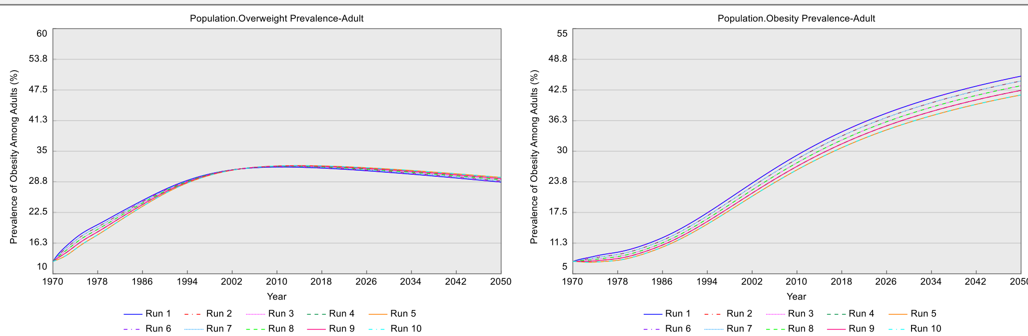
RMR Regression Coefficient of FFM (γ)
Normal Weight, Overweight, Obese



Tested Range: 17.6 - 26.4

The behavior of the model is sensitive to change as expected since the value directly affects the energy expenditure as resting metabolic rate.

RMR Regression Coefficient of FM (γ)Normal Weight, Overweight, Obese

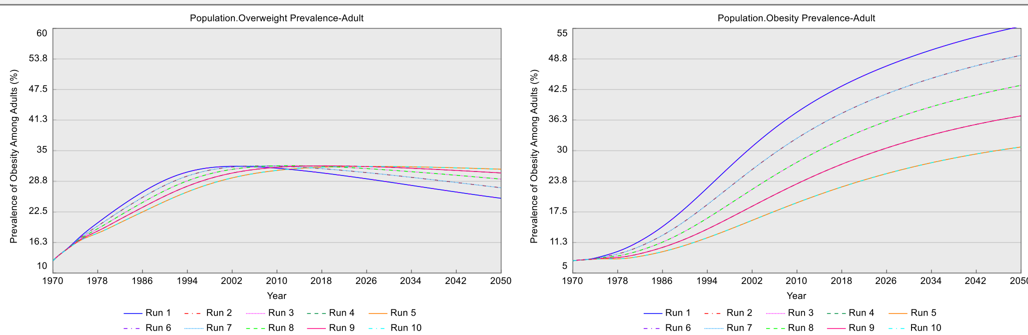


Tested Range: 2.56 - 3.84

The behavior of the model is slightly sensitive to change as expected.

Economy Module

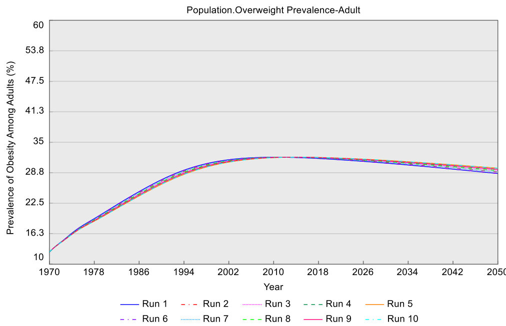
Government Income Delay

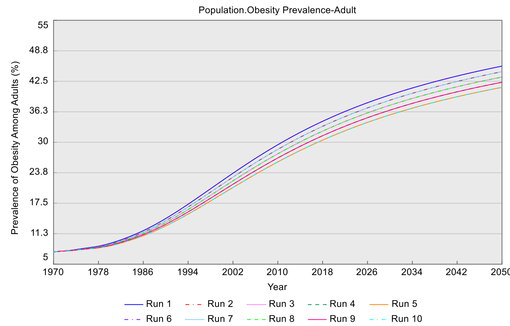


Tested Range: 0.8 – 1.2

The behavior of the model is sensitive to change as expected since the delay in government income affects aggregate demand which affects GDP

Change in GDP Delay

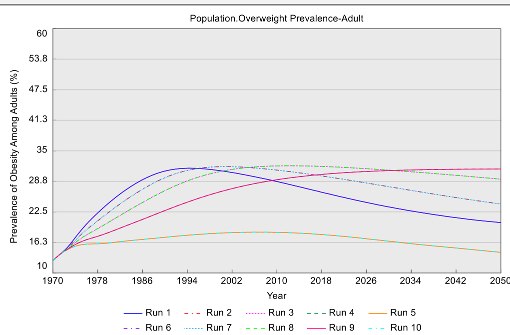


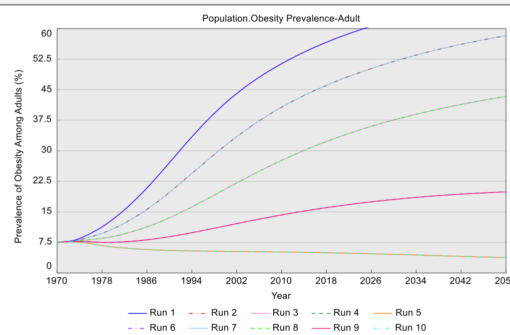


Tested Range: 0.8 – 1.2

The behavior of the model is slightly sensitive to change as expected since the delay in directly affects GDP

Change in revenue delay

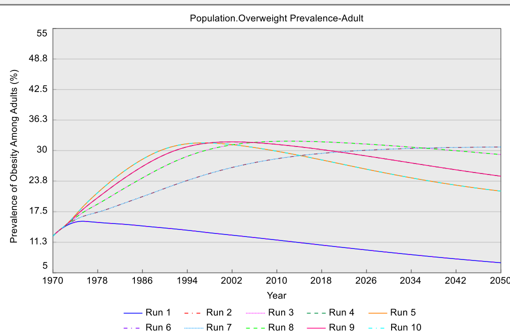


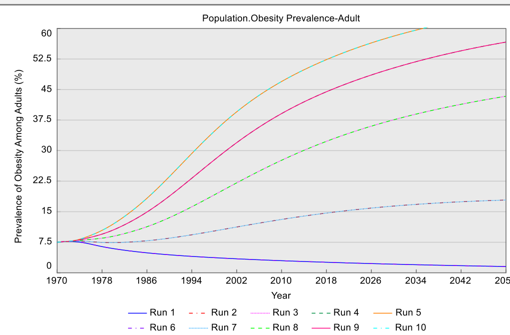


Tested Range: 0.8 – 1.2

The behavior of the model is sensitive to change as expected since the delay is directly affecting the GDP through aggregate demand

Change in expenditure delay

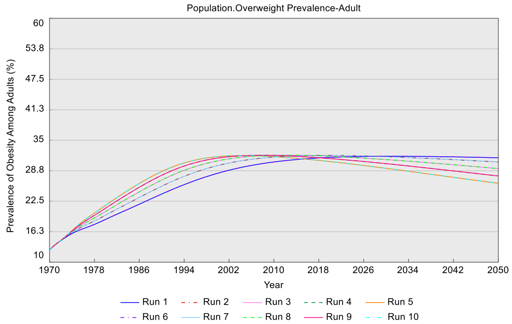


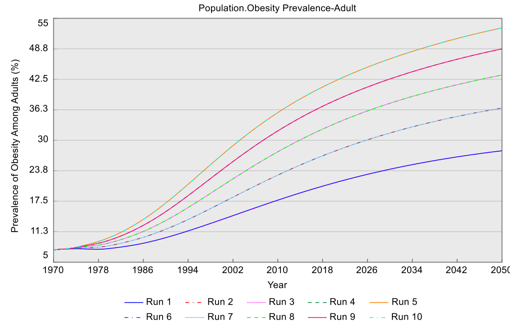


Tested Range: 0.8 – 1.2

The behavior of the model is sensitive to change as expected since the delay is directly affecting the GDP through aggregate demand

Change government expenditure delay

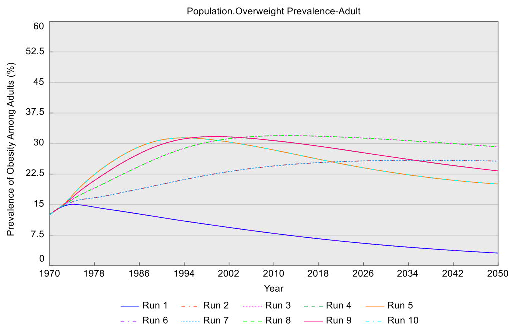


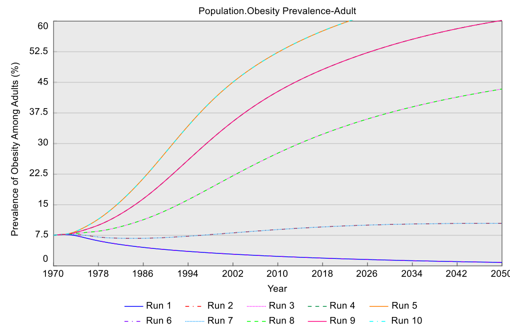


Tested Range: 0.8 – 1.2

The behavior of the model is sensitive to change as expected since the delay in government income affects aggregate demand which affects GDP

Labor Share

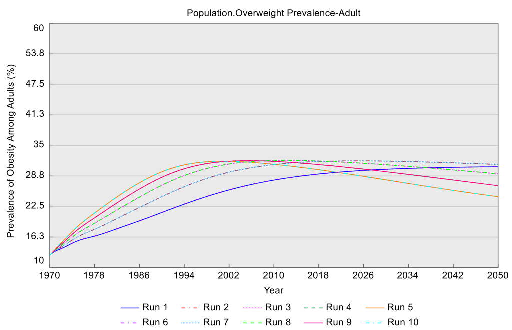


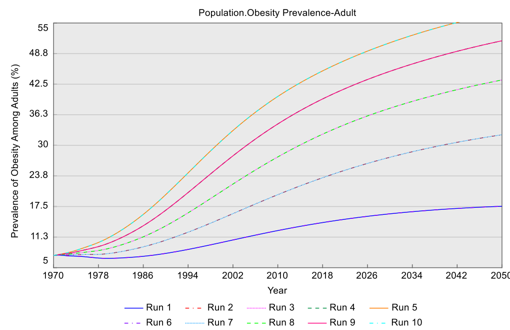


Tested Range: 0.64 - 0.96

The behavior of the model is overly sensitive to change as expected since this value affects the income of consumers which affects demand as well as GDP

Propensity to Invest

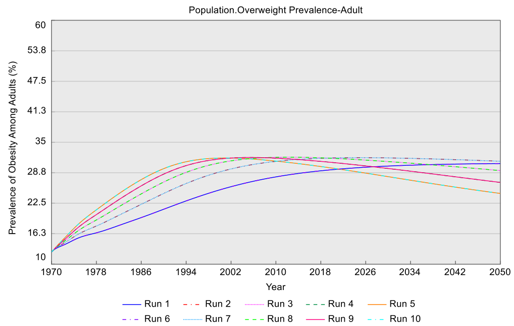


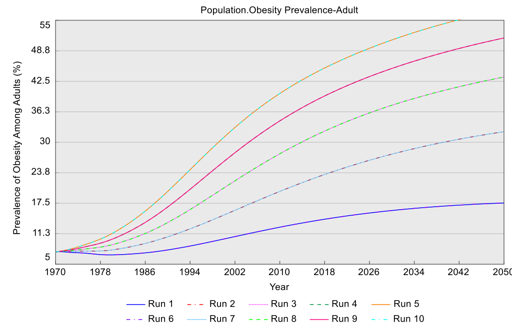


Tested Range: 0.24 - 0.36

The behavior of the model is extremely sensitive to change as expected since this value affects the investment of firms of which affects demand as well as GDP also food environment

Propensity to Invest

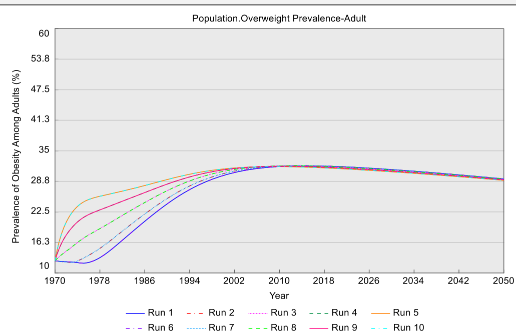


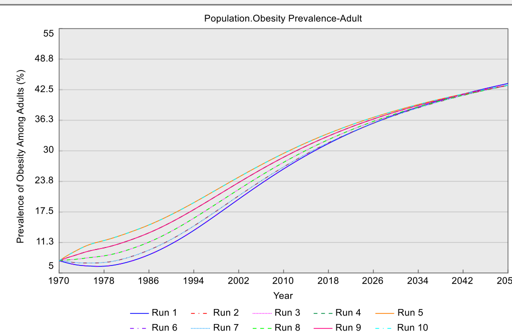


Tested Range: 0.24 - 0.36

The behavior of the model is extremely sensitive to change as expected since this value affects the investment of firms of which affects demand as well as GDP also food environment

Maximum Effect of Investments in Food R&D Activities (L2)

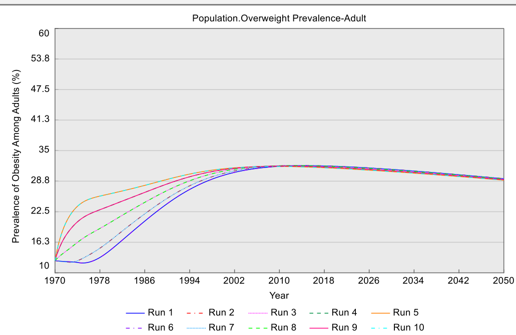


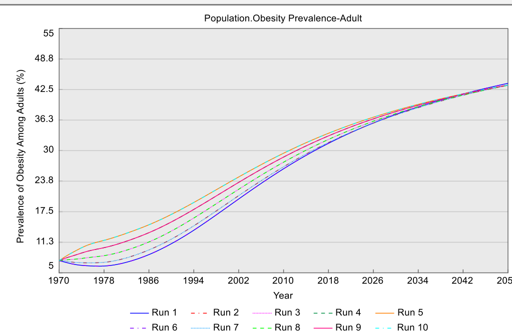


Tested Range: 1.6 – 2.4

The behavior of the model is sensitive to change as expected since this value indicates the maximum number of the effect to RRV

Maximum Effect of Investments in Food Stores and Delivery Services (L1)

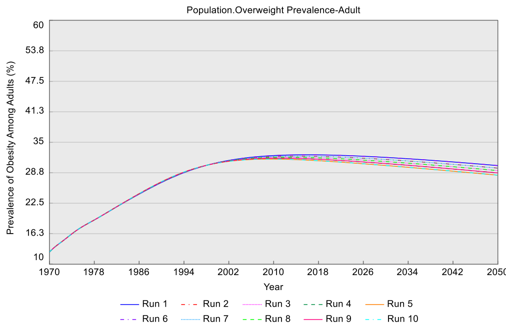


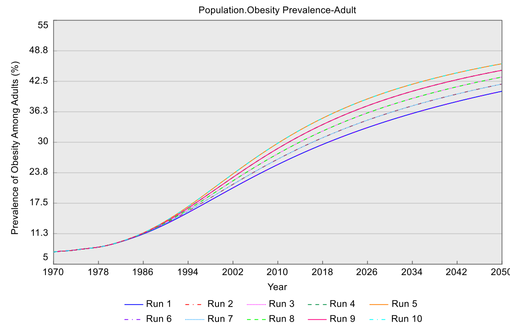


Tested Range: 1.6 – 2.4

The behavior of the model is sensitive to change as expected since this value indicates the maximum number of the effect to RRV

Price elasticity of HED Food (θ6)

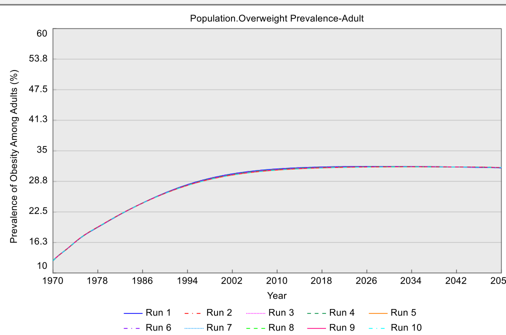


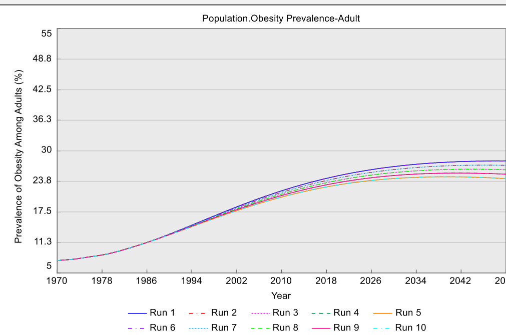


Tested Range: -0.2 - -0.3

The behavior of the model is slightly sensitive to change as expected since this value indicates amount of change in food demand based on price

Price elasticity of LED Food (θ7)



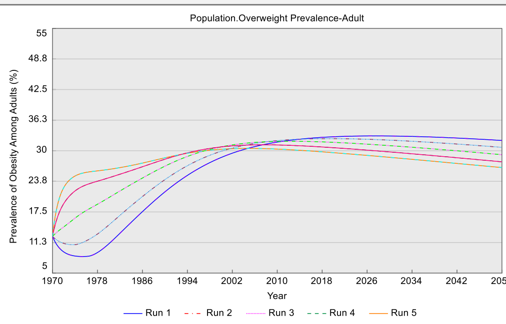


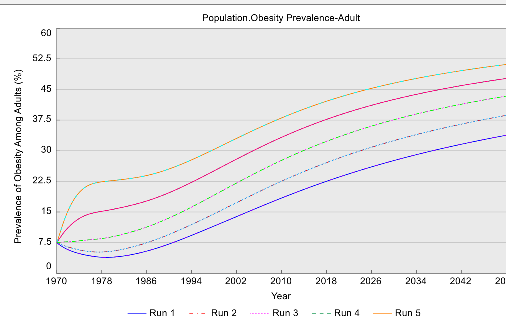
Tested Range: -0.16 - -0.24

The behavior of the model is slightly sensitive to change as expected since this value indicates amount of change in food demand based on price

Individual Decision-Making Module

Energy Density of HED Food

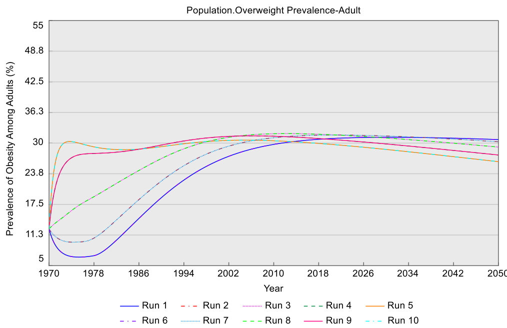


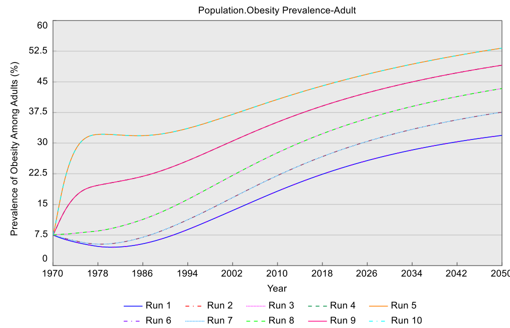


Tested Range: 3.6 - 5.4

The behavior of the model is sensitive to change as expected since this value determines the calorie per gram of HED food which directly affects the energy intake

Energy Density of LED Food

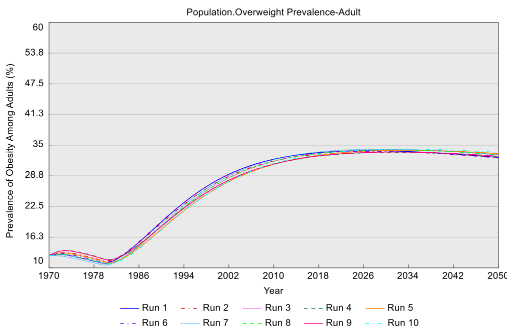


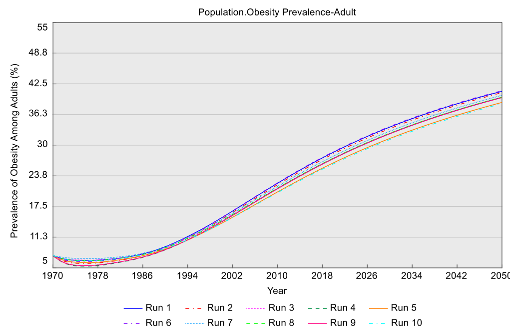


Tested Range: 1.6 - 2.4

The behavior of the model is sensitive to change as expected since this value determines the calorie per gram of LED food which directly affects the energy intake

Initial Health Reward Delay Normal / Overweight / Obese

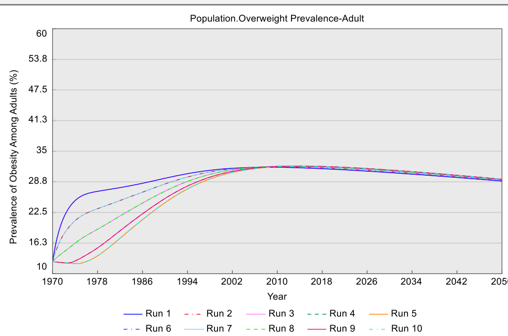


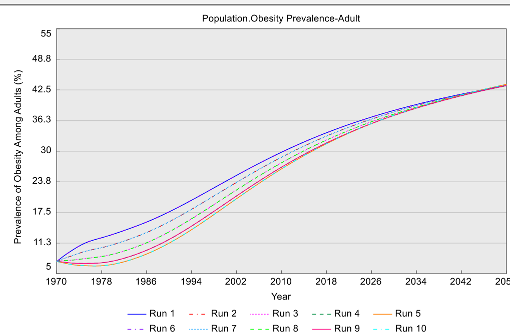


Tested Range: 1.6 - 2.4 / 2.4 – 3.6 / 3.2 – 4.8

The behavior of the model is sensitive to change as expected since this value determines the reward delay for health and as the delay increase, individuals increase their consumption and vice versa.

Initial Reinforcing Value of Health Normal / Overweight / Obese

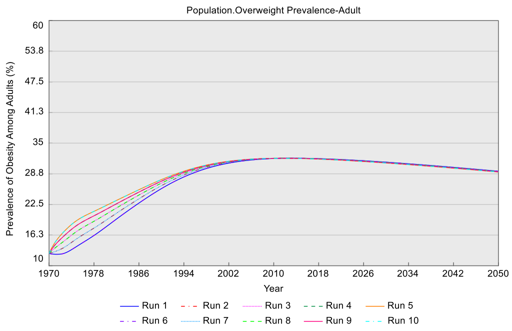


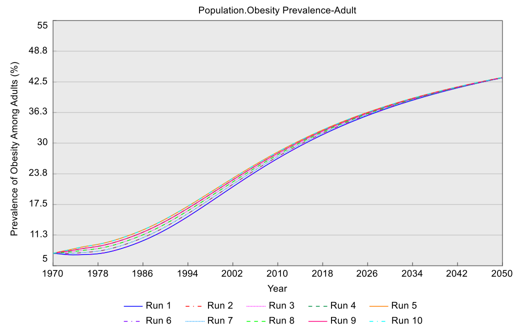


Tested Range: 8 - 12

The behavior of the model is sensitive to change as expected since this value determines the initially how valuable the health is: if health is less valuable initially, then food consumption will increase and vice versa

Initial Reinforcing Value of HED Food Normal / Overweight / Obese

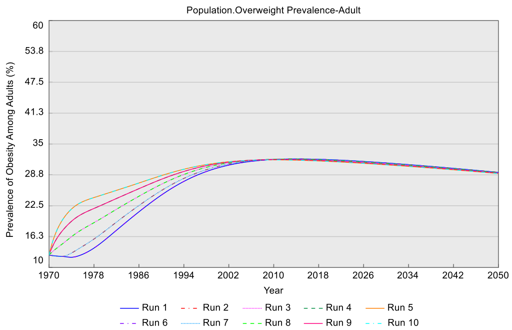


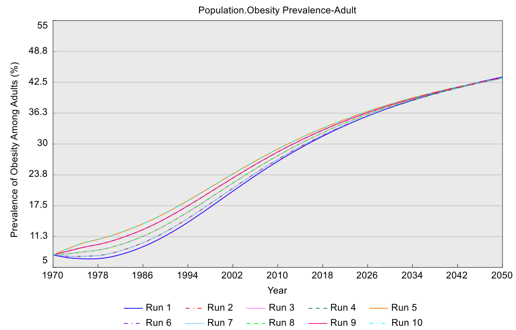


Tested Range: 12 - 18 / 28 - 42 / 36 - 54

The behavior of the model is slightly sensitive to change as expected since this value determines the initially how valuable the HED food is.

Initial Reinforcing Value of LED Food Normal / Overweight / Obese

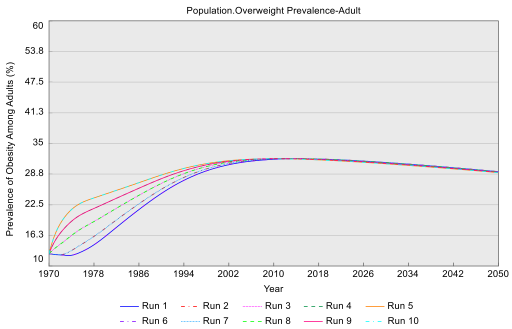


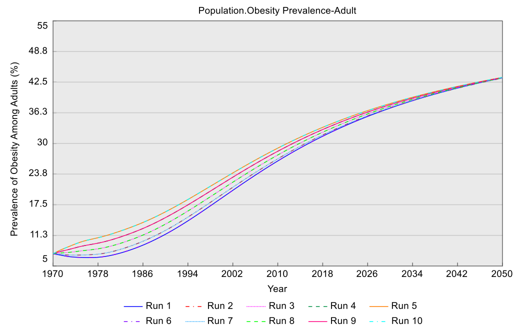


Tested Range: 8 - 12 / 16 - 24 / 20 - 30

The behavior of the model is sensitive to change as expected since this value determines the initially how valuable the LED food is. It is a bit more sensitive comparing to initial reinforcing value of HED food is because LED is consumed more in quantity.

k

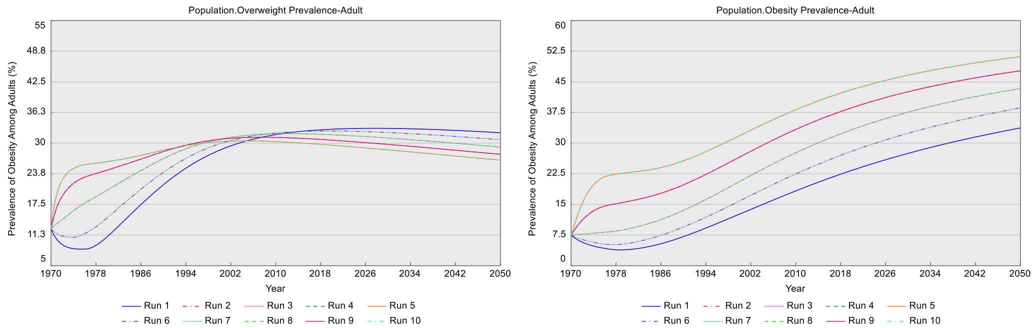




Tested Range: 0.8 – 1.2

The behavior of the model is sensitive to change as expected since this value determines the delay discount factor for both food and health rewards

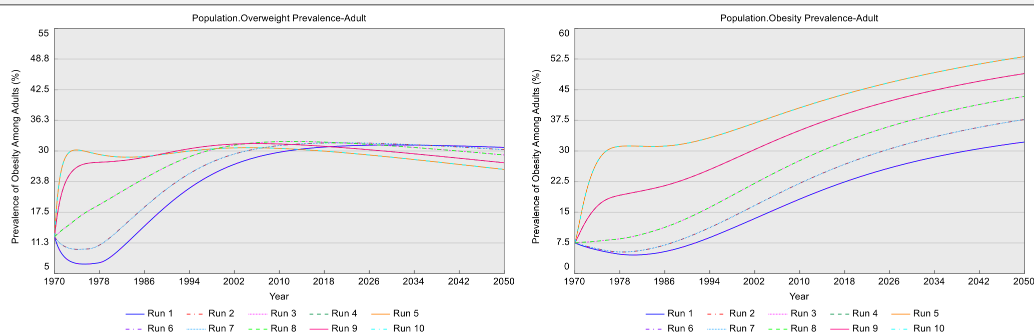
Maximum Effect of Disposable Income on HED Demand (L7)



Tested Range: 1.6 – 2.4

The behavior of the model is sensitive to change as expected since this value determines the amount of food that an individual could buy based on their disposable income

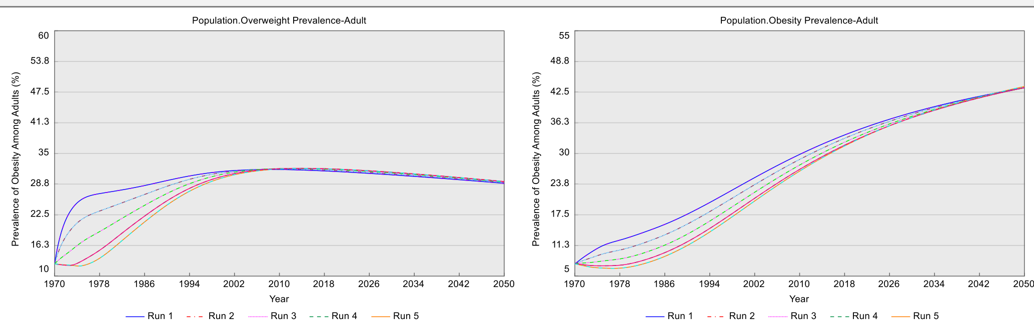
Maximum Effect of Disposable Income on LED Demand (L6)



Tested Range: 1.6 – 2.4

The behavior of the model is sensitive to change as expected since this value determines the amount of food that an individual could buy based on their disposable income

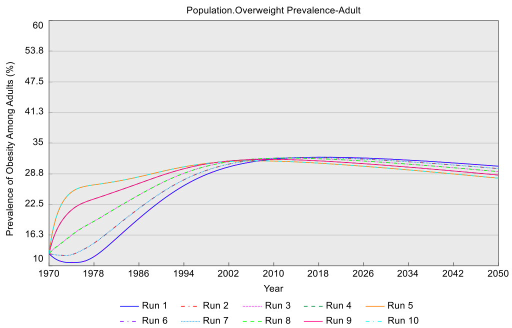
Sensitivity of Reinforcing Value of Health to Body Weight (θ10) Normal / Overweight / Obese

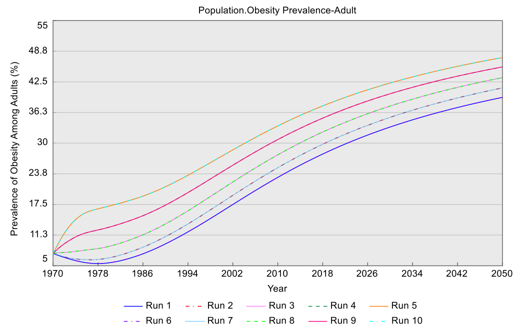


Tested Range: 0.4 – 0.6

The behavior of the model is sensitive to change as expected since this value determines the initially how valuable the health is: if health is less valuable initially, then food consumption will increase and vice versa

λ Normal / Overweight / Obese





Tested Range: 0.2 – 0.3

The behavior of the model is sensitive to change as expected since this value determines the amount of food consumption based on the relative reinforcing value of food, so a percent change in this number directly effects the number of consumed foods

INSENSITIVE VARIABLES		
Insensitive Variables	**Tested Range**	**Result**
Physical Activity Module		
Sensitivity of Physical Activity Level to GDP (α7)	0.8 – 1.2	The behavior of the model is insensitive as expected
Sensitivity of PA Coefficient to PAL (θ13)	0.8 – 1.2	The behavior of the model is insensitive as expected
Maximum Effect of GDP on PAL (L7)	0.12 - 0.18	The behavior of the model is insensitive as expected
Normal PAL	1.4 - 2.1	The behavior of the model is insensitive as expected
Body Weight Module		
Energy cost for FFM Deposition (μ) Normal Weight, Obese, Overweight	184 - 276	The behavior of the model is insensitive as expected
"Energy cost for FM Deposition (μ) Normal Weight"	144 - 216	The behavior of the model is insensitive as expected
Energy Density of FFM Normal Weight, Overweight, Obese	1440 - 2160	The behavior of the model is insensitive as expected
Energy Density of FFM Normal Weight, Overweight, Obese	7520 - 11280	The behavior of the model is insensitive as expected
Forbes' Body Composition Coefficient Normal Weight, Overweight, Obese	8.32 - 12.48	The behavior of the model is insensitive as expected
Representative Age for all groups	25.6 - 38.4	The behavior of the model is insensitive as expected
ß Normal Weight, Overweight, Obese	0.192 - 0.288	The behavior of the model is insensitive as expected
Economy Module		
Change in Firm Revenue Delay	0.8 – 1.2	The behavior of the model is insensitive as expected
Change in Firm Expenditure Delay	0.8 – 1.2	The behavior of the model is insensitive as expected
"Initial Average HED Food Price per ton"	40000 - 60000	The behavior of the model is insensitive as expected
"Initial Average LED Food Price per ton"	40000 - 60000	The behavior of the model is insensitive as expected
"Sensitivity of HED & LED to Price Levels (θ1)"	0.2 – 0.3	The behavior of the model is insensitive as expected
Tax Rate	0.2 – 0.3	The behavior of the model is insensitive as expected
Food Environment Module		
Capacity Adjustment Delay	0.8 – 1.2	The behavior of the model is insensitive as expected
Consumption Delay	0.8 – 1.2	The behavior of the model is insensitive as expected
Export and Waste Delay	0.8 – 1.2	The behavior of the model is insensitive as expected
Export and Waste Fraction	0.04 – 0.06	The behavior of the model is insensitive as expected
Initial HED Food Price Level	0.88 - 1.32	
Initial HED Food Price Level	0.8 – 1.2	The behavior of the model is insensitive as expected

Maximum Effect of Investments in Food Production Methods (L3)	0.8 – 1.2	The behavior of the model is insensitive as expected
Maximum Effect of Investments in Food Production Methods (L4)	0.8 – 1.2	The behavior of the model is insensitive as expected
Maximum Effect of Investments in Food R&D Activities (L2)	1.6 - 2.4	The behavior of the model is insensitive as expected
Maximum Effect of Investments in Food Stores and Delivery Services (L1)	1.6 - 2.4	The behavior of the model is insensitive as expected
"Propensity to Invest in Food Stores and Delivery Services"	0.08 - 0.12	The behavior of the model is insensitive as expected
"Propensity to Invest in R&D Activities"	0.04 – 0.06	The behavior of the model is insensitive as expected
Sensitivity of Food Price Level to Inventory Coverage (θ4)	-0.008 - -0.012	The behavior of the model is insensitive as expected
"Sensitivity of HED Food Price Level to Food R&D Activities (α4)"	1.6 - 2.4	The behavior of the model is insensitive as expected
"Sensitivity of LED Food Price Level to Food R&D Activities (α3)"	0.4 – 0.6	The behavior of the model is insensitive as expected
Sensitivity of HED Food Price on HED Food Production (θ2)	0.4 – 0.6	The behavior of the model is insensitive as expected
Sensitivity of LED Food Price on LED Food Production (θ3)	0.4 – 0.6	The behavior of the model is insensitive as expected
Sensitivity of RVF to Food R&D Activities (α2)	-0.4 – -0.6	The behavior of the model is insensitive as expected
Sensitivity of RVF to Food Stores and Delivery Services (α1)	-0.4 – -0.6	The behavior of the model is insensitive as expected
Total Consumption Adjustment Time	0.8 – 1.2	The behavior of the model is insensitive as expected
Individual Decision-Making Module		
Cross-price elasticity of HED Food (θ9)	0.24 0.36	The behavior of the model is insensitive as expected
Cross-price elasticity of LED Food (θ8)	0.12 0.18	The behavior of the model is insensitive as expected
Sensitivity of Reinforcing Value of Health to Body Weight (θ10) Normal / Overweight / Obese	0.4 – 0.6	The behavior of the model is insensitive as expected
Sensitivity of Reward Delay to Body Weight (θ9) Normal / Overweight / Obese	0.4 – 0.6 / 0.56 – 0.84 / 0.72 – 1.08	The behavior of the model is insensitive as expected
Sensitivity of RVHEDF to BW (θ12) Normal / Overweight / Obese	0.4 – 0.6 / 0.64– 0.96 / 0.72 – 1.08	The behavior of the model is insensitive as expected
Sensitivity of RVLEDF to BW (θ11) Normal / Overweight / Obese	0.4 – 0.6 / 0.56 – 0.84 / 0.64 – 0.96	The behavior of the model is insensitive as expected
Population Module		
Age Group 0 Duration	11.2 - 16.8	The behavior of the model is insensitive as expected
Age Group 1 Duration	27.2 - 40.8	The behavior of the model is insensitive as expected
Age Group 2 Duration	19.2 - 28.8	The behavior of the model is insensitive as expected
Death Delay	0.8 – 1.2	The behavior of the model is insensitive as expected
Death Fraction Age Group 0	0.0000008 - 0.0000012	The behavior of the model is insensitive as expected
Death Fraction Age Group 1	0.0000008 - 0.0000012	The behavior of the model is insensitive as expected

Death Fraction Age Group 3	0.04 – 0.06	The behavior of the model is insensitive as expected
Initial Obese Fraction AG 1 Men / Women	0.04 - 0.06 / 0.08 - 0.12	The behavior of the model is insensitive as expected
Initial Obese Fraction AG 2 Men / Women	0.04 - 0.06 / 0.08 - 0.12	The behavior of the model is insensitive as expected
Initial Obese Fraction AG 3 Men / Women	0.04 - 0.06 / 0.08 - 0.12	The behavior of the model is insensitive as expected
Initial Overweight Fraction AG 1 Men / Women	0.12 - 0.18 / 0.08 – 0.12	The behavior of the model is insensitive as expected
Initial Overweight Fraction AG 2 Men / Women	0.12 - 0.18 / 0.08 – 0.12	The behavior of the model is insensitive as expected
Initial Overweight Fraction AG 3 Men / Women	0.12 - 0.18 / 0.08 – 0.12	The behavior of the model is insensitive as expected
Initial Transition Fraction Obese AG0 Men / Women	0.004 - 0.006 / 0.036 - 0.054	The behavior of the model is insensitive as expected
Initial Transition Fraction Overweight AG0 Men / Women	0.12 - 0.18	The behavior of the model is insensitive as expected
Maximum Effect of Obesity Prevalence on Transition from AG0 (L5)	1.6 – 2.4	The behavior of the model is insensitive as expected
Sensitivity of Transition Fraction from AG 0 (α5)	-0.8 - -1.2	The behavior of the model is insensitive as expected
Normal Death Fraction AG 1	0.2 – 0.3	The behavior of the model is insensitive as expected
Normal Death Fraction AG 2	0.2 – 0.3	The behavior of the model is insensitive as expected
Normal Death Fraction AG 3	0.12 – 0.18	The behavior of the model is insensitive as expected
Obese Death Fraction AG 1	0.36 – 0.54	The behavior of the model is insensitive as expected
Obese Death Fraction AG 2	0.36 – 0.54	The behavior of the model is insensitive as expected
Obese Death Fraction AG 3	0.36 – 0.54	The behavior of the model is insensitive as expected
Overweight Death Fraction AG 1	0.24 – 0.36	The behavior of the model is insensitive as expected
Overweight Death Fraction AG 2	0.24 – 0.36	The behavior of the model is insensitive as expected
Overweight Death Fraction AG 3	0.32 - 0.48	The behavior of the model is insensitive as expected
Women Fertility Period	24 - 36	The behavior of the model is insensitive as expected

II. Detailed Model Structure and Description

This appendix presents the details about the model description that is explained in chapter 5.

a. Notes for Equations

This subsection explains some of the most significant equations and their meanings for the model for each module. For the details and the full list of equations can be found in the Appendixes. Before continuing, it is important to highlight some points related to formulations.

- In the model, there are numerous variables depend nonlinearly on other variables (Sterman, 2000, pp. 525-526). This dependency indicates cause and effect relationship (Barlas, 2009, pp. 1158-1159). For these variables, nonlinear effect formulations are used. To do this, first a variable is set to its normal, reference or initial value. Then, this normal value is multiplied by the product of one or multiple effects. For instance, to measure the effect of A to B:

$$B = B^{*} \times Effect\ of\ A \tag{18}$$

  where B^* is the normal or reference or initial value of B. This normal value is an exogenous or auxiliary variable of the model. For the effect formulation, the effect should be normalized to ensure that when the effect is equal to its normal value, the output is also at its normal or reference or initial value. Hence, the effect A in the example is:

$$Effect\ of\ A\ on\ B = f(A/A^{*}) \tag{19}$$

  where A^* indicates the normal or initial or reference value of A. In other words, when the A is at its normal value, the effect is 1 which means that A has no effect on B. Hence, B will be equal to its normal value.
- Commonly, effect formulations are nonlinear in SD models. Therefore, generally they have sensitivity or elasticity values to measure how responsive the effected value to the effect. In this model, both exponential functions and logistic functions is used to formulate nonlinear effect formulations.
- Most of the cases of effect formulations, following formulation is used:

$$f(x) = M^{\theta} \tag{20}$$

  where “M” is the relative value of the variable (most of the cases it is relative to its initial value), and “θ” is the steepness of the curve which indicates the sensitivity or elasticity. “θ” takes a value between 0 – 1. Depending on the relationship with the effect and the variable, “θ” can either be negative or positive. If the effect is directly proportional, then it takes a positive value and if the effect is inversely proportional, then it takes a negative value.

- Where appropriate, logistic function is used to show that the effect has a limit hence they are formulated as:

$$f(x) = \frac{L}{1 + N^{\alpha}} \quad (21)$$

where "L" is the maximum value, "N" is the normalized value and "α" is the logistic growth rate or steepness of the curve that indicates the sensitivity or elasticity.

Following notations is used for some equations for the sake of simplicity:

$\mathbf{M_n}$	Normalized value of the variable
$\mathbf{N_n}$	Normalized value of the variable for logistic functions
$\mathbf{L_n}$	Maximum value of the effect for logistic functions
$\boldsymbol{\alpha_n}$	Sensitivity or elasticity for logistic functions
$\boldsymbol{\theta_n}$	Sensitivity or elasticity for exponential functions. Can take a value between 0-1 and can have negative or positive sign based on the relationship

b. Economy Module Details

This module represents the macroeconomic dynamics with a simplified fashion within the country. Developments within this model allows generation of obesogenic environment that affects eating behaviors of individuals. Hence, economic development is represented by the Gross Domestic Product (GDP) in real terms. This module is connected to other models through GDP, Business Investments and Disposable Income Per Capita. And Food Environment module connected to this module through Total Food Consumption.

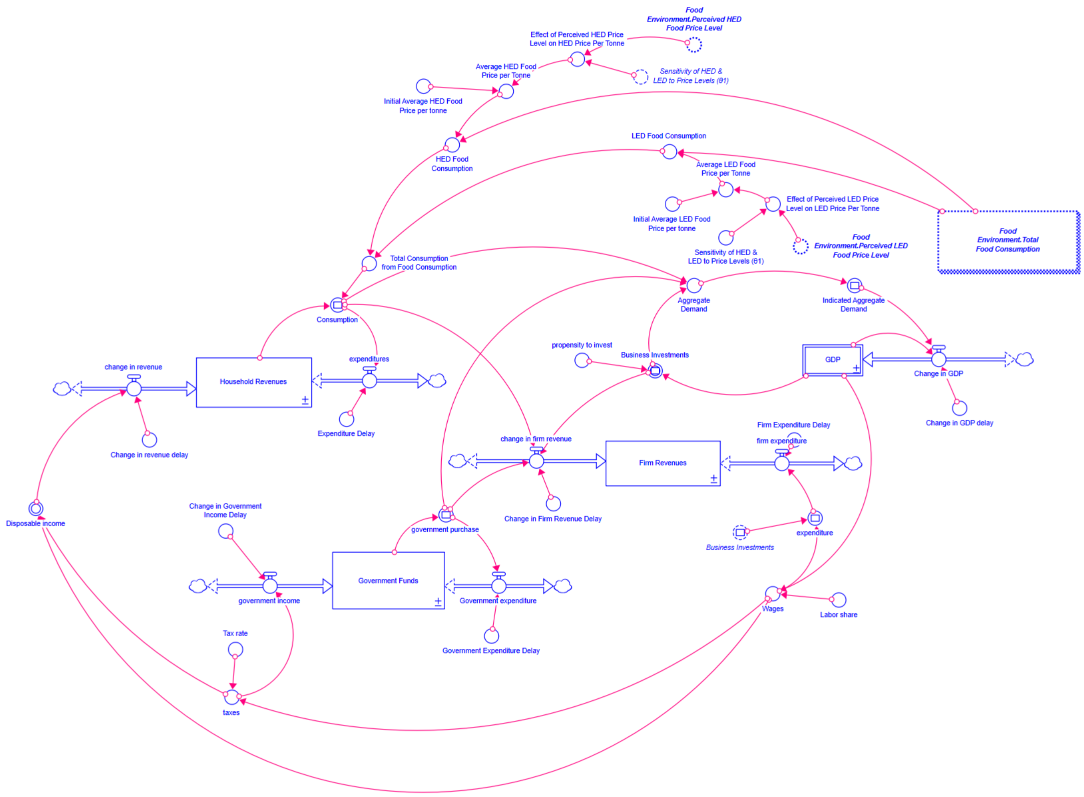


Figure 40 - Economy Module Details

GDP is the main stock in this module. It is hypothesized that the GDP is a function of Aggregate Demand which consists of consumption, business investment and government purchases. It can be shown as:

$$GDP = Consumption + Business\ Investments + Government\ Purchases \tag{22}$$

As mentioned previously, developments outside of the country is not included in the model therefore exports and imports are not part of the GDP in this model. GDP, as a stock, can be formulated as:

$$GDP(t) = GDP(t - dt) + (Change\ in\ GDP) * dt \tag{23}$$

where Change in GDP formulated as:

$$Change\ in\ GDP = (Indicated\ Aggregate\ Demand - GDP)/(Change\ in\ GDP\ Delay) \tag{24}$$

This equation indicates that the change in GDP is updated by the Indicated Aggregate Demand with a delay which is estimated as 1 year in this model to represent the change will happen within a year. The change of Indicated Aggregate Demand is formulated as

$$Indicated\ Aggregate\ Demand = SMTH1(Aggregate\ Demand, 1) \tag{25}$$

where SMTH1 indicates the first order delay function where the delay is again 1 year to indicate that the Aggregate Demand forms within a year. Aggregate Demand as mentioned previously is the sum of Consumption, Business Investments and Government Purchases.

Another important variable is Disposable Income Per Capita. Disposable Income is formulated as:

$$Disposable\ Income\ Per\ Capita = Disposable\ Income\ /\ Total\ Population \tag{26}$$

Disposable Income Per Capita increases with increase in Disposable Income which is formulated as:

$$Disposable\ Income = Wages - Taxes \tag{27}$$

where Wages simply represents the total wages that are paid to individuals. Wages are determined by the labor share which is estimated as 80% of the GDP and taxes are determined via a tax rate which is estimated as 25% of the Wages in this model.

Business Investments affects Food Environment module through increasing the investments in food stores and food delivery methods, and investments in research and development activities which represent the increase in palatability and decrease in production cost of food. It is formulated as:

$$Business\ Investments = SMTH1(GDP \times Propensity\ to\ Invest, 1) \tag{28}$$

where SMTH1 indicates the delay in realization of business investments, and it is increased with the increase in GDP and Propensity to Invest which is estimated as 30% in this model.

Lastly, this module is affected via Food Environment through Total Food Consumption. It feeds into Consumption as a small part of Aggregate Demand since Consumption represents all consumption within the country in a year. Since food types disaggregated into HED Foods and LED Foods, Total Food Consumption is the sum of these two types. LED Food Consumption and HED Food Consumption formulated as the same which is:

$$LED\ Food\ Consumption = Total\ LED\ Food\ Consumption \times (Effect\ of\ Perceived\ LED\ Price\ Level\ to\ LED\ Price\ Per\ Tonne \times Initial\ Average\ LED\ Food\ Price\ Per\ Tonne) \quad (29)$$

Where Initial Average LED Food Price Per Tonne is the reference value. Average LED Food Price Per Tonne is formulated as an effect formulation as:

$$Effect\ of\ Perceived\ LED\ Price\ Level\ to\ LED\ Price\ Per\ Tonne = {M_1}^{\theta_1} \quad (30)$$

where M_1 is the normalized value of Perceived LED Price Level to LED Price Per Tonne. It is normalized by its initial value. The equation indicates that the change in Perceived LED/HED Food Price Level affects LED/HED Price Per Tonne through an estimated sensitivity equals to 0.25 as shown as α_1 in the equation.

Overall, this module is derived by three main reinforcement loops which increases GDP. These feedback loops are (1) from GDP to Household Revenues, from Household Revenues to Aggregate Demand (2) from GDP to Business Investments, from Business Investments to Aggregate Demand, (3) from GDP to Wages, from Wages to Taxes, from Taxes to Government Funds, from Government Funds to Aggregate Demand.

Summary of some exogenous values*

Name of the Parameter	***Value***	***Source***
Tax Rate	0.25	Average value for income tax in Turkey (Ministry of Treasury and FinanceTurkey, 2021)
Propensity to Invest	0.30	Estimated and calibrated
Labor Share	0.80	Estimated and calibrated
Sensitivity of HED & LED Price Per Tonne to Price Levels (α)	0.25	Estimated and calibrated

**Please see the Appendixes for the other parameter and initial values*

c. Food Environment Module Details

This module represents the aggregate food environment that consists of three sub-modules namely food supply-demand, ease of access to food and food attributes. This module makes the ad libitum environment possible through continuously producing food. This module is connected to other modules through effect of price level for HED and LED food on food demand, effect of investments in food research and development activities, effect of investments in food stores and delivery services.

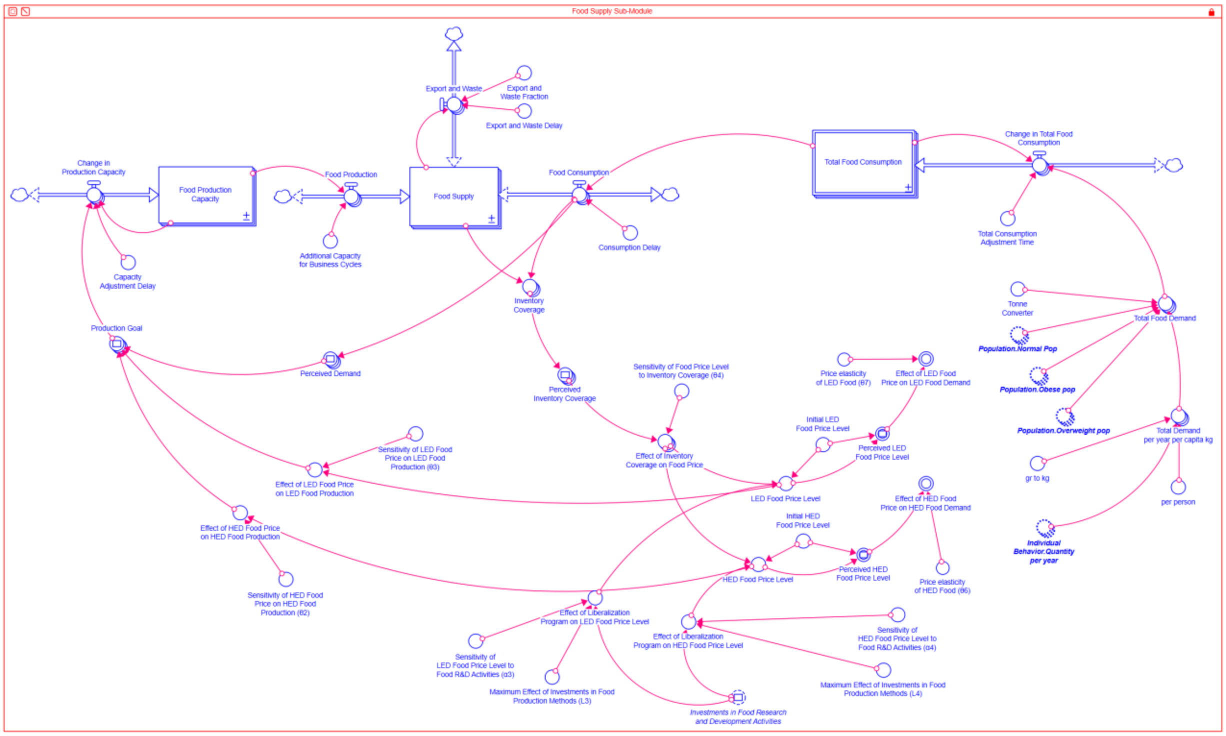


Figure 41 - Food Supply Sub-Module Details

Food supply-demand sub-module is a simplified version of the commodity market model. It has supply and demand mechanism through one balancing feedback loop operates as demand mechanism and one reinforcing feedback loop operates as supply mechanism.

As mentioned earlier, the price is measured as a level rather than an actual price of a commodity.

$$LED\ Food\ Price\ Level = Effect\ of\ Inventory\ Coverage \times Effect\ of\ Liberalization\ Program \times Initial\ LED\ Food\ Price\ Level \quad (31)$$

With this equation, it is hypothesized that price level is affected only by the supply-demand ratio and the liberalization program of Turkish government in the beginning of 1980s (Cizre-Sakallioglu & Yeldan, 2000; Öniş, 2004; Utkulu & Özdemir, 2004). This program is important because it allowed Turkish companies to import food without any official approval and allowed foreign direct investments to Turkey such as fast-food chains like McDonald's and Burger King along with imports of technology which led to decrease in food price level especially in HED foods. This equation is the same with both types of food.

The main stock for this sub-module is the Food Supply which has two dimensions for food types of namely LED food and HED food. This stock is formulated as:

$$Food\ Supply(t) = Food\ Supply(t - dt) + [Food\ Production - (Food\ Consumption + Food\ Export\ \&Waste)] * dt \tag{32}$$

This equation indicates that the Food Supply is increased by the Food Production and depleted by the Food Consumption and Food Waste & Export.

Food Supply and Food Consumption determines the supply-demand ratio or inventory coverage:

$$Inventory\ Coverage\ (Supply/Demand\ Ratio) = Food\ Supply/Food\ Consumption \tag{33}$$

It indicates how much time it takes to deplete the supply. This ratio influences the food price level for both HED and LED through a nonlinear effect formulation.

As mentioned earlier, the price is measured as a level rather than an actual price of a commodity.

$$LED\ Food\ Price\ Level = Effect\ of\ Inventory\ Coverage \times Effect\ of\ Liberalization\ Program \times Initial\ LED\ Food\ Price\ Level \tag{34}$$

With this equation, it is hypothesized that price level is affected only by the supply-demand ratio and the liberalization program of Turkish government in the beginning of 1980s.

This equation is the same with both types of food, but the initial values of food price level is different for LED and HED food. For LED food the initial values are estimated as 1 where for HED food it is estimated as 1.1 to indicate that the HED food was higher in the early 1970s until1980s.

The effect of liberalization program is formulated as:

$$Effect\ of\ Liberalization\ Program\ on\ LED = 0.5 + \frac{L_3}{1 + N_3^{\alpha_3}} \tag{35}$$

where N_3 is the relative value of investments in food research and development activities which leads to decrease in food production costs that leads to decrease in food price. L_3 is the maximum effect which is 1 and α_3 is the sensitivity of price level to this effect which is 0.5. This logistic equation generates an s-shaped decreasing function because the price level is inversely proportional to investments in food research and development. The function also adds with 0.5 to initialize the effect from 1 because it is hypothesized in 1970s investments to food research and development were so small due to non-liberal economy policies. Hence, the function states that in the beginning, the investments had zero or no effect but later, it starts yields more effect. The reason of this effect formulation being a logistic function is that it is hypothesized that this effect has a limited impact on food price level because there are other factors. Hence, it is hypothesized that this effect will stop at 0.5. The effect formulation for HED food is the same with LED food but only the sensitivity is higher for HED food which is estimated as 2 to model the high impact of liberal economy policies on HED food price level.

The effect of inventory coverage is formulated as:

$$Effect\ of\ Inventory\ Coverage\ on\ Food\ Price\ Level = {M_3}^{\theta_3} \quad (36)$$

where M_2 is the relative value of Inventory Coverage to its initial value for each food type and θ_3 is the sensitivity of food price level to inventory coverage. These price levels are perceived by the market after a delay time.

These perceived price levels by the consumers determines how much they are willing to consume each food type. This relationship is formulated through an effect formulation through price elasticity of food.

$$Effect\ of\ LED\ Food\ Price\ Level\ to\ LED\ Food\ Demand = {M_7}^{\theta_7} \quad (37)$$

where M_3 is the relative value of LED Food Price level to its initial value and θ_4 is the price elasticity of LED Food. The formula is the same for both food types, but the price elasticities are different due to difference in food types. As mentioned previously, HED foods can be considered as more luxury foods than FED foods which assumed that the consumers will be more willing to give up these foods easier than the LED foods. Therefore, HED foods are more elastic than LED foods. Hence, the price elasticity of HED food is -0.45 and FED food is -0.30. Based on elasticities, the abovementioned effect formulation means that when food price level increases, food consumption decreases, and when food price level decreases, consumption increases.

Along with the price level, investments in food stores, delivery services and food research and development activities are the significant factors for the food demand in this module. Both investments represented in the model as two reinforcing feedback loops from business investments that depends on GDP to food consumption.

In addition to price level, effect of investments has also effects on food demand. It is hypothesized that the investments in food stores and delivery services have positive effect on reinforcing value of food through increasing ease of access to food and making varied food available. This relation represented in the model as an effect formulation. Figure 42 shows the structure of this relation.

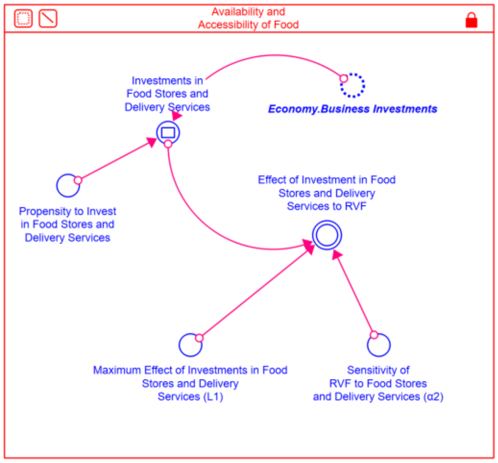


Figure 42 - Availability and Accessibility of Food Details

Since realization of investments takes time, it is modeled with a third order delay formulation. The equation of the effect of investment in food stores and delivery services on reinforcing value of food is:

$$Effect\ of\ Investments\ in\ Food\ Stores\ and\ Delivery\ Services\ on\ RVF = \frac{L_1}{1 + {N_1}^{\alpha_1}} \quad (38)$$

where L_1 is the maximum effect of investments which is 2, N_1 is the relative value of investments in food stores and delivery services to its initial level, and α_1 is the sensitivity of reinforcing value of food to this effect which is estimated and calibrated as -0.75.

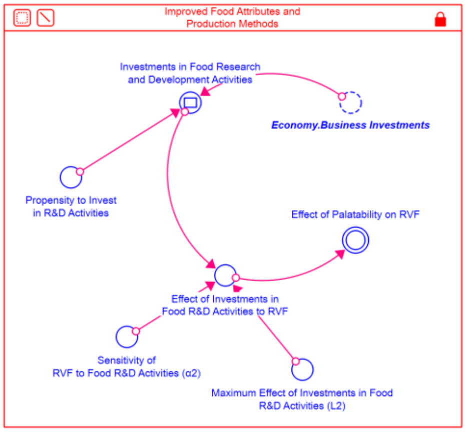


Figure 43 - Improved Food Attributes and Production Methods Details

Figure 43 shows the effect structure for improved food attributes and production methods through investments in food research and development activities like the previous effect structure. These investments have two different effects in the model. First one is the effect on food price level through decreasing the production cost. This effect is explained previously. Second one is related to the reinforcing value of food as shown in Figure 43 It represents the improvements in food taste and marketing methods that makes food more palatable and attractive through investments in R&D activities. The attractiveness of food and palatability increases consumption as explained in the earlier chapters (Johnson & Wardle, 2014). Hence, it is hypothesized that the improved food attributes increase the reinforcing value of food. This effect is formulated as:

$$Effect\ of\ Investments\ in\ Food\ Research\ and\ Development\ Activies\ on\ RVF = \frac{L_2}{1 + {N_2}^{\alpha_2}} \quad (39)$$

where L_2 is the maximum effect of investments which is 2, N_2 is the relative value of investments in food research and development activities to its initial level, and α_2 is the sensitivity of reinforcing value of food to this effect which is estimated and calibrated as -0.85.

Summary of some exogenous values*

Name of the Parameter	***Value***	***Source***
Price elasticity of HED Food (θ_6)	0.45	Estimated (Akbay, 2008; Şengül, 2004)
Price elasticity of LED Food (θ_7)	0.30	Estimated (Akbay, 2008; Şengül, 2004)
Maximum Effect of Investments in Food Stores and Delivery Services (L_1)	2	Estimated and calibrated
Sensitivity of RVF to Food Stores and Delivery Services (α_1)	0.30	Estimated and calibrated
Propensity to Invest in Food Stores and Delivery Services	0.10	Estimated and calibrated
Propensity to Invest in R&D Activities	0.05	Estimated and calibrated
Maximum Effect of Investments in Food R&D Activities (L_2)	2	Estimated and calibrated
Sensitivity of RVF to Food R&D Activities (α_2)	0.85	Estimated and calibrated

**Please see the Appendixes for the other parameter and initial values*

d. Population Module Details

This module represents the population dynamics of the country and calculates the obesity prevalence. The population dynamic is modeled through two aging chain structures. The first is the population aging chain by age categories and the second is the population aging chain by age and body weight categories. The first one is connected to the second one to model and distribute the population into body weight categories. In addition, all aging chain structures has sex dimension. On the top level, population has two main dimensions: sex and age groups. These dimensions are firstly used model the entire population.

To make better calculations for the obesity prevalence, first aging chain needed to be modeled to make accurate estimates for the birth rate and death rate. For this reason, a simplified aging chain is used for the first population aging chain. Figure 44 shows this aging chain.

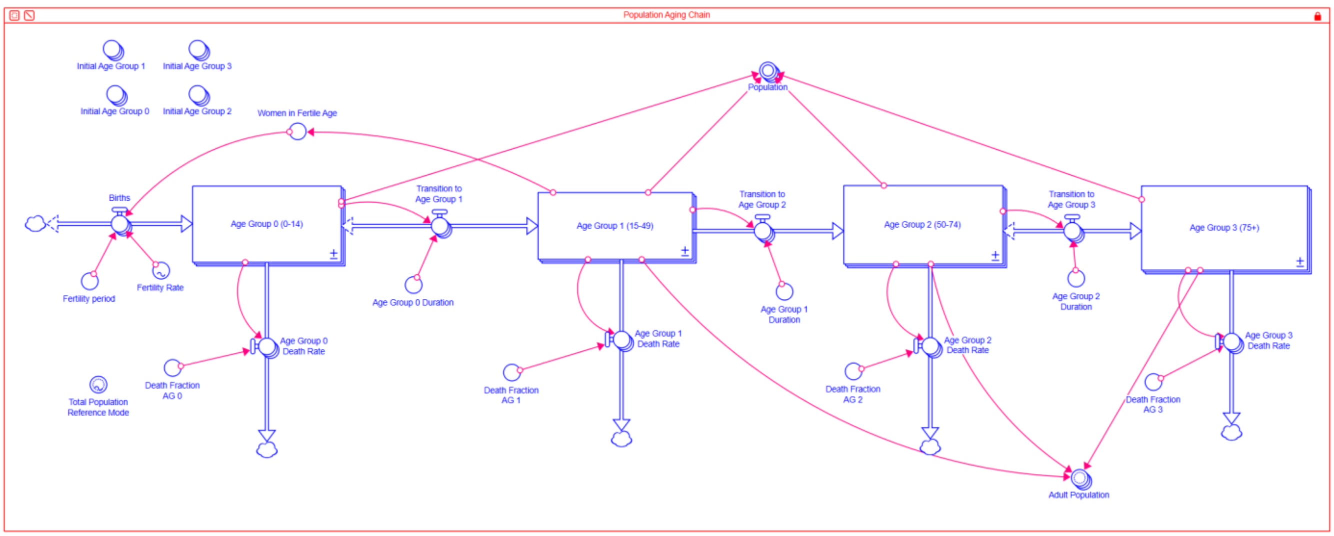


Figure 44 - Population Aging Chain by Age Categories Details

Fertility rate is estimated through a graphical function for the sake of simplicity since the soler purpose of this structure is to calculate the death rates and birth rates. In each stock, individuals move from one stock to another with a rate based on their age. All stocks in this structure are depleted via transition to the next group except the last age group, and death rate based on death fraction. Transition rates from one age group to another calculated as:

$$Transition\ to\ Next\ Age\ Group_{n+1} = \frac{Age\ Group_n}{Age\ Group\ Duration_n} \quad (40)$$

where Age Group stocks are calculated as follows:

$$Age\ Group_n(t) = Food\ Supply(t - dt) + (Transition\ to\ Age\ Group_{n-1} - Transition\ to_{n+1} - Death\ Rate_n) * dt \quad (41)$$

where *n* refers an age group.

Based on first population aging chain, the population is distributed to body weight categories namely normal weight, overweight and obese. This adds body weight dimension into aging chain along with sex and age group.

As mentioned above, transition rates between age groups and death rates by age categories are based on the first population aging chain but the transition rates between body weight categories are calculated with a method developed by Fallah-fini et al. as mentioned previously. This method allows the model to distribute the population into different body weight categories. Figure 45 shows this aging chain.

Transition rates between age groups and death rates by age categories are based on the first population aging chain but the transition rates between body weight categories are calculated with a method developed by Fallah-fini et al. as mentioned previously. This method allows the model to distribute the population into different body weight categories. Figure 45 shows this aging chain.

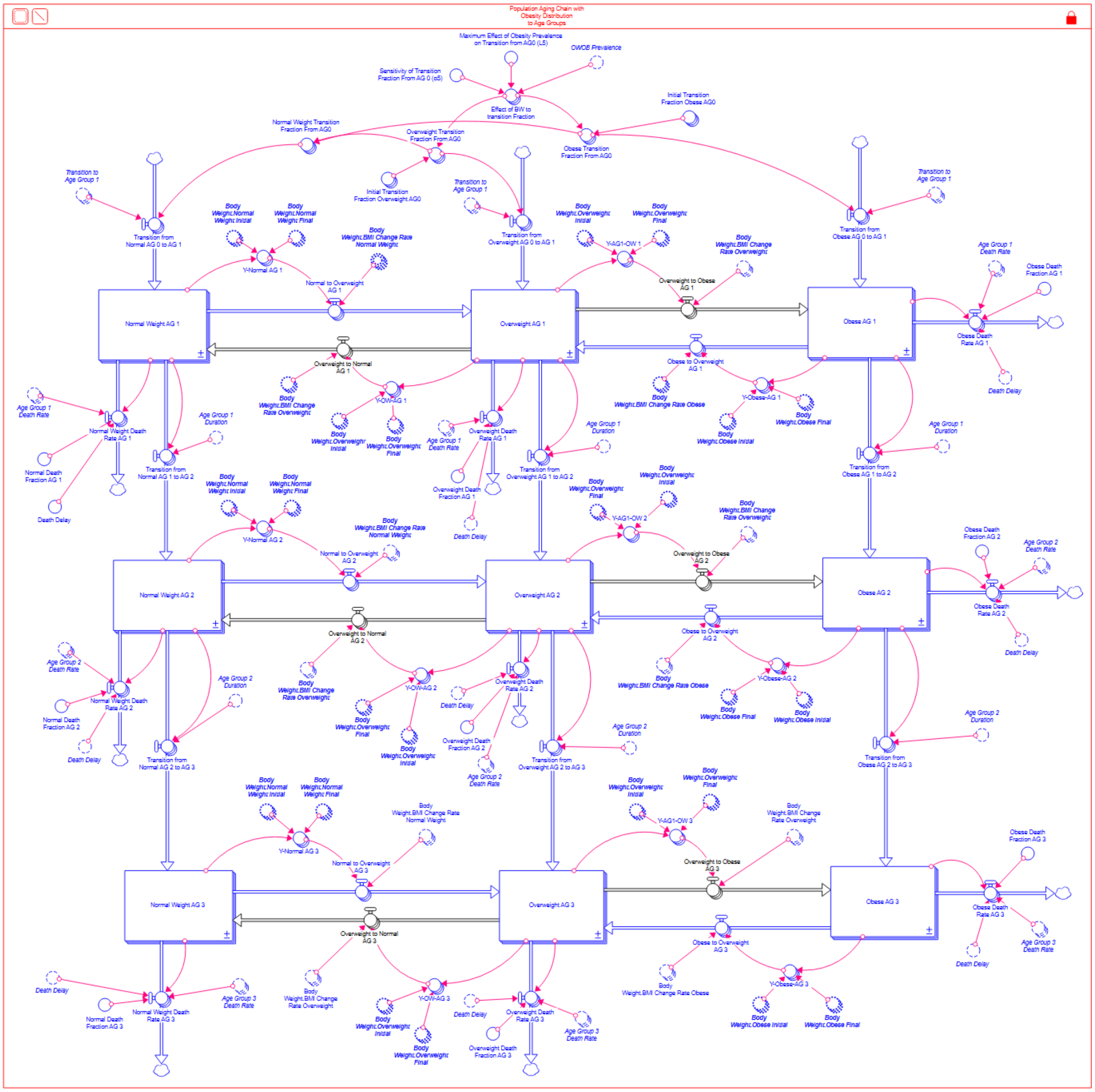


Figure 45 - Population Aging Chain by Age and Body Weight Categories Details

Each body weight category in each age group has a death rate and a transition rate except the last age group. Equations for transition rates are the same as in the first aging chain. Individuals move from one age group to the next, for instance overweight population in Age Group 2 to Age Group 3. However, death rates are calculated differently but still based on the population aging chain structure.

Death rates by body weight category is calculated through taking a fraction of death rates by age group from the first population aging chain in Figure 44. These fractions are estimated values. So, the death rate by body weight category is:

$$Body\ Weight_n\ Age\ Group_n\ Death\ Rate = MIN(Body\ Weight\ Group_n, Age\ Group_n\ Death\ Rate \times Body\ Weight\ Group_n\ Age\ Group_n\ Death\ Fraction) \quad (42)$$

where *Age Group$_n$ Death Rate* is the death rate from the aging chain and *Body Weight Group$_n$ Age Group$_n$ Death Fraction* is the fraction of the death rate belongs to this age body weight group. *MIN* function in Stella software denotes that the smallest value inside the parentheses divided by the coma is true. This function prevents the stock goes below zero.

The significant part of the second aging chain is the transition between body weight categories. In other words, individuals should be able move from normal weight to overweight, and from overweight they should be able return to normal weight. To do this, as mentioned previously, Fallah-fini et al. proposed a distribution method. This method allows a population to be distributed along a dimension. Therefore, the population is divided into intervals to determine how many of the individuals belong to this interval. To do this, initial and final points of the intervals should be determined. Based on that, in each interval, the number of people belong to this interval can be calculated with a distribution equation as (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014):

$$Y_n = \frac{P_n}{X_f - X_i} \quad (43)$$

where Y_n is the number of individuals belong to this category in other words this is sub-population, P_n is the total population, and X_f and X_i are the final and initial values for the intervals to indicate the starting and ending point of that category.

After calculating the sub-population, transition rates can be calculated based on this. Transition rates based on two factors: frequency of the sub-population which is shown in Equation (*7*) as Y_n, and rate of change of the population attribute in this case is body weight. Rate of change of body weight is calculated with change in BMI in the model. Hence, the initial and final values of the intervals are the BMI rates.

Movement from one sub-population to another is based on the change in BMI. If BMI is decreasing, then the individuals should move to previous category but if BMI is increasing, then they should move to the next category.

The equation for the transition rates between body weight categories can be demonstrated with two equations. The first one is

$$Transition\ from\ Group_n\ to\ Group_{n+1} = MAX(\Delta BMI_n \times Y_n, 0) \quad (44)$$

where *MAX* function in Stella denotes that the maximum value inside the parentheses is true. Therefore, the expression cannot take a value less than zero. Also, ΔBMI_n is the change rate of

BMI, and Y_n is the frequency of the body weight group *n*. This equation is only possible when ΔBMI_n is positive meaning that the individuals gaining weight so they should be moving up to the next body weight category. Hence, $Group_{n+1}$ denotes the next body weight category.

When ΔBMI_n is negative, then it means that they are losing weight so they should be moving down from to the previous body weight category. This expression is formulated as:

$$Transition\ from\ Group_n\ to\ Group_{n-1} = ABS(\Delta BMI_n \times Y_n, 0) \qquad (45)$$

where *ABS* and *MIN* expressions indicates that the absolute of the smallest value inside the parentheses is true hence the transition rate cannot be less than 0, and again ΔBMI_n is the change rate of BMI, and Y_n is the frequency of the body weight group *n*. Since in this case ΔBMI_n is negative, $Group_{n-1}$ denotes the previous body weight category.

In addition to transition rates, it is important to note that since the childhood obesity is out of the boundary of this model, transitions from Age Group 0 to Age Group 1 (in other words transition from adolescent to adult) is included in the model to have more accurate results for the obesity prevalence. Because the number of stocks for the first adult population group is dependent on the transition rates from previous age group. Hence, in the model this transition rates are simply estimated and calibrated through a simple effect formulation. It assumed that the obesity prevalence will affect the society and the probability of obese parents to have obese children will be increased. Based on this assumption, it hypothesized transition rate from Age Group 0 to Age Group 1 should be distributed to each body weight categories based on a fraction which is influenced by obesity prevalence.

$$\begin{aligned} &Transition\ from\ Age\ Group_n\ to\ Age\ Group_{n+1}\ By\ Body\ Weight\ Group \\ &\quad = Transition\ Rate\ to\ Age\ Group_{n+1} \\ &\quad \times Body\ Weight\ Group_n\ Transition\ Fraction \end{aligned} \qquad (46)$$

where transition fraction is calculated for overweight and obese categories as:

$$\begin{aligned} &Body\ Weight_n\ Transition\ Fraction\ from\ Age\ Group_{n-1} \\ &\quad = Initial\ Transition\ Fraction\ Body\ Weight_n \\ &\quad \times Effect\ of\ Obesity\ Prevalence\ on\ Body\ Weight_n\ Transition\ Fraction \end{aligned} \qquad (47)$$

where the effect of obesity prevalence on $Body\ Weight_n$ is formulated as logistic function as:

$$Effect\ of\ Obesity\ Prevelance\ on\ Transition\ Fraction = \frac{L_5}{1 + {N_5}^{\alpha_5}} \qquad (48)$$

where L_5 is the maximum effect of obesity prevalence, which is 2, N_5 is the relative value of obesity prevalence to its initial level, and α_5 is the sensitivity of transition rate to this effect which is estimated and calibrated as -1.5. This equation estimated to be the same for both obesity and overweight categories for the sake of simplicity. For the normal body weight transition fraction, the equation is:

$$Normal\ Weight\ Transition\ Fraction = 1 - (Overweight\ Transition\ Rate + Obese\ Transition\ Rate) \quad (49)$$

Summary of some exogenous values*

Name of the Parameter	*Value*	*Source*
Initial Population Age Group (1970)	Total: 35,605,176	(TurkStat, 2015, 2022)
Women Fertility Period	30 years	(Dunson et al., 2002)
Fertility rate	Graphical function	Estimated and calibrated
Death fraction	Age Group 0-2: 0.000001 Age Group 3: 0.05	Estimated and calibrated
Normal Weight Initial BMI	18.5	(WHO, 2021a)
Normal Weight Final BMI	24.9	(WHO, 2021a)
Overweight Initial BMI	25	(WHO, 2021a)
Overweight Final BMI	29.9	(WHO, 2021a)
Obese Initial BMI	30	(WHO, 2021a)
Obese Final BMI	65	(WHO, 2021a)
Initial Transition Fraction from Age Group 0 to 1	Normal: 0.80 Overweight: 0.10 Obese: 0.10	Estimated and calibrated
Initial Body Weight Category Fractions for Population	Normal Women: 0.75 Normal Men: 0.80 Overweight Women & Men: 0.15 Obese Women: 0.10 Obese Men: 0.05	For all age groups. Estimated and calibrated (Erem, 2015; Hatemi et al., 2003; İşeri & Arslan, 2008; Karaoğlan & Tansel, 2019; Yumuk, 2005)

**Please see the Appendixes for the other parameter and initial values*

e. Body Weight Module Details

This module represents the body weight dynamics of individuals. The module consists of body weight model to capture the dynamics of body weight. This model is based on Kevin Hall's model developed for adults (Hall, 2010; Hall et al., 2022; Hall et al., 2012). This model is also used by Fallah-fini et al. when they applied their body weight distribution (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014). Following Fallah-fini et al.'s method, the dynamics of representative individuals is used to calculate BMI change rates which determines the transition rates between body weight categories. Figure 46 shows the overview of the body weight dynamics of normal weight individuals as representative. The model is the same for overweight and obese representative individuals except the initial values such as fat mass, fat free mass and BMI.

This module is connected to other modules through BMI change rate for representative individuals and takes input from physical activity module for physical energy expenditure, and individual behavior module for energy intake.

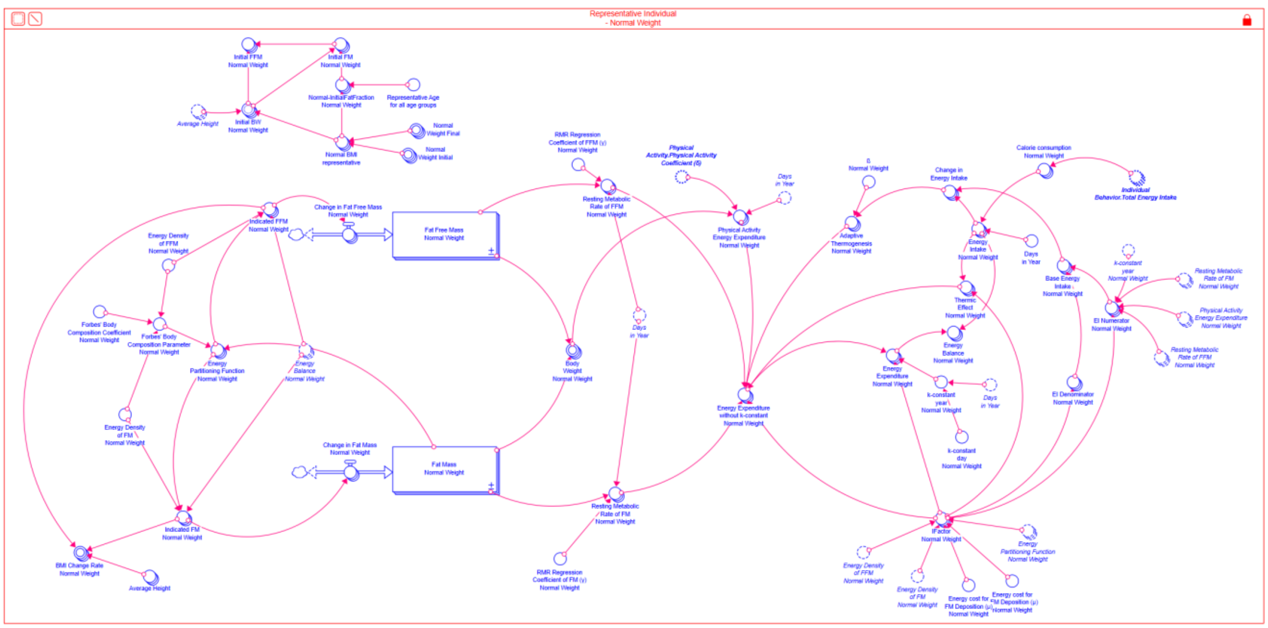


Figure 46 - Body Weight Dynamics Model Details

This model follows the energy balance model of body weight as mentioned in the literature review chapter. The model conceptualizes the body weight as the sum of fat mass (FM) and fat free mass (FFM) where fat mass represents adipose tissue and fat free mass represents the rest of the body mass includes muscle tissue, bone tissue and organ tissue. Energy balance model indicates that the change in FM and FFM depends on the balance of energy:

$$FFM\ Change\ Rate = \frac{Energy\ Partitioning\ Function\ \times Energy\ Balance}{Energy\ Density\ of\ FFM} \quad (50)$$

where *energy density of FFM* is a constant. This equation indicates that the magnitude of change in FFM depends on energy partitioning function and energy balance. If energy balance is negative, then it means that the change is also negative. And energy partitioning function only controls the relationship between FM and FFM (Hall, 2007). FM change rate is formulated as:

$$FM\ Change\ Rate = \frac{(1 - Energy\ Partitioning\ Function)\ \times Energy\ Balance}{Energy\ Density\ of\ FM} \quad (51)$$

where *1-Energy Partitioning Function* indicates that the larger portion of the energy is stored as fat is energy balance is positive and vice versa. This is due to our survival mechanism as mentioned in earlier chapters.

Energy balance is the most principal factor in this model:

$$Energy\ Balance = \ Energy\ Intake - Energy\ Expenditure \quad (52)$$

where energy intake is an input to this module from individual behavior module which regulates the ingestive behavior. Energy expenditure on the other hand is more complicated than energy expenditure due to its function:

$$\begin{aligned} &Energy\ Expenditure \\ &\quad = \ k + (\delta \times BW) + (\gamma_{FM} \times FM) + (\gamma_{FFM} \times FFM) + (\beta \times \Delta EI) \\ &\quad + \left(\mu_{FM} \times \frac{dFM}{dt}\right) + \left(\mu_{FFM} \times \frac{dFFM}{dt}\right) \end{aligned} \quad (53)$$

where k is a constant, δ is the physical activity constant proportional to the *BW* because heavier the body is the more energy it will burn, γ for FM and FFM are constants for resting metabolic rate regression coefficients which are proportional to FMM and FM weight respectively which indicates the required energy to sustain the FM and FFM, β is another constant which is the coefficient for adaptive thermogenesis based on energy intake change rate, μ for FM and FFM are also constants indicates the energy cost for fat and protein turnover which are proportional to change in body composition.

The initial FM and FFM values for normal, overweight, and obese representative individuals calculated based on their initial BMI values which is calculated based on body weight category initial and final values. After calculating the initial BMI values, initial body weight has been calculated.

Fat percentage is calculated with the formula developed by Deurenberg et al. (Deurenberg et al., 2001):

$$Initial\ Adult\ Fat\ Percentage_{Male} = (1.2 \times BMI) + (Age \times 0.23) - 16.2 \quad (54)$$

$$Initial\ Adult\ Fat\ Percentage_{Female} = (1.2 \times BMI) + (Age \times 0.23) - 5.4 \quad (55)$$

where age is the median of the Age Group 1 (age between 15-49) because of this age group is the biggest among other age groups initially for Turkey. Initially, the median age is 32. It assumed that all individual representatives are at the same ag e.

Summary of some exogenous values*

Name of the Parameter	***Value***	***Source***
Forbes' Body Composition Coefficient	10.4 kg	(Hall, 2007, 2010; Hall et al., 2012)
Energy Density of FM	9400 kcal/kg	(Hall, 2010; Hall et al., 2012)
Energy Density of FFM	1800 kcal/kg	(Hall, 2010; Hall et al., 2012)
RMR Regression Coefficient of FM (γ)	3.2 kcal/kg/day	(Hall, 2010; Hall et al., 2012)
RMR Regression Coefficient of FFM (γ)	22 kcal/kg/day	(Hall, 2010; Hall et al., 2012)
Adaptive Thermogenesis coefficient (ß)	0.24	(Hall, 2010; Hall et al., 2012)
k	370.21 kcal/day	(Hall, 2010; Hall et al., 2012)
Energy cost for FM Deposition (μ)	180 kcal/kg	(Hall, 2010; Hall et al., 2012)
Energy cost for FFM Deposition (μ)	230 kcal/kg	(Hall, 2010; Hall et al., 2012)
Representative Age for all body weight categories	32	Estimated
Initial Average height	Male: 1.70 m Female: 1.62 m	(TurkStat, 2022)
Average Height Change Fraction	Male: 0.00025 Female: 0.00015	Estimated

**Please see the Appendixes for the other parameter and initial values*

f. Individual Behavior Module Details

This module represents demand for food which is shaped by both environmental and individual factors. Like body weight dynamics module, this module also consists of representative individuals to calculate the food demand for each body weight category accordingly.

The module is connected to other modules through body weight from body weight dynamics module, LED and HED food price level, effect of price level to food demand from food environment module, and disposable income from economy module. Also, this module gives input to body weight module via total energy intake and food environment module via demand quantity.

It is assumed that the food demand is determined by the price food, reinforcing value of food, and disposable income. As mentioned previously, there are more factors that influence food demand/consumption, but they are out of the boundaries of this research.

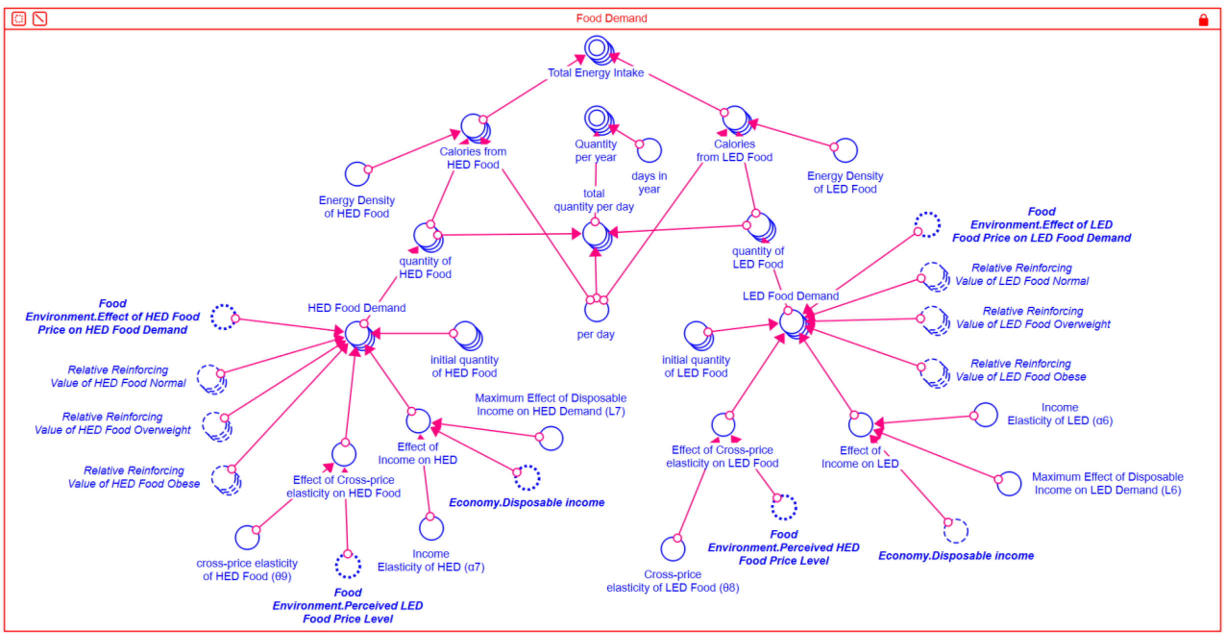


Figure 47 - Food Demand Structure Details

Figure 47 shows the food demand structure. Each food type has different demand based on both their reinforcing values, price, cross-price, and income elasticities. Naturally, representative of each body weight category has different demand for food. Food demand of LED and HED foods are calculated in the same way.

Food demand is calculated as quantity and then this quantity converted into calories because it is assumed that the individuals make their food consumption choices based on the quantities, instead of calories. Food demand is formulated as the multiplication of effect variables related to food demand:

$$Food\ Demand = Initial\ Quantity\ of\ Food \times Effect\ of\ Food\ Price\ Level \\ \times Effect\ of\ Crossprice\ Elasticity\ of\ Food \\ \times Effect\ of\ Disposable\ Income \\ \times Effect\ of\ Relative\ Reinforcing\ Value\ of\ Food \tag{56}$$

Effect of price level is explained in the food environment module. It is hypothesized that if price decreases, food demand increases. Disposable income is another important determinant as mentioned in the Introduction chapter. Income is directly proportional to food consumption, but this effect assumed to be limited because after reaching to a certain income level, priorities of consumers changes. Effect of income elasticity formulated as:

$$Effect\ of\ Disposable\ Income\ on\ Food\ Demand = \frac{L_6}{1 + {N_6}^{\alpha_6}} \tag{57}$$

where N_6 is the relative value of disposable income which leads to increase in budget to be spent on food. L_6 is the maximum effect which is 2 and α_6 is the sensitivity of food demand to this effect which is -0.15 for HED food and 0.10 for LED food.

Another effect is cross-price elasticity. This indicates the sensitivity of demand of a good to change in price of a substitute. In the model, it assumed that the food types are the only substitutes to each other. Therefore, it is hypothesized that a decrease in price of HED food will decrease the demand of LED food and vice versa. So, it plays a counterbalancing role against own price elasticity of each food type (price elasticity of demand). Equation of cross-price elasticity is the same with own price elasticity except the change in depend on other food type rather than its own price.

$$Effect\ of\ Crosspice\ Elasticity\ on\ LED\ Food = {M_7}^{\theta_7} \tag{58}$$

where M_7 is the relative value of HED Food Price level to its initial value and θ_7 is the cross-price elasticity of LED Food. The equation of effect formulation is the same for HED food except the relative value is relative value of FED food instead of HED Food. Since HED is more caloric dense, both more palatable and attractive, it is hypothesized that individuals will choose HED food over LED in default. Therefore, HED foods are less elastic than LED foods towards cross-price change. Hence, the cross-price elasticity of HED food is 0.25 and LED food is 0.10. Based on elasticities, the equation means for HED food demand is that when LED food price level decreases, HED food demand decreases because individuals would switch to LED food instead of HED food. For LED food demand on the other hand, when HED food price level decreases, LED food demand will also decrease but with a larger magnitude due to elasticity because individuals will choose to eat HED food if its price decreases.

Other factor is individual relative reinforcing value of food for each body type. As mentioned earlier, both environmental and the individual factors affect reinforcing value of food. In this model, factors that influence reinforcing value of food has been aggregated to body weight as individual factor, and effect of palatability/attractiveness of the food and ease of access to food as environmental factors. Figure 48 shows this structure. This structure is hypothesized reinforcement pathology structure which is described in Introduction and Dynamic Hypothesis chapters.

Figure 48 shows the conceptualization of a choice structure which an individual makes a choice between two reinforcers: health, and food. As food type is also a choice but, in this research, it is simplified that the choice affects only the amount of food type based on reinforcing value so that the individual cannot replace HED foods with LED foods.

The individual chooses the option that has highest reward relative to the other. But this reward is perceived, so it is biased because the reinforcing value of food is increased due to the environmental and individual factors which causes the increase in food consumption along with the disposable income and price factors. As noted, as the individual gains weight, the food becomes even more reinforcing for the individuals and the individual delay discounts more for health reinforcer (Stojek & MacKillop, 2017; Temple, 2014). This feedback loop leads individual to overeating which initiates a reinforcement pathology.

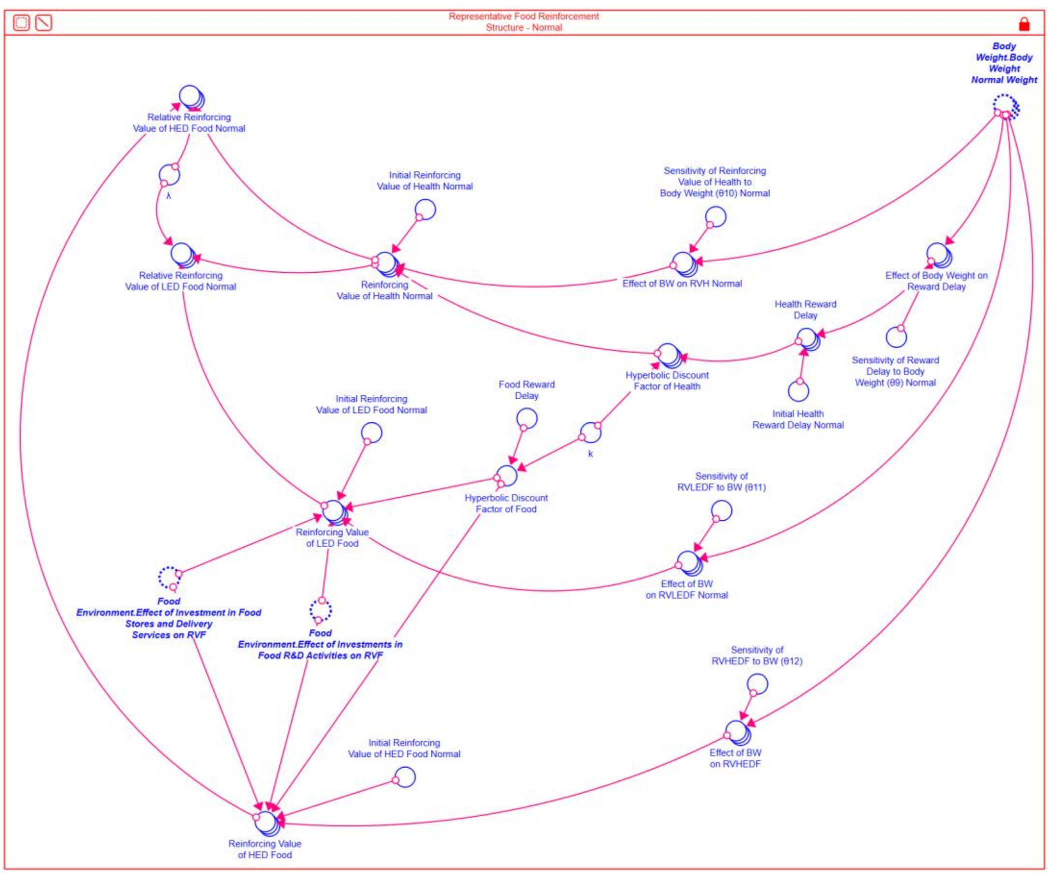


Figure 48 - Individual Food Reinforcement Structure Details

In the literature, reinforcement, which is conceptualized as relative reinforcement value, is used to describe choice among concurrent options that are substitutes or alternatives to each other, and delay discounting is used to conceptualize choice when there is time-inconsistency namely when receiving a reward takes longer than other reward where the reward of the former is discounted (Epstein & Leddy, 2006; Epstein et al., 2007; Epstein et al., 2010).

The model includes the relative reinforcement value as in the literature mentioned above to conceptualize concurrent choices but not between two immediate reward options but two time-inconsistent options namely being healthy and food consumption which is different from the other studies. In that sense, again different from the other studies, this study suggests and hypothesizes that the delay discounting and food reinforcement is connected (Carr et al., 2011). Because in behavioral economics, delay discounting is used to explain how the value of a reward changes with the delay of receiving that reward which ultimately causes a decrease in its value as the delay increases (Odum, 2011; Odum et al., 2020). Therefore, in the individual behavior module, delay discounting formulation and relative reinforcement is used to describe how immediate small reward, food consumption, has more value than larger delayed reward, staying healthy conceptualized simply as health reward.

Increase in body weight affects delay-discounting process, reinforcing value of health and reinforcing value of food. So, it is hypothesized on one hand that increase in body weight leads to increased delay discounting of the alternative against the food consumption via decreasing their reinforcing value or utility (Epstein et al., 2014; O'Brien et al., 2011; Temple, 2014; Vanderveldt et al., 2016). On the other hand, increase in body weight increases reinforcing value of food consumption due to almost creating an addiction (Carr et al., 2011; Stojek & MacKillop, 2017; Volkow et al., 2012). As it shown in the empirical studies, individuals with higher body weights delay discount more and find foods highly reinforcing which together, make them more impatient (Epstein et al., 2014; Ross et al., 2020; Vanderveldt et al., 2016).

However, increase in body weight does not only increase reinforcing value of food, but it also increases reinforcing value of health because it is assumed that the health is also a reinforcer that increases along with the body weight which makes them more aware of their health depreciation with increasing rates and may lead them to look for solutions such as dieting, eating less or bariatric surgery or etc. So, the relative reinforcing value of food is calculated relative to the reinforcing value of health.

To do quantify the influence of body weight on reinforcing value of health, reinforcing value of food, and delay discounting, effect formulations are used. These formulations are the same for each representative individuals though initial values and some sensitivity values are estimated to be different. This estimation is based on assumption of as individuals gain weight, they become more sensitive to food as a reinforcer and delay discount more.

Effect of body weight on reinforcing value of food is quantified as:

$$Effect\ of\ Body\ Weight\ on\ Reinforcing\ Value\ of\ Food = {M_9}^{\theta_{11}} \quad (59)$$

where M_9 is the relative value of body weight to its initial value and θ_{11} is the sensitivity of reinforcing value of LED food to body weight, which is estimated as 0.5 for normal, 0.7 for overweight and 0.8 for obese representative. Effect of body weight on HED food is quantified with the same equation but it is assumed that the individuals would be more sensitive to HED food due their caloric value because of human evolution so the values are 0.6 for normal, 0.8 for overweight and 0.9 for obese representative.

Along with this effect, environmental effects from food environment module, and the delay discount for food, the reinforcing value of food is calculated based on its initial value for each food type:

$$\begin{aligned} Reinforcing\ Value\ of\ Food &= Initial\ Value\ of\ Food \\ &\times Effect\ of\ Body\ Weight\ on\ Reinforcing\ Value\ of\ Health \\ &\times Effect\ of\ Investments\ in\ Food\ Stores\ and\ Delivery\ Services \\ &\times Effect\ of\ Investments\ in\ Food\ R\&D\ Acitivities \\ &\times Hyperbolic\ Discount\ Factor\ of\ Food \end{aligned} \quad (60)$$

where initial value of food is estimated for each body weight representative based on studies of Epstein et al. It is estimated that normal weight representative has the lowest and obese representative has the highest initial reinforcing value of food. This initial value is multiplied by multiple effects and then discounted by the discount factor. This discount function is explained in Delay Discounting under Key Concepts and Discussions section. This equation formulated as:

$$Hyperbolic\ Discount\ Factor_{Food} = \frac{1}{1 + Food\ Reward\ Delay \times k} \quad (61)$$

where k, degree of impatience/discounting, estimated to be 1 because the impatience is modeled through effect of body weight on delay. So, the as the food reward delay increases, the discount on the reinforcing value of food will increase. However, in the model food reward delay estimated to be 0 which indicates an immediate reward because intemporal decision in this model is made comparing to the health. So, relative to receiving health reward, food reward is immediate; the individual will have the utility immediately after consumption. Therefore, hyperbolic discount factor for food is always 1 which means that food reward is not discounted unlike the health reward. Reinforcing value of food is calculated with the same equation for both HED and LED foods for every individual representative. Only initial values differ. These values can be seen on the table at the end of the subsection.

With similar equations, effect of body weight on reinforcing value of health is formulated as:

$$Effect\ of\ Body\ Weight\ on\ Reinforcing\ Value\ of\ Health = {M_9}^{\theta_{10}} \tag{62}$$

where M_9 is the relative value of body weight to its initial value. And θ_{10} is the sensitivity of reinforcing value of health to body weight which is estimated as 0.5 for all body weight individuals because it is assumed that the health is equally important for individuals regardless of the body weight. After calculating the effect, the reinforcing value of health is:

$$\begin{aligned} &Reinforcing\ Value\ of\ Health \\ &\quad = Initial\ Value\ of\ Health \\ &\quad \times Effect\ of\ Body\ Weight\ on\ Reinforcing\ Value\ of\ Health \\ &\quad \times Hyperbolic\ Discount\ Factor \end{aligned} \tag{63}$$

where the initial value of health is estimated to be the same for every body weight representative due to same assumption of sensitivity. Delay discount factor is quantified like food delay discount factor:

$$Hyperbolic\ Discount\ Factor_{Food} = \frac{1}{1 + Health\ Reward\ Delay \times k} \tag{64}$$

where k, degree of impatience/discounting, again estimated to be 1 because the impatience is modeled through effect of body weight on delay. But unlike the food reward delay, health reward delay depends on the body weight. So, the as the health reward delay increases, the discount on the reinforcing value of health also increases. This is because the health reward is distant in the future, so it is not immediate. Health reward delay is quantified as:

$$\begin{aligned} &Health\ Reward\ Delay \\ &\quad = Initial\ Health\ Reward\ Delay \\ &\quad \times Effect\ of\ Body\ Weight\ on\ Health\ Reward\ Delay \end{aligned} \tag{65}$$

where initial health reward delay is different for each individual because individuals with higher body weight delay discount more so in other words, for them the health reward is even farther in the future. And effect of body weight on health reward delay is:

$$Effect\ of\ Body\ Weight\ on\ Health\ Reward\ Delay = {M_9}^{\theta_9} \tag{66}$$

where M_9 is the relative value of body weight to its initial value and θ_9 is the sensitivity of reward delay to body weight, which is estimated as 0.5 for normal, 0.7 for overweight and 0.9 for obese representative. The different sensitivity values are due to the studies mentioned earlier in this subsection. Here, reward is the reward of being healthy or well with the assumption that health is a perceived concept.

After calculating the reinforcing values, then as mentioned in Relative Reinforcing Value under Key Concepts and Discussions section, relative reinforcing values of LED food and HED food calculated differently but with similar equations. But the equation mentioned in Relative Reinforcing Value part, is modified with a coefficient to quantify how relative reinforcing value effects food demand:

$$Relative\ Reinforcing\ Value_{food} = \lambda + \frac{Reinforcing\ Value_{food}}{(Reinforcing\ Value_{food} + Reinforcing\ Value_{health})} \quad (67)$$

where λ is a coefficient and estimated to be 0.25, and the division indicates the relative value of food reinforcement comparing to value of health. So, as the reinforcing value of health increases, the reinforcing value of food and eventually the relative reinforcing value of health decreases. The coefficient, λ, helps formula to effect food demand even in extreme conditions to make the equation more realistic. For instance, if reinforcing value of food is 0 which indicates that the food is not reinforcing, then equation results 0.25 which the demand will be increased but it will never be zero. Because even if the food is not reinforcing, individuals should eat to survive. Without the coefficient, the equation cannot go over 1 which means that it will always have a decreasing effect on food demand. To prevent that, the coefficient is added to the equation.

After calculating the demand of each food type, they multiplied with the initial quantity of food in grams per day per person. Then, this amount is converted to calories through densities of the LED food and HED food.

Summary of some exogenous values*

Name of the Parameter	***Value***	***Source***
Initial Reinforcing Value of Health	10 (for all body weights)	Estimated based on relative reinforcing value of food (Carr & Epstein, 2020; Epstein et al., 2014)
Initial Reinforcing Value of FED Food	10 – Normal 20 – Overweight 25 – Obese	Estimated based on studies (Carr & Epstein, 2020; Epstein et al., 2014)
Initial Reinforcing Value of HED Food	15 – Normal 35 – Overweight 45 – Obese	Estimated based on studies (Carr & Epstein, 2020; Epstein et al., 2014)
k	1	Estimated and calibrated
Health reward delay	2 – Normal 3 – Overweight 4 – Obese	Estimated and calibrated
Energy Density of LED Food	2	(Prentice & Jebb, 2003; Rolls, 2017; Temple et al., 2022; Vadiveloo et al., 2018)
Energy Density of HED Food	4.5	(Prentice & Jebb, 2003; Rolls, 2017; Temple et al., 2022; Vadiveloo et al., 2018)

**Please see the Appendixes for the other parameter and initial values*

a. Physical Activity Module

This module represents physical activity as one of the main factors of energy expenditure. As mentioned earlier, physical activity is out of boundaries of this research, but it is included to calculate energy expenditure accurately. Figure 16 shows the structure for physical activity.

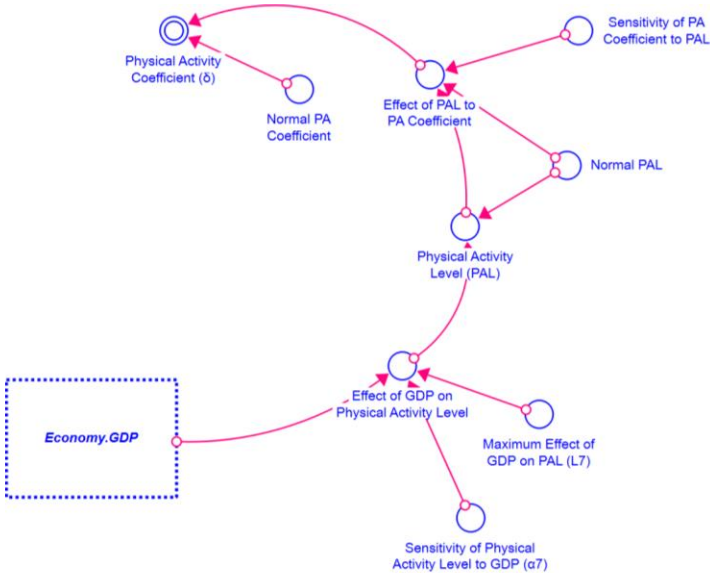


Figure 49 - Physical Activity Structure

This module receives input from economy module and give input to body weight dynamics module. Whole structure is based on a simplified effect structure that hypothesis that as the GDP increases, physical activity level (PAL) decreases due to increased access to modes of transportation, working in job that require less physical activity etc. So, PAL is:

$$PAL = Normal\ PAL \times Effect\ of\ GDP\ on\ PAL \qquad (68)$$

where *normal PAL* is a constant and it is 1.75 initially which is equal to moderately active individual to represent average PAL. The effect of GDP is formulated as:

$$Effect\ of\ Obesity\ Prevelance\ on\ Transition\ Fraction = 0.80 + \frac{L_7}{1 + {N_7}^{\alpha_7}} \qquad (69)$$

where N_7 is the relative value of GDP, L_7 is the maximum effect which is 0.15 and α_7 is the sensitivity of PAL to this effect which is 0.8. This logic function is sum with 0.80 to limit the decrease in PAL to 1.4 because below 1.4 can be ignored because it indicates extreme conditions such as physical activity level of a person an elderly mental patient, or who has cerebral palsy, or myelodysplasia (Bandini et al., 1991; Prentice et al., 1989).

After calculating the PAL, then the effect of PAL on physical activity coefficient is calculated through another effect formulation:

$$PA\ Coefficient\ (\delta) = Normal\ PA\ Coefficient \times Effect\ of PAL\ on\ PA\ Coefficient \tag{70}$$

Where Normal PA Coefficient is 7 kcal per kg per day as constant and the effect of PAL is:

$$Effect\ of\ PAL\ on\ PA\ Coefficient = {M_{10}}^{\theta_{13}} \tag{71}$$

where M_{10} is the relative value of PAL to its initial value, θ_{13} is the sensitivity of PA coefficient to PAL which is estimated as 1 because PA coefficient and PAL is directly connected.

Summary of some exogenous values*

Name of the Parameter	***Value***	***Source***
Normal PAL	1.75	Estimated based on available reports
Normal PA Coefficient	7 kcal/kg/day	(Hall, 2007, 2010; Hall et al., 2012)

**Please see the Appendixes for the other parameter and initial values*

III. Model Documentation

This section presents the documentation of the model, each equation for the variables and values of constant parameters along with their explanations.

Variable Name	Equation	Initial Value	Unit	Notes
		Body Weight Module		
Fat_Free_Mass_Normal_Weight [Sex](t)	Fat_Free_Mass_Normal_Weight [Sex] (t - dt) + (Change_in_Fat_Free_Mass_Normal_Weight [Sex]) * dt	INIT Fat_Free_Mass_Normal_Weight [Sex] = Initial_FFM_Normal_Weight	kg	This is a stock that represents the fat free mass in the representative individual's body. It increases based on the change in the tissue. If the change is negative, stock is updated according to this current information. This update occurs through a first order information delay based on the indicated mass. It is defined by a stock because body mass can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on the calculation of initial weight.
Fat_Free_Mass_Obese [Sex](t)	Fat_Free_Mass_Obese [Sex] (t - dt) + (Change_in_Fat_Free_Mass_Obese [Sex]) * dt	INIT Fat_Free_Mass_Obese [Sex] = Initial_FFM_Obese	kg	This is a stock that represents the fat free mass in the representative individual's body. It increases based on the change in the tissue. If the change is negative, stock is updated according to this current information. This update occurs through a first order information delay based on the indicated mass. It is defined by a stock because body mass can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on the calculation of initial weight.
Fat_Free_Mass_Overweight [Sex](t)	Fat_Free_Mass_Overweight [Sex] (t - dt) + (Change_in_Fat_Free_Mass_Overweight [Sex]) * dt	INIT Fat_Free_Mass_Overweight [Sex] =	kg	This is a stock that represents the fat free mass in the representative individual's body.

Variable Name	Equation	Initial Value	Unit	Notes
		Initial_FFM_Overweight		It increases based on the change in the tissue. If the change is negative, stock is updated according to this current information. This update occurs through a first order information delay based on the indicated mass. It is defined by a stock because body mass can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on the calculation of initial weight.
Fat_Mass_Normal_ Weight [Sex](t)	Fat_Mass_Normal_Weight [Sex] (t - dt) + (Change_in_Fat_Mass_Normal_Weight [Sex]) * dt	INIT Fat_Mass_Normal_ Weight [Sex] = Initial_FM_Normal_ Weight	kg	This is a stock that represents the fat mass in the representative individual's body. It increases based on the change in the tissue. If the change is negative, stock is updated according to this current information. This update occurs through a first order information delay based on the indicated mass. It is defined by a stock because body mass can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on the calculation of initial weight.
Fat_Mass_Obese [Sex](t)	Fat_Mass_Obese [Sex] (t - dt) + (Change_in_Fat_Mass_Obese [Sex]) * dt	INIT Fat_Mass_Obese [Sex] = Initial_FM_Obese	kg	This is a stock that represents the fat mass in the representative individual's body. It increases based on the change in the tissue. If the change is negative, stock is updated according to this current information. This update occurs through a first order information delay based on the indicated mass.

Variable Name	Equation	Initial Value	Unit	Notes
				It is defined by a stock because body mass can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on the calculation of initial weight.
Fat_Mass_Overweight [Sex](t)	Fat_Mass_Overweight [Sex] (t - dt) + (Change_in_Fat_Mass_Overweight [Sex]) * dt	INIT Fat_Mass_Overweight [Sex] = Initial_FM_Overweight	kg	This is a stock that represents the fat mass in the representative individual's body. It increases based on the change in the tissue. If the change is negative, stock is updated according to this current information. This update occurs through a first order information delay based on the indicated mass. It is defined by a stock because body mass can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on the calculation of initial weight.
Change_in_Fat_Free_Mass_Normal_Weight [Sex]	Indicated_FFM_Normal_Weight		kg/year	This is the inflow to fat free mass that represents the rate of change per year in the body mass. Its equation indicates that this change depends on the energy balance and energy partitioning. If energy balance is negative, then it means that the change is also negative.
Change_in_Fat_Free_Mass_Obese [Sex]	Indicated_FFM_Obese		kg/year	This is the inflow to fat free mass that represents the rate of change per year in the body mass. Its equation indicates that this change depends on the energy balance and energy partitioning. If energy balance is negative, then it means that the change is also negative.

Variable Name	Equation	Initial Value	Unit	Notes
Change_in_Fat_Free_Mass_Overweight [Sex]	Indicated_FFM_Overweight		kg/year	This is the inflow to fat free mass that represents the rate of change per year in the body mass. Its equation indicates that this change depends on the energy balance and energy partitioning. If energy balance is negative, then it means that the change is also negative.
Change_in_Fat_Mass_Normal_Weight [Sex]	Indicated_FM_Normal_Weight		kg/year	This is the inflow to fat mass that represents the rate of change per year in the body mass. Its equation indicates that this change depends on the energy balance and energy partitioning. If energy balance is negative, then it means that the change is also negative.
Change_in_Fat_Mass_Obese [Sex]	Indicated_FM_Obese		kg/year	This is the inflow to fat mass that represents the rate of change per year in the body mass. Its equation indicates that this change depends on the energy balance and energy partitioning. If energy balance is negative, then it means that the change is also negative.
Change_in_Fat_Mass_Overweight [Sex]	Indicated_FM_Overweight		kg/year	This is the inflow to fat mass that represents the rate of change per year in the body mass. Its equation indicates that this change depends on the energy balance and energy partitioning. If energy balance is negative, then it means that the change is also negative.
Adaptive_Thermogenesis_Normal_Weight [Sex]	ß_Normal_Weight*Change_in_Energy_Intake		Kilocalories/Years	This is a variable that represents the adaptive thermogenesis which means the required energy that occurs after a shift in diet. Its equation indicates that the energy requirement is calculated based on the value of change in energy intake and the adaptive thermogenesis coefficient.

Variable Name	Equation	Initial Value	Unit	Notes
Adaptive_Thermogenesis_Obese [Sex]	ß_Obese*Change_in_Energy_Intake_Obese		Kilocalories/Years	This is a variable that represents the adaptive thermogenesis which means the required energy that occurs after a shift in diet. Its equation indicates that the energy requirement is calculated based on the value of change in energy intake and the adaptive thermogenesis coefficient.
Adaptive_Thermogenesis_Overweight [Sex]	ß_Overweight*Change_in_Energy_Intake_Overweight		Kilocalories/Years	This is a variable that represents the adaptive thermogenesis which means the required energy that occurs after a shift in diet. Its equation indicates that the energy requirement is calculated based on the value of change in energy intake and the adaptive thermogenesis coefficient.
Average_Height [Men]	1.70		Centimeters	This is a constant that represents the average height for individuals for each gender.
Average_Height [Women]	1.60		Centimeters	This is a constant that represents the average height for individuals for each gender.
Base_Energy_Intake_Normal_Weight [Sex]	EI_Numerator_Normal_Weight/EI_Denominator_Normal_Weight		Kilocalories/Years	This is a variable that represents the energy that body needs to conserve its current state in other words in order to not to lose weight or gain weight.
Base_Energy_Intake_Obese [Sex]	EI_Numerator_Obese/EI_Denominator_Obese		Kilocalories/Years	This is a variable that represents the energy that body needs to conserve its current state in other words in order to not to lose weight or gain weight.
Base_Energy_Intake_Overweight [Sex]	EI_Numerator_Overweight/EI_Denominator_Overweight		Kilocalories/Years	This is a variable that represents the energy that body needs to conserve its current state in other words in order to not to lose weight or gain weight.
BMI_Change_Rate_Normal_Weight [Sex]	(Indicated_FFM_Normal_Weight+Indicated_FM_Normal_Weight)/(Average_Height^2)		Kilograms/(Centimeters^2*Years)	This is a variable that represents the change in body weight calculated as BMI. Its equation indicates that change is depends on the change in body weight calculated through fat mass and fat free mass. The division by the square of height is to convert the body weight in BMI terms
BMI_Change_Rate_Obese [Sex]	(Indicated_FFM_Obese+Indicated_FM_Obese)/(Average_Height^2)		Kilograms/(Centimeters^2*Years)	This is a variable that represents the change in body weight calculated as BMI.

Variable Name	Equation	Initial Value	Unit	Notes
				Its equation indicates that change is depends on the change in body weight calculated through fat mass and fat free mass. The division by the square of height is to convert the body weight in BMI terms
BMI_Change_Rate_Overweight [Sex]	(Indicated_FM_Overweight+Indicated_FFM_Overweight)/(Average_Height^2)		Kilograms/(Centimeters^2*Years)	This is a variable that represents the change in body weight calculated as BMI. Its equation indicates that change is depends on the change in body weight calculated through fat mass and fat free mass. The division by the square of height is to convert the body weight in BMI terms
Body_Weight_Normal_Weight [Sex]	Fat_Free_Mass_Normal_Weight+Fat_Mass_Normal_Weight		kg	This is a variable that represents the total body mass of the individual. The equation indicates that the body weight is the sum of fat free mass and fat mass.
Body_Weight_Obese [Sex]	Fat_Free_Mass_Obese+Fat_Mass_Obese		kg	This is a variable that represents the total body mass of the individual. The equation indicates that the body weight is the sum of fat free mass and fat mass.
Body_Weight_Overweight [Sex]	Fat_Free_Mass_Overweight+Fat_Mass_Overweight		kg	This is a variable that represents the total body mass of the individual. The equation indicates that the body weight is the sum of fat free mass and fat mass.
Calorie_consumption_Normal_Weight [Men]	"Individual_Decision-Making." Total_Energy_Intake [Men, Normal_Weight]		kcal/day	This is a variable that represents the daily energy intake for the individual body weight representative.
Calorie_consumption_Normal_Weight [Women]	"Individual_Decision-Making." Total_Energy_Intake [Women,Normal_Weight]		kcal/day	This is a variable that represents the daily energy intake for the individual body weight representative.
Calorie_consumption_Obese [Men]	"Individual_Decision-Making." Total_Energy_Intake[Men,Obese]		kcal/day	This is a variable that represents the daily energy intake for the individual body weight representative.

Variable Name	Equation	Initial Value	Unit	Notes
Calorie_consumption_Obese [Women]	"Individual_Decision-Making." Total_Energy_Intake[Women,Obese]		kcal/day	This is a variable that represents the daily energy intake for the individual body weight representative.
Calorie_consumption_Overweight [Men]	"Individual_Decision-Making." Total_Energy_Intake[Men,Overweight]		kcal/day	This is a variable that represents the daily energy intake for the individual body weight representative.
Calorie_consumption_Overweight [Women]	"Individual_Decision-Making." Total_Energy_Intake[Women,Overweight]		kcal/day	This is a variable that represents the daily energy intake for the individual body weight representative.
Change_in_Energy_Intake [Sex]	Energy_Intake_Normal_Weight-Base_Energy_Intake_Normal_Weight		Kilocalories/Years	This is a variable that represents the change in energy intake. Its equation indicates that the change depends on the resting metabolic rate of the body.
Change_in_Energy_Intake_Obese [Sex]	Energy_Intake_Obese-Base_Energy_Intake_Obese		Kilocalories/Years	This is a variable that represents the change in energy intake. Its equation indicates that the change depends on the resting metabolic rate of the body.
Change_in_Energy_Intake_Overweight [Sex]	Energy_Intake_Overweight-Base_Energy_Intake_Overweight		Kilocalories/Years	This is a variable that represents the change in energy intake. Its equation indicates that the change depends on the resting metabolic rate of the body.
Days_in_Year	365		day/year	This is a constant that represents the number of days in a year.
EI_Denominator_Normal_Weight [Sex]	1-(IFactor_Normal_Weight)/(1+IFactor_Normal_Weight)		Dimensionless	This is a variable that represents the part of calculation for base energy requirement for the body in its current state. The equation indicates that this energy requirement is based on energy requirement for basic body functions.
EI_Denominator_Obese[Sex]	1-(IFactor_Obese)/(1+IFactor_Obese)		Dimensionless	This is a variable that represents the part of calculation for base energy requirement for the body in its current state. The equation indicates that this energy requirement is

Variable Name	Equation	Initial Value	Unit	Notes
				based on energy requirement for basic body functions.
EI_Denominator_Overweight[Sex]	1-(IFactor_Overweight)/(1+IFactor_Overweight)		Dimensionless	This is a variable that represents the part of calculation for base energy requirement for the body in its current state. The equation indicates that this energy requirement is based on energy requirement for basic body functions.
EI_Numerator_Normal_Weight[Sex]	("k-constant_year_Normal_Weight"+Resting_Metabolic_Rate_of_FFM_Normal_Weight+Resting_Metabolic_Rate_of_FM_Normal_Weight+Physical_Activity_Energy_Expenditure_Normal_Weight)/(1+IFactor_Normal_Weight)		Kilocalories/Years	This is a variable that represents the part of calculation for base energy requirement for the body in its current state. The equation indicates that this energy requirement is based on RMR, constant k and expenditure from physical activity.
EI_Numerator_Obese[Sex]	("k-constant_year_Obese"+Resting_Metabolic_Rate_of_FFM_Obese+Resting_Metabolic_Rate_of_FM_Obese+Physical_Activity_Energy_Expenditure_Obese)/(1+IFactor_Obese)		Kilocalories/Years	This is a variable that represents the part of calculation for base energy requirement for the body in its current state. The equation indicates that this energy requirement is based on RMR, constant k and expenditure from physical activity.
EI_Numerator_Overweight[Sex]	("k-constant_year_Overweight"+Resting_Metabolic_Rate_of_FFM_Overweight+Resting_Metabolic_Rate_of_FM_Overweight+Physical_Activity_Energy_Expenditure_Overweight)/(1+IFactor_Overweight)		Kilocalories/Years	This is a variable that represents the part of calculation for base energy requirement for the body in its current state. The equation indicates that this energy requirement is based on RMR, constant k and expenditure from physical activity.
Energy_Balance_Normal_Weight[Sex]	Energy_Intake_Normal_Weight-Energy_Expenditure_Normal_Weight		Kilocalories/Years	This is a variable that represents the energy balance for the individual representative. Its equation indicates that the balance can be negative or positive based on the magnitudes of expenditure and intake.

Variable Name	Equation	Initial Value	Unit	Notes
Energy_Balance_Obese[Sex]	Energy_Intake_Obese-Energy_Expenditure_Obese		Kilocalories/Years	This is a variable that represents the energy balance for the individual representative. Its equation indicates that the balance can be negative or positive based on the magnitudes of expenditure and intake.
Energy_Balance_Overweight[Sex]	Energy_Intake_Overweight-Energy_Expenditure_Overweight		Kilocalories/Years	This is a variable that represents the energy balance for the individual representative. Its equation indicates that the balance can be negative or positive based on the magnitudes of expenditure and intake.
"Energy_cost_for_FFM_Deposition_(μ)_Normal_Weight"	230		kcal/kg	This is a constant that represents the the energy cost for fat and protein turnover which are proportional to change in body composition. The value is based on studies (Hall, 2010; Hall et al., 2012).
"Energy_cost_for_FFM_Deposition_(μ)_Obese"	230		kcal/kg	This is a constant that represents the the energy cost for fat and protein turnover which are proportional to change in body composition. The value is based on studies (Hall, 2010; Hall et al., 2012).
"Energy_cost_for_FFM_Deposition_(μ)_Overweight"	230		kcal/kg	This is a constant that represents the the energy cost for fat and protein turnover which are proportional to change in body composition. The value is based on studies (Hall, 2010; Hall et al., 2012).
"Energy_cost_for_FM_Deposition_(μ)_Normal_Weight"	180		kcal/kg	This is a constant that represents the the energy cost for fat and protein turnover which are proportional to change in body composition. The value is based on studies (Hall, 2010; Hall et al., 2012).

Variable Name	Equation	Initial Value	Unit	Notes
"Energy_cost_for_FM_Deposition_(μ)_Obese"	180		kcal/kg	This is a constant that represents the the energy cost for fat and protein turnover which are proportional to change in body composition. The value is based on studies (Hall, 2010; Hall et al., 2012).
"Energy_cost_for_FM_Deposition_(μ)_Overweight"	180		kcal/kg	This is a constant that represents the the energy cost for fat and protein turnover which are proportional to change in body composition. The value is based on studies (Hall, 2010; Hall et al., 2012).
Energy_Density_of_FFM_Normal_Weight	1800		kcal/kg	This is a constant that represents the energy density of fat free mass with a body. The value is based on studies (Hall, 2010; Hall et al., 2012).
Energy_Density_of_FFM_Obese	1800		kcal/kg	This is a constant that represents the energy density of fat free mass with a body. The value is based on studies (Hall, 2010; Hall et al., 2012).
Energy_Density_of_FFM_Overweight	1800		kcal/kg	This is a constant that represents the energy density of fat free mass with a body. The value is based on studies (Hall, 2010; Hall et al., 2012).
Energy_Density_of_FM_Normal_Weight	9400		kcal/kg	This is a constant that represents the energy density of fat mass with a body. The value is based on studies (Hall, 2010; Hall et al., 2012).
Energy_Density_of_FM_Obese	9400		kcal/kg	This is a constant that represents the energy density of fat mass with a body.

Variable Name	Equation	Initial Value	Unit	Notes
				The value is based on studies (Hall, 2010; Hall et al., 2012).
Energy_Density_of_FM_Overweight	9400		kcal/kg	This is a constant that represents the energy density of fat mass with a body. The value is based on studies (Hall, 2010; Hall et al., 2012).
Energy_Expenditure_Normal_Weight[Sex]	"k-constant_year_Normal_Weight"/(1+IFactor_Normal_Weight)+"Energy_Expenditure_without_k-constant_Normal_Weight"		Kilocalories/Years	This is a variable that represents the energy expenditure including the constant k. This is the main energy expenditure for the body.
Energy_Expenditure_Obese[Sex]	"k-constant_year_Obese"/(1+IFactor_Obese)+"Energy_Expenditure_without_k-constant_Obese"		Kilocalories/Years	This is a variable that represents the energy expenditure including the constant k. This is the main energy expenditure for the body.
Energy_Expenditure_Overweight[Sex]	"k-constant_year_Overweight"/(1+IFactor_Overweight)+"Energy_Expenditure_without_k-constant_Overweight"		Kilocalories/Years	This is a variable that represents the energy expenditure including the constant k. This is the main energy expenditure for the body.
"Energy_Expenditure_without_k-constant_Normal_Weight"[Sex]	(Resting_Metabolic_Rate_of_FFM_Normal_Weight+Resting_Metabolic_Rate_of_FM_Normal_Weight+Physical_Activity_Energy_Expenditure_Normal_Weight+Adaptive_Thermogenesis_Normal_Weight+Thermic_Effect_Normal_Weight)/(1+IFactor_Normal_Weight)		Kilocalories/Years	This is variable that represents the energy expenditure excluding the constant k. The equation indicates that δ is the physical activity constant proportional to the BW because heavier the body is the more energy it will burn, γ for FM and FFM are constants for resting metabolic rate regression coefficients which are proportional to FMM and FM weight respectively which indicates the required energy to sustain the FM and FFM, β is another constant which is the coefficient for adaptive thermogenesis based on energy intake change rate, μ for FM and FFM are also constants indicates the energy cost for fat and protein turnover which are proportional to change in body composition.
"Energy_Expenditure_without_k-	(Resting_Metabolic_Rate_of_FFM_Obese+Resting_Metabolic_Rate_of_FM_Obese+Ph		Kilocalories/Years	This is variable that represents the energy expenditure excluding the constant k.

Variable Name	Equation	Initial Value	Unit	Notes
constant_Obese"[Sex]	ysical_Activity_Energy_Expenditure_Obese +Adaptive_Thermogenesis_Obese+Thermic _Effect_Obese)/(1+IFactor_Obese)			The equation indicates that δ is the physical activity constant proportional to the BW because heavier the body is the more energy it will burn, γ for FM and FFM are constants for resting metabolic rate regression coefficients which are proportional to FMM and FM weight respectively which indicates the required energy to sustain the FM and FFM, β is another constant which is the coefficient for adaptive thermogenesis based on energy intake change rate, μ for FM and FFM are also constants indicates the energy cost for fat and protein turnover which are proportional to change in body composition.
"Energy_Expenditure_without_k-constant_Overweight"[Sex]	(Resting_Metabolic_Rate_of_FFM_Overweight+Resting_Metabolic_Rate_of_FM_Overweight+Physical_Activity_Energy_Expenditure_Overweight+Adaptive_Thermogenesis_Overweight+Thermic_Effect_Overweight)/(1+IFactor_Overweight)		Kilocalories/Years	This is variable that represents the energy expenditure excluding the constant k. The equation indicates that δ is the physical activity constant proportional to the BW because heavier the body is the more energy it will burn, γ for FM and FFM are constants for resting metabolic rate regression coefficients which are proportional to FMM and FM weight respectively which indicates the required energy to sustain the FM and FFM, β is another constant which is the coefficient for adaptive thermogenesis based on energy intake change rate, μ for FM and FFM are also constants indicates the energy cost for fat and protein turnover which are proportional to change in body composition.
Energy_Intake_Normal_Weight[Sex]	Days_in_Year*Calorie_consumption_Normal_Weight		Kilocalories/Years	This is a variable that represents the energy intake for the individual within a year. Its equation indicates the conversion of energy intake per day to per year.
Energy_Intake_Obese[Sex]	Days_in_Year*Calorie_consumption_Obese		Kilocalories/Years	This is a variable that represents the energy intake for the individual within a year.

Variable Name	Equation	Initial Value	Unit	Notes
				Its equation indicates the conversion of energy intake per day to per year.
Energy_Intake_Overweight[Sex]	Days_in_Year*Calorie_consumption_Overweight		Kilocalories/Years	This is a variable that represents the energy intake for the individual within a year. Its equation indicates the conversion of energy intake per day to per year.
Energy_Partitioning_Function_Normal_Weight[Sex]	Forbes'_Body_Composition_Parameter_Normal_Weight/(Forbes'_Body_Composition_Parameter_Normal_Weight+Fat_Mass_Normal_Weight)		Dimensionless	This is a variable that represents the energy allocation within the body based on fat mass. It controls the relationship between FM and FFM (Hall, 2007) Its equation indicates how much energy there is to be going to be used produce either fat or fat free tissue. (Hall, 2010; Hall et al., 2012)
Energy_Partitioning_Function_Obese[Sex]	Forbes'_Body_Composition_Parameter_Obese/(Forbes'_Body_Composition_Parameter_Obese+Fat_Mass_Obese)		Dimensionless	This is a variable that represents the energy allocation within the body based on fat mass. It controls the relationship between FM and FFM (Hall, 2007) Its equation indicates how much energy there is to be going to be used produce either fat or fat free tissue. (Hall, 2010; Hall et al., 2012)
Energy_Partitioning_Function_Overweight[Sex]	Forbes'_Body_Composition_Parameter_Overweight/(Forbes'_Body_Composition_Parameter_Overweight+Fat_Mass_Overweight)		Dimensionless	This is a variable that represents the energy allocation within the body based on fat mass. It controls the relationship between FM and FFM (Hall, 2007) Its equation indicates how much energy there is to be going to be used produce either fat or fat free tissue. (Hall, 2010; Hall et al., 2012)
Forbes'_Body_Composition_Coefficient_Normal_Weight	10.4		kg	This is a constant that represents the Forbes' body composition coefficient. The value is based on studies (Hall, 2007, 2010; Hall et al., 2012)
Forbes'_Body_Composition_Coefficient_Obese	10.4		kg	This is a constant that represents the Forbes' body composition coefficient.

Variable Name	Equation	Initial Value	Unit	Notes
				The value is based on studies (Hall, 2007, 2010; Hall et al., 2012)
Forbes'_Body_Composition_Coefficient_Overweight	10.4		kg	This is a constant that represents the Forbes' body composition coefficient. The value is based on studies (Hall, 2007, 2010; Hall et al., 2012)
Forbes'_Body_Composition_Parameter_Normal_Weight	Forbes'_Body_Composition_Coefficient_Normal_Weight*(Energy_Density_of_FFM_Normal_Weight/Energy_Density_of_FM_Normal_Weight)		kg	This is a constant that represents the parameter for energy partitioning. The equation is based on studies. (Hall, 2007, 2010; Hall et al., 2012)
Forbes'_Body_Composition_Parameter_Obese	Forbes'_Body_Composition_Coefficient_Obese*(Energy_Density_of_FFM_Obese/Energy_Density_of_FM_Obese)		kg	This is a constant that represents the parameter for energy partitioning. The equation is based on studies. (Hall, 2007, 2010; Hall et al., 2012)
Forbes'_Body_Composition_Parameter_Overweight	Forbes'_Body_Composition_Coefficient_Overweight*(Energy_Density_of_FFM_Overweight/Energy_Density_of_FM_Overweight)		kg	This is a constant that represents the parameter for energy partitioning. The equation is based on studies. (Hall, 2007, 2010; Hall et al., 2012)
IFactor_Normal_Weight[Sex]	"Energy_cost_for_FM_Deposition_(μ)_Normal_Weight"*(1-Energy_Partitioning_Function_Normal_Weight)/Energy_Density_of_FM_Normal_Weight+Energy_Density_of_FFM_Normal_Weight*Energy_Partitioning_Function_Normal_Weight/"Energy_cost_for_FFM_Deposition_(μ)_Normal_Weight"		Dimensionless	This is a variable that represents the energy required for several body functions such as fat and protein turnover, energy partitioning and etc.
IFactor_Obese[Sex]	"Energy_cost_for_FM_Deposition_(μ)_Obese"*(1-Energy_Partitioning_Function_Obese)/Energy_Density_of_FM_Obese+Energy_Density_of_FFM_Obese*Energy_Partitioning_Functi		Dimensionless	This is a variable that represents the energy required for several body functions such as fat and protein turnover, energy partitioning and etc.

Variable Name	Equation	Initial Value	Unit	Notes
	on_Obese/"Energy_cost_for_FFM_Deposition_(μ)_Obese"			
IFactor_Overweight[Sex]	"Energy_cost_for_FM_Deposition_(μ)_Overweight"*(1-Energy_Partitioning_Function_Overweight)/Energy_Density_of_FM_Overweight+Energy_Density_of_FFM_Overweight*Energy_Partitioning_Function_Overweight/"Energy_cost_for_FFM_Deposition_(μ)_Overweight"		Dimensionless	This is a variable that represents the energy required for several body functions such as fat and protein turnover, energy partitioning and etc.
Indicated_FFM_Normal_Weight[Sex]	(Energy_Partitioning_Function_Normal_Weight*Energy_Balance_Normal_Weight)/Energy_Density_of_FFM_Normal_Weight		Kilograms/Years	This is a variable that represents the fat free tissue to be produced based on available energy. The equation indicates that the magnitude of change in FFM depends on energy partitioning function and energy balance. If energy balance is negative, then it means that the change is also negative.
Indicated_FFM_Obese[Sex]	Energy_Partitioning_Function_Obese*(Energy_Balance_Obese)/Energy_Density_of_FFM_Obese		Kilograms/Years	This is a variable that represents the fat free tissue to be produced based on available energy. The equation indicates that the magnitude of change in FFM depends on energy partitioning function and energy balance. If energy balance is negative, then it means that the change is also negative.
Indicated_FFM_Overweight[Sex]	Energy_Partitioning_Function_Overweight*(Energy_Balance_Overweight)/Energy_Density_of_FFM_Overweight		Kilograms/Years	This is a variable that represents the fat free tissue to be produced based on available energy. The equation indicates that the magnitude of change in FFM depends on energy partitioning function and energy balance. If energy balance is negative, then it means that the change is also negative.
Indicated_FM_Normal_Weight[Sex]	(1-Energy_Partitioning_Function_Normal_Weight)*(Energy_Balance_Normal_Weight)/Energy_Density_of_FM_Normal_Weight		Kilograms/Years	This is a variable that represents the fat tissue to be produced based on available energy. The equation indicates that the magnitude of change in FM depends on energy partitioning function and energy balance. If energy balance is negative, then it

Variable Name	Equation	Initial Value	Unit	Notes
				means that the change is also negative. 1-Energy Partitioning Function indicates that the larger portion of the energy is stored as fat is energy balance is positive and vice versa. This is due to our survival mechanism as mentioned in earlier chapters.
Indicated_FM_Obese [Sex]	(1-Energy_Partitioning_Function_Obese)*(Energy_Balance_Obese)/Energy_Density_of_FM_Obese		Kilograms/Years	This is a variable that represents the fat tissue to be produced based on available energy. The equation indicates that the magnitude of change in FM depends on energy partitioning function and energy balance. If energy balance is negative, then it means that the change is also negative. 1-Energy Partitioning Function indicates that the larger portion of the energy is stored as fat is energy balance is positive and vice versa. This is due to our survival mechanism as mentioned in earlier chapters.
Indicated_FM_Overweight[Sex]	(1-Energy_Partitioning_Function_Overweight)*(Energy_Balance_Overweight)/Energy_Density_of_FM_Overweight		Kilograms/Years	This is a variable that represents the fat tissue to be produced based on available energy. The equation indicates that the magnitude of change in FM depends on energy partitioning function and energy balance. If energy balance is negative, then it means that the change is also negative. 1-Energy Partitioning Function indicates that the larger portion of the energy is stored as fat is energy balance is positive and vice versa. This is due to our survival mechanism as mentioned in earlier chapters.
Initial_BW_Normal_Weight[Sex]	Normal_BMI_representative*(Average_Height^2)		kg	This is a constant that represents the initial body weight of the individual. The equation indicates that the initial body weight is depends on the initial BMI.
Initial_BW_Obese[Sex]	Obese_BMI_Representative*(Average_Height^2)		kg	This is a constant that represents the initial body weight of the individual.

Variable Name	Equation	Initial Value	Unit	Notes
				The equation indicates that the initial body weight is depends on the initial BMI.
Initial_BW_Overweight[Sex]	Overweight_BMI_Representative*(Average_Height^2)		kg	This is a constant that represents the initial body weight of the individual. The equation indicates that the initial body weight is depends on the initial BMI.
Initial_FFM_Normal_Weight[Men]	Initial_BW_Normal_Weight[Men]-Initial_FM_Normal_Weight[Men]		kg	This is a constant that represents the initial fat free mass for the representative individual. The equation indicates that the FFM is what is left from body weight after fat mass.
Initial_FFM_Normal_Weight[Women]	Initial_BW_Normal_Weight[Women]-Initial_FM_Normal_Weight[Women]		kg	This is a constant that represents the initial fat free mass for the representative individual. The equation indicates that the FFM is what is left from body weight after fat mass.
Initial_FFM_Obese[Men]	Initial_BW_Obese[Men]-Initial_FM_Obese[Men]		kg	This is a constant that represents the initial fat free mass for the representative individual. The equation indicates that the FFM is what is left from body weight after fat mass.
Initial_FFM_Obese[Women]	Initial_BW_Obese[Women]-Initial_FM_Obese[Women]		kg	This is a constant that represents the initial fat free mass for the representative individual. The equation indicates that the FFM is what is left from body weight after fat mass.
Initial_FFM_Overweight[Men]	Initial_BW_Overweight[Men]-Initial_FM_Overweight[Men]		kg	This is a constant that represents the initial fat free mass for the representative individual. The equation indicates that the FFM is what is left from body weight after fat mass.
Initial_FFM_Overweight[Women]	Initial_BW_Overweight[Women]-Initial_FM_Overweight[Women]		kg	This is a constant that represents the initial fat free mass for the representative individual.

Variable Name	Equation	Initial Value	Unit	Notes
				The equation indicates that the FFM is what is left from body weight after fat mass.
Initial_FM_Normal_Weight[Sex]	(Initial_BW_Normal_Weight*"Normal-InitialFatFraction_Normal_Weight")/100		kg	This is a constant that represents the initial fat mass of the individual. The equation indicates that the fat mass is calculated based on the fat percentage.
Initial_FM_Obese[Sex]	(Initial_BW_Obese*"Normal-InitialFatFraction_Obese")/100		kg	This is a constant that represents the initial fat mass of the individual. The equation indicates that the fat mass is calculated based on the fat percentage.
Initial_FM_Overweight[Sex]	(Initial_BW_Overweight*"Overweight-Initial_Fat_Fraction")/100		kg	This is a constant that represents the initial fat mass of the individual. The equation indicates that the fat mass is calculated based on the fat percentage.
"k-constant_day_Normal_Weight"	370.21		Kcal/day	this is a constant that represents the k coefficient. The value is based on studies (Hall, 2010; Hall et al., 2012).
"k-constant_day_Obese"	370.21		Kcal/day	this is a constant that represents the k coefficient. The value is based on studies (Hall, 2010; Hall et al., 2012).
"k-constant_day_Overweight"	370.21		Kcal/day	this is a constant that represents the k coefficient. The value is based on studies (Hall, 2010; Hall et al., 2012).
"k-constant_year_Normal_Weight"	Days_in_Year*"k-constant_day_Normal_Weight"		Kilocalories/Years	this is a constant that represents the k coefficient. The value is based on studies (Hall, 2010; Hall et al., 2012) and its converted to per year from per day.
"k-constant_year_Obese"	Days_in_Year*"k-constant_day_Obese"		Kilocalories/Years	this is a constant that represents the k coefficient.

Variable Name	Equation	Initial Value	Unit	Notes
				The value is based on studies (Hall, 2010; Hall et al., 2012) and its converted to per year from per day.
"k-constant_year_Overweight"	Days_in_Year*"k-constant_day_Overweight"		Kilocalories/Years	this is a constant that represents the k coefficient. The value is based on studies (Hall, 2010; Hall et al., 2012) and its converted to per year from per day.
Normal_BMI_representative[Sex]	Normal_Weight_Initial+(Normal_Weight_Final-Normal_Weight_Initial)/2		kg/(centimeters*centimeters)	This is a constant that represents the initial BMI of the individual calculated based on initial and final values of BMI for each body weight category.
Normal_Weight_Final[Sex]	24.9		kg/(centimeters*centimeters)	This is a constant that represents the final BMI value of the corresponding body weight category. The value is based on WHO data.
Normal_Weight_Initial[Sex]	18.5		kg/(centimeters*centimeters)	This is a constant that represents the initial BMI value of the corresponding body weight category. The value is based on WHO data.
"Normal-InitialFatFraction_Normal_Weight"[Men]	Normal_BMI_representative[Men]*1.2+(Representative_Age_for_all_age_groups*0.23)-16.2		Dimensionless	This is a constant that represents the initial fat percentage for the individual. It is calculated based on age and BMI. This eqution developed by Deurenberg et al. (Deurenberg et al., 2001)
"Normal-InitialFatFraction_Normal_Weight"[Women]	Normal_BMI_representative[Women]*1.2+(Representative_Age_for_all_age_groups*0.23)-5.4		Dimensionless	This is a constant that represents the initial fat percentage for the individual. It is calculated based on age and BMI. This eqution developed by Deurenberg et al. (Deurenberg et al., 2001)
"Normal-InitialFatFraction_Obese"[Men]	Obese_BMI_Representative[Men]*1.2+(Representative_Age_for_all_age_groups*0.23)-16.2		Dimensionless	This is a constant that represents the initial fat percentage for the individual. It is calculated based on age and BMI. This eqution developed by Deurenberg et al. (Deurenberg et al., 2001)

Variable Name	Equation	Initial Value	Unit	Notes
"Normal-InitialFatFraction_Obese"[Women]	Obese_BMI_Representative[Women]*1.2+(Representative_Age_for_all_age_groups*0.23)-5.4		Dimensionless	This is a constant that represents the initial fat percentage for the individual. It is calculated based on age and BMI. This eqution developed by Deurenberg et al. (Deurenberg et al., 2001)
Obese_BMI_Representative[Sex]	Obese_Initial+(Obese_Final-Obese_Initial)/2		kg/(centimeters*centimeters)	This is a constant that represents the initial BMI of the individual calculated based on initial and final values of BMI for each body weight category.
Obese_Final[Sex]	65		kg/(centimeters*centimeters)	This is a constant that represents the final BMI value of the corresponding body weight category. The value is based on WHO data.
Obese_Initial[Sex]	30		kg/(centimeters*centimeters)	This is a constant that represents the initial BMI value of the corresponding body weight category. The value is based on WHO data.
Overweight_BMI_Representative[Sex]	Overweight_Initial+(Overweight_Final-Overweight_Initial)/2		kg/(centimeters*centimeters)	This is a constant that represents the initial BMI of the individual calculated based on initial and final values of BMI for each body weight category.
Overweight_Final[Sex]	29.9		kg/(centimeters*centimeters)	This is a constant that represents the final BMI value of the corresponding body weight category. The value is based on WHO data.
Overweight_Initial[Sex]	25		kg/(centimeters*centimeters)	This is a constant that represents the initial BMI value of the corresponding body weight category. The value is based on WHO data.
"Overweight-Initial_Fat_Fraction"[Men]	Overweight_BMI_Representative[Men]*1.2+(Representative_Age_for_all_age_groups*0.23)-16.2		Dimensionless	This is a constant that represents the initial fat percentage for the individual. It is calculated based on age and BMI. This eqution developed by Deurenberg et al. (Deurenberg et al., 2001)

Variable Name	Equation	Initial Value	Unit	Notes
"Overweight-Initial_Fat_Fraction" [Women]	Overweight_BMI_Representative[Women]*1.2+(Representative_Age_for_all_age_groups*0.23)-5.4		Dimensionless	This is a constant that represents the initial fat percentage for the individual. It is calculated based on age and BMI. This eqution developed by Deurenberg et al. (Deurenberg et al., 2001)
Physical_Activity_Energy_Expenditure_Normal_Weight[Sex]	Physical_Activity."Physical_Activity_Coefficient_(δ)"*Body_Weight_Normal_Weight*Days_in_Year		Kilocalories/Years	This is a variable that represents the energy expenditure from physical activity. Its equation indicates that δ is the physical activity constant proportional to the BW because heavier the body is the more energy it will burn.
Physical_Activity_Energy_Expenditure_Obese[Sex]	Physical_Activity."Physical_Activity_Coefficient_(δ)"*Body_Weight_Obese*Days_in_Year		Kilocalories/Years	This is a variable that represents the energy expenditure from physical activity. Its equation indicates that δ is the physical activity constant proportional to the BW because heavier the body is the more energy it will burn.
Physical_Activity_Energy_Expenditure_Overweight[Sex]	Physical_Activity."Physical_Activity_Coefficient_(δ)"*Body_Weight_Overweight*Days_in_Year		Kilocalories/Years	This is a variable that represents the energy expenditure from physical activity. Its equation indicates that δ is the physical activity constant proportional to the BW because heavier the body is the more energy it will burn.
Representative_Age_for_all_age_groups	32		Dimensionless	This is a constant. It represents the average age representative age for all age groups.
Resting_Metabolic_Rate_of_FFM_Normal_Weight[Sex]	Fat_Free_Mass_Normal_Weight*"RMR_Regression_Coefficient_of_FFM_(γ)_Normal_Weight"*Days_in_Year		Kilocalories/Years	This is a variable that represents the resting metabolic rate from fat free mass. This is the required energy for body to maintain its regular activities such as breathing, hear beats, cellular activities, protein, and hormonal syntheses and etc. Its equation indicates that as the resting metabolic rate depends on the body mass. When it is increases, RMR increases and vice versa. Also the equation converts per day RMR to per year.

Variable Name	Equation	Initial Value	Unit	Notes
Resting_Metabolic_Rate_of_FFM_Obese[Sex]	Fat_Free_Mass_Obese*"RMR_Regression_Coefficient_of_FFM_(γ)_Obese"*Days_in_Year		Kilocalories/Years	This is a variable that represents the resting metabolic rate from fat free mass. This is the required energy for body to maintain its regular activities such as breathing, hear beats, cellular activities, protein, and hormonal syntheses and etc. Its equation indicates that as the resting metabolic rate depends on the body mass. When it is increases, RMR increases and vice versa. Also the equation converts per day RMR to per year.
Resting_Metabolic_Rate_of_FFM_Overweight[Sex]	Fat_Free_Mass_Overweight*"RMR_Regression_Coefficient_of_FFM_(γ)_Overweight"*Days_in_Year		Kilocalories/Years	This is a variable that represents the resting metabolic rate from fat free mass. This is the required energy for body to maintain its regular activities such as breathing, hear beats, cellular activities, protein, and hormonal syntheses and etc. Its equation indicates that as the resting metabolic rate depends on the body mass. When it is increases, RMR increases and vice versa. Also the equation converts per day RMR to per year.
Resting_Metabolic_Rate_of_FM_Normal_Weight[Sex]	Fat_Mass_Normal_Weight*"RMR_Regression_Coefficient_of_FM_(γ)_Normal_Weight"*Days_in_Year		Kilocalories/Years	This is a variable that represents the resting metabolic rate from fat mass. This is the required energy for body to maintain its regular activities such as breathing, hear beats, cellular activities, protein, and hormonal syntheses and etc. Its equation indicates that as the resting metabolic rate depends on the body mass. When it is increases, RMR increases and vice versa. Also the equation converts per day RMR to per year.
Resting_Metabolic_Rate_of_FM_Obese[Sex]	Fat_Mass_Obese*"RMR_Regression_Coefficient_of_FM_(γ)_Obese"*Days_in_Year		Kilocalories/Years	This is a variable that represents the resting metabolic rate from fat mass. This is the required energy for body to maintain its regular activities such as breathing, hear beats, cellular activities, protein, and hormonal syntheses and etc.

Variable Name	Equation	Initial Value	Unit	Notes
				Its equation indicates that as the resting metabolic rate depends on the body mass. When it is increases, RMR increases and vice versa. Also the equation converts per day RMR to per year.
Resting_Metabolic_Rate_of_FM_Overweight[Sex]	Fat_Mass_Overweight*"RMR_Regression_Coefficient_of_FM_(γ)_Overweight"*Days_in_Year		Kilocalories/Years	This is a variable that represents the resting metabolic rate from fat mass. This is the required energy for body to maintain its regular activities such as breathing, hear beats, cellular activities, protein, and hormonal syntheses and etc. Its equation indicates that as the resting metabolic rate depends on the body mass. When it is increases, RMR increases and vice versa. Also the equation converts per day RMR to per year.
"RMR_Regression_Coefficient_of_FFM_(γ)_Normal_Weight"	22		kcal/kg/day	This is a constant that represents the resting metabolic rate coefficient per fat free mass. The value is based on studies (Hall, 2010; Hall et al., 2012).
"RMR_Regression_Coefficient_of_FFM_(γ)_Obese"	22		kcal/kg/day	This is a constant that represents the resting metabolic rate coefficient per fat free mass. The value is based on studies (Hall, 2010; Hall et al., 2012).
"RMR_Regression_Coefficient_of_FFM_(γ)_Overweight"	22		kcal/kg/day	This is a constant that represents the resting metabolic rate coefficient per fat free mass. The value is based on studies (Hall, 2010; Hall et al., 2012).
"RMR_Regression_Coefficient_of_FM_(γ)_Normal_Weight"	3.2		kcal/kg/day	This is a constant that represents the resting metabolic rate coefficient per fat free mass. The value is based on studies (Hall, 2010; Hall et al., 2012).

Variable Name	Equation	Initial Value	Unit	Notes
"RMR_Regression_ Coefficient_of_FM_(γ)_Obese"	3.2		kcal/kg/day	This is a constant that represents the resting metabolic rate coefficient per fat free mass. The value is based on studies (Hall, 2010; Hall et al., 2012).
"RMR_Regression_ Coefficient_of_FM_(γ)_Overweight"	3.2		kcal/kg/day	This is a constant that represents the resting metabolic rate coefficient per fat free mass. The value is based on studies (Hall, 2010; Hall et al., 2012).
ß_Normal_Weight	0.24		Dimensionless	This is a constant thar represents adaptive Thermogenesis coefficient (ß) which is the energy requirement per kcal after the change in diet. The value is based on studies (Hall, 2010; Hall et al., 2012).
ß_Obese	0.24		Dimensionless	This is a constant thar represents adaptive Thermogenesis coefficient (ß) which is the energy requirement per kcal after the change in diet. The value is based on studies (Hall, 2010; Hall et al., 2012).
ß_Overweight	0.24		Dimensionless	This is a constant thar represents adaptive Thermogenesis coefficient (ß) which is the energy requirement per kcal after the change in diet. The value is based on studies (Hall, 2010; Hall et al., 2012).
Thermic_Effect_Normal_Weight[Sex]	IFactor_Normal_Weight*Energy_Intake_Normal_Weight		Kilocalories/Years	This is a variable that represents the thermic effect of foods in other words the required energy for body to digest food and produce proteins. (Hall, 2010; Hall et al., 2012)
Thermic_Effect_Obese[Sex]	IFactor_Obese*Energy_Intake_Obese		Kilocalories/Years	This is a variable that represents the thermic effect of foods in other words the required energy for body to digest food and produce proteins. (Hall, 2010; Hall et al., 2012)

Variable Name	Equation	Initial Value	Unit	Notes
Thermic_Effect_Overweight[Sex]	IFactor_Overweight*Energy_Intake_Overweight		Kilocalories/Years	This is a variable that represents the thermic effect of foods in other words the required energy for body to digest food and produce proteins. (Hall, 2010; Hall et al., 2012)
		Economy Module		
Firm_Revenues(t)	Firm_Revenues(t - dt) + (change_in_firm_revenue - firm_expenditure) * dt	INIT Firm_Revenues = 1e12	TRY	This is a stock that represents cumulative amount of revenue that companies have. It is depleted by expenditures and increased by change in revenue. It is defined by a stock because revenue can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
GDP(t)	GDP(t - dt) + (Change_in_GDP) * dt	INIT GDP = 1.5e12	TRY	This is a stock that represents the information about total amount of production that is produced in a country within a year. It is based on aggregated demand. It increases as the old information is updated by the current information about the goal. This update occurs through a first order information delay based on the goal. It is defined by a stock because information about GDP can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
Government_Funds(t)	Government_Funds(t - dt) + (government_income - Government_expenditure) * dt	INIT Government_Funds = 4.5e11	TRY	This is a stock that represents cumulative amount of funds that the government has. It is depleted by expenditures and increased by change in income.

Variable Name	Equation	Initial Value	Unit	Notes
				It is defined by a stock because revenue can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
Household_Revenues (t)	Household_Revenues(t - dt) + (change_in_revenue - expenditures) * dt	INIT Household_Revenues = 4e11	TRY	This is a stock that represents cumulative amount of money that households have. It is depleted by expenditures and increased by change in revenue. It is defined by a stock because revenue can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
change_in_firm_revenue	(Business_Investments+Consumption+government_purchase)/Change_in_Firm_Revenue_Delay		TRY/year	This is the inflow for the firm revenue that represents the incoming average revenue. Its equation indicates that change in firm revenue takes certain amount of time.
Change_in_GDP	(Indicated_Aggregate_Demand-GDP)/Change_in_GDP_delay		TRY/Year	This is an inflow to GDP that represents the movement of the current information that updates the GDP hence it is the change in GDP. Its equation indicates that the change in GDP takes a certain amount time. After that time, the change is added to the current GDP.
change_in_revenue	Disposable_income/Change_in_revenue_delay		TRY/Year	This is the inflow for the household revenue that represents the incoming average revenue. Its equation indicates that change in household revenue takes certain amount of time.
expenditures	Consumption/Expenditure_Delay		TRY/Year	This is the outflow for the household revenues that represents the expenditure. Its equation indicates that expending revenue takes certain amount of time.
firm_expenditure	MAX(0, expenditure/Firm_Expenditure_Delay)		TRY/year	This is the outflow for the firm revenues that represents the expenditure.

Variable Name	Equation	Initial Value	Unit	Notes
				Its equation indicates that expending revenue takes certain amount of time.
Government_expenditure	government_purchase/Government_Expenditure_Delay		TRY/Year	This is the outflow for the government funds that represents the expenditure. Its equation indicates that expending the funds takes certain amount of time.
government_income	taxes/Change_in_Government_Income_Delay		TRY/Year	This is the inflow for the government funds that represents the incoming average income. Its equation indicates that change in government income takes certain amount of time.
Aggregate_Demand	Consumption+Business_Investments+government_purchase		TRY	This is a variable that represents the current aggregate demand in the economy. Its equation indicates that the demand is sum off all expenditures within the economy.
Average_HED_Food_Price_per_Tonne	Effect_of_Perceived_HED_Price_Level_on_HED_Price_Per_Tonne*Initial_Average_HED_Food_Price_per_tonne		TRY/Tonne	This is a variable that represents the average food price per ton according to changes in price level. Its equation indicates that the price depends on the changes in price level.
Average_LED_Food_Price_per_Tonne	Effect_of_Perceived_LED_Price_Level_on_LED_Price_Per_Tonne*Initial_Average_LED_Food_Price_per_tonne		TRY/Tonne	This is a variable that represents the average food price per ton according to changes in price level. Its equation indicates that the price depends on the changes in price level.
Business_Investments	SMTH1(GDP*propensity_to_invest, 1)		TRY	This is a stock that represents the total business investments. It increases as the old information is updated by the current information. This update occurs through a first order information delay based on the goal. It is defined by a stock because investments can

Variable Name	Equation	Initial Value	Unit	Notes
				accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
Change_in_Firm_Revenue_Delay	1		year	This is a constant that represents the time it takes the revenue to change. The value estimated and calibrated.
Change_in_GDP_delay	1		year	This is a constant that represents the time it takes the revenue to change. The value estimated and calibrated.
Change_in_Government_Income_Delay	1		year	This is a constant that represents the time it takes the income to change. The value estimated and calibrated.
Change_in_revenue_delay	1		year	This is a constant that represents the time it takes the revenue to change. The value estimated and calibrated.
Consumption	SMTH1(Household_Revenues+Total_Consumption_from_Food_Consumption, 1)		TRY	This is a stock that represents the total consumption. It increases as the old information is updated by the current information. This update occurs through a first order information delay based on the goal. It is defined by a stock because consumption can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
Disposable_income	Wages-taxes		TRY	This is a variable that represents the available disposable income. Its equation indicates that the disposable income is the what is left from wages after the taxes.
Effect_of_Perceived_HED_Price_Level_on_HED_Price_Per_Tonne	(Food_Environment.Perceived_HED_Food_Price_Level/INIT(Food_Environment.Perceived_HED_Food_Price_Level))^"Sensitivity_of_HED_&_LED_to_Price_Levels_(θ1)"		Dimensionless	This is variable that represents the effect of perceived HED price level on HED price per ton. This equation describes a non-linear effect function

Variable Name	Equation	Initial Value	Unit	Notes
				for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_Perceived_LED_Price_Level_on_LED_Price_Per_Tonne	(Food_Environment.Perceived_LED_Food_Price_Level/INIT(Food_Environment.Perceived_LED_Food_Price_Level))^"Sensitivity_of_HED_&_LED_to_Price_Levels_(θ1)"		Dimensionless	This is variable that represents the effect of perceived LED price level on LED price per ton. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
expenditure	SMTH1(Business_Investments+Wages, 1)		TRY	This is a stock that represents the total expenditure that is made by firms. It increases as the old information is updated by the current information. This update occurs through a first order information delay based on the goal. It is defined by a stock because expenditures can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
Expenditure_Delay	1		year	This is a constant that represents the time it takes the expenditure to change. The value estimated and calibrated.
Firm_Expenditure_Delay	1		year	This is a constant that represents the time it takes the expenditure to change. The value estimated and calibrated.
Government_Expenditure_Delay	1		year	This is a constant that represents the time it takes the expenditure to change. The value estimated and calibrated.
government_purchase	SMTH1(Government_Funds, 2)		TRY	This is a stock that represents the total government purchases. It increases as the old information is updated by the

Variable Name	Equation	Initial Value	Unit	Notes
				current information. This update occurs through a first order information delay based on the goal. It is defined by a stock because purchases can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
HED_Food_Consumption	Food_Environment.Total_Food_Consumption[HighED_Food]*Average_HED_Food_Price_per_Tonne		TRY	This is a variable that represents the total consumption of HED food. Its equation indicates that the amount food that is consumed is converted to the currency.
Indicated_Aggregate_Demand	SMTH1(Aggregate_Demand, 1)		TRY	This is a stock that represents the perceived aggregate demand within the economy. It increases as the old information is updated by the current information. This update occurs through a first order information delay based on the aggregate demand which is goal for this stock. It is defined by a stock because demand can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
Initial_Average_HED_Food_Price_per_tonne	50000		TRY/Tonne	This is a constant that represents the initial price of food per ton. The value estimated and calibrated.
Initial_Average_LED_Food_Price_per_tonne	50000		TRY/Tonne	This is a constant that represents the initial price of food per ton. The value estimated and calibrated.
Labor_share	0.80		Dimensionless	This is a constant that represents the labors' share from the GDP which affects their income. Its value calibrated and estimated.

Variable Name	Equation	Initial Value	Unit	Notes
LED_Food_Consumption	Food_Environment.Total_Food_Consumption[LowED_Food]*Average_LED_Food_Price_per_Tonne		TRY	This is a variable that represents the total consumption of HED food. Its equation indicates that the amount food that is consumed is converted to the currency.
propensity_to_invest	0.3		Dimensionless	This is a constant which represents the fraction of investments that companies are willing to make. Its value estimated and calibrated.
"Sensitivity_of_HED_&_LED_to_Price_Levels_(θ1)"	0.25		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
Tax_rate	.25		Dimensionless	This is a constant that represents the tax rate that is set by the government. Its value calibrated and estimated.
taxes	Tax_rate*Wages		TRY	This is a variable that represents tax collection by the government. It determines the government's income. The equation describes that total amount of taxes that is collected at a time unit is determined by wages and tax rate.
Total_Consumption_from_Food_Consumption	HED_Food_Consumption+LED_Food_Consumption		TRY	This is a variable that represents the total number of food that is consumed. Its equation the sum of all food types.
Wages	GDP*Labor_share		TRY	This is a variable that represents wages of individuals. It determines the individuals' disposable income. The equation describes that total amount of wages

Variable Name	Equation	Initial Value	Unit	Notes
				that is earned at a time unit is determined by labor share and GDP.
		Food Environment		
Food_Production_Capacity[Food_Type](t)	Food_Production_Capacity[Food_Type](t - dt) + (Change_in_Production_Capacity[Food_Type]) * dt	INIT Food_Production_Capacity[Food_Type] = 1e6	Tonne/year	This is a stock that represents the information about perceived production goal. It increases as the old information is updated by the current information about the goal. This update occurs through a first order information delay based on the goal. It is defined by a stock because information about production goal can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
Food_Supply[HighED_Food](t)	Food_Supply[HighED_Food](t - dt) + (Food_Production[HighED_Food] - Food_Consumption[HighED_Food] - Export_and_Waste[HighED_Food]) * dt	INIT Food_Supply[HighED_Food] = 5e6	Tonne	This is a stock that represents the total amount of food that is available. It represents all foods and beverages. It is depleted by food consumption and export and waste and increased by food production. It is defined by a stock because food supply can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on UN FAO data.
Food_Supply[LowED_Food](t)	Food_Supply[LowED_Food](t - dt) + (Food_Production[LowED_Food] - Food_Consumption[LowED_Food] - Export_and_Waste[LowED_Food]) * dt	INIT Food_Supply[LowED_Food] = 10e6	Tonne	This is a stock that represents the total amount of food that is available. It represents all foods and beverages. It is depleted by food consumption and export and waste and increased by food production.

Variable Name	Equation	Initial Value	Unit	Notes
				It is defined by a stock because food supply can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on UN FAO data.
Total_Food_Consumption[HighED_Food](t)	Total_Food_Consumption[HighED_Food](t - dt) + (Change_in_Total_Food_Consumption[HighED_Food]) * dt	INIT Total_Food_Consumption[HighED_Food] = 1.27e6	Tonne	This is a stock that represents the cumulative food consumption. It increases as the old information is updated by the current information about the goal. This update occurs through a first order information delay based on the goal. It is defined by a stock because information about production goal can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on UN FAO data.
Total_Food_Consumption[LowED_Food](t)	Total_Food_Consumption[LowED_Food](t - dt) + (Change_in_Total_Food_Consumption[LowED_Food]) * dt	INIT Total_Food_Consumption[LowED_Food] = 3.5e6	Tonne	This is a stock that represents the cumulative food consumption. It increases as the old information is updated by the current information about the goal. This update occurs through a first order information delay based on the goal. It is defined by a stock because information about production goal can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on UN FAO data.
Change_in_Production_Capacity[Food_Type]	(Production_Goal-Food_Production_Capacity)/Capacity_Adjustment_Delay		Tonne/year/Year	This is an inflow to food production capacity that represents the movement of the current information that updates the food production capacity hence it is

Variable Name	Equation	Initial Value	Unit	Notes
				the change in production capacity. According to this information, capacity is adjusted. Its equation indicates that the capacity adjustment takes a certain amount time.
Change_in_Total_Food_Consumption[Food_Type]	((Total_Food_Demand[Men,Food_Type]+Total_Food_Demand[Women,Food_Type])-Total_Food_Consumption)/Total_Consumption_Adjustment_Time		Tonnes/Years	This is the inflow to total food consumption that represents the change in food consumption. Its equation indicates that this change takes certain amount of time and it is based on the current level of consumption. If the current level is lower than the food demand then the consumption increases and vice versa.
Export_and_Waste[Food_Type]	(Food_Supply*Export_and_Waste_Fraction)/Export_and_Waste_Delay		Tonne/year	This is the outflow for the food supply that represents the total export and waste in a unit of time. Its equation indicates that export and waste take certain amount of time and it is based on the certain fraction of supply supply.
Food_Consumption[Food_Type]	Total_Food_Consumption/Consumption_Delay		Tonne/Year	This is the outflow for the food supply that represents the total consumption in a unit of time. Its equation indicates that consumption takes certain amount of time.
Food_Production[Food_Type]	Food_Production_Capacity*Additional_Capacity_for_Business_Cycles		Tonne/Year	This is the inflow for the food supply that represents the incoming total food production in a time unit. Its equation indicates that food production increased by a certain fraction to meet the demand.
Additional_Capacity_for_Business_Cycles	1.5		Dimensionless	This is a constant that represents the additional capacity to meet the demand. The value estimated and calibrated.
Capacity_Adjustment_Delay	1		year	This is a constant that represents the time it takes the expenditure to change.

Variable Name	Equation	Initial Value	Unit	Notes
				The value estimated and calibrated.
Consumption_Delay	1.5		year	This is a constant that represents the time it takes the expenditure to change. The value estimated and calibrated.
Effect_of_HED_Food_Price_on_HED_Food_Demand	(Perceived_HED_Food_Price_Level/INIT(Perceived_HED_Food_Price_Level))^"Price_elasticity_of_HED_Food_(θ6)"		Dimensionless	This is variable that represents the effect of perceived HED price level on HED food demand. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_HED_Food_Price_on_HED_Food_Production	(Indicated_HED_Food_Price_Level/INIT(Indicated_HED_Food_Price_Level))^"Sensitivity_of_HED_Food_Price_on_HED_Food_Production_(θ2)"		Dimensionless	This is variable that represents the effect of perceived HED price level on HED food production. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_Inventory_Coverage_on_Food_Price[Food_Type]	(Perceived_Inventory_Coverage/INIT(Perceived_Inventory_Coverage))^"Sensitivity_of_Food_Price_Level_to_Inventory_Coverage_(θ4)"		Dimensionless	This is variable that represents the effect of perceived inventory coverage on HED and LED food price level. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_Investment_in_Food_Stores_and_Delivery_Services_on_RVF	"Maximum_Effect_of_Investments_in_Food_Stores_and_Delivery_Services_(L1)"/(1+(Investments_in_Food_Stores_and_Delivery_Services/INIT(Investments_in_Food_Stores_and_Delivery_Services))^"Sensitivity_of_RVF_to_Food_Stores_and_Delivery_Services_(α1)")		Dimensionless	This is a variable that represents the effect of investments to food stores and delivery services on reinforcing value of food. The equation describes a non-linear effect formulation. It is formulated via a logistic function which indicates that the effect has a limit. The effect formulation is used to calculate effect of one variable

Variable Name	Equation	Initial Value	Unit	Notes
				to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_Investments_in_Food_R&D_Activities_on_RVF	Effect_of_Investments_in_Food_R&D_Activities_to_RVF		Dimensionless	This is a variable that represents the effect of investments to R&D activities on reinforcing value of food. The equation describes a non-linear effect formulation. It is formulated via a logistic function which indicates that the effect has a limit. The effect formulation is used to calculate effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_Investments_in_Food_R&D_Activities_to_RVF	"Maximum_Effect_of_Investments_in_Food_R&D_Activities_(L2)"/(1+(Investments_in_Food_Research_and_Development_Activities/INIT(Investments_in_Food_Research_and_Development_Activities))^"Sensitivity_of_RVF_to_Food_R&D_Activities_(α2)")		Dimensionless	This is a variable that represents the effect of investments to R&D activities on reinforcing value of food. The equation describes a non-linear effect formulation. It is formulated via a logistic function which indicates that the effect has a limit. The effect formulation is used to calculate effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_LED_Food_Price_on_LED_Food_Demand	(Perceived_LED_Food_Price_Level/INIT(Perceived_LED_Food_Price_Level))^"Price_elasticity_of_LED_Food_(θ7)"		Dimensionless	This is variable that represents the effect of perceived LED price level on LED food demand. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_LED_Food_Price_on_LED_Food_Production	(Indicated_LED_Food_Price_Level/INIT(Indicated_LED_Food_Price_Level))^"Sensitivity_of_LED_Food_Price_on_LED_Food_Production_(θ3)"		Dimensionless	This is variable that represents the effect of perceived LED price level on LED food production. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).

Variable Name	Equation	Initial Value	Unit	Notes
Effect_of_Liberalization_Program_on_HED_Food_Price_Level	0.5+"Maximum_Effect_of_Investments_in_Food_Production_Methods_(L4)"/(1+(Investments_in_Food_Research_and_Development_Activities/INIT(Investments_in_Food_Research_and_Development_Activities))^"Sensitivity_of_HED_Food_Price_Level_to_Food_R&D_Activities_(α4)")		Dimensionless	This is a variable that represents the effect of liberalization program on HED food price. The equation describes a non-linear effect formulation. It is formulated via a logistic function which indicates that the effect has a limit. The effect formulation is used to calculate effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_Liberalization_Program_on_LED_Food_Price_Level	0.5+ "Maximum_Effect_of_Investments_in_Food_Production_Methods_(L3)" / (1+(Investments_in_Food_Research_and_Development_Activities/INIT(Investments_in_Food_Research_and_Development_Activities)) ^"Sensitivity_of_LED_Food_Price_Level_to_Food_R&D_Activities_(α3)")		Dimensionless	This is a variable that represents the effect of liberalization program on LED food price. The equation describes a non-linear effect formulation. It is formulated via a logistic function which indicates that the effect has a limit. The effect formulation is used to calculate effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Export_and_Waste_Delay	1		year	This is a constant that represents the time it takes the expenditure to change. The value estimated and calibrated.
Export_and_Waste_Fraction	0.05		Dimensionless	This is a constant that represents the fraction of waste and export value of food in a time unit. The value calibrated and estimated based on UN FAO data.
gr_to_kg	0.001		kg/gr	This is a constant that is used to convert gram to kilogram. Other than that, it has no other role in the model.
Indicated_HED_Food_Price_Level	Effect_of_Inventory_Coverage_on_Food_Price[HighED_Food]*Initial_HED_Food_Price_Level*Effect_of_Liberalization_Program_on_HED_Food_Price_Level		Dimensionless	This is a variable that represents the food price level that is currently available in the market. Since this information is not immediately available for market actors, market actors perceive this value after a delay. Thus, this is the goal for the perceived price level.

Variable Name	Equation	Initial Value	Unit	Notes
				Its equation indicates a multiplicative effect formulation based on the initial price level value (Barlas, 2009)
Indicated_LED_Food_Price_Level	Effect_of_Inventory_Coverage_on_Food_Price[LowED_Food]*Initial_LED_Food_Price_Level*Effect_of_Liberalization_Program_on_LED_Food_Price_Level		Dimensionless	This is a variable that represents the food price level that is currently available in the market. Since this information is not immediately available for market actors, market actors perceive this value after a delay. Thus, this is the goal for the perceived price level. Its equation indicates a multiplicative effect formulation based on the initial price level value (Barlas, 2009)
Initial_HED_Food_Price_Level	1.1		Dimensionless	This is a constant that represents the initial fraction of food price level in the beginning of the time horizon. Its value estimated and calibrated.
Initial_LED_Food_Price_Level	1		Dimensionless	This is a constant that represents the initial fraction of food price level in the beginning of the time horizon. Its value estimated and calibrated.
Inventory_Coverage[Food_Type]	Food_Supply/Food_Consumption		Year	This is a variable that indicates the inventory coverage or supply/demand ratio. Its equation indicates that how many years it takes the deplete the supply. If there is enough supply, price of the product should decrease and vice versa. This is the current value of the coverage which is the goal for the perceived coverage. Perception takes some time due to market conditions.
Investments_in_Food_Research_and_Development_Activities	SMTH3(Propensity_to_Invest_in_R&D_Activities*Economy.Business_Investments, 15)		TRY	This is a stock that represents the total investments. It increases as the old information is updated by the current information about the goal. This update occurs through a third order information delay based on the goal.

Variable Name	Equation	Initial Value	Unit	Notes
				It is defined by a stock because investments can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
Investments_in_Food_Stores_and_Delivery_Services	SMTH3(Economy.Business_Investments*Propensity_to_Invest_in_Food_Stores_and_Delivery_Services, 15)		TRY	This is a stock that represents the total investments. It increases as the old information is updated by the current information about the goal. This update occurs through a third order information delay based on the goal. It is defined by a stock because investments can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
"Maximum_Effect_of_Investments_in_Food_Production_Methods_(L3)"	1		Dimensionless	This is a constant that represents the maximum value of the curve in other words the maximum value of the effect formulation can go up or down. The value is estimated and calibrated.
"Maximum_Effect_of_Investments_in_Food_Production_Methods_(L4)"	1		Dimensionless	This is a constant that represents the maximum value of the curve in other words the maximum value of the effect formulation can go up or down. The value is estimated and calibrated.
"Maximum_Effect_of_Investments_in_Food_R&D_Activities_(L2)"	2		Dimensionless	This is a constant that represents the maximum value of the curve in other words the maximum value of the effect formulation can go up or down. The value is estimated and calibrated.
"Maximum_Effect_of_Investments_in_Food_Stores_and_Delivery_Services_(L1)"	2		Dimensionless	This is a constant that represents the maximum value of the curve in other words the maximum value of the effect formulation can go up or down. The value is estimated and calibrated.

Variable Name	Equation	Initial Value	Unit	Notes
per_person	1		1/person	This is a constant that is used to convert total quantity of food to per person. Other than this, this constant has no effect on the model.
Perceived_Demand[Food_Type]	SMTH1(Food_Consumption, .5)		Tonnes/Years	This is a stock that represents the perceived demand. Its equation indicates that the demand is perceived after a certain delay. It increases as the old information is updated by the current information about the goal. This update occurs through a first order information delay based on the goal. It is defined by a stock because information about the food production goal can accumulate within the time horizon of the model. Therefore, it is described by a differential equation
Perceived_HED_Food_Price_Level	SMTH1(Indicated_HED_Food_Price_Level, 1, Initial_HED_Food_Price_Level)		Dimensionless	This is a stock that represents the information about perceived price level of food. It is average price level for all foods and beverages. It increases as the old price level is updated by the current information about price level of food. This update occurs through a first order information delay based on the indicated price level which is set in the market and based on the effects and inventory coverage. It is defined by a stock because information about price level of food can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
Perceived_Inventory_Coverage[Food_Type]	SMTH3(Inventory_Coverage/INIT(Inventory_Coverage), 1)		Dimensionless	This is a stock that represents the total investments. It increases as the old information is updated by the current information about the goal. This update occurs through a third order information delay based on the goal.

Variable Name	Equation	Initial Value	Unit	Notes
				It is defined by a stock because information about the food inventory can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
Perceived_LED_Food_Price_Level	SMTH1(Indicated_LED_Food_Price_Level, 1, Initial_LED_Food_Price_Level)		Dimensionless	This is a stock that represents the information about perceived price level of food. It is average price level for all foods and beverages. It increases as the old price level is updated by the current information about price level of food. This update occurs through a first order information delay based on the indicated price level which is set in the market and based on the effects and inventory coverage. It is defined by a stock because information about price level of food can accumulate within the time horizon of the model. Therefore, it is described by a differential equation.
"Price_elasticity_of_HED_Food_(θ6)"	-0.25		Dimensionless	This is variable which represents the strength of the effect of change of price of food on its demand. It is also the degree to desire for something changes as its price changes. In general, people desire things less as those things become more expensive. Its value is below zero because demand is inversely proportional to price of food. If the sensitivity value is equal to -1, then the demand is fully adjusted with respect to relative change of the corresponding variable. But if the sensitivity value is equal to 0, then a change in the corresponding variable will not have any effect. The value is calibrated.

Variable Name	Equation	Initial Value	Unit	Notes
"Price_elasticity_of_LED_Food_(θ7)"	-0.20		Dimensionless	This is variable which represents the strength of the effect of change of price of food on its demand. It is also the degree to desire for something changes as its price changes. In general, people desire things less as those things become more expensive. Its value is below zero because demand is inversely proportional to price of food. If the sensitivity value is equal to -1, then the demand is fully adjusted with respect to relative change of the corresponding variable. But if the sensitivity value is equal to 0, then a change in the corresponding variable will not have any effect. The value is calibrated.
Production_Goal[HighED_Food]	SMTH1(Perceived_Demand[HighED_Food] *Effect_of_HED_Food_Price_on_HED_Food_Production, 3)		Tonnes/Years	This is a stock that represents the production goal for food production. Its equation indicates that the production goal is received after a certain delay and it is affected by the price level. It increases as the old information is updated by the current information about the goal. This update occurs through a first order information delay based on the goal. It is defined by a stock because information about the food production goal can accumulate within the time horizon of the model. Therefore, it is described by a differential equation
Production_Goal[LowED_Food]	SMTH1(Perceived_Demand[LowED_Food] *Effect_of_LED_Food_Price_on_LED_Food_Production, 3)			
Propensity_to_Invest_in_Food_Stores_and_Delivery_Services	0.1		Dimensionless	This is a constant which represents the fraction of investments that companies are willing to make. Its value estimated and calibrated.

Variable Name	Equation	Initial Value	Unit	Notes
Propensity_to_Invest_in_R&D_Activities	0.05		Dimensionless	This is a constant which represents the fraction of investments that companies are willing to make. Its value estimated and calibrated.
"Sensitivity_of_Food_Price_Level_to_Inventory_Coverage_(θ4)"	-0.01		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is below zero because the effect is inversely proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_HED_Food_Price_Level_to_Food_R&D_Activities_(α4)"	2		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is below zero because the effect is directly proportional to change in the relative value since the effect formulation is a logistic function. The value is estimated and calibrated.
"Sensitivity_of_HED_Food_Price_on_HED_Food_Production_(θ2)"	0.5		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_LED_Food_Price_Level_to_Food_R&D_Activities_(α3)"	0.5		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is below zero because the effect is directly proportional to change in the relative value since the effect formulation is a logistic function. The value is estimated and calibrated.
"Sensitivity_of_LED_Food_Price_on_LE	0.5		Dimensionless	This is a constant that represents the strength of one variable on another one.

Variable Name	Equation	Initial Value	Unit	Notes
D_Food_Production_(θ3)"				The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_RVF_to_Food_R&D_Activities_(α2)"	-0.5		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is below zero because the effect is directly proportional to change in the relative value since the effect formulation is a logistic function. The value is estimated and calibrated.
"Sensitivity_of_RVF_to_Food_Stores_and_Delivery_Services_(α1)"	-0.5		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is below zero because the effect is directly proportional to change in the relative value since the effect formulation is a logistic function. The value is estimated and calibrated.
Tonne_Converter	1000		Kg/Tonne	This is a constant which converts kilogram to metric tonnes. Other than that, it has no other role in the model.
Total_Consumption_Adjustment_Time	1		Year	This is a constant that represents the time it takes the expenditure to change. The value estimated and calibrated.
Total_Demand_per_year_per_capita_kg[Sex, BMI_category, Food_Type]	"Individual_Decision-Making".Quantity_per_year*gr_to_kg*per_person		Kilograms/People	This is a variable that represents the total demand for food per year per kilogram. Its equation indicates that the total food demand is sum of all types of food type and demand from each body weight representative that is converted from gram to kilogram.

Variable Name	Equation	Initial Value	Unit	Notes
Total_Food_Demand [Men, HighED_Food]	(Population.Normal_Pop[Men]*Total_Demand_per_year_per_capita_kg[Men,Normal_Weight,HighED_Food])/Tonne_Converter +(Population.Overweight_pop[Men]*Total_Demand_per_year_per_capita_kg[Men,Overweight,HighED_Food])/Tonne_Converter +(Population.Obese_pop[Men]*Total_Demand_per_year_per_capita_kg[Men,Obese,HighED_Food])/Tonne_Converter		Tonne	This is a variable that represents the total demand for food. Its equation indicates that the total food demand is sum of all types of food type and demand from each body weight representative that is converted to ton.
Total_Food_Demand [Men, LowED_Food]	(Total_Demand_per_year_per_capita_kg[Men,Normal_Weight,LowED_Food]*Population.Normal_Pop[Men])/Tonne_Converter +(Population.Overweight_pop[Men]*Total_Demand_per_year_per_capita_kg[Men,Overweight,LowED_Food])/Tonne_Converter +(Total_Demand_per_year_per_capita_kg[Men,Obese,LowED_Food]*Population.Obese_pop[Men])/Tonne_Converter		Tonne	This is a variable that represents the total demand for food. Its equation indicates that the total food demand is sum of all types of food type and demand from each body weight representative that is converted to ton.
Total_Food_Demand [Women, HighED_Food]	(Population.Normal_Pop[Women]*Total_Demand_per_year_per_capita_kg[Women,Normal_Weight,HighED_Food])/Tonne_Converter +(Population.Overweight_pop[Women]*Total_Demand_per_year_per_capita_kg[Women,Overweight,HighED_Food])/Tonne_Converter +(Total_Demand_per_year_per_capita_kg[Women,Obese,HighED_Food]*Population.Obese_pop[Women])/Tonne_Converter		Tonne	This is a variable that represents the total demand for food. Its equation indicates that the total food demand is sum of all types of food type and demand from each body weight representative that is converted to ton.
Total_Food_Demand [Women, LowED_Food]	(Population.Normal_Pop[Women]*Total_Demand_per_year_per_capita_kg[Women,Normal_Weight,LowED_Food])/Tonne_Converter +(Total_Demand_per_year_per_capita_kg[Women,Overweight,LowED_Food]*Population.Overweight_pop[Women])/Tonne_Conv		Tonne	This is a variable that represents the total demand for food. Its equation indicates that the total food demand is sum of all types of food type and demand from each body weight representative that is converted to ton.

Variable Name	Equation	Initial Value	Unit	Notes
	erter +(Population.Obese_pop[Women]*Total_Demand_per_year_per_capita_kg[Women,Obese,LowED_Food])/Tonne_Converter			
	Individual Decision-making Module			
Average_EI_Men	Total_EI_Men/3		kcal/day	This is a variable that represents the average energy intake. The purpose of this variable is just for behavior analysis of the model, so it does not affect any part of the model.
Average_EI_Women	Total_EI_Women/3		kcal/day	This is a variable that represents the average energy intake. The purpose of this variable is just for behavior analysis of the model, so it does not affect any part of the model.
Calories_from_HED_Food[Sex, BMI_category]	Energy_Density_of_HED_Food*quantity_of_HED_Food*per_day		kcal/day	This is a variable that represents the energy intake from food indicated type for each body weight representative. Its equation converts quantity of food to calories per day.
Calories_from_LED_Food[Sex, BMI_category]	Energy_Density_of_LED_Food*quantity_of_LED_Food*per_day		kcal/day	This is a variable that represents the energy intake from food indicated type for each body weight representative. Its equation converts quantity of food to calories per day.
"cross-price_elasticity_of_HED_Food_(θ9)"	0.30		Dimensionless	This is variable which represents the strength of the effect of change in price of a substitute product on another product's demand. It is also the degree to desire this product changes as the price of substitute product changes. In general, people desire substitute

Variable Name	Equation	Initial Value	Unit	Notes
				product more more if the price of the substitute decreases and vice versa. The value is above zero because the effect is directly proportional to change in the relative value. The value is calibrated and estimated based on price elasticity.
"Cross-price_elasticity_of_LED_Food_(θ8)"	0.15		Dimensionless	This is variable which represents the strength of the effect of change in price of a substitute product on another product's demand. It is also the degree to desire this product changes as the price of substitute product changes. In general, people desire substitute product more more if the price of the substitute decreases and vice versa. The value is above zero because the effect is directly proportional to change in the relative value. The value is calibrated and estimated based on price elasticity.
days_in_year	365		day	This is a constant that represents the number of days in a year.
Effect_of_Body_Weight_on_Reward_Delay[Sex]	(Body_Weight.Body_Weight_Normal_Weight/INIT(Body_Weight.Body_Weight_Normal_Weight))^"Sensitivity_of_Reward_Delay_to_Body_Weight_(θ9)_Normal"		Dimensionless	This is variable that represents the effect of body weight on health reward delay. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_Body_Weight_on_Reward_Delay_Obese[Sex]	(Body_Weight.Body_Weight_Obese/INIT(Body_Weight.Body_Weight_Obese))^"Sensitivity_of_Reward_Delay_to_Body_Weight_(θ9)_Obese"		Dimensionless	This is variable that represents the effect of body weight on health reward delay. This equation describes a non-linear effect function for calculating effect of one variable to another as

Variable Name	Equation	Initial Value	Unit	Notes
				suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_Body_Weight_on_Reward_Delay_Overweight[Sex]	(Body_Weight.Body_Weight_Overweight/INIT(Body_Weight.Body_Weight_Overweight))^"Sensitivity_of_Reward_Delay_to_Body_Weight_(θ9)_Overweight"		Dimensionless	This is variable that represents the effect of body weight on health reward delay. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_BW_on_RVH_Normal[Sex]	(Body_Weight.Body_Weight_Normal_Weight/INIT(Body_Weight.Body_Weight_Normal_Weight))^"Sensitivity_of_Reinforcing_Value_of_Health_to_Body_Weight_(θ10)_Normal"		Dimensionless	This is variable that represents the effect of body weight on reinforcing value of health. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_BW_on_RVH_Obese[Sex]	(Body_Weight.Body_Weight_Obese/INIT(Body_Weight.Body_Weight_Obese))^"Sensitivity_of_Reinforcing_Value_of_Health_to_Body_Weight_(θ10)_Obese"		Dimensionless	This is variable that represents the effect of body weight on reinforcing value of health. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_BW_on_RVH_Overweight[Sex]	(Body_Weight.Body_Weight_Overweight/INIT(Body_Weight.Body_Weight_Overweight))^"Sensitivity_of_Reinforcing_Value_of_Health_to_Body_Weight_(θ10)_Overweight"		Dimensionless	This is variable that represents the effect of body weight on reinforcing value of health. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_BW_on_RVHEDF[Sex]	(Body_Weight.Body_Weight_Normal_Weight/INIT(Body_Weight.Body_Weight_Normal_Weight))^"Sensitivity_of_RVHEDF_to_BW_(θ12)"		Dimensionless	This is variable that represents the effect of body weight on reinforcing value of food. This equation describes a non-linear effect function for calculating effect of one variable to another as

Variable Name	Equation	Initial Value	Unit	Notes
				suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_BW_on_RVHEDF_Obese[Sex]	(Body_Weight.Body_Weight_Obese/INIT(Body_Weight.Body_Weight_Obese))^"Sensitivity_of_RVHEDF_to_BW_(θ12)_Obese"		Dimensionless	This is variable that represents the effect of body weight on reinforcing value of food. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_BW_on_RVHEDF_Overweight[Sex]	(Body_Weight.Body_Weight_Overweight/INIT(Body_Weight.Body_Weight_Overweight))^"Sensitivity_of_RVHEDF_to_BW_(θ12)_Overweight"		Dimensionless	This is variable that represents the effect of body weight on reinforcing value of food. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_BW_on_RVLEDF_Normal[Sex]	(Body_Weight.Body_Weight_Normal_Weight/INIT(Body_Weight.Body_Weight_Normal_Weight))^"Sensitivity_of_RVLEDF_to_BW_(θ11)"		Dimensionless	This is variable that represents the effect of body weight on reinforcing value of food. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_BW_on_RVLEDF_Obese[Sex]	(Body_Weight.Body_Weight_Obese/INIT(Body_Weight.Body_Weight_Obese))^"Sensitivity_of_RVLEDF_to_BW_(θ11)_Obese"		Dimensionless	This is variable that represents the effect of body weight on reinforcing value of food. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_BW_on_RVLEDF_Overweight[Sex]	(Body_Weight.Body_Weight_Overweight/INIT(Body_Weight.Body_Weight_Overweight))^"Sensitivity_of_RVLEDF_to_BW_(θ11)_Overweight"		Dimensionless	This is variable that represents the effect of body weight on reinforcing value of food. This equation describes a non-linear effect function for calculating effect of one variable to another as

Variable Name	Equation	Initial Value	Unit	Notes
				suggested by John Sterman (2000), Yaman Barlas (2009).
"Effect_of_Cross-price_elasticity_on_HED_Food"	(Food_Environment.Perceived_LED_Food_Price_Level/INIT(Food_Environment.Perceived_LED_Food_Price_Level))^"cross-price_elasticity_of_HED_Food_(θ9)"		Dimensionless	This indicates the sensitivity of demand of a good to change in price of a substitute. In the model, it assumed that the food types are the only substitutes to each other. Therefore, it is hypothesized that a decrease in price of HED food will decrease the demand of LED food and vice versa. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
"Effect_of_Cross-price_elasticity_on_LED_Food"	(Food_Environment.Perceived_HED_Food_Price_Level/INIT(Food_Environment.Perceived_HED_Food_Price_Level))^"Cross-price_elasticity_of_LED_Food_(θ8)"		Dimensionless	This indicates the sensitivity of demand of a good to change in price of a substitute. In the model, it assumed that the food types are the only substitutes to each other. Therefore, it is hypothesized that a decrease in price of HED food will decrease the demand of LED food and vice versa. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_Income_on_HED	"Maximum_Effect_of_Disposable_Income_on_HED_Demand_(L7)"/(1+(Economy.Disposable_income/INIT(Economy.Disposable_income))^"Income_Elasticity_of_HED_(α7)")		Dimensionless	This is a variable that represents the effect of Income on HED food demand. The equation describes a non-linear effect formulation. It is formulated via a logistic function which indicates that the effect has a limit. The effect formulation is used to calculate effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_Income_on_LED	0.05+"Maximum_Effect_of_Disposable_Income_on_LED_Demand_(L6)"/(1+(Economy.Disposable_income/INIT(Economy.Disposa		Dimensionless	This is a variable that represents the effect of Income on LED food demand.

Variable Name	Equation	Initial Value	Unit	Notes
	ble_income))^"Income_Elasticity_of_LED_(α6)")			The equation describes a non-linear effect formulation. It is formulated via a logistic function which indicates that the effect has a limit. The effect formulation is used to calculate effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Energy_Density_of_HED_Food	4.5		kcal/gr	This is a constant that represents the energy density of LED food. (Prentice & Jebb, 2003; Rolls, 2017; Temple et al., 2022; Vadiveloo et al., 2018)
Energy_Density_of_LED_Food	2		kcal/gr	This is a constant that represents the energy density of LED food. (Prentice & Jebb, 2003; Rolls, 2017; Temple et al., 2022; Vadiveloo et al., 2018)
Food_Reward_Delay	0		Dimensionless	This is a variable that represents the health delay reward. In the presence of intertemporal choice, the end value is discounted based on this delay (Odum, 2011). This phenomenon can be called "present-bias." It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). As the delay time increases, the present value decreases. The value is 0 because the reward of food is immediate unlike the reward of health.
Food_Reward_Delay_Obese	0		Dimensionless	This is a variable that represents the health delay reward. In the presence of intertemporal choice, the end value is discounted based on this delay (Odum, 2011). This phenomenon can be called "present-bias." It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). As the delay time increases, the present value decreases.

Variable Name	Equation	Initial Value	Unit	Notes
				The value is 0 because the reward of food is immediate unlike the reward of health.
Food_Reward_Delay_Overweight	0		Dimensionless	This is a variable that represents the health delay reward. In the presence of intertemporal choice, the end value is discounted based on this delay (Odum, 2011). This phenomenon can be called "present-bias." It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). As the delay time increases, the present value decreases. The value is 0 because the reward of food is immediate unlike the reward of health.
Health_Reward_Delay[Sex]	Effect_of_Body_Weight_on_Reward_Delay*Initial_Health_Reward_Delay_Normal		Dimensionless	This is a variable that represents the health delay reward. In the presence of intertemporal choice, the end value is discounted based on this delay (Odum, 2011). This phenomenon can be called "present-bias." It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). As the delay time increases, the present value decreases. Its indicates that the delay is affected by body weight. As it shown in the empirical studies, individuals with higher body weights delay discount more and find foods highly reinforcing which together, make them more impatient (Epstein et al., 2014; Ross et al., 2020; Vanderveldt et al., 2016).
Health_Reward_Delay_Obese[Sex]	Effect_of_Body_Weight_on_Reward_Delay_Obese*Initial_Health_Reward_Delay_Obese		Dimensionless	This is a variable that represents the health delay reward. In the presence of intertemporal choice, the end value is discounted based on this delay (Odum, 2011). This phenomenon can be called "present-bias." It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). As the delay time increases, the present value decreases.

Variable Name	Equation	Initial Value	Unit	Notes
				Its indicates that the delay is affected by body weight. As it shown in the empirical studies, individuals with higher body weights delay discount more and find foods highly reinforcing which together, make them more impatient (Epstein et al., 2014; Ross et al., 2020; Vanderveldt et al., 2016).
Health_Reward_Delay_Overweight[Sex]	Effect_of_Body_Weight_on_Reward_Delay_Overweight*Initial_Health_Reward_Delay_Overweight		Dimensionless	This is a variable that represents the health delay reward. In the presence of intertemporal choice, the end value is discounted based on this delay (Odum, 2011). This phenomenon can be called “present-bias.” It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). As the delay time increases, the present value decreases. Its indicates that the delay is affected by body weight. As it shown in the empirical studies, individuals with higher body weights delay discount more and find foods highly reinforcing which together, make them more impatient (Epstein et al., 2014; Ross et al., 2020; Vanderveldt et al., 2016).
HED_Food_Demand[Men, Normal_Weight]	initial_quantity_of_HED_Food[Men,Normal_Weight] * Food_Environment.Effect_of_HED_Food_Price_on_HED_Food_Demand * "Effect_of_Cross-price_elasticity_on_HED_Food" * Relative_Reinforcing_Value_of_HED_Food_Normal[Men] * Effect_of_Income_on_HED		gr	This is a variable that represents the HED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each individual representative is calculated based on multiple effects. (Sterman, 2000; Barlas, 2009)
HED_Food_Demand[Men, Overweight]	initial_quantity_of_HED_Food[Men,Overweight] * Food_Environment.Effect_of_HED_Food_Price_on_HED_Food_Demand * "Effect_of_Cross-		gr	This is a variable that represents the HED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each

Variable Name	Equation	Initial Value	Unit	Notes
	price_elasticity_on_HED_Food" * Relative_Reinforcing_Value_of_HED_Food_Overweight[Men] * Effect_of_Income_on_HED			individual representative is calculated based on multiple effects. (Sterman, 2000; Barlas, 2009)
HED_Food_Demand[Men, Obese]	initial_quantity_of_HED_Food[Men,Obese] * Food_Environment.Effect_of_HED_Food_Price_on_HED_Food_Demand * Relative_Reinforcing_Value_of_HED_Food_Obese[Men] * "Effect_of_Cross-price_elasticity_on_HED_Food" * Effect_of_Income_on_HED		gr	This is a variable that represents the HED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each individual representative is calculated based on multiple effects. (Sterman, 2000; Barlas, 2009)
HED_Food_Demand[Women, Normal_Weight]	initial_quantity_of_HED_Food[Women,Normal_Weight] * Food_Environment.Effect_of_HED_Food_Price_on_HED_Food_Demand * Relative_Reinforcing_Value_of_HED_Food_Normal[Women] * "Effect_of_Cross-price_elasticity_on_HED_Food" * Effect_of_Income_on_HED		gr	This is a variable that represents the HED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each individual representative is calculated based on multiple effects. (Sterman, 2000; Barlas, 2009)
HED_Food_Demand[Women, Overweight]	initial_quantity_of_HED_Food[Women,Overweight] * Food_Environment.Effect_of_HED_Food_Price_on_HED_Food_Demand * "Effect_of_Cross-price_elasticity_on_HED_Food" * Relative_Reinforcing_Value_of_HED_Food_Overweight[Women] * Effect_of_Income_on_HED		gr	This is a variable that represents the HED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each individual representative is calculated based on multiple effects. (Sterman, 2000; Barlas, 2009)
HED_Food_Demand[Women, Obese]	initial_quantity_of_HED_Food[Women,Obese] * Food_Environment.Effect_of_HED_Food_Price_on_HED_Food_Demand * "Effect_of_Cross-price_elasticity_on_HED_Food" * Relative_Reinforcing_Value_of_HED_Food		gr	This is a variable that represents the HED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each individual representative is calculated based on

Variable Name	Equation	Initial Value	Unit	Notes
	_Obese[Women] * Effect_of_Income_on_HED			multiple effects. (Sterman, 2000; Barlas, 2009)
Hyperbolic_Discount _Factor_of_Food	1/(1+Food_Reward_Delay*k)		Dimensionless	Delay discounting is an economics term to describe the present value of a thing based on the time that thing received (Doyle, 2013). It derives from discounted utility approach of intertemporal choice. It indicates a decline in the present value of a thing when there is a delay to achieve that thing (Odum, 2011). In other words, smaller but immediate rewards are valued more by consumers than higher but delayed rewards. Hence, the value or utility of the future reward is being discounted by consumers. This phenomenon can be called "present-bias." It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). But every individual discounts differently as it is showed by the empirical studies (Epstein et al., 2014; Ross et al., 2020; Stojek & MacKillop, 2017). Its equation indicates the hyperbolic discount factor derived from the hyperbolic delay discounting (Ainslie, 1975, 2010; Bickel et al., 1999; Mazur, 1987).
Hyperbolic_Discount _Factor_of_Food_Ob ese	1/(1+Food_Reward_Delay_Obese*k)		Dimensionless	Delay discounting is an economics term to describe the present value of a thing based on the time that thing received (Doyle, 2013). It derives from discounted utility approach of intertemporal choice. It indicates a decline in the present value of a thing when there is a delay to achieve that thing (Odum, 2011). In other words, smaller but immediate rewards are valued more by consumers than higher but delayed rewards. Hence, the value or utility of the future reward is being discounted by consumers. This phenomenon can be called "present-bias." It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al.,

Variable Name	Equation	Initial Value	Unit	Notes
				2016). But every individual discounts differently as it is showed by the empirical studies (Epstein et al., 2014; Ross et al., 2020; Stojek & MacKillop, 2017). Its equation indicates the hyperbolic discount factor derived from the hyperbolic delay discounting (Ainslie, 1975, 2010; Bickel et al., 1999; Mazur, 1987).
Hyperbolic_Discount_Factor_of_Food_Overweight	1/(1+Food_Reward_Delay_Overweight*k)		Dimensionless	Delay discounting is an economics term to describe the present value of a thing based on the time that thing received (Doyle, 2013). It derives from discounted utility approach of intertemporal choice. It indicates a decline in the present value of a thing when there is a delay to achieve that thing (Odum, 2011). In other words, smaller but immediate rewards are valued more by consumers than higher but delayed rewards. Hence, the value or utility of the future reward is being discounted by consumers. This phenomenon can be called "present-bias." It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). But every individual discounts differently as it is showed by the empirical studies (Epstein et al., 2014; Ross et al., 2020; Stojek & MacKillop, 2017). Its equation indicates the hyperbolic discount factor derived from the hyperbolic delay discounting (Ainslie, 1975, 2010; Bickel et al., 1999; Mazur, 1987).
Hyperbolic_Discount_Factor_of_Health[Sex]	1/(1+Health_Reward_Delay*k)		Dimensionless	Delay discounting is an economics term to describe the present value of a thing based on the time that thing received (Doyle, 2013). It derives from discounted utility approach of intertemporal choice. It indicates a decline in the present value of a thing when there is a delay to achieve that thing (Odum, 2011). In other words, smaller but immediate rewards

Variable Name	Equation	Initial Value	Unit	Notes
				are valued more by consumers than higher but delayed rewards. Hence, the value or utility of the future reward is being discounted by consumers. This phenomenon can be called "present-bias." It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). But every individual discounts differently as it is showed by the empirical studies (Epstein et al., 2014; Ross et al., 2020; Stojek & MacKillop, 2017). Its equation indicates the hyperbolic discount factor derived from the hyperbolic delay discounting (Ainslie, 1975, 2010; Bickel et al., 1999; Mazur, 1987).
Hyperbolic_Discount_Factor_of_Health_Obese[Sex]	1/(1+Health_Reward_Delay_Obese*k)		Dimensionless	Delay discounting is an economics term to describe the present value of a thing based on the time that thing received (Doyle, 2013). It derives from discounted utility approach of intertemporal choice. It indicates a decline in the present value of a thing when there is a delay to achieve that thing (Odum, 2011). In other words, smaller but immediate rewards are valued more by consumers than higher but delayed rewards. Hence, the value or utility of the future reward is being discounted by consumers. This phenomenon can be called "present-bias." It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). But every individual discounts differently as it is showed by the empirical studies (Epstein et al., 2014; Ross et al., 2020; Stojek & MacKillop, 2017). Its equation indicates the hyperbolic discount factor derived from the hyperbolic delay discounting (Ainslie, 1975, 2010; Bickel et al., 1999; Mazur, 1987).

Variable Name	Equation	Initial Value	Unit	Notes
Hyperbolic_Discount_Factor_of_Health_Overweight[Sex]	1/(1+Health_Reward_Delay_Overweight*k)		Dimensionless	Delay discounting is an economics term to describe the present value of a thing based on the time that thing received (Doyle, 2013). It derives from discounted utility approach of intertemporal choice. It indicates a decline in the present value of a thing when there is a delay to achieve that thing (Odum, 2011). In other words, smaller but immediate rewards are valued more by consumers than higher but delayed rewards. Hence, the value or utility of the future reward is being discounted by consumers. This phenomenon can be called “present-bias.” It is a fundamental process across species in terms of decision making and choice (Vanderveldt et al., 2016). But every individual discounts differently as it is showed by the empirical studies (Epstein et al., 2014; Ross et al., 2020; Stojek & MacKillop, 2017). Its equation indicates the hyperbolic discount factor derived from the hyperbolic delay discounting (Ainslie, 1975, 2010; Bickel et al., 1999; Mazur, 1987).
"Income_Elasticity_of_HED_(α7)"	-0.15		Dimensionless	This is variable which represents the strength of the effect of change in disposable income on food demand. It is also the degree to desire for something changes as income changes. In general, people desire things more if their budget increases. Though it has a limit The value is below zero because the effect is directly proportional to change in the relative value since the effect formulation is a logistic function. The value is calibrated.
"Income_Elasticity_of_LED_(α6)"	-0.10		Dimensionless	This is variable which represents the strength of the effect of change in disposable income on food demand. It is also the degree to desire for something

Variable Name	Equation	Initial Value	Unit	Notes
				changes as income changes. In general, people desire things more if their budget increases. Though it has a limit The value is below zero because the effect is directly proportional to change in the relative value since the effect formulation is a logistic function. The value is calibrated.
Initial_Health_Reward_Delay_Normal	2		Dimensionless	This is a constant that represents the initial value of health reward delay. Since health reward is distant in the future, delay is higher than 0. The value estimated and calibrated.
Initial_Health_Reward_Delay_Obese	4		Dimensionless	This is a constant that represents the initial value of health reward delay. Since health reward is distant in the future, delay is higher than 0. The value estimated and calibrated.
Initial_Health_Reward_Delay_Overweight	3		Dimensionless	This is a constant that represents the initial value of health reward delay. Since health reward is distant in the future, delay is higher than 0. The value estimated and calibrated.
initial_quantity_of_HED_Food[Men, Normal_Weight]	140		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.
initial_quantity_of_HED_Food[Men, Overweight]	200		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.

Variable Name	Equation	Initial Value	Unit	Notes
initial_quantity_of_HED_Food[Men, Obese]	350		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.
initial_quantity_of_HED_Food[Women, Normal_Weight]	120		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.
initial_quantity_of_HED_Food[Women, Overweight]	160		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.
initial_quantity_of_HED_Food[Women, Obese]	325		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.
initial_quantity_of_LED_Food[Men, Normal_Weight]	625		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.
initial_quantity_of_LED_Food[Men, Overweight]	525		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.

Variable Name	Equation	Initial Value	Unit	Notes
initial_quantity_of_LED_Food[Men, Obese]	480		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.
initial_quantity_of_LED_Food[Women, Normal_Weight]	525		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.
initial_quantity_of_LED_Food[Women, Overweight]	450		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.
initial_quantity_of_LED_Food[Women, Obese]	325		gr	This is a constant that represents the initial quantity for indicated food type for each body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.
Initial_Reinforcing_Value_of_Health_Normal	10		Dimensionless	This is a constant that represents the initial reinforcing value of health for the individual body weight representative in the beginning of the time horizon of the model. Its value estimated based on relative reinforcing value of food (Carr & Epstein, 2020; Epstein et al., 2014)
Initial_Reinforcing_Value_of_Health_Obese	10		Dimensionless	This is a constant that represents the initial reinforcing value of health for the individual body weight representative in the beginning of the time horizon of the model.

Variable Name	Equation	Initial Value	Unit	Notes
				Its value estimated based on relative reinforcing value of food (Carr & Epstein, 2020; Epstein et al., 2014)
Initial_Reinforcing_Value_of_Health_Overweight	10		Dimensionless	This is a constant that represents the initial reinforcing value of health for the individual body weight representative in the beginning of the time horizon of the model. Its value estimated based on relative reinforcing value of food (Carr & Epstein, 2020; Epstein et al., 2014)
Initial_Reinforcing_Value_of_HED_Food_Normal	15		Dimensionless	This is a constant that represents the initial reinforcing value of food for the individual body weight representative in the beginning of the time horizon of the model. Its value estimated and calibrated.
Initial_Reinforcing_Value_of_HED_Food_Obese	45		Dimensionless	This is a constant that represents the initial reinforcing value of food for the individual body weight representative in the beginning of the time horizon of the model. Its value estimated based on studies (Carr & Epstein, 2020; Epstein et al., 2014)
Initial_Reinforcing_Value_of_HED_Food_Overweight	35		Dimensionless	This is a constant that represents the initial reinforcing value of food for the individual body weight representative in the beginning of the time horizon of the model. Its value estimated based on studies (Carr & Epstein, 2020; Epstein et al., 2014)
Initial_Reinforcing_Value_of_LED_Food_Normal	10		Dimensionless	This is a constant that represents the initial reinforcing value of food for the individual body weight representative in the beginning of the time horizon of the model.

Variable Name	Equation	Initial Value	Unit	Notes
				Its value estimated based on studies (Carr & Epstein, 2020; Epstein et al., 2014)
Initial_Reinforcing_ Value_of_LED_Food _Obese	25		Dimensionless	This is a constant that represents the initial reinforcing value of food for the individual body weight representative in the beginning of the time horizon of the model. Its value estimated based on studies (Carr & Epstein, 2020; Epstein et al., 2014)
Initial_Reinforcing_ Value_of_LED_Food _Overweight	20		Dimensionless	This is a constant that represents the initial reinforcing value of food for the individual body weight representative in the beginning of the time horizon of the model. Its value estimated based on studies (Carr & Epstein, 2020; Epstein et al., 2014)
k	1		Dimensionless	This is a constant that represents the degree of impatience/discounting, estimated to be 1 because the impatience is modeled through effect of body weight on delay.
LED_Food_Demand[Men, Normal_Weight]	initial_quantity_of_LED_Food[Men,Normal _Weight] * Food_Environment.Effect_of_LED_Food_Pr ice_on_LED_Food_Demand * "Effect_of_Cross-price_elasticity_on_LED_Food" * Relative_Reinforcing_Value_of_LED_Food _Normal[Men] * Effect_of_Income_on_LED		gr	This is a variable that represents the LED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each individual representative is calculated based on multiple effects. (Sterman, 2000; Barlas, 2009)
LED_Food_Demand[Men, Overweight]	initial_quantity_of_LED_Food[Men,Overwe ight] * Food_Environment.Effect_of_LED_Food_Pr ice_on_LED_Food_Demand * "Effect_of_Cross-price_elasticity_on_LED_Food" *		gr	This is a variable that represents the LED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each individual representative is calculated based on

Variable Name	Equation	Initial Value	Unit	Notes
	Relative_Reinforcing_Value_of_LED_Food _Overweight[Men] * Effect_of_Income_on_LED			multiple effects. (Sterman, 2000; Barlas, 2009)
LED_Food_Demand[Men, Obese]	initial_quantity_of_LED_Food[Men,Obese] * Food_Environment.Effect_of_LED_Food_Price_on_LED_Food_Demand * "Effect_of_Cross-price_elasticity_on_LED_Food" * Relative_Reinforcing_Value_of_LED_Food _Obese[Men] * Effect_of_Income_on_LED		gr	This is a variable that represents the LED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each individual representative is calculated based on multiple effects. (Sterman, 2000; Barlas, 2009)
LED_Food_Demand[Women, Normal_Weight]	initial_quantity_of_LED_Food[Women,Normal_Weight] * Food_Environment.Effect_of_LED_Food_Price_on_LED_Food_Demand * "Effect_of_Cross-price_elasticity_on_LED_Food" * Relative_Reinforcing_Value_of_LED_Food _Normal[Women] * Effect_of_Income_on_LED		gr	This is a variable that represents the LED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each individual representative is calculated based on multiple effects. (Sterman, 2000; Barlas, 2009)
LED_Food_Demand[Women, Overweight]	initial_quantity_of_LED_Food[Women,Overweight] * Food_Environment.Effect_of_LED_Food_Price_on_LED_Food_Demand * "Effect_of_Cross-price_elasticity_on_LED_Food" * Relative_Reinforcing_Value_of_LED_Food _Overweight[Women] * Effect_of_Income_on_LED		gr	This is a variable that represents the LED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each individual representative is calculated based on multiple effects. (Sterman, 2000; Barlas, 2009)
LED_Food_Demand[Women, Obese]	initial_quantity_of_LED_Food[Women,Obese] * Food_Environment.Effect_of_LED_Food_Price_on_LED_Food_Demand * "Effect_of_Cross-price_elasticity_on_LED_Food" * Relative_Reinforcing_Value_of_LED_Food		gr	This is a variable that represents the LED food type for each body weight representative. Its equation indicates a multiplicative effect formulation indicates that the food demand for each individual representative is calculated based on

Variable Name	Equation	Initial Value	Unit	Notes
	_Obese[Women] * Effect_of_Income_on_LED			multiple effects. (Sterman, 2000; Barlas, 2009)
"Maximum_Effect_of_Disposable_Income_on_HED_Demand_(L7)"	2		Dimensionless	This is a constant that represents the maximum value of the curve in other words the maximum value of the effect formulation can go up or down. The value is estimated and calibrated.
"Maximum_Effect_of_Disposable_Income_on_LED_Demand_(L6)"	2		Dimensionless	This is a constant that represents the maximum value of the curve in other words the maximum value of the effect formulation can go up or down. The value is estimated and calibrated.
per_day	1		1/day	This is a constant that represents a day in a year.
quantity_of_HED_Food[Sex, BMI_category]	HED_Food_Demand		gr	This is a variable that represents the total quantity of HED food in grams for each body weight type. Its equation is the sum of all food type demand for each body weight representative.
quantity_of_LED_Food[Sex, BMI_category]	LED_Food_Demand		gr	This is a variable that represents the total quantity of LED food in grams for each body weight type. Its equation is the sum of all food type demand for each body weight representative.
Quantity_per_year[Sex, BMI_category, Food_Type]	total_quantity_per_day*days_in_year		gr	This is a variable that represents the total quantity of food that is consumed per year. Its equation indicates that the total is the sum of all food types that and it is converted to per year from days.
Reinforcing_Value_of_Health_Normal[Sex]	Effect_of_BW_on_RVH_Normal*Initial_Reinforcing_Value_of_Health_Normal*Hyperbolic_Discount_Factor_of_Health		Dimensionless	This is a variable that represents the reinforcing value of health for the individual body weight representative. Its equation indicates a multiplicative effect formulation (Sterman, 2000; Barlas, 2009)

Variable Name	Equation	Initial Value	Unit	Notes
				Reinforcing value defines the amount of behavior a subject will show to gain a reward, for instance food (Bickel et al., 2000; Epstein et al., 2010). Therefore, the reinforcing value of food describes the amount of behavior that a subject is willing to spend or will work or to achieve food (Temple, 2014). In an empirical study, reinforcing value of things is measured via completing certain tasks given to the subjects or via a questionnaire for quantification purposes (Epstein et al., 2007; Hill et al., 2009; Kong et al., 2015; Stojek & MacKillop, 2017)
Reinforcing_Value_of_Health_Obese[Sex]	Effect_of_BW_on_RVH_Obese*Initial_Reinforcing_Value_of_Health_Obese*Hyperbolic_Discount_Factor_of_Health_Obese		Dimensionless	This is a variable that represents the reinforcing value of health for the individual body weight representative. Its equation indicates a multiplicative effect formulation (Sterman, 2000; Barlas, 2009) Reinforcing value defines the amount of behavior a subject will show to gain a reward, for instance food (Bickel et al., 2000; Epstein et al., 2010). Therefore, the reinforcing value of food describes the amount of behavior that a subject is willing to spend or will work or to achieve food (Temple, 2014). In an empirical study, reinforcing value of things is measured via completing certain tasks given to the subjects or via a questionnaire for quantification purposes (Epstein et al., 2007; Hill et al., 2009; Kong et al., 2015; Stojek & MacKillop, 2017)
Reinforcing_Value_of_Health_Overweight[Sex]	Effect_of_BW_on_RVH_Overweight*Initial_Reinforcing_Value_of_Health_Overweight*Hyperbolic_Discount_Factor_of_Health_Overweight		Dimensionless	This is a variable that represents the reinforcing value of health for the individual body weight representative. Its equation indicates a multiplicative effect

Variable Name	Equation	Initial Value	Unit	Notes
				formulation (Sterman, 2000; Barlas, 2009) Reinforcing value defines the amount of behavior a subject will show to gain a reward, for instance food (Bickel et al., 2000; Epstein et al., 2010). Therefore, the reinforcing value of food describes the amount of behavior that a subject is willing to spend or will work or to achieve food (Temple, 2014). In an empirical study, reinforcing value of things is measured via completing certain tasks given to the subjects or via a questionnaire for quantification purposes (Epstein et al., 2007; Hill et al., 2009; Kong et al., 2015; Stojek & MacKillop, 2017)
Reinforcing_Value_of_HED_Food[Sex]	Initial_Reinforcing_Value_of_HED_Food_Normal*Effect_of_BW_on_RVHEDF*Food_Environment.Effect_of_Investments_in_Food_R&D_Activities_on_RVF*Hyperbolic_Discount_Factor_of_Food*Food_Environment.Effect_of_Investment_in_Food_Stores_and_Delivery_Services_on_RVF		Dimensionless	This is a variable that represents the reinforcing value of health for the individual body weight representative. Its equation indicates a multiplicative effect formulation (Sterman, 2000; Barlas, 2009) Reinforcing value defines the amount of behavior a subject will show to gain a reward, for instance food (Bickel et al., 2000; Epstein et al., 2010). Therefore, the reinforcing value of food describes the amount of behavior that a subject is willing to spend or will work or to achieve food (Temple, 2014). In an empirical study, reinforcing value of things is measured via completing certain tasks given to the subjects or via a questionnaire for quantification purposes (Epstein et al., 2007; Hill et al., 2009; Kong et al., 2015; Stojek & MacKillop, 2017)
Reinforcing_Value_of_HED_Food_Obese[Sex]	Initial_Reinforcing_Value_of_HED_Food_Obese*Effect_of_BW_on_RVHEDF_Obese*Food_Environment.Effect_of_Investments_in		Dimensionless	This is a variable that represents the reinforcing value of health for the individual body weight representative.

Variable Name	Equation	Initial Value	Unit	Notes
	_Food_R&D_Activities_on_RVF*Hyperbolic_Discount_Factor_of_Food_Obese*Food_Environment.Effect_of_Investment_in_Food_Stores_and_Delivery_Services_on_RVF			Its equation indicates a multiplicative effect formulation (Sterman, 2000; Barlas, 2009) Reinforcing value defines the amount of behavior a subject will show to gain a reward, for instance food (Bickel et al., 2000; Epstein et al., 2010). Therefore, the reinforcing value of food describes the amount of behavior that a subject is willing to spend or will work or to achieve food (Temple, 2014). In an empirical study, reinforcing value of things is measured via completing certain tasks given to the subjects or via a questionnaire for quantification purposes (Epstein et al., 2007; Hill et al., 2009; Kong et al., 2015; Stojek & MacKillop, 2017)
Reinforcing_Value_of_HED_Food_Overweight[Sex]	Initial_Reinforcing_Value_of_HED_Food_Overweight*Effect_of_BW_on_RVHEDF_Overweight*Food_Environment.Effect_of_Investments_in_Food_R&D_Activities_on_RVF*Hyperbolic_Discount_Factor_of_Food_Overweight*Food_Environment.Effect_of_Investment_in_Food_Stores_and_Delivery_Services_on_RVF		Dimensionless	This is a variable that represents the reinforcing value of health for the individual body weight representative. Its equation indicates a multiplicative effect formulation (Sterman, 2000; Barlas, 2009) Reinforcing value defines the amount of behavior a subject will show to gain a reward, for instance food (Bickel et al., 2000; Epstein et al., 2010). Therefore, the reinforcing value of food describes the amount of behavior that a subject is willing to spend or will work or to achieve food (Temple, 2014). In an empirical study, reinforcing value of things is measured via completing certain tasks given to the subjects or via a questionnaire for quantification purposes (Epstein et al., 2007; Hill et al., 2009; Kong et al., 2015; Stojek & MacKillop, 2017)

Variable Name	Equation	Initial Value	Unit	Notes
Reinforcing_Value_of_LED_Food[Sex]	Initial_Reinforcing_Value_of_LED_Food_Normal*Effect_of_BW_on_RVLEDF_Normal*Food_Environment.Effect_of_Investments_in_Food_R&D_Activities_on_RVF*Hyperbolic_Discount_Factor_of_Food*Food_Environment.Effect_of_Investment_in_Food_Stores_and_Delivery_Services_on_RVF		Dimensionless	This is a variable that represents the reinforcing value of health for the individual body weight representative. Its equation indicates a multiplicative effect formulation (Sterman, 2000; Barlas, 2009) Reinforcing value defines the amount of behavior a subject will show to gain a reward, for instance food (Bickel et al., 2000; Epstein et al., 2010). Therefore, the reinforcing value of food describes the amount of behavior that a subject is willing to spend or will work or to achieve food (Temple, 2014). In an empirical study, reinforcing value of things is measured via completing certain tasks given to the subjects or via a questionnaire for quantification purposes (Epstein et al., 2007; Hill et al., 2009; Kong et al., 2015; Stojek & MacKillop, 2017)
Reinforcing_Value_of_LED_Food_Obese[Sex]	Initial_Reinforcing_Value_of_LED_Food_Obese*Effect_of_BW_on_RVLEDF_Obese*Food_Environment.Effect_of_Investments_in_Food_R&D_Activities_on_RVF*Hyperbolic_Discount_Factor_of_Food_Obese*Food_Environment.Effect_of_Investment_in_Food_Stores_and_Delivery_Services_on_RVF		Dimensionless	This is a variable that represents the reinforcing value of health for the individual body weight representative. Its equation indicates a multiplicative effect formulation (Sterman, 2000; Barlas, 2009) Reinforcing value defines the amount of behavior a subject will show to gain a reward, for instance food (Bickel et al., 2000; Epstein et al., 2010). Therefore, the reinforcing value of food describes the amount of behavior that a subject is willing to spend or will work or to achieve food (Temple, 2014). In an empirical study, reinforcing value of things is measured via completing certain tasks given to the subjects or via a questionnaire for quantification

Variable Name	Equation	Initial Value	Unit	Notes
				purposes (Epstein et al., 2007; Hill et al., 2009; Kong et al., 2015; Stojek & MacKillop, 2017)
Reinforcing_Value_of_LED_Food_Overweight[Sex]	Initial_Reinforcing_Value_of_LED_Food_Overweight*Effect_of_BW_on_RVLEDF_Overweight*Food_Environment.Effect_of_Investments_in_Food_R&D_Activities_on_RVF*Hyperbolic_Discount_Factor_of_Food_Overweight*Food_Environment.Effect_of_Investment_in_Food_Stores_and_Delivery_Services_on_RVF		Dimensionless	This is a variable that represents the reinforcing value of health for the individual body weight representative. Its equation indicates a multiplicative effect formulation (Sterman, 2000; Barlas, 2009) Reinforcing value defines the amount of behavior a subject will show to gain a reward, for instance food (Bickel et al., 2000; Epstein et al., 2010). Therefore, the reinforcing value of food describes the amount of behavior that a subject is willing to spend or will work or to achieve food (Temple, 2014). In an empirical study, reinforcing value of things is measured via completing certain tasks given to the subjects or via a questionnaire for quantification purposes (Epstein et al., 2007; Hill et al., 2009; Kong et al., 2015; Stojek & MacKillop, 2017)
Relative_Reinforcing_Value_of_HED_Food_Normal[Sex]	λ+Reinforcing_Value_of_HED_Food/(Reinforcing_Value_of_HED_Food+Reinforcing_Value_of_Health_Normal)		Dimensionless	This is a variable that indicates the relative reinforcing value of food relative to health. Relative reinforcing value indicates the reinforcing value of a behavior or an object relative to another one to measure the strength of the behavior or object. Its equation is a generic oone (Carr & Epstein, 2020; Epstein et al., 2014; Epstein et al., 2007; Kong et al., 2015) that is one extra coefficient is added to quantify the effect of relative reinforcing effect of food.
Relative_Reinforcing_Value_of_HED_Food_Obese[Sex]	λ+Reinforcing_Value_of_HED_Food_Obese/(Reinforcing_Value_of_HED_Food_Obese+Reinforcing_Value_of_Health_Obese)		Dimensionless	This is a variable that indicates the relative reinforcing value of food relative to health.

Variable Name	Equation	Initial Value	Unit	Notes
				Relative reinforcing value indicates the reinforcing value of a behavior or an object relative to another one to measure the strength of the behavior or object. Its equation is a generic oone (Carr & Epstein, 2020; Epstein et al., 2014; Epstein et al., 2007; Kong et al., 2015) that is one extra coefficient is added to quantify the effect of relative reinforcing effect of food.
Relative_Reinforcing_Value_of_HED_Food_Overweight[Sex]	λ+Reinforcing_Value_of_HED_Food_Overweight/(Reinforcing_Value_of_HED_Food_Overweight+Reinforcing_Value_of_Health_Overweight)		Dimensionless	This is a variable that indicates the relative reinforcing value of food relative to health. Relative reinforcing value indicates the reinforcing value of a behavior or an object relative to another one to measure the strength of the behavior or object. Its equation is a generic oone (Carr & Epstein, 2020; Epstein et al., 2014; Epstein et al., 2007; Kong et al., 2015) that is one extra coefficient is added to quantify the effect of relative reinforcing effect of food.
Relative_Reinforcing_Value_of_LED_Food_Normal[Sex]	λ+Reinforcing_Value_of_LED_Food/(Reinforcing_Value_of_LED_Food+Reinforcing_Value_of_Health_Normal)		Dimensionless	This is a variable that indicates the relative reinforcing value of food relative to health. Relative reinforcing value indicates the reinforcing value of a behavior or an object relative to another one to measure the strength of the behavior or object. Its equation is a generic oone (Carr & Epstein, 2020; Epstein et al., 2014; Epstein et al., 2007; Kong et al., 2015) that is one extra coefficient is added to quantify the effect of relative reinforcing effect of food.
Relative_Reinforcing_Value_of_LED_Food_Obese[Sex]	λ+Reinforcing_Value_of_LED_Food_Obese/(Reinforcing_Value_of_LED_Food_Obese+Reinforcing_Value_of_Health_Obese)		Dimensionless	This is a variable that indicates the relative reinforcing value of food relative to health.

Variable Name	Equation	Initial Value	Unit	Notes
				Relative reinforcing value indicates the reinforcing value of a behavior or an object relative to another one to measure the strength of the behavior or object. Its equation is a generic oone (Carr & Epstein, 2020; Epstein et al., 2014; Epstein et al., 2007; Kong et al., 2015) that is one extra coefficient is added to quantify the effect of relative reinforcing effect of food.
Relative_Reinforcing_Value_of_LED_Food_Overweight[Sex]	λ+Reinforcing_Value_of_LED_Food_Overweight/(Reinforcing_Value_of_LED_Food_Overweight+Reinforcing_Value_of_Health_Overweight)		Dimensionless	This is a variable that indicates the relative reinforcing value of food relative to health. Relative reinforcing value indicates the reinforcing value of a behavior or an object relative to another one to measure the strength of the behavior or object. Its equation is a generic oone (Carr & Epstein, 2020; Epstein et al., 2014; Epstein et al., 2007; Kong et al., 2015) that is one extra coefficient is added to quantify the effect of relative reinforcing effect of food.
"Sensitivity_of_Reinforcing_Value_of_Health_to_Body_Weight_(θ10)_Normal"	0.5		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_Reinforcing_Value_of_Health_to_Body_Weight_(θ10)_Obese"	0.5		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.

Variable Name	Equation	Initial Value	Unit	Notes
"Sensitivity_of_Reinforcing_Value_of_Health_to_Body_Weight_(θ10)_Overweight"	0.5		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_Reward_Delay_to_Body_Weight_(θ9)_Normal"	0.5		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_Reward_Delay_to_Body_Weight_(θ9)_Obese"	0.9		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_Reward_Delay_to_Body_Weight_(θ9)_Overweight"	0.7		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_RVHEDF_to_BW_(θ12)"	0.6		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.

Variable Name	Equation	Initial Value	Unit	Notes
"Sensitivity_of_RVHEDF_to_BW_(θ12)_Obese"	0.9		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_RVHEDF_to_BW_(θ12)_Overweight"	0.8		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_RVLEDF_to_BW_(θ11)"	0.5		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_RVLEDF_to_BW_(θ11)_Obese"	0.8		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.
"Sensitivity_of_RVLEDF_to_BW_(θ11)_Overweight"	0.7		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is estimated and calibrated.

Variable Name	Equation	Initial Value	Unit	Notes
Total_EI_Men	SUM(Total_Energy_Intake[Men, *])		kcal/day	This is a variable that represents the total energy intake. The purpose of this variable is just for behavior analysis of the model, so it does not affect any part of the model.
Total_EI_Women	SUM(Total_Energy_Intake[Women, *])		kcal/day	This is a variable that represents the total energy intake. The purpose of this variable is just for behavior analysis of the model, so it does not affect any part of the model.
Total_Energy_Intake [Sex, BMI_category]	Calories_from_HED_Food+Calories_from_LED_Food		kcal/day	This is a variable that represents the total energy intake for each body weight representative. Its equation is the sum of all calories from all food types.
total_quantity_per_day[Men, Normal_Weight, HighED_Food]	quantity_of_HED_Food[Men,Normal_Weight]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.
total_quantity_per_day[Men, Normal_Weight, LowED_Food]	quantity_of_LED_Food[Men,Normal_Weight]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.
total_quantity_per_day[Men, Overweight, HighED_Food]	quantity_of_HED_Food[Men,Overweight]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.

Variable Name	Equation	Initial Value	Unit	Notes
total_quantity_per_day[Men, Overweight, LowED_Food]	quantity_of_LED_Food[Men,Overweight]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.
total_quantity_per_day[Men, Obese, HighED_Food]	quantity_of_HED_Food[Men,Obese]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.
total_quantity_per_day[Men, Obese, LowED_Food]	quantity_of_LED_Food[Men,Obese]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.
total_quantity_per_day[Women, Normal_Weight, HighED_Food]	quantity_of_HED_Food[Women,Normal_Weight]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.
total_quantity_per_day[Women, Normal_Weight, LowED_Food]	quantity_of_LED_Food[Women,Normal_Weight]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.
total_quantity_per_day[Women, Overweight, HighED_Food]	quantity_of_HED_Food[Women,Overweight]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.

Variable Name	Equation	Initial Value	Unit	Notes
total_quantity_per_day[Women, Overweight, LowED_Food]	quantity_of_LED_Food[Women,Overweight]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.
total_quantity_per_day[Women, Obese, HighED_Food]	quantity_of_HED_Food[Women,Obese]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.
total_quantity_per_day[Women, Obese, LowED_Food]	quantity_of_LED_Food[Women,Obese]*per_day		gr/Days	This is a variable that represents the total amount food for each type of food for each body weight representative. Its equation converts total gram of each food type to gram per day.
λ	0.25		Dimensionless	This is a constant which is used to quantify the effect of relative reinforcing value of food on food consumption. The coefficient, λ, helps formula to effect food demand even in extreme conditions to make the equation more realistic. For instance, if reinforcing value of food is 0 which indicates that the food is not reinforcing, then equation results 0.25 which the demand will be increased but it will never be zero. Because even if the food is not reinforcing, individuals should eat to survive.
		Physical Activity Module		
Effect_of_GDP_on_Physical_Activity_Level	0.80+"Maximum_Effect_of_GDP_on_PAL_(L7)"/((Economy.GDP/INIT(Economy.GDP)		Dimensionless	This is a variable that represents the effect of GDP on PAL.

Variable Name	Equation	Initial Value	Unit	Notes
	)^"Sensitivity_of_Physical_Activity_Level_to_GDP_(α7)")			The equation describes a non-linear effect formulation. It is formulated via a logistic function which indicates that the effect has a limit. The effect formulation is used to calculate effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Effect_of_PAL_to_PA_Coefficient	("Physical_Activity_Level_(PAL)"/Normal_PAL)^"Sensitivity_of_PA_Coefficient_to_PAL_(θ13)"		Dimensionless	This is variable that represents the effect of PAL on PA coefficient. PA coefficient is directly proportional to PAL. This equation describes a non-linear effect function for calculating effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
"Maximum_Effect_of_GDP_on_PAL_(L7)"	0.15		Dimensionless	This is a constant that represents the maximum value of the curve in other words the maximum value of the effect formulation can go up or down. The value is estimated and calibrated.
Normal_PA_Coefficient	7		kcal/kg/day	This is a constant that represents the normal or initial physical activity coefficient. This coefficient determines the energy expenditure per kg of the individual per day. The value is based on (Hall, 2007, 2009, 2012)
Normal_PAL	1.75		Dimensionless	This is a constant that represents the average normal or initial PAL. The value represents the moderate physical activity level. The value is based on (Hall, 2009) and TurkStat
"Physical_Activity_Coefficient_(δ)"	Normal_PA_Coefficient*Effect_of_PAL_to_PA_Coefficient		kcal/kg/day	This is a variable that represents the energy expenditure per kg of the individual per day. It is affected by the change in PAL.

Variable Name	Equation	Initial Value	Unit	Notes
				It is based on (Hall, 2007, 2009, 2012)
"Physical_Activity_Level_(PAL)"	Normal_PAL*Effect_of_GDP_on_Physical_Activity_Level		Dimensionless	This is a variable that represents the PAL of individuals. It is affected by the GDP. As GDP increases, PAL decreases and vice versa.
"Sensitivity_of_PA_Coefficient_to_PAL_(θ13)"	1		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is above zero because the effect is directly proportional to change in the relative value. The value is 1 because it is assumed that the PA coefficient is fully adjusted by the PAL. The value is estimated and calibrated.
"Sensitivity_of_Physical_Activity_Level_to_GDP_(α7)"	0.8		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is below zero because the effect is directly proportional to change in the relative value since the effect formulation is a logistic function. The value is estimated and calibrated.
		Population Module		
"Age_Group_0_(0-14)"[Sex](t)	"Age_Group_0_(0-14)"[Sex](t - dt) + (Births[Sex] - Transition_to_Age_Group_1[Sex] - Age_Group_0_Death_Rate[Sex]) * dt	INIT "Age_Group_0_(0-14)"[Sex] = Initial_Age_Group_0	person	This is a stock that represents the population of the corresponding age group. The stock is increased by birth and is depleted by transition to next age group. It is defined by a stock because number of people can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on TurkStat data.

Variable Name	Equation	Initial Value	Unit	Notes
"Age_Group_1_(15-49)"[Sex](t)	"Age_Group_1_(15-49)"[Sex](t - dt) + (Transition_to_Age_Group_1[Sex] - Transition_to_Age_Group_2[Sex] - Age_Group_1_Death_Rate[Sex]) * dt	INIT "Age_Group_1_(15-49)"[Sex] = Initial_Age_Group_1	person	This is a stock that represents the population of the corresponding age group. The stock is increased by transition from previous group and is depleted by transition to the next age group and by death rate. It is defined by a stock because number of people can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on TurkStat data.
"Age_Group_2_(50-74)"[Sex](t)	"Age_Group_2_(50-74)"[Sex](t - dt) + (Transition_to_Age_Group_2[Sex] - Transition_to_Age_Group_3[Sex] - Age_Group_2_Death_Rate[Sex]) * dt	INIT "Age_Group_2_(50-74)"[Sex] = Initial_Age_Group_2	person	This is a stock that represents the population of the corresponding age group. The stock is increased by transition from previous group and is depleted by transition to the next age group and by death rate. It is defined by a stock because number of people can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on TurkStat data.
"Age_Group_3_(75+)"[Sex](t)	"Age_Group_3_(75+)"[Sex](t - dt) + (Transition_to_Age_Group_3[Sex] - Age_Group_3_Death_Rate[Sex]) * dt	INIT "Age_Group_3_(75+)"[Sex] = Initial_Age_Group_3	person	This is a stock that represents the population of the corresponding age group. The stock is increased by transition from previous group and is depleted by death rate. It is defined by a stock because number of people can accumulate within the time horizon of the model. Therefore, it is described by a differential equation. Its initial value is based on TurkStat data.

Variable Name	Equation	Initial Value	Unit	Notes
Normal_Weight_AG_1[Sex](t)	Normal_Weight_AG_1[Sex](t - dt) + (Overweight_to_Normal_AG_1[Sex] + Transition_from_Normal_AG_0_to_AG_1[Sex] - Normal_to_Overweight_AG_1[Sex] - Normal_Weight_Death_Rate_AG_1[Sex] - Transition_from_Normal_AG_1_to_AG_2[Sex]) * dt	INIT Normal_Weight_AG_1[Sex] = Initial_Normal_AG_1	Person	This is the stock for body weight category that represents the total number of population who has the corresponding body weight and the age group. It is depleted by death rate, and transition to the next age group, and transition to the next body weight category. And it is increased by transition from previous age group and transition from the next body weight category. Its initial value calculated based on estimation and calibration
Normal_Weight_AG_2[Sex](t)	Normal_Weight_AG_2[Sex](t - dt) + (Overweight_to_Normal_AG_2[Sex] + Transition_from_Normal_AG_1_to_AG_2[Sex] - Normal_to_Overweight_AG_2[Sex] - Normal_Weight_Death_Rate_AG_2[Sex] - Transition_from_Normal_AG_2_to_AG_3[Sex]) * dt	INIT Normal_Weight_AG_2[Sex] = Initial_Normal_AG_2	Person	This is the stock for body weight category that represents the total number of population who has the corresponding body weight and the age group. It is depleted by death rate, and transition to the next age group, and transition to the next body weight category. And it is increased by transition from previous age group and transition from the next body weight category. Its initial value calculated based on estimation and calibration
Normal_Weight_AG_3[Sex](t)	Normal_Weight_AG_3[Sex](t - dt) + (Overweight_to_Normal_AG_3[Sex] + Transition_from_Normal_AG_2_to_AG_3[Sex] - Normal_to_Overweight_AG_3[Sex] - Normal_Weight_Death_Rate_AG_3[Sex]) * dt	INIT Normal_Weight_AG_3[Sex] = Initial_Normal_AG_3	Person	This is the stock for body weight category that represents the total number of population who has the corresponding body weight and the age group. It is depleted by death rate, and transition to the next age group, and transition to the next body weight category. And it is increased by transition from previous age group and transition from the next body weight category. Its initial value calculated based on estimation and calibration

Variable Name	Equation	Initial Value	Unit	Notes
Obese_AG_1[Sex](t)	Obese_AG_1[Sex](t - dt) + (Overweight_to_Obese_AG_1[Sex] + Transition_from_Obese_AG_0_to_AG_1[Sex] - Obese_to_Overweight_AG_1[Sex] - Transition_from_Obese_AG_1_to_AG_2[Sex] - Obese_Death_Rate_AG_1[Sex]) * dt	INIT Obese_AG_1[Sex] = Initial_Obese_AG_1	Person	This is the stock for body weight category that represents the total number of population who has the corresponding body weight and the age group. It is depleted by death rate and transition to the previous body weight category. And it is increased by transition from previous age group and transition from the next body weight category. Its initial value calculated based on estimation and calibration
Obese_AG_2[Sex](t)	Obese_AG_2[Sex](t - dt) + (Overweight_to_Obese_AG_2[Sex] + Transition_from_Obese_AG_1_to_AG_2[Sex] - Obese_to_Overweight_AG_2[Sex] - Obese_Death_Rate_AG_2[Sex] - Transition_from_Obese_AG_2_to_AG_3[Sex]) * dt	INIT Obese_AG_2[Sex] = Initial_Obese_AG_2	Person	This is the stock for body weight category that represents the total number of population who has the corresponding body weight and the age group. It is depleted by death rate and transition to the previous body weight category. And it is increased by transition from previous age group and transition from the next body weight category. Its initial value calculated based on estimation and calibration
Obese_AG_3[Sex](t)	Obese_AG_3[Sex](t - dt) + (Overweight_to_Obese_AG_3[Sex] + Transition_from_Obese_AG_2_to_AG_3[Sex] - Obese_to_Overweight_AG_3[Sex] - Obese_Death_Rate_AG_3[Sex]) * dt	INIT Obese_AG_3[Sex] = Initial_Obese_AG_3	Person	This is the stock for body weight category that represents the total number of population who has the corresponding body weight and the age group. It is depleted by death rate and transition to the previous body weight category. And it is increased by transition from previous age group and transition from the next body weight category. Its initial value calculated based on estimation and calibration
Overweight_AG_1[Sex](t)	Overweight_AG_1[Sex](t - dt) + (Normal_to_Overweight_AG_1[Sex] + Obese_to_Overweight_AG_1[Sex] +	INIT Overweight_AG_1[Sex] =	Person	This is the stock for body weight category that represents the total number of population who has the corresponding body weight and the age group.

Variable Name	Equation	Initial Value	Unit	Notes
	Transition_from_Overweight_AG_0_to_AG_1[Sex] - Overweight_to_Obese_AG_1[Sex] - Overweight_to_Normal_AG_1[Sex] - Overweight_Death_Rate_AG_1[Sex] - Transition_from_Overweight_AG_1_to_AG_2[Sex]) * dt	Initial_Overweight_AG_1		It is depleted by death rate, and transition to the next age group, and transition to the next body weight category. And it is increased by transition from previous age group and transition from the next body weight category. Its initial value calculated based on estimation and calibration
Overweight_AG_2[Sex](t)	Overweight_AG_2[Sex](t - dt) + (Normal_to_Overweight_AG_2[Sex] + Obese_to_Overweight_AG_2[Sex] + Transition_from_Overweight_AG_1_to_AG_2[Sex] - Overweight_to_Obese_AG_2[Sex] - Overweight_to_Normal_AG_2[Sex] - Overweight_Death_Rate_AG_2[Sex] - Transition_from_Overweight_AG_2_to_AG_3[Sex]) * dt	INIT Overweight_AG_2[Sex] = Initial_Overweight_AG_2	Person	This is the stock for body weight category that represents the total number of population who has the corresponding body weight and the age group. It is depleted by death rate, and transition to the next age group, and transition to the next body weight category. And it is increased by transition from previous age group and transition from the next body weight category. Its initial value calculated based on estimation and calibration
Overweight_AG_3[Sex](t)	Overweight_AG_3[Sex](t - dt) + (Normal_to_Overweight_AG_3[Sex] + Obese_to_Overweight_AG_3[Sex] + Transition_from_Overweight_AG_2_to_AG_3[Sex] - Overweight_to_Obese_AG_3[Sex] - Overweight_to_Normal_AG_3[Sex] - Overweight_Death_Rate_AG_3[Sex]) * dt	INIT Overweight_AG_3[Sex] = Initial_Overweight_AG_3	Person	This is the stock for body weight category that represents the total number of population who has the corresponding body weight and the age group. It is depleted by death rate, and transition to the next age group, and transition to the next body weight category. And it is increased by transition from previous age group and transition from the next body weight category. Its initial value calculated based on estimation and calibration
Age_Group_0_Death_Rate[Sex]	"Age_Group_0_(0-14)"*Death_Fraction_AG_0		person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the age group.

Variable Name	Equation	Initial Value	Unit	Notes
				Its equation describes that the certain fraction of people dies at each time unit.
Age_Group_1_Death_Rate[Sex]	"Age_Group_1_(15-49)"*Death_Fraction_AG_1		person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the age group. Its equation describes that the certain fraction of people dies at each time unit.
Age_Group_2_Death_Rate[Sex]	"Age_Group_2_(50-74)"*Death_Fraction_AG_2		person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the age group. Its equation describes that the certain fraction of people dies at each time unit.
Age_Group_3_Death_Rate[Sex]	Death_Fraction_AG_3*"Age_Group_3_(75+)"		person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the age group. Its equation describes that the certain fraction of people dies at each time unit.
Births[Sex]	(Fertility_Rate*Women_in_Fertile_Age)/Women_Fertility_Period		person/Year	This is the inflow to age group 0 that represents births.m Its equation describes that women who are fertile give birth via a certain fertility rate over their fertility period.
Normal_to_Overweight_AG_1[Sex]	MAX(0, "Y-Normal_AG_1"*Body_Weight.BMI_Change_Rate_Normal_Weight)		Person/Year	This is the inflow for the next body weight category and outflow for the previous body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the corresponding body weight category) and the BMI change rate and it cannot be lower than 0. MAX function in Stella denotes that the maximum value inside the parentheses is true. Therefore, the

Variable Name	Equation	Initial Value	Unit	Notes
				expression cannot take a value less than zero. This equation is only possible when BMI change rate is positive meaning that the individuals gaining weight so they should be moving up to the next body weight category. So the rate is
Normal_to_Overweight_AG_2[Sex]	MAX(0, "Y-Normal_AG_2"*Body_Weight.BMI_Change_Rate_Normal_Weight)		Person/Year	This is the inflow for the next body weight category and outflow for the previous body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the corresponding body weight category) and the BMI change rate and it cannot be lower than 0. MAX function in Stella denotes that the maximum value inside the parentheses is true. Therefore, the expression cannot take a value less than zero. This equation is only possible when BMI change rate is positive meaning that the individuals gaining weight so they should be moving up to the next body weight category. So the rate is
Normal_to_Overweight_AG_3[Sex]	MAX(0, "Y-Normal_AG_3"*Body_Weight.BMI_Change_Rate_Normal_Weight)		Person/Year	This is the inflow for the next body weight category and outflow for the previous body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the corresponding body weight category) and the BMI change rate and it cannot be lower than 0. MAX function in Stella denotes that the maximum value inside the parentheses is true. Therefore, the expression cannot take a value less than zero. This equation is only possible when BMI change rate is positive meaning that the individuals gaining weight so they should be moving up to the next body weight category. So the rate is
Normal_Weight_Death_Rate_AG_1[Sex]	MIN(Normal_Weight_AG_1/Death_Delay, Age_Group_1_Death_Rate*Normal_Death_Fraction_AG_1)		Person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the body weight group.

Variable Name	Equation	Initial Value	Unit	Notes
Normal_Weight_Death_Rate_AG_2[Sex]	MIN(Normal_Weight_AG_2/Death_Delay, Age_Group_2_Death_Rate*Normal_Death_Fraction_AG_2)		Person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the body weight group.
Normal_Weight_Death_Rate_AG_3[Sex]	MIN(Normal_Weight_AG_3/Death_Delay, Age_Group_3_Death_Rate*Normal_Death_Fraction_AG_3)		Person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the body weight group.
Obese_Death_Rate_AG_1[Sex]	MIN(Obese_AG_1/Death_Delay, Age_Group_1_Death_Rate*Obese_Death_Fraction_AG_1)		Person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the body weight group.
Obese_Death_Rate_AG_2[Sex]	MIN(Obese_AG_2/Death_Delay, Age_Group_2_Death_Rate*Obese_Death_Fraction_AG_2)		Person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the body weight group.
Obese_Death_Rate_AG_3[Sex]	MIN(Obese_AG_3/Death_Delay, Age_Group_3_Death_Rate*Obese_Death_Fraction_AG_3)		Person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the body weight group.
Obese_to_Overweight_AG_1[Sex]	ABS(MIN("Y-Obese-AG_1"*Body_Weight.BMI_Change_Rate_Obese))		Person/Year	This is the inflow for the previous body weight category and outflow for the next body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the corresponding body weight category) and the BMI change rate and it cannot be lower than 0. This flow only works when BMI change rate is negative meaning that the average body weight is decreasing. ABS and MIN expressions indicates that the absolute of the smallest value inside the parentheses is true hence the transition rate cannot be less than 0.
Obese_to_Overweight_AG_2[Sex]	ABS(MIN("Y-Obese-AG_2"*Body_Weight.BMI_Change_Rate_Obese))		Person/Year	This is the inflow for the previous body weight category and outflow for the next body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the corresponding body weight category) and the BMI change rate and it cannot be lower than 0. This flow

Variable Name	Equation	Initial Value	Unit	Notes
				only works when BMI change rate is negative meaning that the average body weight is decreasing. ABS and MIN expressions indicates that the absolute of the smallest value inside the parentheses is true hence the transition rate cannot be less than 0.
Obese_to_Overweight_AG_3[Sex]	ABS(MIN("Y-Obese-AG_3"*Body_Weight.BMI_Change_Rate_Obese))		Person/Year	This is the inflow for the previous body weight category and outflow for the next body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the corresponding body weight category) and the BMI change rate and it cannot be lower than 0. This flow only works when BMI change rate is negative meaning that the average body weight is decreasing. ABS and MIN expressions indicates that the absolute of the smallest value inside the parentheses is true hence the transition rate cannot be less than 0.
Overweight_Death_Rate_AG_1[Sex]	MIN(Overweight_AG_1/Death_Delay, Age_Group_1_Death_Rate*Overweight_Death_Fraction_AG_1)		Person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the body weight group.
Overweight_Death_Rate_AG_2[Sex]	MIN(Overweight_AG_2/Death_Delay, Age_Group_2_Death_Rate*Overweight_Death_Fraction_AG_2)		Person/Year	This is the outflow from the age group that represents the number of deaths at each time unit. It depletes the body weight group.
Overweight_Death_Rate_AG_3[Sex]	MIN(Age_Group_3_Death_Rate*Overweight_Death_Fraction_AG_3, Overweight_AG_3/Death_Delay)		Person/Year	This is the outflow from the body weight group that represents the number of deaths at each time unit. It depletes the body weight group. The flow depends on the death rate from the age group.
Overweight_to_Normal_AG_1[Sex]	ABS(MIN("Y-OW-AG_1"*Body_Weight.BMI_Change_Rate_Overweight, 0))		Person/Year	This is the inflow for the previous body weight category and outflow for the next body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the corresponding body weight category) and the BMI change rate and it cannot be lower than 0. This flow

Variable Name	Equation	Initial Value	Unit	Notes
				only works when BMI change rate is negative meaning that the average body weight is decreasing. ABS and MIN expressions indicates that the absolute of the smallest value inside the parentheses is true hence the transition rate cannot be less than 0.
Overweight_to_Normal_AG_2[Sex]	ABS(MIN("Y-OW-AG_2"*Body_Weight.BMI_Change_Rate_Overweight, 0))		Person/Year	This is the inflow for the previous body weight category and outflow for the next body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the corresponding body weight category) and the BMI change rate and it cannot be lower than 0. This flow only works when BMI change rate is negative meaning that the average body weight is decreasing. ABS and MIN expressions indicates that the absolute of the smallest value inside the parentheses is true hence the transition rate cannot be less than 0.
Overweight_to_Normal_AG_3[Sex]	ABS(MIN("Y-OW-AG_3"*Body_Weight.BMI_Change_Rate_Overweight, 0))		Person/Year	This is the inflow for the previous body weight category and outflow for the next body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the corresponding body weight category) and the BMI change rate and it cannot be lower than 0. This flow only works when BMI change rate is negative meaning that the average body weight is decreasing. ABS and MIN expressions indicates that the absolute of the smallest value inside the parentheses is true hence the transition rate cannot be less than 0.
Overweight_to_Obese_AG_1[Sex]	MAX("Y-AG1-OW_1"*Body_Weight.BMI_Change_Rate_Overweight, 0)		Person/Year	This is the inflow for the next body weight category and outflow for the previous body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the

Variable Name	Equation	Initial Value	Unit	Notes
				corresponding body weight category) and the BMI change rate and it cannot be lower than 0. MAX function in Stella denotes that the maximum value inside the parentheses is true. Therefore, the expression cannot take a value less than zero. This equation is only possible when BMI change rate is positive meaning that the individuals gaining weight so they should be moving up to the next body weight category. So the rate is
Overweight_to_Obese_AG_2[Sex]	MAX("Y-AG1-OW_2"*Body_Weight.BMI_Change_Rate_Overweight, 0)		Person/Year	This is the inflow for the next body weight category and outflow for the previous body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the corresponding body weight category) and the BMI change rate and it cannot be lower than 0. MAX function in Stella denotes that the maximum value inside the parentheses is true. Therefore, the expression cannot take a value less than zero. This equation is only possible when BMI change rate is positive meaning that the individuals gaining weight so they should be moving up to the next body weight category. So the rate is
Overweight_to_Obese_AG_3[Sex]	MAX("Y-AG1-OW_3"*Body_Weight.BMI_Change_Rate_Overweight, 0)		Person/Year	This is the inflow for the next body weight category and outflow for the previous body weight category. Its equation indicates that transition to the next body weight category depends on Y (frequency for the corresponding body weight category) and the BMI change rate and it cannot be lower than 0. MAX function in Stella denotes that the maximum value inside the parentheses is true. Therefore, the expression cannot take a value less than zero. This equation is only possible when BMI change rate is positive meaning that the individuals gaining weight

Variable Name	Equation	Initial Value	Unit	Notes
				so they should be moving up to the next body weight category. So the rate is
Transition_from_Normal_AG_0_to_AG_1[Sex]	Transition_to_Age_Group_1*Normal_Weight_Transition_Fraction_From_AG0		Person/Year	This is the inflow to body weight category from age group 0 to the next age group for corresponding body weight category. Its equation indicates that the certain fraction of population who are going to move from age group 1 are normal weight population.
Transition_from_Normal_AG_1_to_AG_2[Sex]	Normal_Weight_AG_1/Age_Group_1_Duration		Person/Year	This is the inflow to corresponding body weight category from previous age group to the next one for the corresponding body weight category. Its equation describes that transition to the next age takes time because of natural maturation processes. After a certain duration, they move to the next age group.
Transition_from_Normal_AG_2_to_AG_3[Sex]	Normal_Weight_AG_2/Age_Group_2_Duration		Person/Year	This is the inflow to corresponding body weight category from previous age group to the next one for the corresponding body weight category. Its equation describes that transition to the next age takes time because of natural maturation processes. After a certain duration, they move to the next age group.
Transition_from_Obese_AG_0_to_AG_1[Sex]	Transition_to_Age_Group_1*Obese_Transition_Fraction_From_AG0		Person/Year	This is the inflow to body weight category from age group 0 to the next age group for corresponding body weight category. Its equation indicates that the certain fraction of population who are going to move from age group 1 are obese population.
Transition_from_Obese_AG_1_to_AG_2[Sex]	Obese_AG_1/Age_Group_1_Duration		Person/Year	This is the inflow to corresponding body weight category from previous age group to the next one for the corresponding body weight category.

Variable Name	Equation	Initial Value	Unit	Notes
				Its equation describes that transition to the next age takes time because of natural maturation processes. After a certain duration, they move to the next age group.
Transition_from_Obese_AG_2_to_AG_3[Sex]	Obese_AG_2/Age_Group_2_Duration		Person/Year	This is the inflow to corresponding body weight category from previous age group to the next one for the corresponding body weight category. Its equation describes that transition to the next age takes time because of natural maturation processes. After a certain duration, they move to the next age group.
Transition_from_Overweight_AG_0_to_AG_1[Sex]	Transition_to_Age_Group_1*Overweight_Transition_Fraction_From_AG0		Person/Year	This is the inflow to body weight category from age group 0 to the next age group for corresponding body weight category. Its equation indicates that the certain fraction of population who are going to move from age group 1 are overweight population.
Transition_from_Overweight_AG_1_to_AG_2[Sex]	Overweight_AG_1/Age_Group_1_Duration		Person/Year	This is the inflow to corresponding body weight category from previous age group to the next one for the corresponding body weight category. Its equation describes that transition to the next age takes time because of natural maturation processes. After a certain duration, they move to the next age group.
Transition_from_Overweight_AG_2_to_AG_3[Sex]	Overweight_AG_2/Age_Group_2_Duration		Person/Year	This is the inflow to corresponding body weight category from previous age group to the next one for the corresponding body weight category. Its equation describes that transition to the next age takes time because of natural maturation processes. After a certain duration, they move to the next age group.

Variable Name	Equation	Initial Value	Unit	Notes
Transition_to_Age_Group_1[Sex]	"Age_Group_0_(0-14)"/Age_Group_0_Duration		person/Year	This is the inflow to next age group that represents the growing up process. Its equation describes that transition to the next age takes time because of natural maturation processes. After a certain duration, they move to the next age group.
Transition_to_Age_Group_2[Sex]	"Age_Group_1_(15-49)"/Age_Group_1_Duration		person/Year	This is the inflow to next age group that represents the growing up process. Its equation describes that transition to the next age takes time because of natural maturation processes. After a certain duration, they move to the next age group.
Transition_to_Age_Group_3[Sex]	"Age_Group_2_(50-74)"/Age_Group_2_Duration		person/Year	This is the inflow to next age group that represents the growing up process. Its equation describes that transition to the next age takes time because of natural maturation processes. After a certain duration, they move to the next age group.
Adult_Population[Sex]	"Age_Group_1_(15-49)"+"Age_Group_2_(50-74)"+"Age_Group_3_(75+)"		person	This is a variable that represents the number of adult population.
Age_Group_0_Duration	14		year	This is a constant which presents the amount time that is needed to move from previous age group to the next. The value is calculated based on the initial and final age at each category.
Age_Group_1_Duration	34		year	This is a constant which presents the amount time that is needed to move from previous age group to the next. The value is calculated based on the initial and final age at each category.
Age_Group_2_Duration	24		year	This is a constant which presents the amount time that is needed to move from previous age group to the next. The value is calculated based on the initial and final age at each category.

Variable Name	Equation	Initial Value	Unit	Notes
Death_Delay	1		year	This is a constant that represents the amount time needed to pass for deaths to occur. It is estimated and calibrated based on data.
Death_Fraction_AG_0	0.000001		Dimensionless/year	This is a constant which represents the fraction death each year for the related age group. It is estimated and calibrated based on data from TurkStat
Death_Fraction_AG_1	0.000001		Dimensionless/year	This is a constant which represents the fraction death each year for the related age group. It is estimated and calibrated based on data from TurkStat
Death_Fraction_AG_2	0.000001		Dimensionless/year	This is a constant which represents the fraction death each year for the related age group. It is estimated and calibrated based on data from TurkStat
Death_Fraction_AG_3	0.05		Dimensionless/year	This is a constant which represents the fraction death each year for the related age group. It is estimated and calibrated based on data from TurkStat
Effect_of_BW_to_transition_Fraction[Sex]	"Maximum_Effect_of_Obesity_Prevalence_on_Transition_from_AG0_(L5)"/(1+(OWOB_Prevalence/INIT(OWOB_Prevalence))^"Sensitivity_of_Transition_Fraction_From_AG_0_(α5)")		Dimensionless	This is a variable that represents the effect of obesity prevalence on body weight transition. The equation describes a non-linear effect formulation. It is formulated via a logistic function which indicates that the effect has a limit. The effect formulation is used to calculate effect of one variable to another as suggested by John Sterman (2000), Yaman Barlas (2009).
Fertility_Rate	GRAPH(TIME) Points: (1970.00, 6.000), (1978.00, 2.368), (1986.00, 1.225), (1994.00, 0.8653), (2002.00, 0.752), (2010.00, 0.7164), (2018.00, 0.7052), (2026.00, 0.7016), (2034.00, 0.7005), (2042.00, 0.7002), (2050.00, 0.7001)		Dimensionless	This is a fraction that represents the fertility rate based and determines the amount of births based on number fertile females at a given time. This value is calculated through a graphical function to simplify the fertility rate and calibrated based on real demographics data from TurkStat
Initial_Age_Group_0 [Men]	7634306		person	This is a variable that represents the initial men and women population in 1970. It is based on TurkStat demographics data.
Initial_Age_Group_0 [Women]	7243881		person	This is a variable that represents the initial men and women population in 1970.

Variable Name	Equation	Initial Value	Unit	Notes
				It is based on TurkStat demographics data.
Initial_Age_Group_1 [Men]	8230585		person	This is a variable that represents the initial men and women population in 1970. It is based on TurkStat demographics data.
Initial_Age_Group_1 [Women]	8005135		person	This is a variable that represents the initial men and women population in 1970. It is based on TurkStat demographics data.
Initial_Age_Group_2 [Men]	1972751		person	This is a variable that represents the initial men and women population in 1970. It is based on TurkStat demographics data.
Initial_Age_Group_2 [Women]	2071211		person	This is a variable that represents the initial men and women population in 1970. It is based on TurkStat demographics data.
Initial_Age_Group_3 [Men]	169344		person	This is a variable that represents the initial men and women population in 1970. It is based on TurkStat demographics data.
Initial_Age_Group_3 [Women]	277963		person	This is a variable that represents the initial men and women population in 1970. It is based on TurkStat demographics data.
Initial_Normal_AG_1[Sex]	Initial_Age_Group_1*Initial_Normal_Fraction_AG_1		person	This is a variable that represents the initial population of the body weight category who belong to the age group indicated in the variable name. Its equation calculates the how many of people from the given initial age group belongs to indicated body weight category.
Initial_Normal_AG_2[Sex]	Initial_Age_Group_2*Initial_Normal_Fraction_AG_2		person	This is a variable that represents the initial population of the body weight category who belong to the age group indicated in the variable name.

Variable Name	Equation	Initial Value	Unit	Notes
				Its equation calculates the how many of people from the given initial age group belongs to indicated body weight category.
Initial_Normal_AG_3[Sex]	Initial_Age_Group_3*Initial_Normal_Fraction_AG_3		person	This is a variable that represents the initial population of the body weight category who belong to the age group indicated in the variable name. Its equation calculates the how many of people from the given initial age group belongs to indicated body weight category.
Initial_Normal_Fraction_AG_1[Men]	1-(Initial_Overweight_Fraction_AG_1[Men]+Initial_Obese_Fraction_AG_1[Men])		Dimensionless	This is a variable that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value depends on the fraction of obese and overweight population.
Initial_Normal_Fraction_AG_1[Women]	1-(Initial_Overweight_Fraction_AG_1[Women]+Initial_Obese_Fraction_AG_1[Women])		Dimensionless	This is a variable that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value depends on the fraction of obese and overweight population.
Initial_Normal_Fraction_AG_2[Men]	1-(Initial_Overweight_Fraction_AG_2[Men]+Initial_Obese_Fraction_AG_2[Men])		Dimensionless	This is a variable that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value depends on the fraction of obese and overweight population.
Initial_Normal_Fraction_AG_2[Women]	1-(Initial_Overweight_Fraction_AG_2[Women]+Initial_Obese_Fraction_AG_2[Women])		Dimensionless	This is a variable that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value depends on the fraction of obese and overweight population.

Variable Name	Equation	Initial Value	Unit	Notes
Initial_Normal_Fraction_AG_3[Men]	1-(Initial_Obese_Fraction_AG_3[Men]+Initial_Overweight_Fraction_AG_3[Men])		Dimensionless	This is a variable that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value depends on the fraction of obese and overweight population.
Initial_Normal_Fraction_AG_3[Women]	1-(Initial_Obese_Fraction_AG_3[Women]+Initial_Overweight_Fraction_AG_3[Women])		Dimensionless	This is a variable that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value depends on the fraction of obese and overweight population.
Initial_Obese_AG_1[Sex]	Initial_Obese_Fraction_AG_1*Initial_Age_Group_1		person	This is a variable that represents the initial population of the body weight category who belong to the age group indicated in the variable name. Its equation calculates the how many of people from the given initial age group belongs to indicated body weight category.
Initial_Obese_AG_2[Sex]	Initial_Obese_Fraction_AG_2*Initial_Age_Group_2		person	This is a variable that represents the initial population of the body weight category who belong to the age group indicated in the variable name. Its equation calculates the how many of people from the given initial age group belongs to indicated body weight category.
Initial_Obese_AG_3[Sex]	Initial_Obese_Fraction_AG_3*Initial_Age_Group_3		person	This is a variable that represents the initial population of the body weight category who belong to the age group indicated in the variable name. Its equation calculates the how many of people from the given initial age group belongs to indicated body weight category.
Initial_Obese_Fraction_AG_1[Men]	0.05		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable.

Variable Name	Equation	Initial Value	Unit	Notes
				The value estimated and calibrated.
Initial_Obese_Fraction_AG_1[Women]	0.10		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value estimated and calibrated.
Initial_Obese_Fraction_AG_2[Men]	0.05		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value estimated and calibrated.
Initial_Obese_Fraction_AG_2[Women]	0.10		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value estimated and calibrated.
Initial_Obese_Fraction_AG_3[Men]	0.05		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value estimated and calibrated.
Initial_Obese_Fraction_AG_3[Women]	0.10		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value estimated and calibrated.
Initial_Overweight_AG_1[Sex]	Initial_Age_Group_1*Initial_Overweight_Fraction_AG_1		person	This is a variable that represents the initial population of the body weight category who belong to the age group indicated in the variable name. Its equation calculates the how many of people from the given initial age group belongs to indicated body weight category.
Initial_Overweight_AG_2[Sex]	Initial_Age_Group_2*Initial_Overweight_Fraction_AG_2		person	This is a variable that represents the initial population of the body weight category who belong to the age

Variable Name	Equation	Initial Value	Unit	Notes
				group indicated in the variable name. Its equation calculates the how many of people from the given initial age group belongs to indicated body weight category.
Initial_Overweight_AG_3[Sex]	Initial_Age_Group_3*Initial_Overweight_Fraction_AG_3		person	This is a variable that represents the initial population of the body weight category who belong to the age group indicated in the variable name. Its equation calculates the how many of people from the given initial age group belongs to indicated body weight category.
Initial_Overweight_Fraction_AG_1[Men]	0.15		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value estimated and calibrated.
Initial_Overweight_Fraction_AG_1[Women]	0.10		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value estimated and calibrated.
Initial_Overweight_Fraction_AG_2[Men]	0.15		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value estimated and calibrated.
Initial_Overweight_Fraction_AG_2[Women]	0.10		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value estimated and calibrated.
Initial_Overweight_Fraction_AG_3[Men]	0.15		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable.

Variable Name	Equation	Initial Value	Unit	Notes
				The value estimated and calibrated.
Initial_Overweight_Fraction_AG_3[Women]	0.10		Dimensionless	This is a constant that represents the initial fraction of population who belongs to the body weight category indicated in the name of the variable. The value estimated and calibrated.
Initial_Transition_Fraction_Obese_AG0[Men]	0.005		Dimensionless	This is a constant that represents the initial fraction of obese population among the transition rate from age group 0 to the next group. Its value estimated and calibrated.
Initial_Transition_Fraction_Obese_AG0[Women]	0.045		Dimensionless	This is a constant that represents the initial fraction of obese population among the transition rate from age group 0 to the next group. Its value estimated and calibrated.
Initial_Transition_Fraction_Overweight_AG0[Men]	0.15		Dimensionless	This is a constant that represents the initial fraction of overweight population among the transition rate from age group 0 to the next group. Its value estimated and calibrated.
Initial_Transition_Fraction_Overweight_AG0[Women]	0.15		Dimensionless	This is a constant that represents the initial fraction of overweight population among the transition rate from age group 0 to the next group. Its value estimated and calibrated.
lancet	GRAPH(TIME) Points: (1975.00, 35.55072452), (1976.00, 36.35550421), (1977.00, 37.14690867), (1978.00, 37.92701678), (1979.00, 38.69622229), (1980.00, 39.4582048), (1981.00, 40.30301918), (1982.00, 41.22127966), (1983.00, 42.20308617), (1984.00, 43.24059215), (1985.00, 44.32444933), (1986.00, 45.42323913), (1987.00,		Dimensionless	This is a historical data variable. Purpose of this part is just to analyze the behavior of the system therefore it is not a part of the model structure.

Variable Name	Equation	Initial Value	Unit	Notes
	46.52901757), (1988.00, 47.63311923), (1989.00, 48.7275626), (1990.00, 49.80704585), (1991.00, 50.81549016), (1992.00, 51.76156092), (1993.00, 52.6530624), (1994.00, 53.49912672), (1995.00, 54.30648923), (1996.00, 55.07932471), (1997.00, 55.82528862), (1998.00, 56.55108312), (1999.00, 57.26121591), (2000.00, 57.9591999), (2001.00, 58.65754414), (2002.00, 59.35539415), (2003.00, 60.0512316), (2004.00, 60.74572128), (2005.00, 61.43762036), (2006.00, 62.12509935), (2007.00, 62.80906843), (2008.00, 63.48940378), (2009.00, 64.1638364), (2010.00, 64.83289189), (2011.00, 65.49362025), (2012.00, 66.14655977), (2013.00, 66.79156905), (2014.00, 67.42876822), (2015.00, 68.05828291), (2016.00, 68.67560731)			
"Maximum_Effect_of_Obesity_Prevalence_on_Transition_from_AG0_(L5)"	2		Dimensionless	This is a constant that represents the maximum value of the curve in other words the maximum value of the effect formulation can go up or down. The value is estimated and calibrated.
Normal_Death_Fraction_AG_1	0.25		Dimensionless	This is a constant which represents the fraction death each year for the indicated age group and body weight category on variable name. It is estimated and calibrated based.
Normal_Death_Fraction_AG_2	0.25		Dimensionless	This is a constant which represents the fraction death each year for the indicated age group and body weight category on variable name. It is estimated and calibrated based.

Variable Name	Equation	Initial Value	Unit	Notes
Normal_Death_Fraction_AG_3	0.15		Dimensionless	This is a constant which represents the fraction death each year for the indicated age group and body weight category on variable name. It is estimated and calibrated based.
Normal_Men	Normal_Weight_AG_1[Men]+Normal_Weight_AG_2[Men]+Normal_Weight_AG_3[Men]		person	This is a variable that represents the total number of men who has normal weight. Its equation is the sum of all people who belongs to this category.
Normal_Pop[Sex]	Normal_Weight_AG_1+Normal_Weight_AG_2+Normal_Weight_AG_3		person	This is a variable that represents the total number of women and men who has normal weight. Its equation is the sum of all people who belongs to this category.
Normal_Weight_Transition_Fraction_From_AG0[Sex]	1-(Obese_Transition_Fraction_From_AG0+Overweight_Transition_Fraction_From_AG0)		Dimensionless	This is a variable that represents the fraction of normal population among the transition rate from age group 0 to the next group. Its equation indicates that the population who are not overweight or obese are normal weight.
Normal_Women	Normal_Weight_AG_1[Women]+Normal_Weight_AG_2[Women]+Normal_Weight_AG_3[Women]		person	This is a variable that represents the total number of women who has normal weight. Its equation is the sum of all people who belongs to this category.
Obese_Death_Fraction_AG_1	0.45		Dimensionless	This is a constant which represents the fraction death each year for the indicated age group and body weight category on variable name. It is estimated and calibrated based.
Obese_Death_Fraction_AG_2	0.45		Dimensionless	This is a constant which represents the fraction death each year for the indicated age group and body weight category on variable name. It is estimated and calibrated based.

Variable Name	Equation	Initial Value	Unit	Notes
Obese_Death_Fraction_AG_3	0.45		Dimensionless	This is a constant which represents the fraction death each year for the indicated age group and body weight category on variable name. It is estimated and calibrated based.
Obese_Men	Obese_AG_1[Men]+Obese_AG_2[Men]+Obese_AG_3[Men]		person	This is a variable that represents the total number of men who are obese. Its equation is the sum of all people who belongs to this category.
Obese_pop[Sex]	Obese_AG_3+Obese_AG_2+Obese_AG_1		person	This is a variable that represents the total number of women and men who are obese. Its equation is the sum of all people who belongs to this category.
Obese_Prevalence	((Obese_pop[Men]+Obese_pop[Women])/"POPULATION_-_TURKEY")*100		Dimensionless	This is a variable that represents the prevalence of obese people among the total population. Its equation indicates that the percentage of obese population among the total population.
Obese_Transition_Fraction_From_AG0[Sex]	Initial_Transition_Fraction_Obese_AG0*Effect_of_BW_to_transition_Fraction		Dimensionless	This is a variable that represents the fraction of overweight population among the transition rate from age group 0 to the next group. Its value estimated and calibrated.
Obese_Women	Obese_AG_1[Women]+Obese_AG_2[Women]+Obese_AG_3[Women]		person	This is a variable that represents the total number of women who are obese. Its equation is the sum of all people who belongs to this category.
obesity_percentage	"Obesity_Prevalence-Adult"/100		Dimensionless	
Obesity_Prevalence_Men	(Obese_Men/Total_Adult_Population_Men)*100		Dimensionless	This is a variable that represents the prevalence of obese men. Its equation indicates that the percentage of obese men among the total population.

Variable Name	Equation	Initial Value	Unit	Notes
Obesity_Prevalence_Women	(Obese_Women/Total_Adult_Population_Women)*100		Dimensionless	This is a variable that represents the prevalence of obese women. Its equation indicates that the percentage of obese women among the total population.
"Obesity_Prevalence-Adult"	((Obese_pop[Men]+Obese_pop[Women])/Total_Adult_population)*100		Dimensionless	This is a variable that represents the prevalence of obese people among the adult population. Its equation indicates that the percentage of obese population among the adult population.
Overweight_Death_Fraction_AG_1	0.3		Dimensionless	This is a constant which represents the fraction death each year for the indicated age group and body weight category on variable name. It is estimated and calibrated based.
Overweight_Death_Fraction_AG_2	0.3		Dimensionless	This is a constant which represents the fraction death each year for the indicated age group and body weight category on variable name. It is estimated and calibrated based.
Overweight_Death_Fraction_AG_3	0.4		Dimensionless	This is a constant which represents the fraction death each year for the indicated age group and body weight category on variable name. It is estimated and calibrated based.
Overweight_Men	Overweight_AG_1[Men]+Overweight_AG_2[Men]+Overweight_AG_3[Men]		person	This is a variable that represents the total number of men who are overweight. Its equation is the sum of all people who belongs to this category.
Overweight_percentage	"Overweight_Prevalence-Adult"/100		Dimensionless	
Overweight_pop[Sex]	Overweight_AG_1+Overweight_AG_2+Overweight_AG_3		person	This is a variable that represents the total number of women and men who are overweight.

Variable Name	Equation	Initial Value	Unit	Notes
				Its equation is the sum of all people who belongs to this category.
Overweight_Prevalence	((Overweight_pop[Men]+Overweight_pop[Women])/"POPULATION_-_TURKEY")*100		Dimensionless	This is a variable that represents the prevalence of overweight people among the total population. Its equation indicates that the percentage of overweight population among the total population.
Overweight_Prevalence_Men	(Overweight_Men/Total_Adult_Population_Men)*100		Dimensionless	This is a variable that represents the prevalence of overweight men. Its equation indicates that the percentage of overweight men among the total population.
Overweight_Prevalence_Women	(Overweight_Women/Total_Adult_Population_Women)*100		Dimensionless	This is a variable that represents the prevalence of overweight women. Its equation indicates that the percentage of overweight women among the total population.
"Overweight_Prevalence-Adult"	((Overweight_pop[Men]+Overweight_pop[Women])/Total_Adult_population)*100		Dimensionless	This is a variable that represents the prevalence of overweight people among the adult population. Its equation indicates that the percentage of overweight population among the adult population.
Overweight_Transition_Fraction_From_AG0[Sex]	Initial_Transition_Fraction_Overweight_AG0*Effect_of_BW_to_transition_Fraction		Dimensionless	This is a variable that represents the fraction of overweight population among the transition rate from age group 0 to the next group. Its value estimated and calibrated.
Overweight_Women	Overweight_AG_1[Women]+Overweight_AG_2[Women]+Overweight_AG_3[Women]		person	This is a variable that represents the total number of women who are overweight. Its equation is the sum of all people who belongs to this category.
Overweight&Obese_Population	Obese_pop[Men]+Obese_pop[Women]+Overweight_pop[Men]+Overweight_pop[Women]		person	This is a variable that represents the total overweight and obese population.

Variable Name	Equation	Initial Value	Unit	Notes
OWOB_Prevalence	(Overweight&Obese_Population/"POPULATION_-_TURKEY")*100		Dimensionless	This is a variable that represents the prevalence of overweight and obese people among the total population. Its equation indicates that the percentage of overweight and obese population among the total population.
Population[Sex]	"Age_Group_0_(0-14)"+"Age_Group_1_(15-49)"+"Age_Group_2_(50-74)"+"Age_Group_3_(75+)"		person	This is a variable that represents the population. Its equation describes the sum of all people from different age groups. Purpose of this part is just to analyze the behavior of the system therefore it is not a part of the model structure.
"POPULATION_-_TURKEY"	SUM("Age_Group_3_(75+)"[*]) + SUM("Age_Group_2_(50-74)"[*]) + SUM("Age_Group_1_(15-49)"[*]) + SUM("Age_Group_0_(0-14)"[*])		person	This is a variable that represents the population. Its equation describes the sum of all people from different age groups. Purpose of this part is just to analyze the behavior of the system therefore it is not a part of the model structure.
"Sensitivity_of_Transition_Fraction_From_AG_0_(α5)"	-1		Dimensionless	This is a constant that represents the strength of one variable on another one. The value is below zero because the effect is directly proportional to change in the relative value since the effect formulation is a logistic function. The value is estimated and calibrated.
Total_Adult_population	Total_Adult_Population_Women+Total_Adult_Population_Men		person	This is a variable that represents the total number of adult population.
Total_Adult_Population_Men	Obese_pop[Men]+Overweight_pop[Men]+Normal_Pop[Men]		person	This is a variable that represents the total number of adult men.

Variable Name	Equation	Initial Value	Unit	Notes
Total_Adult_Population_Women	Normal_Pop[Women]+Overweight_pop[Women]+Obese_pop[Women]		person	This is a variable that represents the total number of adult women.
Total_Population_Reference_Mode	GRAPH(TIME) Points: (1970.00, 35605176), (1972.55, 40347719), (1975.10, 44736957), (1977.65, 50664458), (1980.20, 56473035), (1982.75, 67803927), (1985.30, 70586256), (1987.85, 71517100), (1990.40, 72561312), (1992.95, 73722988), (1995.50, 74724269), (1998.05, 75627384), (2000.60, 76667864), (2003.15, 77695904), (2005.70, 78741053), (2008.25, 79814871), (2010.80, 80810525), (2013.35, 82003882), (2015.90, 83154997), (2018.45, 83614362), (2021.00, 84680273)		person	This is historical data for Turkish population from 1970 to 2022. Purpose of this part is just to analyze the behavior of the system therefore it is not a part of the model structure.
TSI_Historical	GRAPH(TIME) Points: (1970.00, 0.0), (1971.00, 0.0), (1972.00, 0.0), (1973.00, 0.0), (1974.00, 0.0), (1975.00, 0.0), (1976.00, 0.0), (1977.00, 0.0), (1978.00, 0.0), (1979.00, 0.0), (1980.00, 0.0), (1981.00, 0.0), (1982.00, 0.0), (1983.00, 0.0), (1984.00, 0.0), (1985.00, 0.0), (1986.00, 0.0), (1987.00, 0.0), (1988.00, 0.0), (1989.00, 0.0), (1990.00, 0.0), (1991.00, 0.0), (1992.00, 0.0), (1993.00, 0.0), (1994.00, 0.0), (1995.00, 0.0), (1996.00, 0.0), (1997.00, 0.0), (1998.00, 0.0), (1999.00, 0.0), (2000.00, 0.0), (2001.00, 0.0), (2002.00, 0.0), (2003.00, 0.0), (2004.00, 0.0), (2005.00, 0.0), (2006.00, 0.0), (2007.00, 0.0), (2008.00, 47.6), (2009.00, 48.0), (2010.00, 49.89), (2011.00, 50.0), (2012.00, 51.99), (2013.00, 52.0), (2014.00, 53.63), (2015.00, 53.7), (2016.00, 53.87), (2017.00, 54.0), (2018.00, 55.0), (2019.00, 56.1), (2020.00, 0.0), (2021.00, 0.0), (2022.00, 0.0), (2023.00, 0.0), (2024.00, 0.0), (2025.00, 0.0), (2026.00, 0.0), (2027.00, 0.0), (2028.00, 0.0), (2029.00, 0.0), (2030.00, 0.0),		Dimensionless	This is a historical data variable. Purpose of this part is just to analyze the behavior of the system therefore it is not a part of the model structure.

Variable Name	Equation	Initial Value	Unit	Notes
	(2031.00, 0.0), (2032.00, 0.0), (2033.00, 0.0), (2034.00, 0.0), (2035.00, 0.0), (2036.00, 0.0), (2037.00, 0.0), (2038.00, 0.0), (2039.00, 0.0), (2040.00, 0.0), (2041.00, 0.0), (2042.00, 0.0), (2043.00, 0.0), (2044.00, 0.0), (2045.00, 0.0), (2046.00, 0.0), (2047.00, 0.0), (2048.00, 0.0), (2049.00, 0.0), (2050.00, 0.0)			
Women_Fertility_Period	30		year	This is a constant that represents the average duration of women to be fertile. The value is based on (Dunson et al., 2002).
Women_in_Fertile_Age	"Age_Group_1_(15-49)"[Women]		person	This is a variable that represents the number of fertile women who can give birth. Its equation describes that the women in age group 1 are fertile.
"Y-AG1-OW_1"[Sex]	Overweight_AG_1/(Body_Weight.Overweight_Final-Body_Weight.Overweight_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).
"Y-AG1-OW_2"[Sex]	Overweight_AG_2/(Body_Weight.Overweight_Final-Body_Weight.Overweight_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).
"Y-AG1-OW_3"[Sex]	Overweight_AG_3/(Body_Weight.Overweight_Final-Body_Weight.Overweight_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the

Variable Name	Equation	Initial Value	Unit	Notes
				initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).
"Y-Normal_AG_1"[Sex]	Normal_Weight_AG_1/(Body_Weight.Normal_Weight_Final-Body_Weight.Normal_Weight_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).
"Y-Normal_AG_2"[Sex]	Normal_Weight_AG_2/(Body_Weight.Normal_Weight_Final-Body_Weight.Normal_Weight_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).
"Y-Normal_AG_3"[Sex]	Normal_Weight_AG_3/(Body_Weight.Normal_Weight_Final-Body_Weight.Normal_Weight_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).
"Y-Obese-AG_1"[Sex]	Obese_AG_1/(Body_Weight.Obese_Final-Body_Weight.Obese_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the

Variable Name	Equation	Initial Value	Unit	Notes
				initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).
"Y-Obese-AG_2"[Sex]	Obese_AG_2/(Body_Weight.Obese_Final-Body_Weight.Obese_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).
"Y-Obese-AG_3"[Sex]	Obese_AG_3/(Body_Weight.Obese_Final-Body_Weight.Obese_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).
"Y-OW-AG_1"[Sex]	Overweight_AG_1/(Body_Weight.Overweight_Final-Body_Weight.Overweight_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).
"Y-OW-AG_2"[Sex]	Overweight_AG_2/(Body_Weight.Overweight_Final-Body_Weight.Overweight_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the

Variable Name	Equation	Initial Value	Unit	Notes
				initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).
"Y-OW-AG_3"[Sex]	Overweight_AG_3/(Body_Weight.Overweight_Final-Body_Weight.Overweight_Initial)		Centimeters^2*People/Kilograms	This is a variable that represents the frequency of the corresponding body weight category based on the initial and final values of this category. This equation indicates a distribution at the given interval represented by initial and final values. This distribution equation is based on (Fallah-Fini et al., 2013; Fallah-Fini et al., 2014).

Run Specs	
Start Time	1970
Stop Time	2050
DT	1/24
Fractional DT	True
Save Interval	0.0833333333333
Sim Duration	0
Time Units	Year
Pause Interval	0
Integration Method	Runge-Kutta 4th order
Keep all variable results	True
Run By	Run
Calculate loop dominance information	False

Array Dimension	**Indexed By**	**Elements**
BMI_category	Label (3)	Normal_Weight Overweight Obese
Food_Type	Label (2)	HighED_Food LowED_Food
Sex	Label (2)	Men Women