Conflicting Choices: Food versus Health

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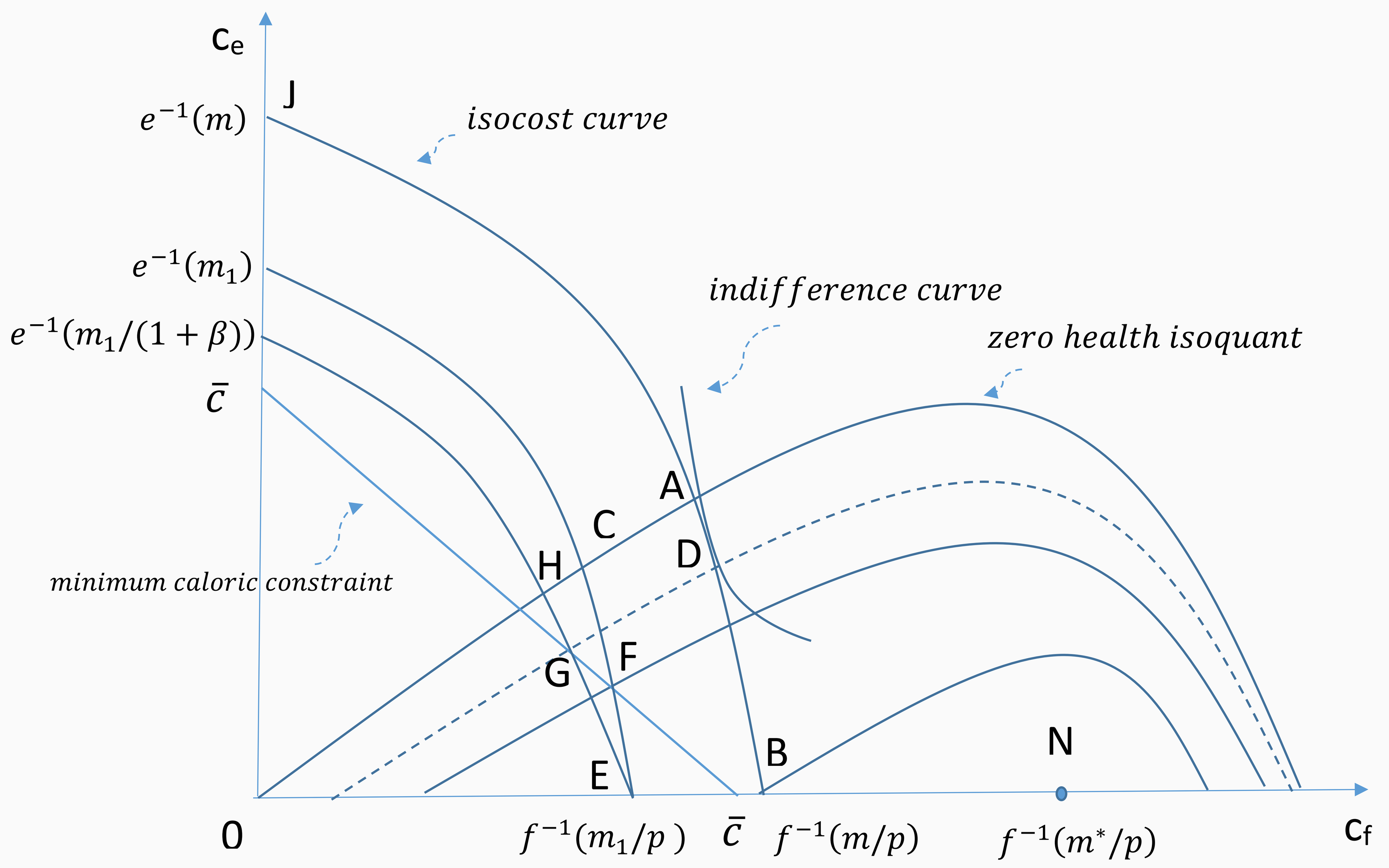
"Health is, therefore, seen as a resource for everyday life, not the objective of living. Health is a positive concept emphasizing social and personal resources, as well as physical capacities." (World Health Organization, 2017).

This paper explores the trade-off between health and food consumption, and the effectiveness of health interventions such as taxing unhealthy foods. Rational agents maximize utility over health and consumption of healthy and unhealthy foods, while health is a function calories and nutrients. Calories and nutrients are not available for purchase in the market, thus their pricing is derived via a "household" production technology used to convert healthy and unhealthy foods into health outcomes. Additionally, consumers face a physiological constraint, a minimum calorie intake, which has further implications in terms of reducing potential health benefits associated with governmental interventions, such as taxing high-calorie foods. The future budget available to consumers depends on the consumption of discretionary calories. The theoretical model is calibrated using financial and consumption data reflecting farmworkers' food consumption in the US.

Figure 1. Health Choices



Description of the figure

Figure 1 ilustrates the theoretical model developed in this paper. Some of the points in Figure 1 are as follows:

Point A: behaviour consistent with zero health.
Point B: maximum health given the budget m and prices $(p, 1)$.
Point D: optimal choice of health given the preferences over health and consumption.
Point F: the highest health outcome given the minimum caloric - intake constraint is binding for the budget m_1 and prices $(p, 1)$.
Point G: identical to F for the budget m_1 and new prices $(p, 1/(1+\mu))$.
Point N: the maximum level of health given the current technology.

If you would like to follow up on the paper, please email me at d.voica@massey.ac.nz A draft of the paper is available on agecon-search.umn.edu. Thank you.

Table 1: Full and Empty Calories Consumption for a Health Economist Agent and Consumer with Cobb-Douglas Utility

	Health Economist				Consumer ($\alpha = 0.5$)[3]				Consumer ($\alpha = 0.1$)				Consumer ($\alpha = 0.9$)			
Income (%)[1]	10%	20%	30%	40%	10%	20%	30%	40%	10%	20%	30%	40%	10%	20%	30%	40%
Income ($)[2]	8.64	17.28	25.92	34.56	8.64	17.28	25.92	34.56	8.64	17.28	25.92	34.56	8.64	17.28	25.92	34.56
$\beta = 0$ [4]																
c_{f_1}	548	1338	2,041	2,632	548	1338	2,017	2,454	548	1,338	2,040	2,324	548	1,338	2,029	2,588
c_{e_1}	952	162	0	0	952	162	168	1,925	952	162	5	2,867	952	162	83	958
c_{f_2}	548	1338	2,041	2,632	548	1338	2,017	2,454	548	1,338	2,040	2,324	548	1,338	2,029	2,588
c_{e_2}	952	162	0	0	952	162	168	1,925	952	162	5	2,867	952	162	83	958
$\beta = 0.5$																
c_{f_1}	548	1,338	2,041	2632	548	1338	1,980	2,398	548	1,338	1,986	2,194	548	1,338	2,019	2,569
c_{e_1}	952	162	0	0	952	162	436	2,329	952	162	392	3,802	952	162	159	1,093
c_{f_2}	625	1,351	2,041	2632	625	1351	2,045	2,492	625	1,351	2,067	2,342	625	1,351	2,040	2,612
c_{e_2}	875	149	0	0	875	149	186	2,813	875	149	8	4,638	875	149	85	1,335
$\beta = 1$																
c_{f_1}	530	1,294	2,041	2,632	499	1,262	1,912	2,358	434	1,221	1,878	2,074	524	1,290	1,981	2,560
c_{e_1}	1,086	482	0	0	1,308	714	930	2,616	1,776	1,007	1,171	4,666	1,130	506	428	1,163
c_{f_2}	723	1,416	2,041	2,632	759	1,453	2,133	2,525	834	1,500	2,190	2,359	730	1,419	2,087	2,629
c_{e_2}	777	84	0	0	741	47	265	4,033	667	0	92	7,276	770	81	95	1,827
$\beta = 1.5$																
c_{f_1}	296	1,189	1,962	2,632	314	1,144	1,865	2,329	264	1,094	1,806	1,962	300	1,177	1,927	2,555
c_{e_1}	2,775	1,235	570	0	2,646	1,565	1,265	2,827	3,005	1,922	1,692	5,476	2,744	1,324	821	1,199
c_{f_2}	1,218	1,617	2,159	2,632	1,187	1,677	2,242	2,549	1,273	1,760	2,278	2,376	1,211	1,630	2,194	2,641
c_{e_2}	282	0	0	0	313	59	445	5,479	227	0	824	10,705	290	39	125	2,379

[1] Percentage of the daily income spent on food purchases. [2] Daily dollar amount spent on food purchases.
[3] α is utility power associated with the consumption of full calorie $c_{f_i}, i = 1, 2$.
[4] β is the marginal effect of consuming an empty calorie in the first period on the second period budget. For each c_{e_1} consumed the second period budget increases by $\beta \times 0.00176$, where 0.00176 is the price of c_{e_1}.

Conflicting Choices: Food versus Health. Are We Spending or Wasting Health?

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Conflicting Choices: Food versus Health. Are We Spending or Wasting Health?

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Abstract

This paper explores the trade-off between health and food consumption, and the effectiveness of health interventions such as taxing unhealthy foods. Rational agents maximize utility over health and consumption of healthy and unhealthy foods, while health is a function of calories and nutrients. Calories and nutrients are not available for purchase in the market, thus their pricing is derived via a "household" production technology used to convert healthy and unhealthy foods into health outcomes. Additionally, consumers face a physiological constraint, a minimum calorie intake, which has further implications in terms of reducing potential health benefits associated with governmental interventions, such as taxing high-calorie foods. The future budget available to consumers depends on the consumption of discretionary calories. The theoretical model is calibrated using financial and consumption data reflecting farmworkers' food consumption in the US.

1 Motivation

The World Health Organization defines health as a "resource". In its words, "Health is, therefore, seen as a resource for everyday life, not the objective of living. Health is a positive concept emphasizing social and personal resources, as well as physical capacities."(WHO, 2017a). This definition is consistent with observed behaviour. People trade health for consumption in a way that resembles any other resource. For example, immigrant farmworkers in the US often find themselves in poor health despite harvesting healthy products (Fuller, 2016). The main reason is budgetary constraints, that prevent purchasing healthy foods, thus effectively inducing a trade off between health and current consumption. On the other hand, there are plenty of examples when budget constraints are not binding, but consumers prefer to overindulge (Rashad, 2006).

This issue is naturally linked to the problem of obesity, a major health issue, that is pervasive in today's world. Since 1980 obesity has doubled, with more than 1.9 billion adults, 18 years and older being overweight in 2014, while almost a third of these were obese (WHO, 2017b). In the US alone the prevalence of obesity was over 36% in adults and 17% in youth between $2011 - 2014$ (Ogden et al., 2015), while in Europe, obesity was responsible for more than 1 million deaths and 12 million life-years of health reduction in 2010 (Cuschieri and Mamo, 2016). Attempts to reduce the obesity epidemic and to improve the health outcomes of the population, have prompted governmental interventions, such as taxes on high-calorie foods (Jacobson and Brownell, 2000).[1] Proponents of these interventions argued that taxes will change the relative prices of healthy and unhealthy foods, inducing rational consumers to substitutes towards a healthier diet while improving the health outcomes.

The effectiveness of these interventions has been debated in literature, where potential factors that could reduce the health benefits of these interventions were

[1] A calorie is the amount of heat required at a pressure of one atmosphere to raise the temperature of one gram of water one degree Celsius (Merriam-Webster).

proposed. Among them, the substitution between taxed and non-taxed high-calorie foods (Schroeter, Lusk, and Tyner, 2008; Fletcher, Frisvold, and Tefft, 2010), an inverse relation between healthier foods consumption and physical exercise (Yaniv, Rosin, and Tobol, 2009), taste and inventory decisions (Wang, 2015), or addiction (Becker and Murphy, 1988; Becker, Grossman, and Murphy, 1991; Richards, Patterson, and Tegene, 2007).

In order to explore the trade-off between health and consumption and the effectiveness of health interventions such as taxing unhealthy foods, this paper proposes a theoretical model where rational agents maximize utility over health and consumption of healthy and unhealthy foods, while health is a function of calories and nutrients. Calories and nutrients are not available for purchase in the market, thus their pricing is derived via a "household" production technology used to convert healthy and unhealthy foods into health outcomes.[2] Additionally, consumers face a physiological constraint, a minimum calorie intake, which has further implications in terms of reducing potential health benefits associated with governmental interventions, such as taxing high-calorie foods. We model the future budget of consumers as depending directly on the consumption of discretionary calories[3].

The structure of the paper is as follows. The next section places the paper in the literature, while the third section presents the theoretical model. The fourth section reports empirical results from a calibrated version of the theoretical model. The final section concludes.

[2]The "household" production was popularized by Deaton and Muellbauer (1993), while Chambers (2017) provides a set-theoretical approach.

[3]Unhealthy foods are characterized by a lower ratio of nutrients to calories. They deliver a lot of energy (i.e. calories), but fewer nutrients. Because of the relative fix proportion of nutrients to calories delivered by each type of foods, we call the bundle "calories-nutrients" discretionary or "empty "calories if the ratio of nutrients to calories is low and full calories if the ratio is high.

2 Comparison with the Literature

The observation that rational economic agents trade health for the consumption of other goods is not new. For example, addiction (reinforcement and tolerance) was investigated by Becker and Murphy (1988) and Becker, Grossman, and Murphy (1991), counter cyclical consumption effects on health were examined by Dockner and Feichtinger (1993). The economics of consumption of foods with negative effects on health were investigated, among others, by Grossman (1972a), Forster (2001), Chavas (2013) and Bolin and Lindgren (2016), while Chavas (2015) provides a benefit function treatment.

Furthermore, the health economics literature, in particular the economic literature concerning the health effects of food consumption, has investigated theoretically and empirically the effects of various government interventions, such as taxing calorie-rich foods, on the rational agents's food choices and health outcomes. While not always in agreement, the general consensus is that governmental interventions targeting improvements in health outcomes are rarely fully successful. For example, with some exceptions (Richards, Patterson, and Tegene, 2007), the attempts to improve the health outcomes of consumers by taxing high-calorie foods had mixed results, and the taxes proved to be regressive. Ignoring consumers' inventory behaviors and the persistence of their tastes overestimates the benefits of soda taxes (Wang, 2015), in addition to offsetting some of the benefits due to the substitution between various types of high-calorie foods (Schroeter, Lusk, and Tyner, 2008; Fletcher, Frisvold, and Tefft, 2010). Assuming a Leontief technology for the production of healthy foods and perfect substitution in consumption between healthy and unhealthy foods, Yaniv, Rosin, and Tobol (2009) show that a "fat" tax can decrease the health outcomes of consumers, if the reduction in the unhealthy food due to the tax is not enough to compensate the reduction in time allocation to physical exercise, now needed for cooking the healthy food. Alternatively, taxing or subsidizing calories rather than foods avoids potential substitution effects between similarly perceived items increasing the health benefits of the interventions (Richards, Patterson, and Tegene, 2007; Okrent and Alston, 2012).

The contribution of this paper to the previous literature is as follows. First, we account for physiological constraints imposed by biological processes. There is a minimum calorie intake a person needs to fulfill in order to maintain the energy level required to engage in productive activities. This intake is independent of the nutrient density of calories consumed, however health is not. Thus, a potential trade off dictated by budgetary constraints is apparent. Furthermore, as long as this minimum calorie intake is binding, taxing high-calorie foods will have the opposite effect of decreasing the nutrient density of the foods consumed, while increasing the intake of high-calorie foods. This provides an alternative explanation to justify the mixed results of tax interventions on improving health outcomes, especially in the case of poor consumers.

Second, previous literature has modeled the budget available to consumers as an increasing function of health (Grossman, 1972b; Chavas, 2013; Bolin and Lindgren, 2016). While intuitively correct, people tend to be more productive if they are healthy, in the short run people might find it in their best interest to push the health "envelope" so to speak. For example, diabetes will impact a person's ability to generate income in the long run, but in the initial stages of the disease the person's ability to perform is less likely to be affected.[4] On the other hand, consumption of unhealthy foods that provide a boost in energy is more likely to increase productivity. Consider farmworkers. Their income is contingent on how much they harvest at a given time (i.e., piece rate payment). An unhealthy boost in energy will increase their productivity and so their income at the expense of health. Another example can be found in academics. Tenure track assistant professors will, at times, find themselves

[4]Diamond (2003) argues that changes in diets and life style can precede negative health outcomes by as much as two decades.

in the position of trading health in order to increase the time budget available to beat the tenure clock. In both instances, budget is a function of unhealthy food consumption, rather than health. This avenue seems worth exploring. Finally, we calibrate the theoretical model with data pertaining to the US farm-workers food choices.

3 Theoretical Model

There are two time periods. The agent has preferences over health, $h \in \mathbb{R}_{++}$, and two food products, $t_i \in \mathbb{R}_+$ and $s_i \in \mathbb{R}_+$, where $i = 1, 2$ represents consumption of food products in the first and second periods. Preferences are represented by the utility function $u : \mathbb{R}^5_+ \to \mathbb{R}_{++}$, where u is assumed to be increasing and concave in health, s_i and t_i. The agent can buy the food product t_i for a price $q_i \in \mathbb{R}_{++}$, which for simplicity is assumed to be equal across periods and is normalized to 1, and the good s_i for a price $p_i \in \mathbb{R}_{++}$, which for simplicity is assumed to equal p across periods. Health can not be purchased from the market, it is a nonmarketable good.

However, the agent can produce health using a technology where the inputs are calories and nutrients delivered by the two food products. Calories come in two flavours: discretionary calories, also known as "empty calories", $c_{e_i} \in \mathbb{R}_+$, which are produced by nutrient deficient food products, t_i in this case, and full calories, $c_{f_i} \in \mathbb{R}_+$, which are produced along side nutrients by healthy food products, s_i in this case. The difference between empty and full calories is that the latter calories deliver energy and nutrients while the former deliver only energy. The health technology is represented by the health production function $H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2})$, where[5]

$$H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2}) = \max\{h : (c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2}) \text{ can produce } h\}$$

[5] The health production function refers to the ability of the body to transform calories and nutrients in health, keeping constant genetics and environment, exercise, life style, and other contributing factors.

The health production function $H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2})$ is increasing in c_{f_i} and nonincreasing in c_{e_i}. The full calories technology is represented by the input requirement function $f(c_{f_i})$, where

$$f(c_{f_i}) = \min\{s_i : s_i \text{ can produce } c_{f_i}\}$$

and the empty calories technology is represented by the input requirement function $e(c_{e_i})$, where

$$e(c_{e_i}) = \min\{t_i : t_i \text{ can produce } c_{e_i}\}$$

In the first period, the agent faces the budget constraint, $ps_1 + t_1 \leq m$, and, in the second period, the budget constraint $ps_2 + t_2 \leq (1 + \beta(c_{e_1}))m$, where m is the agent's income and $\beta(c_{e_1})$ is a productivity bonus (i.e., agricultural workers can harvest more products in the field if they consume c_{e_1}). I assume that $\beta(c_{e_1})$ is concave in c_{e_1} (i.e., $\beta^{'}(c_{e_1}) > 0$, $\beta^{''}(c_{e_1}) < 0$).

Additionally, in each period, the agent must reach a minimum level of calories consumption, $\bar{c}$, in order to insure a minimum level of energy necessary to sustain life and productive activities. I assume that the income m is sufficiently large to allow the consumer to cover the minimum calories requirement, $\bar{c}$, at least from the consumption of empty calories c_{e_1}. Technically, this requires $e(\bar{c}) \leq m$. Similarly, the consumer will be able to cover $\bar{c}$ only from the consumption of full calories c_{f_i} if $pf(\bar{c}) \leq m$.

The consumer chooses s_i, t_i, c_{f_i} and c_{e_i}, $i = 1, 2$, to solve:

$$\max \Big\{ u_1(t_1, s_1) + \delta u_2(h, t_2, s_2) : h \leq H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2}), s_i \geq f(c_{f_i}), t_i \geq e(c_{e_i}), \quad (1)$$
$$ps_1 + t_1 \leq m, ps_2 + t_2 \leq (1 + \beta(c_{e_1}))m, c_{e_i} + c_{f_i} \geq \bar{c}, i = 1, 2 \Big\}$$

where δ is an intertemporal discount factor.

In words, the consumer maximizes consumption of health and food products over two periods conditional on technology, budget and physiology constraints. The technology constraints are the health constraint, $h \leq H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2})$, and the production of calories, $s_i \geq f(c_{f_i})$ and $t_i \geq e(c_{e_i})$ for $i = 1, 2$. The budget constraints are $ps_1 + t_1 \leq m$ in the first period, and $ps_2 + t_2 \leq (1 + \beta(c_{e_1}))m$ in the second period. Finally, the physiology constraints are $c_{e_i} + c_{f_i} \geq \bar{c}, i = 1, 2$, the consumer must achieve at least the minimum calorie intake in each period.

It is convenient to recast (1) exclusively in terms of health inputs, c_{e_i} and c_{f_i}. Because the agent is the residual claimant, at optimum, $h = H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2})$, $s_i = f(c_{f_i})$ and $t_i = e(c_{e_i})$ for all i. Thus, the first period budget constraint becomes $pf(c_{f_1}) + e(c_{e_1}) \leq m$, and the second period budget constraint becomes $pf(c_{f_2}) + e(c_{e_2}) \leq (1 + \beta(c_{e_1}))m$. Both budget constraints are binding at the optimum.

The consumer chooses c_{f_i} and c_{e_i}, $i = 1, 2$, to solve:

$$\max \Big\{ u_1(e(c_{e_1}), f(c_{f_1})) + \delta u_2(H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2}), e(c_{e_2}), f(c_{f_2})) : \qquad (2)$$

$$pf(c_{f_1}) + e(c_{e_1}) = m,$$

$$pf(c_{f_2}) + e(c_{e_2}) = (1 + \beta(c_{e_1}))m,$$

$$c_{e_i} + c_{f_i} \geq \bar{c}, i = 1, 2 \Big\}$$

Figure 3.1 illustrates the optimal consumption of calories and the optimal choice of health for one period in the calories space. For a budget m and prices $(p, 1)$, the maximum amount of full and empty calories available for consumption are $f^{-1}(m/p)$, point B, and $e^{-1}(m)$, point J, respectively. The isocost connecting B and J represents all possible combinations of full and empty calories (c_{f_i}, c_{e_i}) available for consumption given the budget m and prices $(p, 1)$. The indifference curve represents all possible combinations of full and empty calories (c_{f_i}, c_{e_i}) that deliver the same level of satisfaction to the consumer. The optimal consumption of calories, point D, is given by the tangency between the indifference curve and the isocost curve. The optimal health corresponding to point D is given by the health isoquant at D. The minimum caloric intake is represented by the line of slope -1 (i.e. line $[\bar{c}, \bar{c}]$).

3.1 Equilibrium Behavior

In order to characterize the optimal decisions of the agent in (2), first we need to consider whether the minimum caloric intake constraints are binding or not. To focus the analysis, we consider only the polar cases: both constraints are binding and none of the constraints are binding. The mixed cases are similar.

If the minimal calories intake constraints are not binding, $c_{e_i} + c_{f_i} > \bar{c}$, (2) can be written as:

$$\begin{aligned} \max \Big\{ u_1(e(c_{e_1}), f(c_{f_1})) + &\delta u_2(H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2}), e(c_{e_2}), f(c_{f_2})) \\ &+ \gamma_1(m - pf(c_{f_1}) - e(c_{e_1})) \\ &+ \gamma_2((1+\beta(c_{e_1}))m - pf(c_{f_2}) + e(c_{e_2})) \end{aligned} \tag{3}$$

where γ_1 and γ_2 are shadow prices, and the optimal consumption of discretionary and full calories, assuming interior solutions, are characterized by the first order conditions:

$$\frac{\partial u_1}{\partial s_1}\frac{\partial f}{\partial c_{f_1}} + \delta\frac{\partial u_2}{\partial H}\frac{\partial H}{\partial c_{f_1}} - \gamma_1 p\frac{\partial f}{\partial c_{f_1}} = 0 \tag{4}$$

$$\frac{\partial u_1}{\partial t_1}\frac{\partial e}{\partial c_{e_1}} + \delta\frac{\partial u_2}{\partial H}\frac{\partial H}{\partial c_{e_1}} - \gamma_1\frac{\partial e}{\partial c_{e_1}} + \gamma_2\beta' m = 0 \tag{5}$$

$$\frac{\partial u_2}{\partial s_2}\frac{\partial f}{\partial c_{f_2}} + \frac{\partial u_2}{\partial H}\frac{\partial H}{\partial c_{f_2}} - p\frac{\gamma_2}{\delta}\frac{\partial f}{\partial c_{f_2}} = 0 \tag{6}$$

$$\frac{\partial u_2}{\partial t_2}\frac{\partial e}{\partial c_{e_2}} + \frac{\partial u_2}{\partial H}\frac{\partial H}{\partial c_{e_2}} - \frac{\gamma_2}{\delta}\frac{\partial e}{\partial c_{e_2}} = 0 \tag{7}$$

In Figure 3.1, an example of the range of possible solutions is the isoquant map $(A, B]$, where A represents behaviour consistent with zero health, and B is maximum health given the budget m and prices $(p, 1)$. In this case, the minimum caloric constraint is not binding, and the optimal mix between empty and full calories, (c_e, c_f) is given by the preferences over health, and the consumption of other goods. The optimum choice is at point D, where the indifference curve is tangent to the isocost curve.

Alternatively, if the constraints are binding, $c_{e_i} + c_{f_i} = \bar{c}$, the empty calories consumed $c_{e_i} = \bar{c} - c_{f_i}$ and the optimum consumption of full calories is determined by the budget constraints $pf(c_{f_1}) + e(\bar{c} - c_{f_1}) = m$ in the first period, and $pf(c_{f_2}) + e(\bar{c} - c_{f_2}) = (1 + \beta(c_{e_1}))m$ in the second period.

Denote the first period optimal consumption of full calories by $\hat{c}_{f_1}$, where $\hat{c}_{f_1}$ represents the implicit solution for c_{f_1} in terms of the budget constraint $pf(c_{f_1}) + e(\bar{c} - c_{f_1}) = m$, and the second period optimal consumption of full calories by $\hat{c}_{f_2}$, where $\hat{c}_{f_2}$ represents the implicit solution for c_{f_2} in terms of the budget constraint $pf(c_{f_2}) + e(\bar{c} - c_{f_2}) = (1 + \beta(c_{e_1}))m$. Then, the first period optimal consumption of empty calories is $\bar{c} - \hat{c}_{f_1}$, the second period optimal consumption of empty calories is $\bar{c} - \hat{c}_{f_2}$ and the consumer reaches the indifference curve corresponding to the utility level

$$u_1(e(\bar{c} - \hat{c}_{f_1}), f(\hat{c}_{f_1})) + \delta u_1(H(\bar{c} - \hat{c}_{f_1}, \hat{c}_{f_1}, \bar{c} - \hat{c}_{f_2}, \hat{c}_{f_2}), e(\bar{c} - \hat{c}_{f_2}), f(\hat{c}_{f_2}))$$

In Figure 3.1, points F and G are examples of such an optimum. These points are the intersection between the minimum calorie intake constraint, and the corresponding isocost curves and the health isoquants. Furthermore, they are consistent with health maximization behaviour. Contingent on the minimum caloric-intake, F and G are the highest health outcomes feasible for the budget m_1 and prices $(p, 1)$ in the case of F, and prices $(p, 1/(1 + \mu))$ in the case of G.

3.2 The Nutritionist Standard and The Health Economist

Before analyzing the agent's optimal choices in the presence of a "fat" tax, additional insights can be gathered from two related problems. The first problem is that of an agent who maximizes health given the constraints imposed by the health technology, $H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2})$, and the minimum calorie intake, $\bar{c}$. Mnemonically, we refer to it as the nutritionist's standard. This is a technology driven problem, and its solution is independent of income and prices considerations. Thus, it will generate the highest level of health. In Figure 3.1, this corresponds to the point N.

The second problem is derived by adding the budget constraints, $ps_1 + t_1 \leq m$ and $ps_2 + t_2 \leq (1 + \beta(c_{e_1}))m$, to the nutritionist's problem. Mnemonically, we refer to it as the health economist's problem because this agent maximizes health conditional on the budget constraints, available health technology and the minimum calorie intake constraints. The difference between the optimal level of health of the nutritionist and that of the health economist is due to the income and prices pressure.

In short, the nutritionist's standard is:

$$\max \left\{ H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2}) \right\} \tag{8}$$

The nutritionist can always cover the minimum calorie intake requirement, because her decisions are not subject to budget constraints. Considering that health is decreasing in empty calories, the optimal level of c_{e_i} is zero. [6] Let the optimal health level of this problem be h^*, then h^* is the highest level of health feasible given the technology $H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2})$. Denote by $*$ the inputs associated with h^*. The minimum budget required to reach the health level $h^\star$ is $m^\star$ and $pf(c^*_{f_i}) = m^*$.

For budgets $m > m^*$, the health level decreases independent of the type of calo-

[6] According to the Dietary Guidelines released jointly by the U.S. Departments of Agriculture (USDA) and Health and Human Services (HHS), a healthy diet allows for a certain proportion of the total calories consumed to be discretionary calories. They provide energy but without nutrients, hence inducing a nonincreasing effect on health. Without lost of generality, in this analysis we assume that health is decreasing rather that nonincreasing in empty calories.

ries consumed (i.e., malnutrition due to overnutrition). The case where too many nutrients are consumed is consistent with a negative health marginal product of full calories c_{f_i} (i.e., the inverse "U" shape curve discuss by Bolin and Lindgren (2016)).

Next, consider the health economist's problem:

$$\max \Big\{ H(c_{e_1}, c_{f_1}, c_{e_2}, c_{f_2}) : pf(c_{f_1}) + e(c_{e_1}) \leq m,\ pf(c_{f_2}) + e(c_{e_2}) \\ \leq (1 + \beta(c_{e_1}))m, c_{f_i} + c_{e_i} \geq \bar{c}, i = 1, 2 \geq \bar{c} \Big\} \tag{9}$$

Problem (9) mirrors (8) with the addition of the budget constraints, where $m(1 + \beta(c_{e_1}) \leq m^*$, and the minimum calories intake constraints. For expositional convenience, we assume $\beta(c_{e_1}) = 0$. Later, this assumption will be relaxed. Depending on the income, the minimum caloric intake requirement could be binding. Hence, two cases emerge depending on whether this constraint is binding or not.

First, if $pf(\bar{c}) \geq m$, the health economist can cover the minimum caloric intake requirement exclusively from the consumption of full calories. The minimum caloric intake is not binding. Hence, $c_{e_i} = 0$, $i = 1, 2$, and the optimal health level is $H(0, c_{f_1}(m, p, 1, \bar{c}), 0, c_{f_2}(m, p, 1, \bar{c}))$. For $m < m^\star$, the optimal health level in (9) is lower than in (8), because the budget constraint forces the health economist to consume a lower amount of full calories than the nutritionist. For a visual representation, compare point B (i.e. health economist choice) with point N in Figure 3.1.

An observation is in order. For comparison purposes, $\beta(c_{e_1})$ was assumed to be 0. However, for $\beta(c_{e_1}) > 0$ (i.e., the productivity of empty calories in the first period is strictly positive), the health economist will find it optimal to consume a strictly positive amount of empty calories in the first period, if the loss in health is offset by the gain in health from consuming additional full calories c_{f_2} in the second period. The nutritionist, however, will always choose to consume only full calories because she does not face any budget constraints.

Second, if $pf(\bar{c}) < m$, the health economist can not cover the minimum calories intake requirement, $\bar{c}$, exclusively from the consumption of full calories, c_{f_2}. Thus, the amount of empty calories consumed will be strictly positive, $c_{e_2} > 0$. However, because health is decreasing in the consumption of c_{e_2}, the amount of empty calories consumed will be just enough to cover the minimum consumption level $\bar{c}$. Hence, the minimum caloric intake constraint will be binding $c_{e_2} + c_{f_2} = \bar{c}$. Furthermore, $\hat{c}_{f_2} < \bar{c}$ implies that $\hat{c}_{f_1} < \bar{c}$, thus $c_{e_1} > 0$ even if $\beta(c_{e_1}) = 0$, in which case $c_{e_1} + c_{f_1} = \bar{c}$. Visually, these choices are represented by points such as F and G in Figure 3.1.

Because the budget does not cover the minimum calorie intake requirement exclusively from the consumption of full calories, the amount of empty calories consumed is strictly positive. Furthermore, the health economist has no preference over the consumption of c_{e_2}, hence the additional consumption of empty calories is just enough to cover the minimum calorie intake requirement $\bar{c}$. In Figure 3.1, for the budget m_1 and prices $(p, 1)$, the health economist chooses the health level corresponding to point F. The consumer, however, can choose anything between C and F, the consumer's optimum health level being decided by the preferences over health and the consumption goods. Thus, the health economist's optimal health derived from problem (9) will serve as a higher bound for the health level derived by the consumer in (1).

3.3 Tax Effects on Health

Consider a tax $\mu > 0$ on the consumption of the nutrient deficient food products t (i.e., sugar tax, fat tax). The tax raises the price of t_i from 1 to $1 + \mu$, changing the relative prices of t_i and s_i. It is expected that the tax will induce the consumers to change the mix of calories in the favor of c_{f_i} increasing the health level.

However, this may not occur when the minimum calorie intake is binding. In this case, the optimal consumption of full calories in the first and second periods must satisfy the budget constraints $pf(c_{f_1}) + (1+\mu)e(\bar{c} - c_{f_1}) \leq m$ in the first period, and $pf(c_{f_2}) + (1+\mu)e(\bar{c} - c_{f_2}) \leq (1+\beta(c_{e_1}))m$ in the second period, respectively.

By the implicit function theorem, it follows that

$$\frac{\partial c_{f_i}}{\partial \mu} = \frac{e(\bar{c} - c_{f_i})}{(1+\mu)\partial e/\partial c_{e_i} - p\partial f/\partial c_{f_i}}, i = 1, 2 \tag{10}$$

Because $p\partial f/\partial c_{f_i} - (1+\mu)\partial e/\partial c_{e_i}$ equals the inverse of the shadow price of the budget constraint i, it follows that $\partial c_{f_i}/\partial \mu < 0$. Increasing the price of empty calories, by imposing a tax on t_i, will decrease health if the minimum calorie intake is binding. Visually, this is equivalent to moving from a health level F, in Figure 3.1, to a lower health level G. Clearly, a health conscious consumer will be made worse off by the tax. If $(1+\beta(m))m/p < \bar{c}$, then for any level of the tax $\partial c_{f_2}/\partial \mu < 0$.

4 Empirical Analysis

This section presents calibration results of the theoretical model based on data characterizing immigrant farmworkers in the US. While providing a vital service to the agriculture and food system in the U.S., immigrant farmworkers and their families are vulnerable to health issues resulting from food insecurity (Weigel et al., 2007; Kilanowski and Moore, 2010). Specific data used consists of farm workers income, daily wage, daily calories needs and optimal consumption of full calories.

According to the findings of the National Agricultural Workers Survey (NAWS), the average age of a farmworker is 38, and males comprised 72% of the hired crop labor force in 2013 – 2014.[7] Based on the Dietary Guidelines for Americans for 2015 – 2020, the estimated calorie needs per day for a physically active individual in the age group 36 – 40 are 2,800 for men and 2,200 for a women.[8][9] Thus, the

[7] https://www.doleta.gov/agworker/pdf/NAWS_Research_Report_12_Final_508_Compliant.pdf

[8] Active means a lifestyle that includes physical activity equivalent to walking more than 3 miles per day at 3 to 4 miles per hour, in addition to the activities of independent living.

[9] Jointly released by the U.S. Departments of Agriculture (USDA) and the U.S. Department of

weighted average calorie needs of a farmworker is $2,632$ calories. Borre, Ertle, and Graff (2010), surveying migrant and seasonal farmworkers families, find the median calorie intake of food insecure farmworkers is around $1,500$, which considering the level of physical activity is consistent to minimum intake required to sustain life.[10]

We use available data to characterize the optimal behaviour of a health economist agent facing budget and minimum calorie intake constraints. Health is assumed to be an increasing function of full calories consumption, with a maximum health reached at a consumption of $2,632$ full calories, and a minimum calorie intake of at least $1,500$ calories. Health is assumed to be decreasing in the consumption of empty calories.

Specifically health is assumed to follow the quadratic equation[11]

$$H(c_{f_1}, c_{e_1}, c_{f_2}, c_{f_2}) = -c_{f_1}^2 + 5,264c_{f_1} - c_{e_1} + \delta(-c_{f_2}^2 + 5,264c_{f_2} - c_{e_2}) \qquad (11)$$

where δ is a discount factor equal to 95%, which is consistent with discount rates used in other studies (Laibson, Repetto, and Tobacman, 2007) and $5,264$ is chosen to ensure that the production function of health reaches a maximum at a consumption of $2,632$ full calories. I assumed that the consumption of empty calories in the first period, c_{e_1}, increases the budget available in the second period by a factor β, where β is the marginal effect of consuming an empty calorie in the first period on the second period budget. For each c_{e_1} consumed, the second period budget increases by $\beta \times 0.00176$, where 0.00176 is the price of c_{e_i} (Monsivais and Drewnowski, 2007). This is consistent with a piece rate payment (i.e. payment is contingent on the

Health and Human Services (HHS), the Dietary Guidelines for Americans is designed as a resource for health professionals and policymakers. The calories needs are provided in Appendix 2 of the guidelines (https://health.gov/dietaryguidelines/2015/guidelines/appendix-2/#table-a2-1)

[10] A low-calorie diet requires a daily calorie intake between $1,200$ to $1,500$ calories for women, but no less than $1,000$, and $1,500$ to $1,800$ calories for men, but no less than $1,200$ (http://www.webmd.com/diet/low-caloriediet).

[11] The functional representation of the health technology was selected because of its tractability and simplicity.

quantity harvested) that characterized farm workers remuneration. In order to boost their productivity, and so increase their income, farm workers can consumed energy-dense, but nutrient poor, food products. For the analysis, different values for β are considered.

While health is positively correlated with the consumption of nutrient-dense foods (i.e., whole grains, lean meats, low fat dairy products, vegetables and fruits) and negatively correlated with the consumption of energy-dense, but nutrient poor foods (i.e., refined grains, sweets and fats), the energy cost of foods (i.e, the price of calories ($\$/kcal$)) increases with the nutritional content (Drewnowski, 2010). Furthermore, the energy-density of foods, measured as kilocalories per gram ($kcal/g$), is negatively correlated with the nutrient content and the energy cost (Monsivais, Mclain, and Drewnowski, 2010). Estimation based on retail food prices puts the energy cost of foods, in the lower quintile of energy density, at $\$1.8/100kcal$ compared to $\$0.17/100kcal$ in the top quintile (Monsivais and Drewnowski, 2007). Similarly, the average cost of foods in the top quintile of nutrient density is $\$2.7/100kcal$ compared to an average of $\$0.33/100kcal$ in the lower quintile (Monsivais, Mclain, and Drewnowski, 2010). Because these food prices correspond to bottom and top quintile of nutrient and energy densities foods, and to insure that farmworkers can purchase foods with a caloric content of $2,632$ full calories, the cost of healthy calories is decreased by 30%.

According to the Farm Labor Survey of the National Agricultural Statistics Service, the wage for a non-supervisory farm laborer was \$10.80 per hour in 2012, and according to the Bureau of Labor Statistics the average annual wage for agricultural workers is $\$25,650$. Based on the The National Agricultural Workers Survey, the average daily number of hours worked by migrant farm workers is 8 hours. While farm workers shifts may be longer than 8 hours, the 8-hour figure is reasonable if we think in terms of total number of hours worked per year divided by the total number of days available in a year.

I use available data to calibrate the optimal consumption of calories by a consumer with Cobb-Douglas utility facing budget and minimum caloric intake constraints. Specifically, the consumer maximizes:

$$Ac_{f_1}^{\alpha}c_{e_1}^{1-\alpha} - c_{f_1}^2 + 5,264c_{f_1} - c_{e_1} + \delta(Ac_{f_2}^{\alpha}c_{e_1}^{1-\alpha} - c_{f_2}^2 + 5,264c_{f_2} - c_{e_2}) \tag{12}$$

where $A = 100$ to allow utility values to be comparable with health values (i.e. health reaches a maximum at a consumption of $2,632$ full calories). The parameter α takes three distinct values (i.e. 0.5, 0.1 and 0.9), in order to allow for variation in taste over consumption of full and empty calories. A higher value of α suggests a higher taste preference for the consumption of full calories, and a lower preference for the consumption of empty calories.

Table 1 provides estimates of the optimal consumption of calories for the health economist agent and the consumer under different scenarios. First, β is assumed to take four distinct values: 0, 0.5, 1, and 1.5. A value $\beta = 0$ means the consumption of empty calories in the first period has no effect on the second period budget. Anecdotal evidence suggests farmworkers, especially illegal immigrants who are socially more vulnerable, spend most of their resources on rent, off-season savings and to support their families back home. Thus, I assumed that farmworkers spend between 10% and 40% of their daily income on food purchases. Based on data available, this is equivalent to an expenditure in the range of \$8.64 to \$34.56 per day. This is consistent with Borre, Ertle, and Graff (2010), who find that the minimum daily grocery spending per person by the food insecure families is \$9.52 while the maximum spending by migrant farmworks is \$22.86.

Calibration results suggest that health is not decreasing in β for the health economist. As long as the minimum caloric intake constraint is binding, the health level is increasing. The necessary consumption of empty calories in the first period relaxes the budget constraint in the second period allowing a higher consumption of full calories. This holds independent of the value of β.

For sufficiently large values of β, the health economist will consume additional empty calories in the first period, reducing first period health, in order to increase the second period consumption of full calories, and overall health. This is the case for $\beta = 1.5$, when the consumption of empty calories increases from 0 to 570 in the case of a 30% food expenditure allocation. For the 40% food expenditure, the health economist already reaches the maximum health, thus β has no effect on empty calories consumption.

For lower values of β (i.e. 0 and 0.5) and income allocation (i.e., 10% and 20%), consumer's health choices coincide with those of the health economist independent of the taste (i.e., value of α). Nonetheless, it suggests that information campaigns, tailored at decreasing the weight consumers place on the utility derived from consumption of foods versus the effect on health, could have beneficial results. Outside these values, for a fixed level of β and income allocation, consumer's health is increasing in α (i.e., the taste preference for the consumption of full calories, $c_{f_i}, i = 1, 2$).

For a fixed level of income and taste, the consumption of both type of calories increases in β, but the consumption of empty calories increases at higher rate than the consumption of full calories. For example, for income allocation of 30% and $\alpha = 0.5$, consumption of empty calories increases by 44% for a change in β from 1 to 1.5, while the full calories consumption increases only by 2%.

Finally, keeping constant both β and α, the consumption of full calories increases at a decreasing rate in income, while the consumption of empty calories initially decreases, but afterwards increases at an increasing rate in income. For example, for $\beta = 1$ and $\alpha = 0.5$, the consumption of full calories in the first period increases from 499, for a 10% budget allocation, to $1,262$, for 20% budget allocation, to $1,912$, for a 30% budget allocation, to finally $2,358$ calories, for a 40% budget allocation. While, empty calories consumption in the first period decreases from $1,308$ to 714 between a 10% and 20% budget allocation, to increase afterwards to 913 and $2,616$ in the case of a 30% and 40% budget allocations. This provides some evidence that budget relaxing policies (i.e., food stamps) might have an effect only on the very poor consumers.

Table 2 provides estimates of the tax effect on the optimal consumption of full and empty calories for the health economist and the consumer under four different tax regimes (i.e. 0%, 5%, 10%, and 15%), and $\beta = 0$. Previous studies have employed tax regimes of 10% (Fletcher, Frisvold, and Tefft, 2010; Wang, 2015), while lower tax regimes were reported in other studies (Jacobson and Brownell, 2000; Schroeter, Lusk, and Tyner, 2008).

As long as the minimum calorie intake is binding, the tax raises the consumption of empty calories and decreases the consumption of full calories. This result provides evidence that changing the relative prices of full and empty calories is not sufficient to increase the consumption of full calories. Furthermore, this result holds independent of the taste preferences, since even the health economist responds to the tax regimes by increasing the consumption of empty calories, despite a decrease in health.

Alternatively, for the case where the minimum caloric intake is not binding, taxes decrease the consumption of empty calories, but they have a small effect on the consumption of full calories. Part of the reason is the big gap between the price of full calories and the price of empty calories.

5 Conclusion

This paper provides an alternative explanation to the observed trend of unhealthy food consumption. To accomplish this a theoretical model of unhealthy food consumption is provided, where the consumer maximizes utility over health and consumption of food over two periods. The consumer faces a minimum caloric intake constraint and benefits from a productivity boost derived from the consumption of unhealthy foods. If the minimum caloric intake is binding, a tax on the unhealthy food will have the opposite effect of decreasing the consumption of healthy foods and increasing the consumption of unhealthy foods. Another contribution of the paper is to allow the productivity boost (i.e. β) to be a function of empty calories, as compared to full calories which was the norm in previous studies. Potential extensions of the model could allow β to be a function of both empty and full calories.

The theoretical model predictions are calibrated with data on food consumption patterns of immigrant farmworkers in the U.S. In terms of robustness, the calibration's results can be improved by testing alternative functional forms for the health technology and the consumer's utility. For example, the currently Cobb-Douglas utility function can be replaced by a more general constant elasticity of substitution utility. Also as mentioned above, the theoretical predictions can be expanded by allowing β to be a function of both type of calories. Future directions of research could also explore in detail the effect of information and subsidy on the optimal consumption of calories considering the above constraints imposed by minimum calorie requirement and intertemporal productivity.

Table 1: Full and Empty Calories Consumption for a Health Economist Agent and Consumer with Cobb-Douglas Utility

	Health Economist				Consumer ($\alpha = 0.5$)[3]				Consumer ($\alpha = 0.1$)				Consumer ($\alpha = 0.9$)			
Income (%)[1]	10%	20%	30%	40%	10%	20%	30%	40%	10%	20%	30%	40%	10%	20%	30%	40%
Income ($)[2]	8.64	17.28	25.92	34.56	8.64	17.28	25.92	34.56	8.64	17.28	25.92	34.56	8.64	17.28	25.92	34.56
$\beta = 0$ [4]																
c_{f_1}	548	1338	2,041	2,632	548	1338	2,017	2,454	548	1,338	2,040	2,324	548	1,338	2,029	2,588
c_{e_1}	952	162	0	0	952	162	168	1,925	952	162	5	2,867	952	162	83	958
c_{f_2}	548	1338	2,041	2,632	548	1338	2,017	2,454	548	1,338	2,040	2,324	548	1,338	2,029	2,588
c_{e_2}	952	162	0	0	952	162	168	1,925	952	162	5	2,867	952	162	83	958
$\beta = 0.5$																
c_{f_1}	548	1,338	2,041	2632	548	1338	1,980	2,398	548	1,338	1,986	2,194	548	1,338	2,019	2,569
c_{e_1}	952	162	0	0	952	162	436	2,329	952	162	392	3,802	952	162	159	1,093
c_{f_2}	625	1,351	2,041	2632	625	1351	2,045	2,492	625	1,351	2,067	2,342	625	1,351	2,040	2,612
c_{e_2}	875	149	0	0	875	149	186	2,813	875	149	8	4,638	875	149	85	1,335
$\beta = 1$																
c_{f_1}	530	1,294	2,041	2,632	499	1,262	1,912	2,358	434	1,221	1,878	2,074	524	1,290	1,981	2,560
c_{e_1}	1,086	482	0	0	1,308	714	930	2,616	1,776	1,007	1,171	4,666	1,130	506	428	1,163
c_{f_2}	723	1,416	2,041	2,632	759	1,453	2,133	2,525	834	1,500	2,190	2,359	730	1,419	2,087	2,629
c_{e_2}	777	84	0	0	741	47	265	4,033	667	0	92	7,276	770	81	95	1,827
$\beta = 1.5$																
c_{f_1}	296	1,189	1,962	2,632	314	1,144	1,865	2,329	264	1,094	1,806	1,962	300	1,177	1,927	2,555
c_{e_1}	2,775	1,235	570	0	2,646	1,565	1,265	2,827	3,005	1,922	1,692	5,476	2,744	1,324	821	1,199
c_{f_2}	1,218	1,617	2,159	2,632	1,187	1,677	2,242	2,549	1,273	1,760	2,278	2,376	1,211	1,630	2,194	2,641
c_{e_2}	282	0	0	0	313	59	445	5,479	227	0	824	10,705	290	39	125	2,379

[1] Percentage of the daily income spent on food purchases. [2] Daily dollar amount spent on food purchases.
[3] α is utility power associated with the consumption of full calorie $c_{f_i}, i = 1, 2$.
[4] β is the marginal effect of consuming an empty calorie in the first period on the second period budget. For each c_{e_1} consumed the second period budget increases by $\beta \times 0.00176$, where 0.00176 is the price of c_{e_1}.

Table 2: Full and Empty Calories Consumption for a Health Economist Agent and Consumer with Cobb-Douglas Utility under Empty Calories Taxation

	Health Economist				Consumer ($\alpha = 0.5$)[3]				Consumer ($\alpha = 0.1$)				Consumer ($\alpha = 0.9$)			
Income (%)[1]	10%	20%	30%	40%	10%	20%	30%	40%	10%	20%	30%	40%	10%	20%	30%	40%
Income ($)[2]	8.64	17.28	25.92	34.56	8.64	17.28	25.92	34.56	8.64	17.28	25.92	34.56	8.64	17.28	25.92	34.56
Tax = 0%																
c_{f_1}	548	1338	2,041	2,632	548	1338	2,017	2,454	548	1,338	2,040	2,324	548	1,338	2,029	2,588
c_{e_1}	952	162	0	0	952	162	168	1,925	952	162	5	2,867	952	162	83	958
c_{f_2}	548	1338	2,041	2,632	548	1338	2,017	2,454	548	1,338	2,040	2,324	548	1,338	2,029	2,588
c_{e_2}	952	162	0	0	952	162	168	1,925	952	162	5	2,867	952	162	83	958
Tax = 5%																
c_{f_1}	541	1,337	2,041	2,632	541	1,337	2,018	2,457	541	1,337	2,040	2,336	541	1,337	2,029	2588.1
c_{e_1}	959	163	0	0	959	163	153	1,814	959	163	3	2,648	959	163	79	912.2
c_{f_2}	541	1,337	2,041	2,632	541	1,337	2,018	2,457	541	1,337	2,040	2,336	541	1,337	2,029	2588.1
c_{e_2}	959	163	0	0	959	163	153	1,814	959	163	3	2,648	959	163	79	912.2
Tax = 10%																
c_{f_1}	533	1,335	2,041	2,632	533	1,335	2,019	2,460	533	1,335	2,040	2,347	533	1,335	2,029	2,588
c_{e_1}	967	165	0	0	967	165	140	1,714	967	165	2	2,456	967	165	75	871
c_{f_2}	533	1,335	2,041	2,632	533	1,335	2,019	2,460	533	1,335	2,040	2,347	533	1,335	2,029	2,588
c_{e_2}	967	165	0	0	967	165	140	1,714	967	165	2	2,456	967	165	75	871
Tax = 15%																
c_{f_1}	525	1334	2,041	2,632	525	1,334	2,020	2,462	525	1,334	2,040	2,357	525	1,334	2,029	2,588
c_{e_1}	975	166	0	0	975	166	129	1,623	975	166	1	2,285	975	166	71	832
c_{f_2}	525	1334	2,041	2,632	525	1,334	2,020	2,462	525	1,334	2,040	2,357	525	1,334	2,029	2,588
c_{e_2}	975	166	0	0	975	166	129	1,623	975	166	1	2,285	975	166	71	832

[1] Percentage of the daily income spent on food purchases. [2] Daily dollar amount spent on food purchases.
[3] α is utility power associated with the consumption of full calorie $c_{f_i}, i = 1, 2$.

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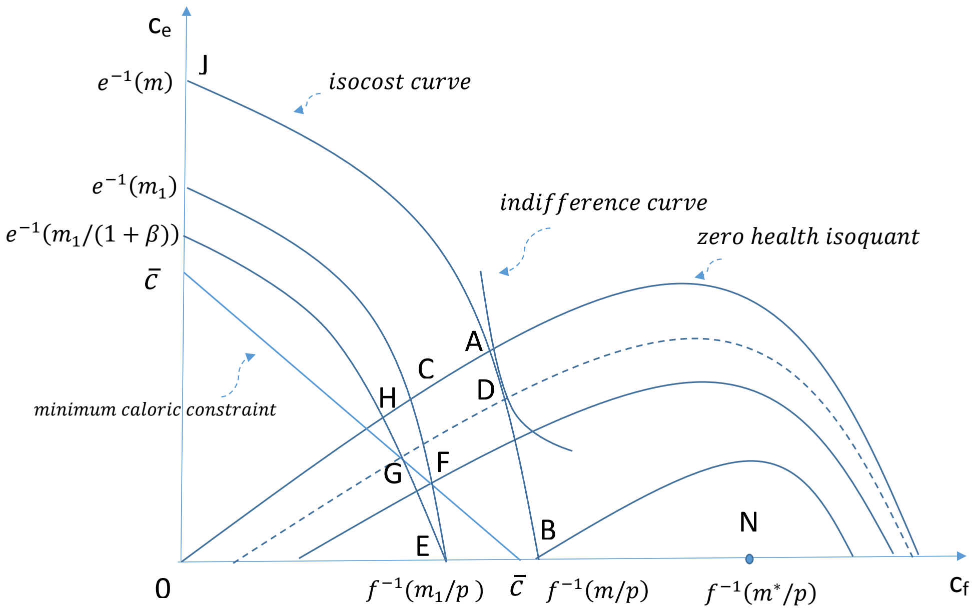

Figure 1: Health Choices