Addiction and Health: How Consumer Goods become Bads?

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Abstract

The purpose of this paper is to discuss addiction from the perspective of relationships between health and addictive behavior, by focusing on delayed symptoms (health effects). Some consumer goods are not simply "good," but have an aspect of "bad," which might cause damage to health a while after consumption. Our study deals with goods which turn into "bads" after a while. In this paper, we first assume that addictive goods can either be good or bad, depending on each individual's situation. Our results indicate that the intake of addictive goods will increase over time. They also imply that individuals who are cautious about the future are less prone to addiction problems, while short-sighted individuals are more likely to suffer from a serious addiction.

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1 Introduction

There are goods in the world that simply cannot be viewed as "good." Some goods have a "bad" aspect, which gives them positive utility in the short term, but negative utility in the long term, or through excessive consumption. For example, excessive carbohydrate intake increases the risk of diseases such as diabetes and obesity. On the other hand, alcohol can cause damage to the body and increase the risk of addiction. Both are "goods" that provide positive benefits immediately after consumption, but then become "bads" that provide negative benefits. In this paper, we focus on the latter, goods called "addictive goods," which cause addiction, and examine their consumption trends.

Addiction is a complex condition in which people cannot control the overuse of a substance despite suffering negative outcomes from the addiction. In other words, it is a state in which a person gains utility immediately after consuming a good, but cannot stop using that good despite the short- or long-term disutility that outweighs the utility. This means that addictive goods contain both properties, "goods" increase utility and the "bads" properties decrease utility. Furthermore, when an individual gets an addiction, the intake of certain goods increases day by day. In summary, addiction is a state in which the consumption of a good gradually increases despite future disutility. It is commonly associated with usage of drugs, drinking alcohol, smoking, and gambling; but several behaviors such as excessive use of digital media including smartphone use and compulsive shopping, are also categorized as an addiction. Addiction has a significant impact not only on the addicted individual but also on society (Krauth et al., 2002, Sut et al., 2016, Tannous et al., 2021).

There have been several economic models on addictive goods, as shown in Section 2. In its early stage (around 1980), addiction study focused on illegal drug use, mainly because it was a social problem they were trying to prevent during that period. The purpose of researchers was to stop the usage of these drugs. This is because, by implication, addictive goods were considered to be bads. Still, people dare to consume such bads, mainly because they provide positive utility in the short run.

Some goods which have been traditionally treated as general consumer goods, have been recently discovered as addictive goods. For example, smartphones have become an essential part of human life, but the excessive use of a smartphone can cause addiction. Another example includes Over-the-counter (OTC) drugs which are considered to be safe as long as the intake follows the dosage instruction on the label. However, when a large amount of drugs is ingested, it can lead to addiction. The object of our study contains the variety of addictive goods. These addictive goods might be safe if they are properly used.

In this study, we consider the characteristics of addiction from a health perspective. As mentioned earlier, addictive goods include not only highly toxic substances, such as drugs, alcohol, or tobacco, but any goods can cause addiction. If the addictive goods are highly toxic, the individual's health may be restored if they stop them. Some addictive goods are essential only if they are consumed in a moderate amount. For example, if an individual has headache, avoiding all headache-relieving medicine is not the best option. It is not plausible for an individual with bulimia to stop eating completely.[*1] addictive goods are not bads. Regardless of their toxicity, if used in appropriate amounts that are not detrimental to health, addictive goods can be harmless. However, if used in excess, addictive goods can be harmful to health and become bads. We clarify the extent to which addictive goods can be considered as goods and bads.

How does an addictive good differ from general consumer goods? When an individual consume an addictive good, it is followed by a pleasant feeling. Because general consumer goods yield positive utility, it is the same in this point. However, after a while, different negative effects such damage to the health or anxious depression attacks are observed. They are called as withdrawal symptoms. If the addicted individuals do not consume more of the addictive good, the symptoms will gradually digress. To get rid of the negative effects some patients take more doses of the addictive substance, and get caught in a negative spiral.

[*1] For clarity, an individual with bulimia is addicted to regurgitating their food and not consuming it.

In this paper, we draw conclusions about addiction under simple assumptions only. We do not distinguish between physical and mental health. We assume: (1) the consumption of an addictive good will yield better health in the immediate or first period; however, (2) it will damage health in the second period; and then; (3) the individual will recover from the damage gradually. When there is no damage, the good is considered as general consumer goods. In the consumption of general consumer goods, as opposed to addictive goods better health can be observed in the first period. No damage is observed in the second period. And the effect of the good disappears in the next period.

Our main result suggests that the amount of intake of addictive goods intake will increase over time, under the assumption of a convex damage function. This shows the two key factors involved in an addiction problem include: how much damage they cause and how fast the damage diminishes. This result occurs regardless of individual characteristics. In a sense, this result indicates that people tend to consume all goods addictively. However, from a health perspective, we also show that there are individuals who suffer from serious addiction and individuals who are not easily prone to addictive goods. The key to this is the individual's subjective discount rate.

Our model also explains the difference between general consumer goods and addictive goods, by defining the toxicity of the good as a property of the addictive good. It provides an insight into the diminishing nature of consumption of non-toxic goods and the increasing nature of addictive goods. addictive goods are "goods" for farsighted people, while they could be "bads" for short-sighted people.

2 Literature Review

As discussed in the previous section, the study of addiction is important. Addiction was not regarded as an economic problem until Becker and Murphy (1988), instead it was studied under psychology. This is because it has been considered that individuals who are prone to addictions are irrational or short-sighted.

Becker and Murphy (1988) promoted the idea of the rational addiction. It hypothesized that every individual who considers their future rationally, analyzes addiction patterns. In their paper, they discovered the following stylized facts about addiction: the more the addictive good is used, the higher is the tolerance against it; the closer an individual is to addictive good, the more they consume. The important assumptions of their model include tolerance and reinforcement. Reinforcement suggests that if an individual consumes addictive goods, the more their consumption of that good increases. Tolerance denotes the current consumption must be greater than the past consumption. Their model consists of two steady states. In the first state, the possibility of an individual consuming addictive goods is infinitely high. In the second or stable stage, the individual will consume the good in moderate quantity.

In contrast to Becker and Murphy, Ainslie (1992) adopted the short-sighted hypothesis. They criticized the rational addiction model, suggesting that the main cause of addiction is the disregard for future. Ainslie suggests that people who consume addictive goods think about the present only, and consume a lot in the present.

Frank (1996) also attempted to model the inner conflicts of addicted individuals, based on the internal game framework. The main conflict is that the addicted individual wants to stop using the addictive goods and get rid of the addiction, but they can not do so. In Frank's model, two selves exist within the inner world of an individual, playing a game of whether or not to consume an addictive good. Consequently, individuals who consume the addictive goods, will eventually suffer from the addiction, regardless of the gain or discount.

Other similar models incorporate various addictive goods of different nature into the model (Dockner and Feichtinger, 1993). Some models also examine different types of individuals, such as dependent and non-dependent individuals, but they fail to explain the reasons as to why an addiction occurs. In addition, none of the models clearly explain why consumption of addictive goods has increased. In other words, to explain the occurrence of withdrawal symptoms in relation to consumption at a previous point in time, we have to assume a complementary relationship exists between the past and the present. However, it does not provide a fundamental explanation.

Becker and Murphy state that any good can be considered as an addictive good. However, in their model, as well as in other extended models, certain goods are considered to be addictive to a greatersome extent, goods such as alcohol, cocaine, and other highly addictive goods. Auld and Grootendorst (2004) showed that any goods can cause addiction. Previous models cannot explain addiction to different goods using the same framework.

The reason behind addiction is a concern, the addiction itself is the problem because it has a negative impact on health. As mentioned previously, the health hazards of addictions hugely impact society.

Therefore, we will examine addiction using a health investment model, in the next section. This could also help us to examine the reasons for the occurrence of addiction.

3 The Model

In this section, we will set up a model to explain addictive behavior. In addition, we will confirm the model's results by numerical examples. Finally, we will discuss some implications given by the model's results.

We compare an addictive good with a general consumer goods. We consider an individual who lives for finite T periods from when they consumed an addictive good and a general consumer good. In each period t $(t = 1, 2, \cdots, T)$, the individual consumes an addictive good $a_t \geq 0$ and a general consumer good $c_t \geq 0$. The addictive good consumed by the individual until period t, affects the health H_t. In this paper, we assume that health indicates both physical and mental health, and $H_t = 0$ means they are dead. Their utility function u remains constant, depending only on the health H_t at time t. We assume that the utility function is strictly increasing, differentiable, and concave.[*2] Furthermore, the dead individual will have zero utility, or $u(0) = 0$. Their lifetime utility is shown as

$$U = \sum_{t=1}^{T} \delta^{t-1} u(H_t\langle \boldsymbol{a}, \boldsymbol{c}\rangle), \tag{1}$$

where $\delta \in (0, 1)$ is the subjective discount factor $\boldsymbol{a}$ is the vector of addictive goods at whole period $t = 1, 2, ..., T$, that is, $\boldsymbol{a} = (a_1, ..., a_T)$, and $\boldsymbol{c}$ is the vector of general consumer goods at whole period $t = 1, 2, ..., T$, that is, $\boldsymbol{c} = (c_1, ..., c_T)$.

We assume that the individual devotes their resources to consuming only addictive goods and general consumer goods. In other words, they do not invest or save, in any form. Thus, the individual's budget constraint is

$$\sum_{t=1}^{T} (pa_t + c_t) \leq W_0, \tag{2}$$

where p indicates the relative price of addictive goods, which is constant. W_0 indicates the initial wealth of an individual and it stays constant for all individuals. Here, the price of general consumer goods is normalized as price 1. For simplicity, we do not consider the additional income from labor, health status, and so on.

We describe the influence of the addictive good in the following manner. Assume that the individual consumes an addictive good $a_1 \geq 0$ and a general consumer good $c_1 \geq 0$ at period 1, but does not consume any more goods in and onwards the second period. The consumption vector is $\boldsymbol{a}^{(1)} = (a_1, 0, \cdots, 0)$ and $\boldsymbol{c}^{(1)} = (c_1, 0, \cdots, 0)$. Whether they consume an addictive good or consumer good, the individual will enjoy the benefit through mental satisfaction; in medical and psychological terms, the reward system in the brain is activated, raising the levels of dopamine. In economics terms, it improves the good's utility. In our model, we assume that utility is derived from the individual's

[*2] In this paper, we assume that the utility function is concave, but our results hold for some non-decreasing functions.

health, which might be affected by the consumption of an addictive good or a general consumer good. Their health, immediately after the consumption, is defined as

$$H_1 = H_0 + a_1 + c_1, \tag{3}$$

where H_0 indicates the initial health of the individual. The damage from addictive goods attacks become observable in second period. To represent this, we define a damage function, $d(\cdot)$, as the function dependent on the amount of addictive goods ingested in the previous period The damage function $d(\cdot)$ is assumed to be increasing, convex and $d(0) = 0$. In other words, the marginal damage is increasing. We express the value of the damage caused by an addictive good in period t, as

$$\gamma d(a_t).$$

The constant value γ shows the addictive good's level of toxicity. When γ is zero, the effect is the same as consuming a general consumer good. Thus, we can define c_t as the harmless goods, resulting in no damage. There positive effects disappear in the next period. Thus, we assume γ is positive for any addictive goods. In this paper, we assume health after taking addictive goods and general consumer goods. Health depends on $d(\cdot)$, γ, and the consumption sequence of the addictive goods and general consumer goods.[*3]

In the second period, we assume that the individual suffers the damage without experiencing any satisfaction, that is,

$$H_2\langle \boldsymbol{a}^{(1)}, \boldsymbol{c}^{(1)}\rangle = H_0 - \gamma d(a_1).$$

Note that the effect of the general consumer good no longer remains because the general consumer good is defined as zero-toxicity good.

From the third period, recovery called "self-healing" begins. We assume that the recovery is subject to exponential decay. For simplicity, we assume that the rate of recovery is halved for every successive period. Thus, the health in the third period and onwards, will be

$$\begin{aligned}
H_3\langle \boldsymbol{a}^{(1)}, \boldsymbol{c}^{(1)}\rangle =& H_2\langle \boldsymbol{a}^{(1)}\rangle + \frac{\gamma d(a_1)}{2} = H_0 - \frac{\gamma d(a_1)}{2}, \\
H_4\langle \boldsymbol{a}^{(1)}, \boldsymbol{c}^{(1)}\rangle =& H_3\langle \boldsymbol{a}^{(1)}\rangle + \frac{\gamma d(a_1)}{2^2} = H_0 - \frac{\gamma d(a_1)}{4}, \\
&\vdots \\
H_k\langle \boldsymbol{a}^{(1)}, \boldsymbol{c}^{(1)}\rangle =& H_{k-1}\langle \boldsymbol{a}^{(1)}\rangle + \frac{\gamma d(a_1)}{2^{k-2}} = H_0 - \frac{\gamma d(a_1)}{2^{k-2}}.
\end{aligned} \tag{4}$$

Once the health $H_k\langle \boldsymbol{a}^{(1)}, \boldsymbol{c}^{(1)}\rangle$ decreases to zero or below for some k, we assume that the individual is dead.

Likewise, if an individual consumes the addictive good a_t and the general consumer good c_t at period $t = 2, 3, \cdots, T$ only, the consumption vectors' t-th element are $a_t, c_t \geq 0$ and the others are 0, that is, the vectors are $\boldsymbol{a}^{(t)} = (0, \cdots, a_t, \cdots, 0)$ and $\boldsymbol{c}^{(t)} = (0, \cdots, c_t, \cdots, 0)$. The transition of the health will be

$$H_k\langle \boldsymbol{a}^{(t)}, \boldsymbol{c}^{(1)}\rangle = \begin{cases} 0, & \text{(for } k < t) \\ H_0 + a_t + c_t, & \text{(for } k = t) \\ H_0 - \frac{1}{2^{k-t-1}}\gamma d(a_t). & \text{(for } k > t) \end{cases}$$

[*3] Several studies on addiction have pointed out that the worse the mental state, the stronger are the symptoms (Goeders, 2002, Ruisoto and Contador, 2019). In this paper, we assume that health does not depend on the initial mental state.

If the individual consumes the addictive good in every period, the consumption vector is written as $\boldsymbol{a} = (a_1, a_2, \cdots, a_T)$. We assume that the health function is additive. Therefore, the health transition is written as

$$H_k\langle \boldsymbol{a}, \boldsymbol{c}\rangle = \sum_{t=1}^{T} H_k\langle \boldsymbol{a}, \boldsymbol{c}\rangle.$$

Specifically, it is expressed as follows:

$$H_k = H_0 + a_k + c_t - \gamma \sum_{t=2}^{k} d(a_{t-1}) \frac{1}{2^{k-t}}. \tag{5}$$

If an individual quit to consume the addictive goods in period k ($k = 2, 3, \cdots, T$), a_k, in Equation (5), becomes zero. In this case, if it holds that $pa_k = W_0 - \sum_{t=1}^{k-1}(pa_t + c_t),\ k \neq T$, then the individual will die in the next period, due to the damage caused by addictive goods. When a_k becomes zero at $k = 1$, it is optimal for the individual to quit the consumption of the addictive goods.

3.1 The Optimization

Using Using Equations (1), (2), and (5), we represent the individual's optimization problem:

$$\begin{aligned}
\max_{\{a_t\}_{t=1}^T, \{c_t\}_{t=1}^T} \quad & U = \sum_{t=1}^{T} \delta^{t-1} u(H_t(a_1, a_2, ..., a_t, c_1, c_2, ..., c_t)) \\
\textit{subject to} \quad & \sum_{t=1}^{T} (pa_t + c_t) \leq W_0; \\
& H_t = H_0 + a_t + c_t - \sum_{t=2}^{k} \frac{1}{2^{k-(t-1)}} \gamma d(a_{t-1}).
\end{aligned}$$

Note that in the first equation, the control variable is a_t. An individual cannot control their health.

In this case, a rational individual will consider the consumption plan of the addictive goods and the state of health. Hence, by determining the optimal quantity of each addictive good in the final period, T, we can also determine the optimal consumption quantity of addictive goods in other periods, less than the Tth period. Here, Equation (5) satisfies Karush-Kuhn-Tucker condition. We can then solve the maximization problem by the Lagrangian. Thus, substituting Equation (5) into Equation (1), we express the Lagrangian as:

$$\mathscr{L} = \sum_{t=1}^{T} \delta^{t-1} u(H_t(a_1 ..., a_t, c_1, ..., c_t)) + \lambda[W_0 - \sum_{t=1}^{T}(pa_t + c_t)]$$

Differentiating $\mathscr{L}$ with respect to a_k, c_t, and λ, we get

$$\frac{\partial U}{\partial a_k} = \delta^{k-1} u'_{a_k}(H_k) - d'(a_k) \left(\gamma \sum_{t=1}^{T-k} \delta^{t+(k-1)} u'_{a_k}(H_{t+k}) \frac{1}{2^{t-1}} \right) - p\lambda = 0 \tag{6}$$

$$\frac{\partial U}{\partial c_k} = \delta^{k-1} u'_{c_k}(H_k) - \lambda = 0 \tag{7}$$

$$\frac{\partial U}{\partial \lambda} = W_0 - \sum_{t=1}^{T}(pa_k + c_k) = 0. \tag{8}$$

Substituting Equation (7) into Equation (6), we get

$$p\delta^{k-1}u'_{c_k}(H_k) = \delta^{k-1}u'_{a_k}(H_k) - d'(a_k)\left(\gamma\sum_{t=1}^{T-k}\delta^{t+(k-1)}u'_{a_k}(H_{t+k})\frac{1}{2^{t-1}}\right) \tag{9}$$

$$\Leftrightarrow d'(a_k) = \delta^{k-1}\left[u'_{a_k}(H_k) - pu'_{c_k}(H_k)\right]\left(\gamma\sum_{t=1}^{T-k}\delta^{t+(k-1)}u'_{a_k}(H_{t+k})\frac{1}{2^{t-1}}\right)^{-1} \tag{10}$$

$$\Leftrightarrow a_k = d'^{-1}\left(\delta^{k-1}\left[u'_{a_k}(H_k) - pu'_{c_k}(H_k)\right]\left(\gamma\sum_{t=1}^{T-k}\delta^{t+(k-1)}u'_{a_k}(H_{t+k})\frac{1}{2^{t-1}}\right)^{-1}\right). \tag{11}$$

Because of the continuity in the objective function and compactness of the budget constraint, the optimal value of addictive goods, a_t^*, can be obtained. Moreover, we obtain the consumption stream of the optimal addictive goods for period 1 to T as below:

$$\boldsymbol{a}^* = (a_1^*, ..., a_T^*). \tag{12}$$

Thus, from Equations (11) and (12), we obtain the following proposition:

Proposition 1. *If utility function is concave, damage function, $d(\cdot)$, is convex. If $\gamma > 0$ holds, then the following inequalities hold at period 1 to T:*

$$0 < a_1^* < a_2^* < \cdots < a_T^*. \tag{13}$$

Proof. See Appendix. □

Proposition 1 states that the rational individual consumes addictive goods from 1 to Tth periods continuously, and the quantity of consumption is non-zero. Moreover, the quantity of consumption increases through the periods. Therefore, it can be assumed that, the individual considers their lifetime health and consumes less addictive goods, at first.

Furthermore, Proposition 1 shows the important interpretation. This result supports the tolerance and reinforcement assumptions put forth by Becker and Murphy. We derived this result directly, by assuming the damage function as convex. This result also arises from the fact that while consuming addictive goods, individuals also consider their possible future damage. In this sense, our model provides a clear representation of the rationality of individuals consuming addictive goods. It is important that the consumption of the addictive goods should not reach zero. This means that the consumption of the addictive goods is acceptable, only if they are consumed in optimal quantities. The larger is the toxicity of an addictive good, γ, the smaller is its optimal consumption quantity. However, if γ is sufficiently small, the optimal consumption of the addictive good can be similar to the consumption of a normal consumer good, and the optimal consumption is also large. Conversely, consuming more than the optimal consumption will cause addiction, regardless of the size of γ. This implies that any goods can be considered as addictive goods.

However, from Equation (11), if the indirect effect on the utility obtained from the general consumer good is sufficiently large, the consumption of the addictive good is zero. In this case, the one-period impact of general consumer goods on health is sufficiently larger than the long-term impact of addictive goods consumption on health. Thus, the non-toxic goods become more attractive than addictive goods. Moreover, if the price of the addictive good is sufficiently large, then the consumption of the addictive good is zero.

On the other hand, we obtain the following consumption stream for general consumer goods:

$$\boldsymbol{c}^* = (c_1^*, ..., c_T^*). \tag{14}$$

This can be derived by Equation (12) and the budget constraint. The property of this consumption stream of general consumer goods is given by the following Equations (9), (13), and (14):

Proposition 2. *Suppose that utility function is concave, damage function, $d(\cdot)$, is convex, and it holds that $\gamma > 0$. If there exists $\boldsymbol{a}^* = (a_1^*, ..., a_T^*)$ and this satisfies that $0 < a_1^* < a_2^* < \cdots < a_T^*$, then the following inequalities hold for periods 1 to T:*

$$c_1^* > c_2^* > \cdots > c_T^* > 0. \tag{15}$$

This proposition states that the optimal consumption of general consumer goods decreases with each period. This contradicts the consumption stream of addictive goods. General consumer goods cause no damage in the next period because they have zero toxicity. However, instead of causing damage, they have a one-period impact on health and utility. On the other hand, addictive goods cause damage in the next period because they are toxic. However, from the next period, they have a positive effect on health and utility, as the self-healing restores the damage. Thus, individuals try to increase their lifetime utility by diverting the consumption of general consumer goods to the consumption of addictive goods. As mentioned in the explanation of Proposition 1, individuals must increase their consumption to account for the damage caused by addictive goods. Alternatively, they decrease their consumption of general consumer goods. Hence, Propositions 1 and 2 show the substitution relationship between addictive goods and general consumer goods.

Regarding the quantity of consumption of addictive goods, even in the case of the optimal quantity of consumption, we obtain the following proposition:

Proposition 3. *If the subjective discount factor of an individual, δ, is within the open interval 0 to 1, then the smaller δ indicates higher consumption of the addictive good in each period, compared to the larger δ.*

Proof. See Appendix. □

We can interpret the person who has the larger δ as the tolerant person, and the person who has the smaller δ as the intolerant person. Note that the intolerant person can consider their future, but they do not attach importance to their future. This means that the intolerant person understates the damage they may have to suffer in the future. Higher consumption of addictive goods leads to a higher amount of damage resulting from the consumption of the addictive goods. In other words, there is a possibility that $H_t \leq 0$ will come to pass, at a certain period in time. In addition, because the price of the addictive goods is assumed to be constant, if the consumption of the same good increases, the expenditure for that consumption will also increase. Thus, even if the individual's health is positive, there is a possibility that they will run out of their lifetime budget along the way. If an individual diminishes their budget at tth ($t = 1, 2, ..., T-1$) period, they will die at $t+1$th period from the damage caused by the consumption of addictive goods. Supposinge now that the equality condition of the budget constraint is established by the consumption stream of the addictive goods of the individual with some subjective discount factor, δ. Thus, we obtain the following theorem:

Theorem 1. *Suppose that the utility function is strictly increasing and concave and the damage function is convex. Let $\bar{\delta} \in (0,1)$ be the subjective discount factor when $\boldsymbol{a}^* = (a_1^*, ..., a_T^*)$ and $\boldsymbol{c}^* = (c_1^*, ..., c_T^*)$ satisfy the below:*

$$\sum_{t=1}^{T} (pa_t^* + c_t^*) = W_0.$$

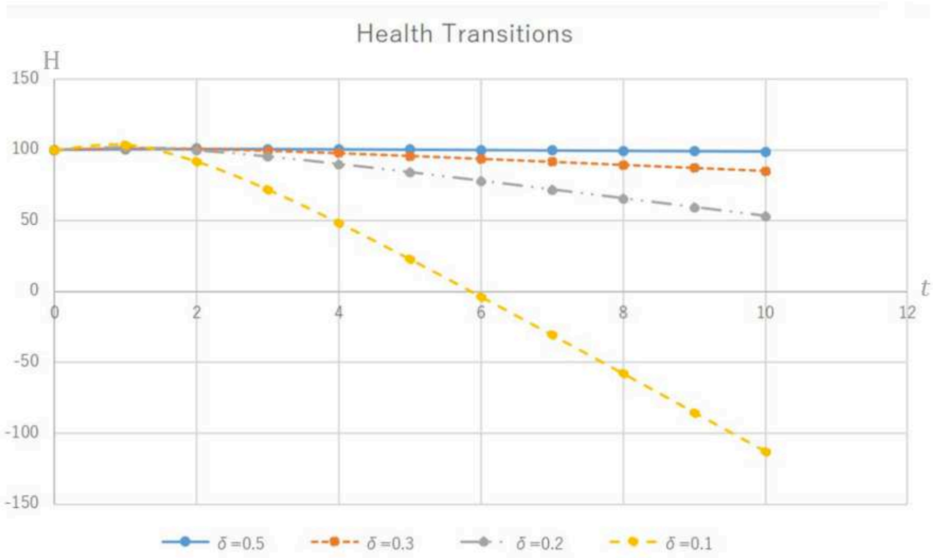

Figure 1 Health Transitions with Different Discount Factors ($T = 10, H_0 = 100, \gamma = 1.2, d(x) = x^2, u(H_t) = \sqrt{H_t}$).

Then, there exists δ' *such that* $0 < \delta' < \bar{\delta}$ *which gives* $\mathbf{a}'^* = (a_1'^*, ..., a_T'^*)$ *and* $\mathbf{c}'^* = (c_1'^*, ..., c_T'^*)$ *satisfying*

$$\sum_{t=1}^{k}(pa_t'^* + c_t'^*) = W_0,$$

for all $k = 1, 2, \cdots, T-1$.

Proof. See Appendix. □

Therefore, we obtain the following propositions:

Proposition 4. *Individuals with a lower subjective discount rate will have lower health in each period than individuals with a higher subjective discount rate.*

Proof. See Appendix. □

According to Theorem 1, there exist individuals who exhaust their budget before the last period, T, when T is fixed for all individuals. Furthermore, Proposition 4 states that people with lower subjective discount rates have lower health than individuals with higher discount rates. For example, if an individual spent the entire budget on addictive goods in the first period, the damage in the next period is drastically large. Therefore, assuming the worst, the individual will die in the next period. Thus, Theorem 1 and Proposition 4 show that short-sighted individuals are more prone to severe addictions, leading to an early death, at worst. Thus, for the short-sighted individual with a small subjective discount rate, addictive goods are no longer goods, but bads, as they inflict significant damage upon their health. In the next section, we will confirm that the short-sighted individual is comparatively easy to become a serious addiction by the numerical example.

3.2 Numerical Example

In the previous section, we stated that the short-sighted individual is more likely to suffer from a severe addiction. This is the interpretation of Propositions 3 and 4, in all sections. This section confirms the above statement by presenting a numerical example.

Before we discuss the results, let us confirm the basic assumptions. The main characteristics of the addiction goods in this paper are as follows: (1) it will improve (mental) health as soon as an individual consumes it, (2) then, it yields damage, and the individual has to undergo a slow recovery. The assumed damage function is increasing and convex.

Proposition 1 stated that the consumption of the addiction good increases throughout the individuals' lives, despite the damage. The quantity of consumption of amount they take the addiction goods, depends on the individual's discount rate δ. Figure 1 shows how health changes under the optimal consumption of the addiction goods for different δ =0.5, 0.3, 0.2, and 0.1. As observed in the graph, serious addiction occurs when the discount factor $\delta = 0.1$, and the individual will be dead by period 6.

In other cases, the individual will not die, but the intake of the addiction good will increases over time, and harm their health. In this numerical example, when $\delta = 0.5$, optimal addiction good consumption is 0.64 in the first period, but it gradually increases and reaches to 0.83 by the final period 10. Despite the increasing intakes, the this individual's health in the tenth period is still 98.7, which indicates that they are healthy.

	Discount rate (δ)		
Toxicity (γ)	$\delta = 0.9$	$\delta = 0.5$	$\delta = 0.1$
$\gamma = 2$	0.17	0.39	2.25
$\gamma = 1$	0.33	0.77	4.25
$\gamma = 0.5$	0.63	1.50	7.73

Table 1 The Optimal Consumption in the First Period. (In the case of $T = 10, H_0 = 100, d(x) = x^2, u(H_t) = \sqrt{H_t}$.)

When an individual is severely addicted, they tend to recklessly consume the addiction good, regardless of the potential harm to their health or how expensive it is. Before their symptoms devolve get worse, a high price might be effective in preventing individuals from consuming the addiction good. Considering that several addiction goods such as OTC drugs and smartphone services are very common, it might be difficult price them higher than the market price.

The susceptibility to addiction depends on an individual's discount rate. An individual with a lower discount rate will underestimate future damage, and overestimate the reward. As a result, even a rational individual will consume higher amounts of the addiction good, as opposed to individuals with higher discount rate, whose consumption does not harm their health. In the numerical example presented, the individual with $\delta = 0.1$ will consume 3.60 units of addiction good in the first period, which is 5.6 times more than the individual with $\delta = 0.5$. On the other hand, the optimal consumption of addiction goods depends on the good's toxicity γ. Table 1 shows how optimal consumption in the initial period changes, depending on δ and γ. Unsurprisingly, the consumption of addiction good increases as the toxicity of the good decreases. However, the problem is that, the lower the toxicity, the higher is accessibility of that good. Thus, low toxicity goods might be addictive to age number of people.

3.3 Some Implications from Results of The Model

This section discusses several treatments for addiction, and proposes an effective policy for decreasing addictive individuals, as additionally suggested by the results of the model.

Cold Turkey

Becker and Murphy (1988) explained that when an addicted individual is suddenly deprived of their addiction good, it is called "cold turkey." They suggest that ‘cold turkey’ is the only effective method to terminate an addiction. Additionally, Frank (1996) also concludes that the cold turkey method is effective in reducing addiction. Highly toxic addiction goods will cause serious addictions for individuals. We call such goods "bads." We propose that the deprivation of such addiction goods is effective, according to our model, because the any further damage is likely to disappear.

However, not all addiction goods are bads. As mentioned previously, any goods can be addiction goods. Some of these goods cannot be abruptly and entirely withdrawn. To take an extreme example, an individual with bulimia cannot completely stop consuming food.

Moreover, goods such as OTC drugs, which have greater health risks from stopping consuming medication than addiction, are useful if used optimally. However, if an overdose causes greater damage, these goods become bads. For such addiction goods, treatments that include the gradual reduction of intake, may be considered.

We also consider individuals with extremely weak health, who might die if they do not consume addiction goods. To consider such low-health individuals, let us imagine that an individual with $\delta = 0.1$ is in the fifth period (according to the numerical example in the previous section). This individual will be dead in the sixth period, but is it the dose of the addiction good, administered in the sixth period, that causes the death them? The answer is no. Their death is the result of the previously accumulated damage. Formally, such a serious problem occurs when there exists a period k $(k = 1, 2, \cdots, T-1)$ such that

$$H_k \leq 0.$$

In such a case, when the damage accumulated is severe, the individual does not need utility optimization. The individuals needs to maintain their health, H_k, at a positive value, for all k $(k = 1, 2, \cdots, T)$.

Our model concludes that the most important factor in determining an individual’s likelihood of suffering from a serious addiction, is the subjective discount rate. Basically, for individuals with low discount rates, it is important to increase their discount rates or make them aware of their own low discount rates through counseling or seminars, in similar addiction groups. Christoph et al. (2001) and Weinrieb et al. (2011) have noted that counseling therapy can be effective and increase individuals’ subjective discount rates.

Replacement with Lower Toxic Addiction Goods

We will show that replacing a current addiction good with another addiction good might be a better option for addiction and health.

$\gamma_1 > 0$ denotes the toxicity of the present addiction good, and assume that another addiction good with γ_2 is available, where $\gamma_1 > \gamma_2 > 0$. We also assume that the price of the both addiction goods is the same. Therefore, if the consumption quantities are the same, so are the expenditures. Under these assumptions, replacing the present addiction goods with the lower-toxicity addiction good can effectively improve an individual's health, given that they consume the same quantity. To prove this, we consider the same case as cold turkey, focusing only on addiction goods.

$$H_0 - \gamma \sum_{t=2}^{k} d(a_{t-1}) \frac{1}{2^{k-t}} \leq 0 \text{ and } H_0 + a_k - \gamma \sum_{t=2}^{k} d(a_{t-1}) \frac{1}{2^{k-t}} > 0,$$

where $k = 1, 2, \cdots, T$. The case

$$H_0 - \gamma \sum_{t=2}^{k} d(a_{t-1}) \frac{1}{2^{k-t}} > 0$$

follows from the previous proof.

Let us assume δ is constant, and $\gamma_1 > \gamma_2 > 0$. From Equation (11) it follows for all $k = 1, \cdots, T$ such that

$$\frac{1}{\gamma_1 \sum_{t=1}^{T-k} \delta^{t+(t-1)} u'(H_{t+k}) \frac{1}{2^{t-1}}} < \frac{1}{\gamma_2 \sum_{t=1}^{T-k} \delta^{t+(t-1)} u'(H_{t+k}) \frac{1}{2^{t-1}}}.$$

When an individual shifts to a new addiction good, goods which toxicity γ_2 satisfy the following condition:

$$\gamma_2 d(a_k) + \frac{1}{2} \gamma_1 d(a_{k-1}) > 0,$$

where a_k in the above is the same amount of a_k^* given by γ_1. Here, the amount of a_k^* given by γ_2 is different and given by γ_1. Subsequently, the recovery outweighs the damage of the low toxicity good; and as a result, health is recovered by consuming a low-toxicity addiction good. Theoretically, this result supports the validity of the treatment that uses an alternative low-toxicity addiction good (Fiore, 2000, Gonzales et al., 2006, Wu et al., 2006, Mills et al., 2010, Polosa et al., 2013, Blanco et al., 2014). We have showed that low toxicity addiction goods can lead to overdoses and the therapeutic replacement of an addiction good, should be managed carefully. The above condition clarifies what kinds of alternative goods and quantities can be effective for the recovery.

Finally, we discuss the financial problem. If the price of the alternative addiction good is too high, it might be difficult to continue its consumption. Low-toxicity addiction goods are not regarded as medical goods, and the patients might be ineligible for subsidies.

Price Increasing of Addiction Goods

Finally, we propose a policy to reduce the consumption of addiction goods.

From Equation (11) and convexity of damage function, $d^{-1}(\cdot)$, it can be determined that the quantity of consumption of addiction goods is the decreasing function of price, p. Because the consumption of addiction goods can never be negative, if the price of the addiction good rises until $u'_{a_k}(H_k) - pu'_{c_k}(H_k)$ is nonpositive, and the consumption of the addiction good decreases to zero. In this regard, raising the price of addiction goods by taxation and other penalties, has the same effect as cold turkey, reducing their consumption to zero.

However, if the individual is severely addicted, raising the price of the addiction goods leads to the same problems as with cold turkey. Therefore, the inability to consume addiction goods because of rising prices, can be severely damaging. Thus, if an individual anticipates an increase in the price of an addiction good in the next period, they may consume more quantities if the good in the current period. *4

In addition, raising the price of addiction goods with high toxicity may have a temporary effect of reducing its consumption, but may not be effective in the long run (Dills et al., 2021). Further, sudden and severe price increases in addiction goods are not realistic. In addition, taxation cannot be applied to all goods. Taxation on necessary goods can affect the livelihood of non-addicted individuals. However, it may be possible to gradually reduce the consumption of addiction goods through continuous and gradual increment in price.

4 Conclusion

Traditionally, the consumption of goods and bads has been clearly divided, depending on whether it yields positive or negative utility. Some goods yield positive utility at first; but the damage appears after a short delay, for example drinking alcohol, smoking, et cetera. In this paper, we have constructed a simple model and discussed how damage indicates the consumption characteristics of addiction goods. We assumed that the consumption of addiction goods provides positive utility in the first period; but yields damage in the following periods. However, the damage decreases as time goes by. We divided goods into two categories: goods that are damaging to health and goods that are not, considered individuals who earn utility from their health through these goods. Under an increasing and convex damage function, the consumption of addiction goods increases over time, showing a similar trend as addictive behavior. In contrast, the consumption of general consumer goods without toxicity decreases over time. These results support Becker and Murphy (1988) and provide a new perspective. Our results show that far-sighted people also increase their consumption of the addiction goods over time, as a result of rational behavior, but their the quantities are not concerning. However, such individuals are not addicted even if they continue to consume addiction goods. This is because the extent of their consumption does not interfere with their health. This suggests that it is possible to deal well with addiction goods as well. If we assume that the subjective discount rate is unstable, depending on the emotion of the individual, addictive behavior is not special. This contrasts with general consumer goods, as people want to consume more general goods in the first period.

We also showed that low toxicity addiction goods can lead to addiction, implying that any goods can cause addiction. The optimal consumption of addiction goods decreases as they become more toxic. This indicates that a rational individual considers the toxicity of an addiction good, before making a decision about its consumption. If the toxicity is sufficiently large, the consumption of the addiction good can be zero.

The most important factor in determining addiction is the subjective discount rate. We showed that people can develop serious addictions under a low subjective discount rate. This is because short-sighted people overrate the reward they obtain immediately after the intake of the good, and underrate its future damage. Individuals with sufficiently high subjective discounting may consume addiction goods, but their consumption is small. Because such individuals do not consume addiction goods excessively, the damage they receive from the good is small. Therefore, even if they abruptly stop consuming the addiction good, they will not suffer much damage. In this respect, addiction goods are harmless for individuals with a large subjective discount rate. Thus, individuals with high subjective discount rates cannot be considered as addicts, even if they consume addiction goods. However, individuals with

*4 This is also mentioned by Becker and Murphy (1988).

low subjective discount rates will consume more quantities of the addiction good and receive greater disutility in the next period. Such individuals will not be able to surpass the disutility if they do not consume increasing amounts of the addiction good. They will continue to consume the addiction good because if they abruptly stop their consumption, they will be severely damaged. Thus, for individuals with small subjective discount rates, addiction goods are bads. However, for individuals who can successfully deal with addiction goods, addiction goods are not necessarily bads.

This concern can be addressed by increasing individuals' subjective discount rates. For people who are aware of their addiction and trying to recover from it, counseling and seminars among patients with the same addiction can help to increase individuals' subjective discount rates. It is also important to examine under what circumstances an individual's subjective discount rate may increase or decrease. Moreover, it may be necessary to examine models in which an individual's subjective discount rate increases or decreases.

Our model also gives some useful suggestions. In terms of treatments, we have shown that completely stopping the consumption of addiction goods through cold turkey, could be a solution, but has a risky aspect. For individuals that are suffering from serious addiction, complete cessation of the consumption of addiction goods may cause more severe health problems, resulting from the damage caused by previous consumption of addiction goods. For such goods, we can consider that the option of gradually reduction of their use. Replacing the addiction goods with lower toxicity alternatives, could be a better option. For example, for individuals with nicotine addiction, subsidies could be offered to buy e-cigarettes, or price discounts could be offered to those who have been diagnosed with the addiction. Increasing the price of addiction goods is also effective in reducing their consumption. However, if an individual anticipates an increase in the price of a good and consumes more quantities of the addiction good, it will cause may lead to severe damage. In the case of necessary goods, people who are not addicted, will also be affected by the price increase. We presented the possibility that any good can become an addiction good. This includes necessary goods. Furthermore, it may reduce the utility of individuals who are able to manage their consumption of addiction goods.

This model described a singular aspect of addictive behavior: an increasing and convex damage function will cause increasing consumption over time. Although the withdrawal symptoms or tolerance might escalate the addiction, an individual increases the consumption of the addiction goods as a result of rational behavior. Of course, the occurrence of damage varies with every substance and individual. For some substances, damage occurs immediately after consumption, as in this model, but for other goods, damage occurs gradually. Several foods which cause illness, such as allergies, will cause immediate damage immediately, or several decades after consumption. The damage function might enable us to treat negative externalities, like environmental problems, which will occur after a delay of several years, or even several decades.*5 These cases should be studied in contrast with addiction goods in the future.

Our model also has room for expansion because the duration of an individual's life is fixed. The model could be made more realistic by introducing a death probability. The delayed increase in disutility is applicable in case of many other goods apart from addiction goods. As mentioned above, this can be the case with allergies. Extension to a continuous-time model might enable us to deal with these differences. As for addiction, the weaker is the initial health, the more susceptible to addiction is the individual(Earle et al., 2005, Gluck, 2006, Leeies et al., 2010, Schulz and Laessle, 2012, Jappe et al., 2014, Hawn et al.,2020). For people with weaker mental health, the benefits of using addiction goods may be higher than those for healthier people. At this viewpoint, we cannot say that our model fully explains addiction behavior.

*5 These cases are numerically explained in Ono-Yoshida (2021).

However, although one-sided, this study provides a useful model for analyzing addiction from an economic perspective.

Appendix

This appendix provides the proof of propositions and theorem.

Proof of Proposition 1

Proof. The damage function $d(a_k)$ is convex, so $d'(a_k)$ is not decreasing function and $d'^{-1}(\cdot)$ is also not. Here, δ is in the open interval $(0, 1)$ and $\frac{1}{2^{t-1}}$ is decreased with t increased, so the following inequality holds that

$$a_t^* < a_{t+1}^*,$$

for all $t = 1, 2, \cdots, T$ since the following inequality:

$$\frac{u'_{a_k}(H_k) - pu'_{c_k}(H_k)}{\gamma \sum_{t=1}^{T-k} \delta^t u'_{a_k}(H_{t+k}) \frac{1}{2^{t-1}}} < \frac{u'_{a_{k+1}}(H_{k+1}) - pu'_{c_{k+1}}(H_{k+1})}{\gamma \sum_{t=1}^{T-k+1} \delta^t u'_{a_k}(H_{t+k+1}) \frac{1}{2^{t-1}}}.$$

Hence, Proposition 1 is proven. □

Proof of Proposition 2

Proof. From Proposition 1, we have $\boldsymbol{a}^* = (a_1^*, ..., a_T^*)$ satisfying $a_1^* < \cdots < a_T^*$. Substituting $\boldsymbol{a}^*$ into Equation (9) for each periods, then we obtain

$$u'_{c_k}(H_k) = \left[u'_{a_k^*}(H_k) - d'(a_k^*) \left(\gamma \sum_{t=2}^{T-k} \delta^t u'_{a_k^*}(H_{t+k}) \frac{1}{2^{t-1}} \right) \right] p^{-1}. \tag{16}$$

Besides, each H_k is determined as follows by given a_k^*:

$$H_k = H_0 + a_k^* + c_k - \gamma \sum_{t=2}^{k} d(a_{t-1}^*) \frac{1}{2^{k-(t-1)}}.$$

Here, $u'_{c_k}(H_k)$ is a increment of c_t relative to health with $h_k(a_1^*, ..., a_k^*, c_1, ...c_k)$. In Equation (16), the second term of right-hand side increases by t increase. Then, the whole right-hand side in Equation (16) decreases and t increase. Thus, the effect of c_t on health decreases for each period. Hence, from concavity and continuity of $u(\cdot)$, there exists $\boldsymbol{c}^* = (c_1^*, ..., c_T^*)$ and it holds that

$$c_1^* > \cdots > c_T^*.$$

□

Proof of Proposition 3

Proof. The subjective discount factor, δ is less than one. Thus, the smaller δ leads to the right-hand side of Equation (11) increase more. Proposition 1 is established without the relation on the size of δ. Thus, for all period $t = 1, \cdots, T$, the consumption of the individual with smaller δ is greater than the with larger δ. Hence, Proposition 3 is proven. □

Proof of theorem 1

Proof. From Equation (2), attainable maximal value of a_k^* is $\frac{W_0}{p}$ if c_k is zero for all $k = 1, ..., T$. The damage function $d(a_t)$ is strictly increasing and convex, so $d'(a_t)$ is also increasing along with $d'^{-1}(\cdot)$. Besides, the right-hand side in Equation (12) is not bounded from the property of the damage function. Thus, we have $\boldsymbol{a}'^* = (a_1'^*, ..., a_T'^*)$ by taking arbitrary δ' satisfying the below:

$$d'(a_k'^*) = \frac{\delta'^{k-1}[u'_{a_k}(H_k) - pu'_{c_k}(H_k)]}{\left(\gamma \sum_{t=1}^{T-k} \delta'^{t+(k-1)} u'(H_{t+k}) \frac{1}{2^{t-1}}\right)} \geq d'(\frac{W_0}{p})$$
$$> d'(a_k^*) = \frac{\bar{\delta}^{k-1}[u'_{a_k}(H_k) - pu'_{c_k}(H_k)]}{\left(\gamma \sum_{t=1}^{T-k} \bar{\delta}^{t+(k-1)} u'(H_{t+k}) \frac{1}{2^{t-1}}\right)},$$

for all $k = 1, \cdots, T$. In this case, for any k ($k = 1, \cdots, T$) period, an individual cannot consume after the next period in which they have consumed $a_k'^*$ satisfying the above equation. Hence, Theorem 1 is proven. □

Proof of Proposition 4

Proof. There are two subjective discount rates, δ and δ', and these satisfy $\delta > \delta' > 0$. Additionally, there are optimal consumption streams $\boldsymbol{a}^* = (a_1^*, ..., a_T^*)$ and $\boldsymbol{a}^{'*} = (a_1^{'*}, ..., a_T^{'*})$ given by δ and δ'. Besides, let H_t and H_t' be health at period t given by $\boldsymbol{a}^*$ and $\boldsymbol{a}^{'*}$. From Proposition 3, it holds that $a_t^* < a_t^{'*}$ for all $t = 1, 2, \cdots, T$, and also $d(a_t^*) < d(a_t^{'*})$. Due to budget constraint, an attainable amount of addictive goods is W_0. Then, it holds that

$$W_0 - \sum_{t=1}^{T} a_t^* = \sum_{t=1}^{T} c_t^* > \sum_{t=1}^{T} c_t^{'*} = W_0 - \sum_{t=1}^{T} a_t^{'*},$$

where $c_t^{'*}$ is the optimal value of the general consumer good given by δ'. That is, the total amount of addictive goods given by a smaller subjective discount rate is greater than larger ones. Then, it holds that

$$\sum_{t=1}^{T} d(a_t^*) < \sum_{t=1}^{T} d(a_t^{'*}).$$

Hence, for each $t = 2, \cdots, T$, it holds that $H_t > H_t'$. Therefore, this proposition is proven. □

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