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On the causes and consequences of hedonic adaptation

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ABSTRACT

We provide a simple evolutionary explanation for the emergence of hedonic adaptation. The model's key assumption is that, apart from guiding long-term behavior, some sensations fulfill warning and defense roles (e.g., pain). Contrary to the alternative evolutionary explanations for hedonic adaptation (Robson, 2002; Rayo and Becker, 2007), our theory can explain why some sensations are adaptive, while others (with warning/defense roles) are not adaptive at all. Finally, we show that differential adaptation has important welfare and policy implications.

1. Introduction

In economics, the term utility has two possible meanings. On the one hand, *decision utility* is inferred from the observed choices in Samuelson's Revealed Action spirit. On the other hand, Bentham's concept of *experienced utility* refers to the actual feelings of pleasure and pain (from now on, sensations) that an organism experiences in response to certain stimuli (Samuelson, 1947; Bentham, 1789). Behavioral economists have studied a number of situations in which experienced utility deviates systematically from decision utility (e.g., Kahneman et al., 1997; Beshears et al., 2008[1]; Robson and Samuelson, 2011). This paper is concerned with one such departure. Hedonic adaptation denotes the tendency of experienced utility to systematically bounce back to "normal" levels. If people fail to anticipate adaptation and adaptation is differential across sensations, then a wedge between decision and experienced utility arises.

There is empirical evidence consistent with hedonic adaptation and evidence that people fail to anticipate adaptation (for an extensive review, see Frederick and Loewenstein, 1999). For instance, people's happiness seems to change in response to many life events, such as lottery windfalls and terminal illnesses (e.g., Oswald & Powdthavee, 2008). Hedonic adaptation may be of interest to economists insofar as it has systematic welfare and policy implications.[2] The contributions of this paper are twofold. First, we provide an evolutionary explanation for the existence of hedonic adaptation. In contrast to existing evolution-

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[1] They use the terms *revealed preferences* and *normative preferences*.

[2] Additionally, it may be of interest if it puts limitations on what we can infer about welfare from observed actions (Loewenstein & Ubel, 2008).

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ary theories (e.g., Rayo and Becker, 2007), our explanation can show why some sensations are highly adaptive, while other sensations (with warning/defense roles) do not seem to adapt at all. Second, this paper shows that differential adaptation (i.e., different rates of adaptation for different sensations) can have systematic welfare and policy implications: if individuals do not fully anticipate adaptation, then they will overconsume the goods that elicit more adaptive sensations.

To the best of our knowledge, within economic theory, Robson (2002) was the first to propose an evolutionary explanation for hedonic adaptation by comparing the adaptive utility function to a voltmeter.[3] Later, Rayo and Becker (2007) provided a full-fledged model in which the key assumption is that there are limitations to the agent's perception sensitivity. Similar to Rayo and Becker (2007), Section 2 presents a principal-agent model between Nature and men as a metaphor for evolution. The emergence of hedonic adaptation rests on two key assumptions inspired by well-documented biological facts. The first assumption is that, as in Rayo and Becker (2007), intense sensations are costly in a fitness sense, which is related to the functioning of the brain (e.g., energy consumption). The second assumption, which departs from Rayo and Becker (2007), is that some sensations need to be "intense" to fulfill their warning and defense roles (e.g., pain).

For instance, we can distinguish between two roles of pain. One is the long-term motivational role, which discourages the individual from repeating some actions in the future, such as touching fire. If Nature wants the agent to choose action A instead of B, then the (pleasurable) sensation triggered by action A must be more intense than that of B. The second role of pain is the warning/defense role, which serves to alert the individual that he or she needs to take an immediate action to avoid being injured any further, such as removing his or her hand from a fire. The more intense the sensation is, the quicker the individual will react and therefore the greater the chances of preventing further harm, which is beneficial in fitness terms. That is, if Nature wants to fulfill a warning/defense role, then she needs to provide the individual with intense sensations in an absolute sense. We discuss the biological evidence supporting this second assumption. For instance, people with a rare congenital syndrome called indifference to pain have much lower survival rates than people without this condition; even in modern times, almost all of them are dead by their mid-thirties (Sternbach, 1963). More importantly, those individuals can detect being burned, pricked, or pinched, but they do not perceive such experiences as unpleasant. That is, consistent with our assumption, the lack of intensity renders those sensations useless as warning/defense mechanisms.

In our evolutionary model, Nature faces a tradeoff: intense sensations are costly (e.g., they are a waste of energy), but at the same time, some sensations need to be intense enough to fulfill their warning/defense roles. As a solution, Nature writes a hedonic contract in which the hedonic states are adaptive. For example, instead of making experienced utility a mere function of consumption, Nature makes it a function of the difference between actual consumption and expected consumption (or the difference between current and past consumption). As a result, the reward systems have a tendency to systematically bounce back to "baseline" levels (i.e., hedonic adaptation). More importantly, Nature's optimal contract introduces a higher degree of hedonic adaptation for those sensations without warning/defense roles, which is consistent with the empirical evidence. Finally, in Section 3, we show that this prediction—differential adaptation—can have systematic welfare/policy implications, as individuals who do not fully anticipate adaptation will overconsume those goods that elicit more adaptive sensations.

2. On the causes of hedonic adaptation

2.1. The principal-agent problem

The quest for happiness is considered the main concern for every individual. Nevertheless, we must bear in mind that happiness has been an evolutionary mean and not an end for mankind. Nature developed an incentive scheme of prizes and punishments to drive human behavior towards greater fitness. We will not study the process of natural selection itself, but we will follow scholars such as Samuelson (2004), Rayo and Becker (2007), and Smith and Tasnádi (2007) in describing the limiting outcome by means of a principal-agent problem between Nature, the principal, and men, the agent.

Nature chooses a utility function $U(c)$, where $c \in C$ is the consumption vector attained by the individual. This consumption is perceived by the individual through a certain number of sensitivities that elicit sensations. If $U(\cdot)$ has more than one dimension, then each of those dimensions will denote a different sensation. Everyday examples of stimuli are eating food and being burned, and everyday examples of sensations are the pleasure derived from eating food and the pain from being burned. The consumption vector (c) is a function of the decisions of the individuals ($x \in X$) and the characteristics of the environment ($z \in Z$):$c = f(x,z)$. The agent observes z and chooses x to maximize his or her utility.

Nature shapes the agent's utility function to maximize her own preferences: the reproduction and survival of the species. Nature's fitness depends only on final consumption $V(c)$, which is always of dimension one.[4] Different individuals will be exposed to different scenarios (e.g., bad or good weather and abundance or scarcity of food). The characteristics of the environment (z) are not known ex ante to Nature. In the jargon of the principal-agent problem, $U(\cdot)$ represents the incentive payment,

[3] Robson (2002): *"To obtain an accurate reading from this device, it is necessary to first estimate the range in which the unknown voltage falls. Only if the right range is selected on the device, such that the needle moves to the middle of the scale, is an accurate reading obtained."*

[4] Note that any monotonically-increasing transformation of $V(c)$ would represent the same fitness function.

and z is the information hidden to the principal. Of course, this stylized model of evolution makes a number of implicit assumptions, none of which are believed to affect the main results.[5]

It is important to note that hedonic adaptation is most likely not a product of human evolution alone but a product of the long evolutionary history of the brain. Take as an example the prefrontal cortex, which is the brain center most strongly implicated in qualities such as intelligence. The neocortex appeared with the early mammals and has expanded greatly in size throughout hominid evolution. Rather than replace an older region of the brain, the neocortex was built on top of other structures in the brain. As Allman (1999) noted, "The brain can never be shut down." All of the old control systems must remain in place and functional while new ones evolve. Because hedonic adaptation may be the result of evolutionary forces long before the appearance of the first hominids, this model should not necessarily be interpreted as a model of human evolution. However, insofar as it facilitates the interpretation of the results, we use our ancestral hunter-gather environment as a leading example.[6] We can think of a primitive hunter who must choose how to allocate the time between hunting and resting (x), which, depending on the abundance of prey and the climate conditions (z), will determine the consumption vector, which is composed of physical deterioration and calorie intake (c).

We begin with a unidimensional utility function ($U(\cdot)$) and introduce the multi-dimensional case later. Up to this point, Nature can simply choose $U(\cdot) = V(\cdot)$ (or any monotonic transformation). The individual will choose x to maximize $U(f(x,z)) = V(f(x,z))$. He or she will then attain the exact consumption vector that maximizes Nature's fitness.

In the following two subsections, we will introduce the two assumptions that, when taken together, can explain the emergence of hedonic adaptation.

2.2. Intense sensations are costly

The first assumption is that sensations that are intense in an *absolute* sense are costly from a fitness point of view. Indeed, this assumption is equivalent to one of the two key assumptions in Rayo and Becker (2007). At first glance, it may be difficult to realize how costly intense sensations can be, simply because nature is highly effective at keeping those costs low.

First, there are direct costs from eliciting intense sensations, a phenomenon that is related to the functioning of the brain. Despite its elegance, the brain of an average adult human represents approximately 2% of the total body weight while still consuming approximately 20% of the energy (Clark and Sokoloff, 1999). Sensations are the product of chemical reactions (e.g., the release of neurotransmitters), so more intense sensations imply a waste of energy. Moreover, extra brain activity produces heat, and one key goal throughout the evolutionary history of the brain has been to minimize heat production (Montague, 2006). For instance, without the GABA inhibition neurotransmitter, the neurons would continuously send out action potentials and would "eventually literally fire themselves to death" (LeDoux, 2002).

Second, intense sensations (positive or negative) can critically diminish our state of awareness. For instance, if we experienced sensations ten times more intense than an orgasm in response to ordinary stimuli (e.g., eating a berry), we would not be able to focus properly (especially during our evolutionary time period, when such a response would have made us easy prey for any lucky predator). Last, researchers have discussed other potential adverse consequences of intense unhappiness in humans and non-humans beyond the case of lower awareness (e.g., Sapolsky, 1999).

Because of the reasons listed above, intense sensations can have a detrimental effect on the survival and reproduction of the organism. To represent this effect, we will split the fitness function into two components: $V(c,U) = \Psi(c) - \Omega(U(c))$. The first term on the RHS, $\Psi(c)$, represents Nature's direct preferences over the agent's consumption. We assume that $\Omega(\cdot)$ is nonnegative (i.e., both positive and negative sensations are costly), strictly increasing in the absolute value of its argument, and convex.[7] The second term $\Omega(U(c))$ represents the fact that the intensity of the sensations that the organism experiences is costly in terms of fitness.[8]

Given that the agent's behavior only depends on the utility function in an ordinal sense, Nature can avoid fitness costs by simply scaling the individual's utility function. That is, Nature can simply set $U(c) = \alpha\Psi(c)$, where α is a scalar arbitrarily close to zero, and attain the First-Best fitness. Because Nature can achieve the optimal fitness in this way, there is no need for her to use adaptive contracts (i.e., hedonic adaptation).

2.3. Warning/defense roles

The second assumption is that some sensations have more immediate roles than that of guiding long-term behavior, which we denominate warning/defense roles. For example, when a person experiences the prickle of a rose, the "long-term"

[5] For example, in a richer model of evolution the utility function would be over goods that are only intermediate from a biological viewpoint (e.g., Robson, 2001a, Robson, 2001b).

[6] Humans lived as hunter-gatherers for the vast majority of their evolutionary history: the genus Homo has existed for about 2 million years, while agriculture originated only 10,000 years ago and has been practiced by the majority of the world's population for just 3000 years, a relatively brief period of time for selection to act (Ehrlich, 2000).

[7] Intuitively, if the individual is about to pass out from pain, the marginal harm from a more intense sensation is large. Note that if $\Omega(\cdot)$ was concave, then Nature would have found it optimal to design a system of "stochastic" sensations: i.e. you would feel almost infinitely-intense sensations with almost zero probability (or similarly, sensations with infinitely large intensities but infinitely short length).

[8] An alternative would be to assume that sensations are bounded above and below, as discussed in Rayo and Becker (2007). The results and intuitions of the model would be similar.

motivational role behind the pain that the person feels is to discourage him or her from touching the rose again in the future. The warning/defense role is meant to trigger an immediate response from that person to avoid being injured any further. Sensations with warning/defense roles (e.g., pain) cause most of us to seek to avoid sprains, fractures, burns, and other injuries that would otherwise leave us crippled and vulnerable to severe infections. If we were to "turn down the volume" of those sensations, that would significantly decrease our chances of surviving and reproducing. This was true during our evolutionary history and is still true in modern times. For instance, Sternbach (1963) documents that modern individuals with a rare congenital syndrome called *indifference to pain* are almost all dead by their mid-thirties. Many young children with this syndrome have mutilated themselves by chewing off their fingers and their tongues and have suffered severe burns when leaning against stoves or sitting in scalding baths (e.g., Madonick, 1954).

If the sensations behind warning/defense mechanisms were weak, then people could ignore those messages and be exposed to serious harm. In modern times, we may be able to survive without some warning/defense mechanisms. For instance, we ask doctors for drugs to ignore some messages pre-programmed by Nature, such as the urge to vomit and fevers, because the modern standards of living allow us to ignore them. However, the lack of warning/defense systems would have been fatal in a previous era during our evolutionary history. Interestingly, even physicians seem to ignore the defense function for diarrhea, fever, and others. Nesse and Williams (1994) called this tendency "the Clinician's Illusion."

The information about the external environment, such as being burned or tasting an apple, is perceived by the organism through a number of sensitivities. According to Cabanac (1971), some sensitivities give rise to a phenomenon of consciousness that induces affective content, described in common language as pleasure or displeasure. However, not all stimuli evoke affective content. For instance, the mere action of seeing is neither pleasant nor unpleasant by itself, even though the cognitive processing of the images may carry affective content. Young (1959) provided a characterization similar to that of Cabanac (1971) by distinguishing between *discriminative* and *affective* dimensions. Cabanac et al. (1969) showed that people with indifference to pain feel all of the stimuli applied to them, including what normal subjects describe as painful. They can detect being burned, pricked, or pinched, but they do not perceive such experiences as unpleasant (i.e., they have the *discriminative* part of the sensation but not the *affective* component). Consistent with our assumption, the lack of intensity renders those sensations useless as warning/defense mechanisms.

We must incorporate the warning/defense roles into the model. We allow U to be two-dimensional. The second element of U, U_2, will be the sensation with a warning/defense role. The first element, U_1, will not play such a secondary role. Because there is more than one sensation, we need to establish an "hedonic metric" such that the individual can compare different sensations: we assume that the individual maximizes $S(U(c)) = U_1(c) + U_2(c)$.[9]

In order to represent the fact that U_2 plays a secondary role, we incorporate an additional term to the fitness function:

$$V(c, U_1, U_2) = \Psi(c) - \Omega(U_1(c)) - \Omega(U_2(c)) + \Gamma(U_2)$$

Note that $\Omega(U_1(c))$ and $\Omega(U_2(c))$ enter additively: i.e., having one very intense positive sensation does not cancel out with having one very intense negative sensation. As studies from neuroscience show, there is not such a thing as a single continuum from good to bad feelings. People can feel sad and happy at the same time, and an increment of pleasure does not cancel out an equal increment of pain (Larsen et al., 2001).

The fourth term on the RHS, $\Gamma(\cdot)$, is a mapping from a function U_2 to a scalar. $\Gamma(\cdot)$ is expected to be increasing and concave in the absolute value of its argument in a point-wise sense. This mapping is meant to represent the fact that some choices of U_2 – those that are more intense – are better at fulfilling the warning/defense roles and thereby increase fitness. It is important to note that $\Gamma(\cdot)$ does not depend on $U_2(c)$, but on the entire shape of U_2.[10]

Intuitively, the individual will experience very temporary states of c that represent emergency situations, like stepping on fire. This creates the need for intense sensations in those temporary states, as an alert system. One example is $\Gamma(U_2) = \alpha \int_{\underline{c}}^{\bar{c}} T(U_2(v)) f(v) dv$, with $T(\cdot)$ strictly increasing (and concave) in the absolute value of its argument and $f()$ being a density function. $f(c)$ stands for the likelihood that the individual will encounter the (very temporary) emergency state c (e.g., stepping on fire). For a given c, $T(c)$ represents that more intense sensations are more likely to elicit an immediate reaction from the individual in the (very temporary) state c, thereby increasing the chances of survival and reproduction (i.e., fitness).

Nature still wants U_1 to be as close to zero as possible, in order to prevent fitness costs from $\Omega(U_1(c))$. But Nature faces a trade-off regarding U_2: while less intense sensations are still desirable due to $\Omega(U_2(c))$, they come at a cost because they do not fulfill properly the warning/defense roles.

2.4. Hedonic adaptation

2.4.1. Expectation-based utility

Earlier we mentioned that Nature could attain First-Best fitness by simply scaling the utility function by an arbitrarily-small number. That is not a viable option anymore, because a very weak U_2 would compromise the organism's survival. Nat-

[9] Note that the utility function is not separable in the usual sense, since the $U_j(c)$ can depend on overlapping subsets of c for different j's. Indeed, both theory and evidence from neuroscience suggest that such interrelations exist (Camerer et al., 2005).

[10] In other words, the intensity of pain needed to make an individual jump when it steps on fire does not depend on the value of c that the individual is consuming.

ure cannot scale-down U_1 only, because that would lead the agent to choose a very inefficient c. Thus, Nature needs to take advantage of more complex hedonic contracts in order to attain higher fitness.

There are multiple ways in which Nature can write adaptive contracts. We will start with the simplest case: expectation-based utility. Suppose that the individual can predict z, and denote z^e to that prediction. For the sake of simplicity, we will assume that the individual has perfect forecasting: i.e., $z^e = z$. Let $\hat{c}^*(z)$ be the consumption that an agent chooses given his utility function and z. We let Nature choose a utility function that can depend on $c^e = \hat{c}^*(z^e)$. In other words, Nature can reward the agent for how his or her consumption compares to the agent's expectations.[11]

It is straightforward to show that the optimal hedonic contract involves full hedonic adaptation in U_1. Consider a candidate for the hedonic contract $\widehat{U} = \{\widehat{U}_1, \widehat{U}_2\}$. We can show that we can always improve Nature's fitness by allowing for full adaptation in $\widehat{U}_1$. First, note that adding a term that does not depend on c to $\widehat{U}_1$ does not affect $\hat{c}^*(z)$. Define $\widehat{U}_1^a$ as the fully-adaptive transformation of $\widehat{U}_1$:

$$\widehat{U}_1^a(c) = \widehat{U}_1(c) - \widehat{U}_1(\hat{c}^*(z^e))$$

Because the second term on the RHS does not depend on c, the agent's behavior is the same if we replace $\widehat{U}_1$ by $\widehat{U}_1^a$. But the intensity of the sensation at the actual consumption level will be always zero under $\widehat{U}_1^a$, so it attains the lower bound of $\Omega(U_1)$. As a result, the fully-adaptive transformation improves fitness through $\Omega(U_1)$ without any secondary fitness costs.

Second, the model does not necessarily predict that the optimal hedonic contract will involve full hedonic adaptation in U_2. Consider a candidate for the hedonic contract, $\widehat{U} = \{\widehat{U}_1, \widehat{U}_2\}$. Imagine that we attempted to use the same fully-adaptive transformation for $\widehat{U}_2$:

$$\widehat{U}_2^a(c) = \widehat{U}_2(c) - \widehat{U}_2(\hat{c}^*(z^e))$$

This would certainly minimize the fitness costs from $\Omega\,(U_2(c))$. However, in the case of U_2 this transformation can come at a cost: translating the function $\widehat{U}_2$ by $\widehat{U}_2(\hat{c}^*(z^e))$ will push the entire function U_2 towards zero, which means less intense sensations and therefore can decrease fitness through a worse fulfillment of the defense/warning roles (i.e., through $\Gamma(U_2)$). Although *some* adaptation may be desirable, the degree of adaptation will depend upon the parameters of the model. Intuitively, if the costs from intense sensations, $\Omega(U_2(c))$, are of second order when compared to the benefits from the defense/warning roles, $\Gamma(U_2)$, then the optimum will involve virtually no adaptation in U_2. Thus, the model can rationalize the fact that those sensations without warning/defense roles are subject to hedonic adaptation while those sensations with warning/defense roles do not seem to be adaptive.

The idea that experienced utility depends on consumption expectations is not new in Economics (e.g., Koszegi and Rabin, 2006), and is widely discussed in fields like psychology and consumer behavior (e.g., Allison and Uhl, 1964). Moreover, this idea is widely studied in neuroscience (for a review see Fehr and Rangel, 2011). For instance, recent physiological work on dopaminergic neurons in primates suggests that activity in that part of the brain is not elicited by changes in consumption only, but also by changes in expectations (Schultz et al., 1997). In a nutshell, bursts of impulse activity in those regions of the brain mean that the reward is more than expected, a pause means that the reward is less than expected, and no change means that the reward is just as expected. In a similar spirit, Nitschke et al. (2006) show that activity in the primary taste cortex responds to changes in expectations about how bad something will taste.

2.4.2. Auto-regressive utility

In the previous case – expectation-based utility – we assumed perfect forecasting, so the model was not truly dynamic. Now we consider a truly dynamic model. Furthermore, we make several functional form assumptions in order to obtain tractable results.

Let's start with the static setup. The agent has to choose an action $x \in (0,\kappa)$, where the parameter κ is given by the environment and is equally likely to take the values $\underline{\kappa} = 1$ and $\bar{\kappa} > 1$. This action determines the consumption of two goods: $c_1 = x$ and $c_2 = \kappa - x$ (and thus both c_1 and c_2 are bound to be positive). Nature must choose the parameters $\{a_1, a_2, b_1, b_2\}$ for the agent's (logarithmic) utility functions $U_1(c_1) = a_1 + b_1 \ln(c_1)$ and $U_2(c) = a_2 + b_2 \ln(c_2)$,[12] with $b_1 > 0$ and $b_2 > 0$. As a result, the agent maximizes: $a_1 + a_2 + b_1 \ln(c_1) + b_2 \ln(\kappa - c_1)$. From the FOCs we obtain $c_j = \frac{b_j}{b_1+b_2}\kappa$, where $\{b_1 > 0, b_2 > 0\}$ guarantees that the SOCs are satisfied. The second sensation, U_2, is the only sensation with warning/defense roles. The (expected) fitness function is given by[13]:

$$\sum_{\kappa\in\{1,\bar{\kappa}\}} \frac{1}{2} \left[\begin{array}{c} \ln\left(\frac{b_1}{b_1+b_2}\kappa\right) + v_2 \ln\left(\frac{b_2}{b_1+b_2}\kappa\right) \\ -\frac{v_3}{2}\left(a_1 + b_1 \ln\left(\frac{b_1}{b_1+b_2}\kappa\right)\right)^2 - \frac{v_4}{2}\left(a_2 + b_2 \ln\left(\frac{b_2}{b_1+b_2}\kappa\right)\right)^2 \end{array} \right] - \frac{v_5}{2}\int_{\underline{c}}^{\bar{c}} \frac{1}{\bar{c}-\underline{c}}(a_2 + b_2\ln(s) - a_2^* - b_2^*\ln(s))^2 ds$$

The v's are parameters of the fitness function, which we assume to be strictly positive. Without loss of generality we normalized $v_0 = 0$ and $v_1 = 1$. The first two terms in brackets represent Nature's own preference over the agent's consumption

[11] One of the many implicit assumptions is that the agent does not have direct control over his expectations, otherwise he could just lower his expectations in order to boost happiness.

[12] This is an important simplification, since the characterization of the solution is much more complicated for the case of non-parametric utility functions.

[13] We replaced for the agent's optimal choices of c_1 and c_2.

of c_1 and c_2. If Nature was only interested in maximizing these first two terms she would simply choose any pair $\{b_1,b_2\}$ such as $\frac{b_1}{b_1+b_2}=\frac{1}{1+v_2}$. Note that v_3 and v_4 weight the importance of the fitness costs from intense sensations (e.g., due to the waste of energy), which are quadratic loss functions centered at zero. Last, the term v_5 weights how important for fitness are the warning/defense roles associated to the second sensation, U_2. This specification says that there is a unique utility function $U_2^*(c_2)=a_2^*+b_2^*\ln(c_2)$ that would optimize the warning/defense roles (with $b_2^*>0$), and punishes any deviations from that function in a squared-error fashion uniformly over the range $c_2\in[\bar{c},\underline{c}]$. Intuitively, there are very temporary states of c_2 (e.g., stepping on fire), uniformly distributed over $[\bar{c},\underline{c}]$, for which Nature needs to make sure that the individual ''notices'' the need to take an action (e.g., step out of the fire), something that is achieved if the intensity is high enough (i.e., if the U_2 is not significantly below U_2^* in a pointwise sense).[14]

Now we can move to the dynamic setup. In a given period there is a probability q that κ will be the same than the last period, and a probability $(1-q)$ that it will take the alternative value. Note that if $q\neq\frac{1}{2}$a ''pattern'' will arise in the sequence of κ's: if $q>\frac{1}{2}\,(q<\frac{1}{2})$ then it is more likely that this period's environment will be the same (the opposite) than the previous period's. Nature will try to take advantage of that pattern in order to increase fitness through an adaptive contract. Let the superscript t denote time periods. We assume that Nature can write a contract of the following form: $U_j\left(c_j^t,c_j^{t-1};a_j,b_j,\phi_j\right)=a_j+b_j\ln\left(c_j^t\right)-\phi_j\left[a_j+b_j\ln\left(c_j^{t-1}\right)\right]$. This can be interpreted in at least two ways. One is that utility is auto-regressive: i.e., effective utility is equal to current utility, $a_j+b_j\ln\left(c_j^t\right)$, minus last period's utility, $\left[a_j+b_j\ln\left(c_j^{t-1}\right)\right]$, weighted by ϕ_j (e.g., Bottan and Perez-Truglia, 2011). The other interpretation can be grasped by re-arranging the utility in the following manner: $a_j(1-\phi_j)+b_j\left[(1-\phi_j)\ln\left(c_j^t\right)+\phi_j\ln\left(\frac{c_j^t}{c_j^{t-1}}\right)\right]$, so the utility is a function of both current consumption and the ratio of current to past consumption, weighted respectively by $(1-\phi_j)$ and ϕ_j.

It is important to note the difference between hedonic adaptation and addiction. The key feature of addiction is that the marginal utility changes with the cue (Laibson, 2001). On the contrary, it is straightforward to see in the case above that the marginal utility from current consumption is not affected by the cue, c_j^{t-1}. Nevertheless, we must note that Nature could achieve a similar outcome by using a contract where the marginal utility changes with the cue, such as $\ln\left(c_j^t-\phi_j c_j^{t-1}\right)$. Similarly, as explained in Rayo and Becker (2007), Nature can attain hedonic adaptation by using other benchmarks, like the consumption of peers. The question of why Nature prefers one benchmark over another (e.g., autoregressive utility, addiction, expected consumption) is well beyond the scope of this paper. However, we would like to emphasize that there are more ''direct'' evolutionary explanations for the emergence of utility functions with features like peer comparisons and addiction (e.g., Samuelson, 2004; Smith and Tasnádi, 2007).

We assume that the agent does not anticipate hedonic adaptation.[15] This last assumption has to hold only during the human evolutionary history, which is a reasonable assumption to make. Indeed, because the reward systems in our brain have a long evolutionary history, the condition would have to apply for the organisms whose evolution shaped the ancient parts of our brain. Also, note that it is an entirely different issue whether modern humans do or do not anticipate hedonic adaptation, a discussion that we leave for the next section when we explore the modern-time welfare implications of hedonic adaptation. Additionally, we assume that the agent cannot store consumption units. As a result, the agent faces a repetition of static problems.

For the sake of simplicity, we assume that Nature maximizes the average fitness over the four possible scenarios $\kappa_t=\kappa_{t-1}=\underline{\kappa},\ \kappa_t=\kappa_{t-1}=\bar{\kappa},\ \{\kappa_t=\underline{\kappa},\kappa_{t-1}=\bar{\kappa}\}$, and $\{\kappa_t=\bar{\kappa},\kappa_{t-1}=\underline{\kappa}\}$, weighted by the probabilities $\frac{1}{2}q$, $\frac{1}{2}q$, $\frac{1}{2}(1-q)$ and $\frac{1}{2}(1-q)$, respectively.[16] The agent still chooses $c_j=\frac{b_j}{b_1+b_2}\kappa$, so the value of the ϕ_j's do not affect the agent's consumption. As a result, the problem of choosing $\{a_j,b_j,\phi_j\}_{j\in\{1,2\}}$ is equivalent to the problem of choosing $\{\bar{a}_j,\underline{a}_j,b_j\}_{j\in\{1,2\}}$:

$$U_j\left(c_j^t;\bar{a}_j,\underline{a}_j,b_j\right)=\begin{cases}\bar{a}_j+b_j\ln\left(c_j^t\right) & \text{if } \kappa_{t-1}=\overline{\kappa}\\ \underline{a}_j+b_j\ln\left(c_j^t\right) & \text{if } \kappa_{t-1}=\underline{\kappa}\end{cases}$$

In other words, choosing the rates of adaptation $\{\phi_1,\phi_2\}$ is equivalent to choosing environment-specific ''intercepts'' for the utility functions, $\{\bar{a}_j,\underline{a}_j\}$.[17]

First, we must note that if $v_5=0$ then Nature could choose $\bar{a}_1=\underline{a}_1=\bar{a}_2=\underline{a}_2=0$ and b_1 and b_2 arbitrarily small but with a ratio of $\frac{b_1}{b_1+b_2}=\frac{1}{1+v_2}$, and as a consequence she would attain the maximum fitness in all environments. Thus, when $v_5=0$ Nature has no need for using adaptive contracts. On the contrary, when $v_5>0$ then hedonic adaptation arises. Define $E\bar{U}_j^*$ $(E\underline{U}_j^*)$

[14] This specification is convenient because it allows for tractable results. It is true that, technically speaking, this penalty term punishes the function (U_2) for going above (U_2^*). However, for the equilibrium the only thing that matters is the quadratic penalty for going below (U_2^*) in a pointwise sense).

[15] This assumption is relevant insofar Nature uses differential adaptation, as will become clear in Section 3. As long as learning about adaptation is incomplete, the results would be qualitatively similar in a model where the agent learns about adaptation over time.

[16] This assumption is just meant to simplify the notation, and does not change the qualitative results by any means. It is helpful by ensuring that: i. the first-period utility does not matter; and ii. there is no additional notation related to Nature's discount rate over the agent's lifetime.

[17] The equivalence is given by: $\bar{a}_j=a_j-\phi_j\left[a_j+b_j\ln\left(\frac{b_j}{b_1+b_2}\bar{\kappa}\right)\right]$ and $\underline{a}_j=a_j-\phi_j\left[a_j+b_j\ln\left(\frac{b_j}{b_1+b_2}\underline{\kappa}\right)\right]$.

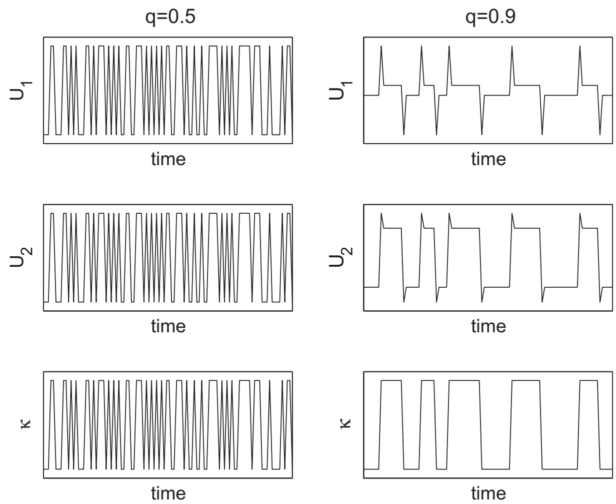

Fig. 1. Simulated outcomes corresponding to a calibration of the model used in the proposition.

as the expected utility for the current period when $\kappa_{t-1} = \bar{\kappa}$ ($\kappa_{t-1} = \underline{\kappa}$). We assume $q > \frac{1}{2}$ (it is straightforward to adapt the proposition for the case $q < \frac{1}{2}$).

Proposition 1. *Under Nature's optimal contract:*

i. $E\overline{U}_1^* - E\underline{U}_1^* = 0$.
ii. $E\overline{U}_2^* - E\underline{U}_2^* > 0$.
iii. $\frac{db_2}{dv_5} \geqslant 0$ *implies* $\frac{d\left(E\overline{U}_2^* - E\underline{U}_2^*\right)}{dv_5} > 0$.

The proof is in the Appendix. Part (i) says that U_1 is fully adaptive: i.e., the expected utility is the same across all possible environments. Nature chooses $\{\bar{a}_1, \underline{a}_1\}$ as to neutralize the expected intensity of the first sensation. This is not surprising, as a higher intensity of that sensation has fitness costs, $\frac{v_3}{2} U_1(c_1)^2$, but no benefits. Because $q > \frac{1}{2}$, if the past environment was good (bad) then it is more likely that the current environment will be good (bad). As a response, Nature uses an "intercept" for U_1 which is lower when the environment was good (and thus it is expected to remain good) and higher when the environment was bad (and thus it is expected to remain bad). Suppose that the agent transitions from the bad environment to the good environment. The agent will experience positive utility in U_1, but the following period (U_1) will adapt downwards, so if the agent happens to be blessed by the good environment again he or she will experience a much lower (positive) utility in U_1.

With respect to the second sensation, part (ii) says that U_2 is adaptive, but not fully adaptive, because the expected utility is different in different environments. Indeed, part (iii) shows that the importance of warning/defense roles, v_5, exacerbates the deviation from full adaptation in U_2: the higher v_5 the further away the contract is from equating expected utility across the different environments.[18]

Fig. 1 illustrates the main results with simulations for a calibration of the model. The left panel shows a simulation of 100 periods for $q = 0.5$, while the right panel shows a simulation for $q = 0.9$ – all the rest of the parameters are identical. When $q = 0.5$ the current environment is uncorrelated to the past environment, and thus there is no room for adaptive contracts. As expected, the left panel shows that there is no adaptation at all. On the contrary, the right panel shows that both sensations are adaptive when $q = 0.9$: when the individual goes from the bad state to the good state he or she experiences a positive boost in both sensations, but if the individual remains in the good state in the following period then the sensations partially bounce back towards zero. Moreover, while the first sensation bounces back dramatically, the second sensation (the one with the warning/defense roles) bounces back only slightly. The greater v_5 the more minuscule the bounce of U_2 will be.

2.5. Empirical evidence on differential adaptation

We already mentioned that several empirical studies have tested hedonic adaptation regarding a wide array of situations, most of which find some evidence for adaptation (Frederick and Loewenstein, 1999). It is reasonable to say that it is much easier to become accustomed to the pleasure of eating good food every day than to being punched in the arm every day.[19] Unfortunately, perhaps because it is too obvious, there is little empirical evidence about this claim. To the best of our knowl-

[18] There is a reason why $\frac{db_2}{dv_5} \geqslant 0$ is the interesting case, but for space constraints we do not discuss this in detail.
[19] It is important not to confound hedonic adaptation with sensory habituation.

edge, only a couple of studies have tested hedonic adaptation in sensations with warning/defense roles. Consistent with our predictions, they find no evidence of adaptation.

First, Cometto-Muniz and Cain (1992) studied the human irritant sense, which is the chemical sensitivity of the mucosae (e.g., ocular, nasal). For example, people who lack the sense of smell can detect airborne chemicals only through the irritant sense. The irritant sense makes it impossible for the individual to remain in toxic environments, which we can reasonably assume plays a warning role. As expected, Cometto-Muniz and Cain (1992) found practically no adaptation to pungent, harmful chemicals. Second, Weinstein (1982) studied adaptation to sound perception, which we can also reasonably assume plays a warning role. For example, during our evolutionary history, the auditive system was meant to elicit a quick response in the presence of predators or prey. Weinstein (1982) interviewed a panel of residents for 4 months and 16 months after a highway was opened. As expected, he found no evidence of adaptation to noise, a conclusion that was supported by many subsequent studies.

Finally, we must mention that some studies have argued that chronic pain patients exhibit higher-than-normal thresholds for various types of experimental pain (e.g., Merskey and Evans, 1975). Although this finding would not constitute direct evidence of adaptation to pain, it is still closely related. However, the validity of the findings has been challenged (e.g., Dar et al., 1995). First, the estimates are not experimental estimates but simple mean comparisons, which can merely reflect the fact that those who once were less afraid from getting injured have, on average, more tolerance to pain (Dar et al., 1995). Second, painful experiences may merely change the internal anchor points for the subjective evaluation of pain (Dar et al., 1995). Indeed, Peters and Schmidt (1992) showed that, even though chronic pain patients reported higher tolerance to pain, they did not differ in objective measures, such as nociceptive flexion reflexes.

3. On the consequences of hedonic adaptation

In this section we provide a simple model to illustrate that the prediction of differential adaptation across sensations has important welfare and policy implications. Consider an infinite-horizon model with discrete time. An agent must choose effort (e_t) and consumption (c_t) in every period. The per-period utility (dis-utility) from consumption (effort) is given by $U^c(\cdot)(U^e(\cdot))$. Both sources of utility are discounted by the same factor, δ. Additionally, both sources of utility are subject to mean-reverting hedonic adaptation. For every unit of utility from consumption (effort) at period t, the utility at t+1 will be lower by $\gamma_c(\gamma_e)$ units, where $0 \leqslant \gamma_c \leqslant 1/\delta(0 \leqslant \gamma_e \leqslant 1/\delta)$ is the parameter that determines the degree of hedonic adaptation.

An agent can be naïve, which means that he does not anticipate hedonic adaptation, or sophisticated. Let superscripts n and s denote those cases, respectively. By construction, a naïve agent maximizes the following lifetime utility:

$$U_n = \sum_{s=t}^{\infty} \delta^s [U^c(c_t) + U^e(e_t)]$$

While a sophisticated agent maximizes:

$$U_s = \sum_{s=t}^{\infty} \delta^s [(1 - \delta\gamma_c)U^c(c_t) + (1 - \delta\gamma_e)U^e(e_t)]$$

By definition, any difference in behavior between the naïve and sophisticated agents must be interpreted as sub-optimal behavior by the naïve agent. Denote $C = \{c_s\}_{s=t}^{\infty}$ and $E = \{e_s\}_{s=t}^{\infty}$. Let BC be the set of consumption and effort choices, $\{C,E\}$, that satisfy the lifetime budget constraint. We can re-write the problem of an agent of type $i \in \{n,s\}$ in the following manner:

$$\max_{\{C,E\} \in BC} \sum_{s=t}^{\infty} \delta^s [U^c(c_t) + \kappa^i U^e(e_t)]$$

where $\kappa^n = 1$ and $\kappa^s = \frac{(1-\delta\gamma_e)}{(1-\delta\gamma_c)}$. There are two immediate results. First, if all sensations were subject to the same rate of adaptation $\gamma_c = \gamma_e = \overline{\gamma}$, then $\kappa^s = \kappa^n$ and thus a naïve agent would behave as a sophisticated. Naïve agents misperceive the level of utility that they will obtain, but they still make optimal choices. On the contrary, if the rates of adaptation are differential (i.e., $\gamma_c \neq \gamma_e$), then the problems of the naïve and the sophisticated agents differ. Therefore, the naïve agent makes suboptimal choices. Because κ^i enters as a weight on the per-period utility from effort, the Euler equation is not affected by κ^i. The only difference between naïve and sophisticated agents arises in the intra-temporal allocation between consumption and effort (more generally, between activities subject to different degrees of hedonic adaptation).

Because the naïve agent does not anticipate that one type of pleasure adapts more than the other, he or she chooses too much of the action that elicits the more adaptive sensation. Indeed, hedonic adaptation can be seen as a special case of the "projection biases" discussed in Loewenstein et al. (2003). For instance, sensations associated with the displeasure from working may be more likely to have warning/defense roles (e.g., pain, stress) and therefore be less adaptive than those sensations associated with consumption (e.g., eating, having fun). As a consequence, the model would predict that naïve agents will work too hard (or equivalently, consume too much). Last, note that the behavioral bias of the naïve agent can be easily corrected by imposing a Pigou tax on consumption (more generally, on the activity whose utility adapts with a higher rate).

Because no sub-optimal behavior would arise if people anticipated adaptation correctly, the key question is whether people in modern times anticipate adaptation. The evidence suggests that people do not fully anticipate that some hedonic states will bounce back to "normal" levels after a bad or good event. For example, Riis et al. (2005) found that hemodialysis patients eventually obtain a level of happiness similar to that of healthy people, but at first, when trying to forecast, these patients fail to anticipate this bounce back in well-being.[20] Indeed, there is vast evidence on imperfect affective forecasting beyond the particular case of hedonic adaptation (for an extensive review, see Loewenstein and Schkade, 1999; Loewenstein et al., 2003). However, we must note that recent studies have challenged the validity of the existing evidence on hedonic adaptation (e.g., Smith et al., 2006; for a discussion, see Loewenstein & Ubel (2008)).

Last, we could analyze a model where people are not fully naïve but ''learn'' about γ over time while cognitively processing past information on stimuli and hedonic responses. As a result, they become increasingly aware of hedonic adaptation over time. This response would make the model more complex, but asides from the reduced scale of the magnitudes, the results would be qualitatively similar. In other words, instead of asking whether people anticipate adaptation, the question would become whether learning about hedonic adaptation is complete. Interestingly, the evidence suggests that people fail to anticipate adaptation even if the event is experienced more than once (Frederick and Loewenstein, 1999).

4. Conclusions

We showed that the warning/defense roles of some sensations give Nature a reason to use adaptive utility functions. Contrary to the existing evolutionary explanations for hedonic adaptation, our theory can accommodate the evidence that the rates of adaptation are differential (i.e., while sensations without warning/defense roles are adaptive, sensations with such roles are not). If modern humans do not fully anticipate adaptation, then the differential rates of adaptation have welfare and policy consequences because agents will overconsume those goods whose utility adapts relatively more.[21] We hope that our model provides further theoretical support for the incorporation of adaptive utility functions into economic models (e.g., income aspirations and consumption habituation). Those features can increase the predictive power of economic models and provide more accurate welfare/policy analyses.

Finally, a second contribution of the paper is the introduction of the warning/defense roles. This assumption may have other interesting implications beyond the evolutionary origin of hedonic adaptation. For instance, policy recommendations often rely—implicitly or explicitly—on interpersonal utility comparisons (e.g., when the policy-maker maximizes a utilitarian social welfare function). If utility only matters in an ordinal sense, then there are no reasons to believe that utility is comparable across different people. On the contrary, the warning/defense roles suggest that –from an evolutionary viewpoint– experienced utility can also matter in a cardinal sense. Therefore, the warning/defense roles may imply that some sensations (e.g., pain) could be comparable across different individuals.

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Appendix A. Proof of Proposition

Nature's objective function is:

$$\begin{aligned}
&\ln\left(\frac{b_1}{b_1+b_2}\right) + v_2 \ln\left(\frac{b_2}{b_1+b_2}\right) + \frac{1+v_2}{2}\ln(\bar{\kappa}) \\
&-\frac{v_5}{4}\left(\left(\bar{a}_2 - a_2^*\right)^2 + 2\left(\bar{a}_2 - a_2^*\right)\left(b_2 - b_2^*\right)\Omega_1 + b_2^2\Omega_2 + \left(\underline{a}_2 - a_2^*\right)^2 + 2\left(\underline{a}_2 - a_2^*\right)\left(b_2 - b_2^*\right)\Omega_1 + b_2^2\Omega_2\right) \\
&-\frac{q}{4}\left[v_3\left(\bar{a}_1 + b_1\ln\left(\frac{b_1}{b_1+b_2}\bar{\kappa}\right)\right)^2 + v_4\left(\bar{a}_2 + b_2\ln\left(\frac{b_2}{b_1+b_2}\bar{\kappa}\right)\right)^2\right] \\
&-\frac{1-q}{4}\left[v_3\left(\bar{a}_1 + b_1\ln\left(\frac{b_1}{b_1+b_2}\right)\right)^2 + v_4\left(\bar{a}_2 + b_2\ln\left(\frac{b_2}{b_1+b_2}\right)\right)^2\right] \\
&-\frac{q}{4}\left[v_3\left(\underline{a}_1 + b_1\ln\left(\frac{b_1}{b_1+b_2}\right)\right)^2 + v_4\left(\underline{a}_2 + b_2\ln\left(\frac{b_2}{b_1+b_2}\right)\right)^2\right] \\
&-\frac{1-q}{4}\left[v_3\left(\underline{a}_1 + b_1\ln\left(\frac{b_1}{b_1+b_2}\bar{\kappa}\right)\right)^2 + v_4\left(\underline{a}_2 + b_2\ln\left(\frac{b_2}{b_1+b_2}\bar{\kappa}\right)\right)^2\right]
\end{aligned}$$

The FOCs w.r.t. the intercepts are:

$$\bar{a}_1 : \bar{a}_1 = -b_1 \ln\left(\frac{b_1}{b_1+b_2}\bar{\kappa}^q\right) \tag{A.1}$$

[20] A standard counter-argument is that people may anticipate adaptation at an unconscious level.

[21] Hedonic adaptation can have other implications for the policy-maker, which may or may not depend on whether adaptation is differential.

$$\underline{a}_1 : \underline{a}_1 = -b_1 \ln\left(\frac{b_1}{b_1+b_2}\bar{\kappa}^{1-q}\right) \tag{A.2}$$

$$\bar{a}_2 : \bar{a}_2 = -\frac{v_5}{v_4+v_5}\left(-a_2^* + \left(b_2 - b_2^*\right)\Omega_1\right) - b_2 \ln\left(\frac{b_2}{b_1+b_2}\bar{\kappa}^{q}\right)\frac{v_4}{v_4+v_5} \tag{A.3}$$

$$\underline{a}_2 : \underline{a}_2 = -\frac{v_5}{v_4+v_5}\left(-a_2^* + \left(b_2 - b_2^*\right)\Omega_1\right) - b_2 \ln\left(\frac{b_2}{b_1+b_2}\bar{\kappa}^{1-q}\right)\frac{v_4}{v_4+v_5} \tag{A.4}$$

For obvious space constraints we do not reproduce the FOCs with respect to b_1 and b_2, as well as the SOCs.

By definition:

$$E\overline{U}_j^* \equiv \bar{a}_j + qb_j \ln\left(\frac{b_j}{b_1+b_2}\bar{\kappa}\right) + (1-q)b_j \ln\left(\frac{b_j}{b_1+b_2}\right) = \bar{a}_j + b_j \ln\left(\frac{b_j}{b_1+b_2}\bar{\kappa}^q\right)$$

$$E\underline{U}_j^* \equiv \underline{a}_j + qb_j \ln\left(\frac{b_j}{b_1+b_2}\right) + (1-q)b_j \ln\left(\frac{b_j}{b_1+b_2}\bar{\kappa}\right) = \underline{a}_j + b_j \ln\left(\frac{b_j}{b_1+b_2}\bar{\kappa}^{1-q}\right)$$

Combining these conditions with (A.1) and (A.2) we get:

$$E\overline{U}_1^* = E\underline{U}_1^* = 0$$

Which implies $E\overline{U}_1^* - E\underline{U}_1^* = 0$. This proves part (i). Next we combine the definitions of $E\overline{U}_2^*$ and $E\underline{U}_2^*$ with (A.3) and (A.4) to get:

$$E\overline{U}_2^* \equiv \bar{a}_2 + b_2 \ln\left(\frac{b_2}{b_1+b_2}\bar{\kappa}^q\right) = -\frac{v_5}{v_4+v_5}\left(-a_2^* + \left(b_2 - b_2^*\right)\Omega_1\right) + b_2 \ln\left(\frac{b_2}{b_1+b_2}\bar{\kappa}^q\right)\frac{v_5}{v_4+v_5}$$

$$E\underline{U}_2^* \equiv \underline{a}_2 + b_2 \ln\left(\frac{b_2}{b_1+b_2}\bar{\kappa}^{1-q}\right) = -\frac{v_5}{v_4+v_5}\left(-a_2^* + \left(b_2 - b_2^*\right)\Omega_1\right) + b_2 \ln\left(\frac{b_2}{b_1+b_2}\bar{\kappa}^{1-q}\right)\frac{v_5}{v_4-v_5}$$

Substracting one from the other:

$$E\overline{U}_2^* - E\underline{U}_2^* = (2q-1)b_2 \ln(\bar{\kappa})\frac{v_5}{v_4+v_5} > 0$$

This proves part (ii). Finally, we differentiate the last expression with respect to v_5:

$$\frac{d\left(E\overline{U}_2^* - E\underline{U}_2^*\right)}{dv_5} = \frac{db_2}{dv_5}(2q-1)\ln(\bar{\kappa})\frac{v_5}{v_4+v_5} + (2q-1)b_2\ln(\bar{\kappa})\frac{v_4}{\left(v_4+v_5\right)^2}$$

So $\frac{db_2}{dv_5} \geqslant 0$ implies that the above expression is positive, which completes part (iii).

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