serie ad
WP-AD 2018-04

The Evolution of Self-Control in the Brain

David Jimenez-Gomez

La edición y difusión de los documentos de trabajo del Ivie es una actividad subvencionada por la Generalitat Valenciana, Conselleria de Hacienda y Modelo Económico, en el marco del convenio de colaboración para la promoción y consolidación de las actividades de investigación económica básica y aplicada del Ivie.

The editing and dissemination process of Ivie working papers is funded by the Valencian Regional Government's Ministry for Finance and the Economic Model, through the cooperation agreement signed between both institutions to promote and consolidate the Ivie's basic and applied economic research activities.

La Serie AD es continuadora de la labor iniciada por el Departamento de Fundamentos de Análisis Económico de la Universidad de Alicante en su colección "A DISCUSIÓN" y difunde trabajos de marcado contenido teórico. Esta serie es coordinada por Carmen Herrero.

The AD series, coordinated by Carmen Herrero, is a continuation of the work initiated by the Department of Economic Analysis of the Universidad de Alicante in its collection "A DISCUSIÓN", providing and distributing papers marked by their theoretical content.

Versión: julio 2018 / Version: July 2018

Edita / Published by:
Instituto Valenciano de Investigaciones Económicas, S.A.
C/ Guardia Civil, 22 esc. 2 1º - 46020 Valencia (Spain)

DOI: http://dx.medra.org/10.12842/WPAD-2018-04

WP-AD 2018-04

The Evolution of Self-Control in the Brain

David Jiménez-Gómez[*]

Abstract

Temptation and self-control evolved as single mechanism to make humans behave against their own self-interest. I analyze the evolution of self-control in a principal-agent framework, in which the agent has access to private information but his utility cannot depend on all relevant variables. The principal can obtain the first best asymptotically by biasing the utility of the agent (from which an endogenous conflict emerges) and simultaneously endowing the agent with a limited amount of self-control.

Several empirical properties of self-control, observed in psychological experiments, are explained in terms of the model: 1) self-control grows over time as it is exercised; 2) self-control is lower when the level of glucose in the blood is low, but does not depend on a physical resource; 3) as the environment becomes more tempting, individuals exhibit less self-control. The model sheds light on the difference between self-control and hyperbolic discounting and provides a framework for understanding the recent surge of chronic non-communicable diseases, suggesting that the current environment could be welfare-reducing.

Keywords: neuroeconomics, evolution of preferences, self-control.

JEL: D60, D90, C72, D81.

---

[*] Universidad de Alicante. Email: davidjimenezgomez@ua.es. I thank Daron Acemoglu, Benjamin Brooks, Luigi Butera, Dana Chandler, Alexander Franklin, Max Kleiman-Weiner, Hugo Sonnenschein, Josh Tenenbaum and the members of his research group, Citlalli Vivar, and Nils Wernerfelt for their comments.

1 Introduction

Conventional wisdom says that more self-control is always better, and therefore that self-control evolved because it helped individuals. This idea is so ingrained in our culture, that it can even be found in the introduction to two well-known books on self-control (Baumeister and Tierney, 2011; McGonigal, 2011). I argue, however, that temptation and self-control evolved as a single mechanism to make people behave against their own self-interest. But what exactly is self-control? According to Gailliot *et al.* (2007): "Self-control (or self-regulation) is the ability to control or over-ride one's thoughts, emotions, urges, and behavior."[1] There are several reasons why scholars and policymakers alike should be interested in self-control: higher levels of self-control are correlated with lower incidence of mental illness, less alcohol abuse and better emotional responses (Tangney *et al.*, 2004).[2] Moreover, self-control has been recognized as a necessary component of interpersonal interactions, and people who have more self-control are better educated, wealthier and healthier (Mischel, 2014). Perhaps more impressively, self-control is a better predictor of college grades than IQ or SAT score (Duckworth and Seligman, 2005).

---

[1] For an alternative definition, Ainslie (2001) writes that the *will* is "the faculty by which we impose some overriding value of ours on the array of pressures and temptations that seem extrinsic."

[2] Baumeister *et al.* (1994) go as far as to consider lack of self-control as "the major social pathology of our time".

For centuries, thinkers have considered the presence of conflicting preferences, and the need for self-control. For example, Plato compared the human mind to a chariot pulled by two horses: one horse is noble and virtuous, the other is base and vicious; the driver of the chariot needs to take control of these (conflicting) horses.[3] In modern Economics, Schelling (1978) and Thaler and Shefrin (1981), among many others,[4] proposed a model where behavior is the outcome of two conflicting modules. I follow this intellectual tradition, and consider self-control as arising from an endogenous conflict between the genes and the human individual. I propose a Principal-Agent model, where natural selection is represented by the Principal, and the human individual by the Agent. Natural selection maximizes the replication of genes (adaptive fitness) subject to constraints. Despite the fact that evolution is a mindless process with no goal,[5] we can derive insightful conclusions by using a Principal-Agent model precisely because natural selection maximizes adaptive fitness. This approach has been quite successful at providing explanations for a variety of features in human behavior.[6] The Agent has superior information (relative to the Princi-

---

[3] In *Phaedrus* (Haidt, 2006). Other classic authors who studied this problem include Adam Smith (Smith, 1759) and Sigmund Freud, who developed an influential theory of the mind divided in ego, id, and superego, where the id has primal desires, the superego strives to comply with moral and social norms, and the ego mediates between the two, Freud (1961).

[4] Loewenstein (1996) argues that "visceral factors", which can be understood as a present-biased, non-strategic self, are the cause of behavior that is against the individual's self-interest. More recently, Economists have modeled self-control issues as a game between multiple selves, Bernheim and Rangel (2004), Benhabib and Bisin (2005), Fudenberg and Levine (2006).

[5] That is, evolution is not teleological, meaning that evolution is the result of random mutations and natural selection, and there is no final "objective" to which evolution strives.

[6] The approach has yielded insights into: why people have preferences in the first place, instead of automatic behaviors (Robson, 2001), conspicuous consumption, (Samuelson, 2004), utility dependence on unchosen alternatives (Samuelson and Swinkels, 2006), hedonic adaptation (Rayo and Becker, 2007), time and risk preferences (Netzer, 2009), hedonic forecast bias (Robson and Samuelson, 2011). See Robson and Samuelson (2010) for a review of the literature.

pal) with respect to a variable that represents idiosyncratic details of the environment, and therefore the Principal has an incentive to extract this information from the Agent. The Principal chooses the utility function of the Agent and, upon receiving information from the Agent, the action to be implemented. If there were no further constraints, the Principal could achieve the first best simply by choosing an unbiased utility for the Agent. However, the evidence from neuroscience (which I review in Section 2) shows that the brain is composed of several more-or-less independent modules, and that these modules can generate conflicting behavior (Livnat and Pippenger, 2006). Because the evolution of the human brain was constrained by an initial structure which exhibited this separation into modules, and because these different modules are isolated from each other, I make the reasonable assumption that the evolution of the brain was constrained in the amount of information that could be used by the Agent. Formally, this is captured in the model by the Principal being constrained in the *arguments* she can use to generate the Agent's utility function. What I argue in this paper is that the way natural selection balanced the functioning of these conflicting modules was by endowing the human individual with a certain degree of autonomy, so that it could adapt to a changing environment, while at the same time limiting that autonomy by providing a "self-control budget".

This idea is more easily illustrated through an analogy, used in Frankel (2014). Consider a school, where the teacher knows the students in her class well, and can assess them accurately. However, the teacher's salary depends on the student's evaluations, which in turn can be influenced by their grade. Because of that, the teacher has an incentive to inflate grades. The school principal can still extract the teacher's knowledge about the students, by giving her a grade distribution (so many As, so many Bs, etc.) over which she must grade the students. In this way, the teacher will give the best possible grades to the students *as a whole*, given the distribution, but will also preserve the relative distribution of grades (i.e. better students will get better grades). The same intuition applies to the evolution of the human brain. The Principal (natural selection) biases the Agent (the human individual) in the direction of respecting the social norms, because this was the optimal solution to an evolutionary constraint. At the same time, natural selection endows the Agent with a limited amount of self-control, so that the Agent respects social norms only when they are truly costly to break. The key insight is that the optimum can be achieved, by having a biased Agent while simultaneously providing a constraint on the decisions he can take, by *linking the decisions* (Jackson and Sonnenschein, 2007), through a self-control budget.[7]

The structure of the paper is as follows. Section 2 discusses the relevant evidence from psychology and neuroscience. In Section 3 I show that when the number of decisions grows large, the Principal can achieve her first-best payoff.[8] The main result of this paper is Proposition 1, where I show that if the Principal cannot condition the Agent's utility on all the relevant variables, the Principal will bias the Agent's utility to exploit his information while simultaneously endowing the Agent with a limited budget of self-control in order to discipline him, still achieving the first best asymptotically. While the Principal could always choose an unbiased utility function for the Agent (in which case no conflict would exist), that would not be optimal, because the Principal could not extract all the relevant information from the Agent.

The model presented in this paper can also explain several other interesting facts about self-control. In Section 4, I extend the model in several directions, to account for many of the empirical facts about self-control observed in the psychology literature. A straightforward implication is that when someone uses self-control for a task, she will have less amount of willpower left for subsequent tasks, Proposition 4. This is simply because self-control is a

---

[7] This paper is related to a literature on "veto-based delegation", in which the principal chooses a default option and allows the agent to choose the action only within a certain set of options – otherwise the default decision is implemented, Mylovanov (2008), Alonso and Matouschek (2008). It is also related to models where the Principal selects a biased Agent: in Aghion and Tirole (1997) the Principal gives control to the biased Agent to generate incentives to collect information; in Che and Kartik (2009) a Principal who can choose from a pool of Agents (including unbiased ones), will choose a biased Agent while retaining control so that the Agent has an incentive to collect information in order to convince the Principal. In my model, the Principal can choose the utility function of the Agent but is constrained in the arguments she can include in the Agent's utility, and therefore she will endogenously choose to bias him (to extract more accurate information for the Agent) and simultaneously discipline him through a self-control budget.

[8] A related paper, Frankel (2014), incorporates decision linkage in a principal-agent framework, and shows that the principal can achieve the first best by rationing the choices of the agent across several decisions. Moreover, under quadratic loss functions and agent's constant bias, budgets are max-min optimal. The main difference is that in this paper the Agent's utility function is not exogenous but rather chosen by the Principal.

budget, and using more of on a task leaves less left for other tasks (Baumeister and Tierney, 2011). Psychologists have also observed that when a person exercises self-control regularly, her stock of willpower grows over time, Proposition 5 (Oaten and Cheng, 2006b, 2007). This is because if the environment is changing over time, the Principal can do better by allowing the budget to endogenously change to better match the environment. Finally, psychologists have observed that when people have a low level of glucose in the blood, they exert less self-control, Proposition 6. I show that this can be true of any signal that is correlated with the Agent "doing worse" (and hence having less value for the Principal), and argue that the model is consistent with self-control being a function of the glucose level on the blood, without necessarily consuming glucose to exert self-control.

In Section 5, I discuss the welfare implications of the model. Firstly, I argue that economists should be very careful in distinguishing self-control from hyperbolic discounting, because they are two distinct phenomena with very different welfare implications. In particular, the social planner might want to satisfy the time-inconsistent wishes of an individual with hyperbolic discounting, but not those of an individual with self-control problems: this is because the preferences about the present for a hyperbolic discounting should always be honored, whereas someone with self-control problems might *do things that they don't actually want*. Moreover, because the current environment is more tempting than the environment where our genes evolved, people might not have enough self-control to make the right decisions on all their choices, what entails a reduction in welfare, Proposition 7. Section 6 concludes. Proofs of the results can be found in the Appendix.

2 Evidence from psychology and neuroscience

There is ample evidence that the brain and the mind are modular (they are composed of several more-or-less insulated modules which do not necessarily share information); and behavior stems from a conflict between competing processes Fodor (1983); Sanfey *et al.*

(2006).[9] Fodor (1983) argued that several cognitive processes take place at specialized brain modules. Two of the main characteristics that Fodor ascribed to these modules are: 1) domain specificity (each module specializes in a given task); and 2) they are informationally encapsulated: modules do not share most of their information with other modules (Cartwright, 2007). Informational encapsulation is similar to computer programs which do not share their intermediate computations, only the final output (Kurzban, 2012).[10] Moreover, it has been showed that an area in the brain, namely the ventromedial prefrontal cortex (vmPFC) is responsible for valuation of different alternatives (Kable, 2013), and exercising self-control happens by activating another area, the dorsolateral prefrontal cortex (DLPFC), which modulates the value signal in the vmPFC (Hare *et al.*, 2009).[11]

In addition to the experimental evidence mentioned above, and even more relevant for this paper, there is a small literature that shows how the modularity of the mind could have evolved. Livnat and Pippenger (2006) argue that, from a computational point of view, a mind that evolved to solve complex tasks would be composed of a number of conflicting modules which solve simpler tasks. The intuition for this result is that the cost of solving a complex task is not linear: the cost of solving a number of simple tasks, the combination of which yields a solution to the complex problem, is smaller than the cost of solving the original problem directly. Within Economics, Bisin and Iantchev (2017) show a similar result, namely that a hierarchical mind with conflicting modules is evolutionarily adaptive.[12]

---

[9] According to Sanfey *et al.* (2006): "There is a long legacy of research within psychology, strongly supported by findings from neuroscience, to suggest that human behavior is not the product of a single process, but rather reflects the interaction of different specialized subsystems. Although most of the time these systems interact synergistically to determine behavior, at times they compete, producing different dispositions towards the same information." (Ainslie, 2001, p.43) agrees with this view: "This process – power bargaining made necessary by finite means of expression – may be all that unifies a person. [...] The factor that impels towards unity the various behavioral tendencies that grow from a person's rewards may be the realization that they are, in effect, locked up in a room together". See also McClure *et al.* (2004), and Haidt (2006) for a book-length treatment for the general public.

[10] Fodor (1983) was actually skeptical about he modularity of higher cognitive functions.

[11] Notably, when the choice task is reframed in such a way that temptation is reduced, the choice that previously required self-control can be taken without extertion of self-control (i.e. activation of the DLPFC Magen *et al.*, 2014).

[12] Other authors that advance this thesis are Brocas and Carrillo (2008) and Kurzban (2012). I would like to emphasize that I am not arguing that there exactly two subsystems in the mind. The evidence I have presented suggests that the mind is composed of N modules, with N potentially much larger than one. In order to make my argument clear, I have simplified the model presented in this paper, and therefore I have chosen to consider only the case of two modules, because that is the simplest possible case with $N > 1$. However, the argument in

In psychology, there is a literature on self-control which claims that self-control becomes depleted in the short-run (exerting previous acts of self-control makes it more difficult to subsequently exert self-control), what is known as **ego depletion** (Baumeister *et al.*, 1998; Muraven *et al.*, 1998). However, while a 2010 meta-analysis found this effect to be robust (Hagger, 2010), a more recent meta-analysis which used a methodology that accounted for small sample experiments and publication bias, found a zero effect (Carter and McCullough, 2014). A multi-lab replication of a classic version of the experiment used to determine the ego depletion phenomenon also failed to find an effect distinguishable from zero (Hagger and Chatzisarantis, 2016). While I use some of the results in this literature to provide intuition, the results in this paper do not rely on the validity of the ego depletion effect.

3 The Model

> Everything should be made as simple as possible, but not simpler.
>
> – Albert Einstein

The model I present is quite streamlined, and purposefully so: I have left out every superfluous element of the evolution of the human mind, in order to focus on the evolution of self-control as an optimal disciplining mechanism. Whenever important assumptions or simplifications are made, I have provided a justification for their plausibility, based on the current evidence we have from psychology and neuroscience.

There are two players: the Principal, which stands for the evolutionary process,[13] and the Agent, which represents the human individual.[14] The Principal's objective is to maximize fitness y, interpreted as quality-adjusted offspring. There are two possible actions available,

---

this paper can be easily extended to any $N > 2$, and in particular I do not endorse any of view of a "dual self" or a "dual mind", except when used as a metaphor for a modular mind.

[13] Even though I consider the evolutionary process as the Principal in this model, this should be understood as the undirected and unconscious process of Natural selection. No design or teleology is implied. See Robson and Samuelson (2010) for a review paper on the literature that takes the approach of modeling the evolutionary process in a Principle-Agent relationship; and the Introduction for a more thorough discussion.

[14] In particular, the Agent represents what has lately been called "System 2" (Kahneman, 2011), i.e. the brain areas associated with reflective, logical thinking.

$a \in \{0, 1\}$. Action 1 is to be interpreted as a long-term investment, which will yield a fitness payoff in the future, such as following social norms. Action 0, on the contrary, yields short-term fitness gains, at the expense of the future: for example, breaking social norms by having a sexual encounter outside of marriage (Buss, 2015, Ch. 6). Adaptive fitness (i.e. quality-adjusted offspring produced) is given by $y = \xi(a)$. For notational simplicity, in the following I will denote $\xi(1) = \xi^1$, and $\xi(0) = \xi^0$.

The Principal (but not the Agent) observes ξ^0, which should be interpreted as a long-term but hard to observe characteristic, such as the importance of protein and sugar in the diet, or of vitamin D generation (Rayo and Robson, 2017), and which is independent of social norms. Variable ξ^0 is generated randomly according to distribution G, which I assume to be strictly concave and differentiable.[15] The Agent (but not the Principal) observes ξ^1, which should be interpreted as a characteristic specific to the complex social environment of the individual (ξ^1 indicates the importance of respecting the social norms at any given moment). Variable ξ^1 is distributed according to distribution F, and ξ^1 and ξ^0 are independent. Higher ξ^1 means that the investment $a = 1$ will yield higher payoffs in the future, whereas higher ξ^0 means that short-term fitness gain is larger. Therefore, when $\xi^1 \geq \xi^0$, the fitness maximizing action is the long-term investment $a = 1$; when $\xi^1 < \xi^0$, short-term fitness gains are more important, and the fitness maximizing action is $a = 0$.

The Principal chooses the utility function $u(\cdot)$ of the Agent,[16] subject to constraints (which I describe below). This follows the previous literature on the evolution of preferences, where the Principal maximizes fitness by choosing the Agent's utility function (Robson and Samuelson, 2010).[17] I depart from this literature in two important aspects. The first is that,

---

[15] An exponential distribution, for example, satisfies this property. The reason for this assumption is that it makes the first-order conditions in the Agent's problem sufficient for an optimal solution; dropping this assumption would require a more convoluted solution that would take away clarity from the main argument.

[16] Robson (2001) showed that the reason an utility function would evolve in the first place is because it allows for flexibility in a fast-changing environment. Since social competition was one of the main causes of the evolution of intelligence, and the social environment can be very fast-changing, it is therefore not surprising that I take the choice of utility function by the Principal as the starting point of my analysis.

[17] Each paper in the literature studies a particular phenomenon by selecting which constraints the Principal faces. For example, Rayo and Becker (2007) derive the fact that happiness adapts over time (the phenomenon known as hedonic adaptation) from two constraints: utility is bounded, and the Agent has a threshold of perception under

although the Principal observes ξ^0, she cannot make the Agent's utility contingent on it.

Assumption 1. *The Principal and the Agent have the following restrictions:*

1. *The Principal observes ξ^0, but not ξ^1.*
2. *The Agent observes ξ^1, but not ξ^0.*
3. *The utility function of the Agent $u(a, \xi^1)$ cannot depend on ξ^0.*

I provide here an intuitive justification for Assumption 1. During the course of human evolution, the human brain greatly increased in size, most likely due to intra-species social competition (Dunbar and Shultz, 2007). Because of that, the aspects of the environment related to social interactions and social norms (which I have identified with ξ^1) had an increase in their evolutionary importance. Social interactions presumably follow a stable structure, what would allow natural selection to include ξ^1 as an argument in the utility function; however, any particular social environment is too fast changing for natural selection to observe (Richerson and Boyd, 2005), hence only the human individual is able to observe ξ^1. Moreover, the brain and the mind are modular, what means that they are composed of several more-or-less insulated modules, which do not necessarily share information (Sanfey *et al.*, 2006; Cartwright, 2007; Kurzban, 2012, see Section 2 for a summary of the neuroscientific evidence). This means that there are at least some relevant variables, such as ξ^0 in the present model, that cannot be observed or included as arguments in the utility function of the individual.

Another departure from the previous literature on the evolution of preferences, stems from the way in which the actions are implemented. In this model, the incentives for the agent of K different choices are linked together with $K > 1$ (as opposed to $K = 1$ in the previous literature). The Agent, after observing signals $(\xi^1_1, \ldots, \xi^1_K)$ sends messages $(m_1, \ldots, m_K) \in \mathbb{R}^K$ to the Principal. Upon observing each signal m_i, the Principal forms beliefs $\eta(\xi^1_i | m_i)$ about the value of ξ^1_i, and then implements the fitness-maximizing action a_i.[18]

---

which cannot differentiate two alternatives with similar utility.

[18] Previous models in the "evolution of preferences" literature assume that although the Principal can choose the

Assumption 2. *The Agent sends messages* $m_1, \dots, m_K$ *over* K *different actions. The Principal chooses actions* $a_1, \dots, a_K$*, in such a way that*

$$a_i = \arg\max_a \mathbb{E}_\eta[\xi(a)|m_i].$$

Let $\mu(m_i) = \int \xi^1 \eta(\xi^1|m_i)\, d\xi^1$, i.e. $\mu(m_i)$ is the mean of ξ^1 after observing m_i, according to the Principal's beliefs $\eta(\xi^1|m_i)$. Then, Assumption 2 implies:

$$a_i = 1 \iff \mu(\xi^1|m_i) > \epsilon_i. \tag{1}$$

Finally, I assume that the Principal has an extra way of disciplining the Agent: the Principal can impose a "budget" B, such that the Agent can only send messages within the budget.

Assumption 3. *The messages* $m_1, \dots, m_K$ *must be such that* $\sum_{i=1}^K m_i \leq B$*.*

Empirically, assumptions 2 and 3 can be thought of as representing the functioning of the dorsolateral prefrontal cortex (DLPFC) in conflict resolution: an area in the human prefrontal cortex that is activated when self-control is exerted, and modulates the valuation of actions that happens in the ventromedial prefrontal cortex (vmPFC Hare *et al.*, 2009). Assumptions 1-3 make this model depart from others in the literature of evolution of preferences. We define the following solution concept similar to that in Jackson and Sonnenschein (2007).

Definition 1. *An* ***Asymptotic Equilibrium*** *is given by a utility function* $u(a, \xi^1)$*, a budget* B*, actions* $a_1, \dots, a_K$ *and messages* $m_1, \dots, m_K$*, with the following properties:*

- ◇ *The Principal chooses a utility function* $u(a, \xi^1)$ *a budget* B*, and actions* a_i *such that she obtains the first best asymptotically, i.e.*

$$\lim_{K\to\infty} \mathbb{P}\left[(a_i)_{i=1}^K = \arg\max \sum_{i=1}^K \xi(a_i)\right] = 1.$$

Agent's utility function, it is the Agent who ultimately has all the control on which action becomes implemented. Instead, I assume that the Principal retains de facto "veto power" (Mylovanov, 2008), and only allows the Agent to implement her preferred actions under certain conditions, which will become clear below.

◇ *The Agent choses* $m_i, \dots, m_K$ *such that it maximizes* $\sum_{i=1}^{K} \mathbb{E}[u(a, \xi_i^1)]$, *subject to the Principal's behavior and to* $\sum_{i=1}^{K} m_i \leq B$

Having defined the main ingredients for the model and the equilibrium concept, I turn now to analyze the behavior of the Agent and the Principal.

3.1 The Agent's Problem

The Agent observes $(\xi_1^1, \dots, \xi_K^1)$ and then chooses messages $m_1, \dots, m_K$, such that $\sum_{i=1}^{K} m_i \leq B$. From the point of view of the Agent, whether the Principal chooses $a_i = 1$ conditional on sending message m_i is a random event, which has probability:

$$\mathbb{P}[\mu(m_i) > \xi_i^0] = G\left(\mu(m_i)\right).$$

Because the Principal chooses a utility function $u(a, \xi^1)$ for the Agent, that is equivalent to choosing function $v(\xi^1)$ defined as $v(\xi^1) := u(1, \xi^1) - u(0, \xi^1)$, therefore:

$$(1 - G(\omega_i))u(0, \omega) + G(m(\omega_i))u(1, \omega_i) = u(0, \omega) + G(m(\omega_i))v(\omega_i).$$

Therefore, the Agent's problem is to choose m_i such that

$$\max \sum_{i=1}^{K} u(0, \omega_i) + G(\mu(m_i))v(\omega_i)$$
$$s.t. \quad \sum_{i=1}^{K} m_i \leq B.$$

Definition 2. *We say beliefs* η *are well-behaved if* μ *is increasing and concave.*

Well-behaved beliefs are such that an increase in m is interpreted as the Agent having observed a higher ξ^1, but with the Principal interpreting further increases in m with decreasing intensity.

Assumption 4. *The Principal's beliefs* η *are well-behaved.*

When beliefs are well-behaved, then the problem is well defined and the first order conditions are sufficient for optimality:

$$g(\mu(m_i)) \cdot \mu'(m_i) \cdot v(\xi_i^1) = \lambda, \qquad \text{and hence} \qquad m_i = \alpha^{-1}\left(\frac{\lambda}{v(\xi_i^1)}\right), \tag{2}$$

where λ is the Lagrange multiplier, g is the derivative of G, and $\alpha(m) = g(\mu(m))\cdot\mu'(m)$.[19]

3.2 The Principal's Problem

The Principal's problem consists on choosing utility function $v(\xi^1)$ for the Agent, as well as a budget B such that m_i comes from the solution to the Agent's problem. The Principal has two tools to influence the behavior of the Agent: by choosing $v(\xi^1)$, the Principal gives the Agent incentives to consider a certain state more important than other; by choosing B, the Principal decides how much to limit the autonomy of the agent. It turns out that these two tools are enough for the Principal to achieve the first best asymptotically.[20]

Proposition 1. *If beliefs are well-behaved, there is a unique Asymptotic Equilibrium with*

$$v(\xi^1) = \frac{c}{\alpha(\mu^{-1}(\xi^1))}, \qquad \textit{and} \qquad \frac{B}{K} = \mathbb{E}[\mu^{-1}(\xi^1)],$$

for any $c > 0$.

The intuition for the result is as follows. Because the Principal cannot include ξ^0 into the Agent's utility function, she chooses a utility function $v(\xi^1)$ for the Agent which is biased towards always choosing action $a = 1$, and the more so the higher ξ^1 is.[21] At the same time, the Principal endows the Agent with a limited amount of self-control B, so that the Agent is constrained in his autonomy. Proposition 1 shows that the Principal can achieve the first best asymptotically, by endowing the Agent with a utility function such that it is optimal for the Agent to choose m_i proportional to ξ_i^1, and then endow the Agent with a budget

---

[19] Since G and μ are concave and increasing by assumption, α is injective and its inverse is well defined.

[20] As it is standard in contract theory, the first-best is defined as the maximal payoff for the Principal *in the absence of constraints*. In this case, it is the maximal utility the Principal could attain if she observed ξ_i^1 and chose a_i directly.

[21] If the Principal wanted to have an unbiased Agent, then she would choose $v(\xi^1) = \xi^1 - \mathbb{E}[\xi^0]$. In this case, the Agent would be unbiased, but the Principal would be unable to combine her information about ξ^0, with the Agent's information about ξ^1. By biasing the Agent through his utility function, and then disciplining him through the budget B, the Principal can do better and achieve the first best.

which is exactly equal to the expected number of truthful messages.

Because the Principal's beliefs do not play an important role in the previous result, we can simply consider a special case in which the Principal believes the Agent is truthful.

Definition 3. *The Principal's beliefs* η *are* ***trusting*** *if* $\mu(\xi^1|m) = m$.

In other words, when the beliefs are trusting, the Principal takes messages at face value, and believes that the expected value of ξ^1 coincides with the message. In this case, the unique Asymptotic Equilibrium takes a simple form that will help with the intuition.

Proposition 2. *If beliefs are well-behaved and trusting, there is a unique Asymptotic Equilibrium with*

$$v(\xi^1) = \frac{c}{g(\xi^1)}, \qquad \textit{and} \qquad \frac{B}{K} = \mathbb{E}[\xi^1].$$

Unlike in the previous literature on decision linkage (Jackson and Sonnenschein, 2007), the utility function of the Agent v is endogenous. The Agent chooses $m_i = g^{-1}\left(\frac{\lambda}{v(\xi_i^1)}\right)$; the Principal chooses $v(\xi^1) = \frac{1}{g(\xi^1)}$, so that $m_i = g^{-1}(\lambda \cdot g(\xi^1))$, and then chooses B such that $\lambda = c$ asymptotically. It is the combination of being able to choose both $v(\xi^1)$ and B that allows the Principal to reach the first best asymptotically.[22] Notice that the constant c in the result does not change behavior, because the Lagrange multiplier is proportional to c. **Therefore, for the rest of the paper I will simply take** $c = 1$**, and hence** $v(\xi^1) = \frac{1}{g(\xi^1)}$. Observe that $v(\xi^1)$ is increasing in ξ^1,[23] so the Agent cares more about $a = 1$ being implemented in states where ξ^1 is higher. In a sense, the Principal makes the Agent an "advocate" of action $a = 1$ (respecting the social norms). The intuition follows other models on decision linkage such as Jackson and Sonnenschein (2007) and Frankel (2014): although the Principal cannot observe ξ^1, she can incentivize the Agent to reveal ξ^1 truthfully by restricting the messages she can send. Even if the Agent has an incentive to send high m_i

---

[22] Note that the Principal can achieve the first best asymptotically even if the Agent had distorted beliefs. If the Agent believed that $\xi^0 \sim \tilde{G}(\xi^0)$, all the previous arguments hold if the Principal chose $v(\xi^1) = \frac{1}{\tilde{g}(\xi^1)}$. The only requirement is that, in that case, the distorted beliefs operate in an evolutionarily long time – an assumption which is made for example by Rayo and Robson (2017).

[23] As $g(\xi^1)$ is strictly decreasing by virtue of $G(\xi^1)$ being strictly concave in ξ^1.

(because $v(\xi^1)$ is increasing in ξ^1), the Principal can discipline the Agent by limiting the amount of messages the Agent can send. Because of that, the Agent has an incentive to send high m_i only when ξ_i^1 is truly high. Going back to the example in the Introduction, this is analogous to the principal of a school choosing an incentive scheme $v(\cdot)$ that encourages teachers to inflate grades, but who sets a cap B on the number of students who can receive a grade of "A", while allowing the teacher to choose which students get each grade.

Therefore, for natural selection, there is a sort of "self-control Laffer curve": too little self-control is detrimental because the individual cannot convey the relevant information about the environment and always succumb to temptation, whereas too much self-control implies that the individual can always implement his preferred action, what is not evolutionary adaptive. Hence, against the naive intuition that "more self-control is always more adaptive", there is actually an optimal amount of self control that maximizes genetic fitness.

3.3 Dynamic Choice

So far, the problem we have analyzed had the Agent observing $(\xi_i^1)_{i=1}^K$, and then making the choice of m_i. However in real life decisions do not happen simultaneously, but rather as they appear into one's life. In this section I will show that, asymptotically, the solution for the static and the dynamic problem coincide.[24] Suppose that the Principal chooses the same utility function $v(\xi^1) = \frac{1}{g(\xi^1)}$ and budget $B = K \cdot \mathbb{E}[\xi^1]$ which solved the static problem. Moreover, suppose the Agent naively chooses $m_i(\xi^1) = \xi^1$ as long as that option is within the budget, and otherwise chooses the maximal m possible. In other words:

$$m_i = \begin{cases} \xi_i^1 & \text{if } \sum_{j=1}^{i} \xi_j^1 \leq B, \\ \max\left\{B - \sum_{j=1}^{i-1} \xi_j^1, 0\right\} & \text{if } \sum_{j=1}^{i} \xi_j^1 > B. \end{cases} \tag{3}$$

In that case, his average payoff is given by

---

[24] I follow Jackson and Sonnenschein (2007) in solving the static problem first, and then showing that the solutions for the static and dynamic problem are asymptotically identical.

$$\frac{1}{K}\sum_{i=1}^{K} u(0,\xi^1) + G(m_i)\cdot v(\xi_i^1) \to \mathbb{E}_{\xi^1}[u(0,\xi^1) + G(m_i)\cdot v(\xi^1)] = E_{\xi^1}[u(0,\xi^1) + G(\xi_i^1)\cdot v(\xi^1)],$$

That means that the average payoff in the dynamic case converges to the payoff in the static case. We have the following result.

Proposition 3. *For every $\nu > 0$ there exists $\bar{K}$ such that for all $K > \bar{K}$, if the Agent chooses m_i as in Equation 3, he obtains a payoff of at least $\mathbb{E}_{\xi^1}[u(0,\xi^1) + G(\xi^1)\cdot v(\xi^1)] - \nu$.*

If we interpret B as a self-control budget, we can see how the model applies to self-control and impulsivity. Throughout the day, the individual observes a series of situations $(\xi_1^1, \ldots, \xi_K^1)$, and must take a decision at each point in time. The individual always prefers to take action 1, which represents the long-term optimal action that respects social norms (being patient, cultivating relations, etc.). However, the individual's preference varies in intensity with ξ^1. When ξ^1 is low the situation is not really important, and the individual does not exert a lot of self-control. Intuitively, a low ξ^1 would correspond to a situation that has little relevance in the future, for example the possibility of stealing food when nobody will ever find you. In these cases, the individual exerts little self-control, and there is a high likelihood that she will cave in to temptation. On the other hand, a high ξ^1 corresponds to a situation which has large payoffs in the future, for example sharing a little bit of food with a hungry neighbor, who might return the favor in turn and save you from starvation down the line.

Asymptotically, the Principal achieves the first best. The individual behaves impulsively choosing $a = 0$ when the immediate reward is greater than the long-term consequences of respecting social norms ($\xi^0 \geq \xi^1$), and exerts enough self-control to choose $a = 1$ when the long-term consequences are sufficiently important ($\xi^0 \leq \xi^1$). Note that this situation is not optimal for the individual: while the maximal attainable average payoff for the individual is $\mathbb{E}[v(\xi^1)]$, she only obtains $\mathbb{E}[G(\xi^1)\cdot v(\xi^1)]$ asymptotically, which is obviously lower (since $G(\cdot) \leq 1$). Intuitively, the individual would prefer to always do the things which are beneficial in the long term, but she does not have the self-control to choose those things consistently.

4 Is Self-Control Like a Muscle? An Imperfect Metaphor

4.1 Self-control becomes exhausted

Researchers of self-control have found that, after an individual exerts self-control in a given task, they show less self-control in subsequent (possibly unrelated) tasks, a phenomenon which has been termed **ego depletion** (Baumeister *et al.*, 2007).[25] Note that as outside observers, we cannot directly observe m_i, only whether $a_i = 1$ or $a_1 = 0$. In other words, if we ask a subject to have his hands in ice-cold water for one minute, we can only observe whether he succeeded at doing so or not; we cannot observe the amount of self-control he exerted. Because of that, I define a measure of self-control which simply amounts to counting the times when $a_i = 1$, in all tasks except the first.

Definition 4. *The reveled self-control in subsequent tasks is given by* $\sum_{i=2}^{K} a_i$.

Suppose that the Agent is given a task in two different treatments τ: let $\tau = C$ be a control condition, and $\tau = S$ be a treatment that requires self-control. Crucially, the first task is such that $\xi_1^0(\tau) = \rho(\tau) + \xi_1^0$, where $\xi_1^0 \sim G$. In the control $\tau = C$, we have that $\rho(C) = 0$, so that we are back to the original model. However, in the treatment, we have $\rho(S) > 0$. All other tasks $i \geq 2$ are such that $\xi_i^0(\tau) = \xi_i^0$ as usual. The interpretation of $\rho(S)$ is that in the treatment condition, the temptation is higher for the first task. The following Proposition can explain the ego depletion effect.[26]

---

[25] But see Section 2 for a nuanced view of this phenomenon in light of the recent replication crisis.

[26] To relate the Proposition to an actual psychological experiment consider Baumeister *et al.* (1998), who brought students who had been previously fasting to the lab: in the Control condition, the students were seated at a table that contained warm cookies and candies, as well as radishes. They were instructed to eat whatever they wanted – so they mostly eat cookies and candy. In the Treatment condition, the hungry students were seated at the same table, but instructed that they could only eat radishes *being forced to ignore the tempting smell and sight of candy and cookies.* To make sure that the subjects in the Treatment condition had to exert self-control, they were left alone to eat the radishes, while they were (unknowingly) observed by the experimenters. In the Treatment condition impulsivity is high, because the caloric difference between radishes and chocolate cookies is very large. After this "eating task", the subjects were instructed to solve geometric puzzles – with the twist that the puzzles were in fact unsolvable. The experimenters used the time subjects spent on puzzles before quitting as a measure of revealed self-control in a subsequent task, and found that those in the control tried for longer than those in the treatment.

Proposition 4. *Revealed self-control in subsequent tasks* $\sum_{i=2}^{K} a_i$ *is smaller in the Treatment versus the Control condition.*[27]

The intuition for Proposition 4 is simple: as $\rho(S)$ increases, the amount of self-control exerted in the first task increases too, and the remaining budget $B - m_1$ decreases accordingly. Since there is less budget left in the Treatment than in the Control condition, then the Agent will be more likely to exhaust his budget and therefore to have smaller revealed self-control. This shows that ego-depletion is a natural consequence of the fact that the Agent has a limited budget of self-control and, in that respect, the muscle metaphor is apt. We turn now to whether the “self-control muscle” can become stronger with enough exercise.

4.2 Self-control grows when it is exercised

For at least 25 centuries, philosophers have been advocating for us to exercise self-control, in order to grow it over time. For example, the philosopher Epictetus recommended to his students to strengthen their self-control daily. Recently, psychologists have showed that this is a good advice, as indeed self-control grows when we exercise it, just as a muscle. For example, exercising self-control in any domain (be it physical exercise, dutifully attending one’s academic obligations, or improving personal finance) improved people’s performance in an unrelated self-control task (Muraven *et al.*, 1999; Oaten and Cheng, 2006b,a, 2007). Why would this be an evolutionarily sound strategy? It turns out that having self-control depend on previous usage is a simple way to adapt to a changing environment.

So far we have assumed that the distribution of ξ^1 is fixed over time. This, however, seems unlikely, especially since ξ^1 is supposed to represent idiosyncratic characteristic of the environment related to social norms, like the local culture or the social tolerance towards adultery (Ch. 4-6 Buss, 2015), which might not be stationary. In this section, I assume instead that the distribution of ξ^1 depends on a parameter θ, which is unknown *a priori*: ξ^1 is distributed according to $F(\xi^1|\theta) \sim \mathcal{N}(\theta, \sigma^2)$. Suppose that the Principal-Agent relation happens at different time periods $t \in \{0, 1, 2, \dots\}$; within each period, the Principal endows

---

[27] In this section I assume throughout that the Principal’s beliefs are trusting, i.e. $\mu(m) = m$.

the Agent with a budget $B(t)$, and the Agent makes K choices. Crucially, I assume that the Principal observes $\bar{\xi}^1(t) = \sum_{i=1}^{K} \xi_i^1(t)$ at the end of Period t, after $a_1(t), \ldots, a_K(t)$ have been chosen, and then can update the budget $B(t+1)$ for the following period.

Proposition 5. *The self-control budget $B(t+1)$ is increasing in $\bar{\xi}^1(t)$.*

The main intuition behind Proposition 5 is that $\bar{\xi}^1(t)$ is informative about θ, and therefore the Principal tailors the level of the self-control budget to the distribution of ξ^1, which depends on θ.[28] The interpretation is that when individuals start new habits, such as maintaining good posture, this is interpreted as evidence for higher $\bar{\xi}^1(t)$. When the Principal observes high $\bar{\xi}^1(t)$, she infers that the realizations of ξ^1 were high. But one can prove that high realizations of $\bar{\xi}^1(t)$ mean that θ must be higher than expected, in which case the Principal updates her beliefs about θ upwards. This in turn means that the Principal expects higher realizations of ξ^1, and therefore she increases the self-control budget accordingly.

So far we have seen that self-control behaves much like a muscle: it gets tired when we use it continuously (Proposition 4), and it grows when we exercise it (Proposition 5). However, the muscle metaphor might be imperfect: as we will see the next self-control, unlike a muscle, does not need to depend directly on a physical resource such as glucose.

4.3 Is glucose consumed or only monitored?

In the last decade, a series of papers found that self-control is linked to glucose. For example, hypoglycemia (low blood sugar) is correlated with unlawful behavior such as shoplifting, child or spouse abuse or destruction of property among others (Gailliot and Baumeister, 2007). Going beyond correlational studies, Gailliot *et al.* (2007) proposed the hypothesis that the brain consumes extra glucose during self-control tasks, therefore suggesting that hypoglycemia would cause lack of self-control because there was no glucose left for the brain to exert the required self-control. However, Kurzban (2010) re-analyzed the data from Gailliot *et al.* (2007) and found no support for that hypothesis. He hypothesizes instead that glucose should be considered as an input that is monitored, rather than as a constraint, into

---

[28] The assumption that $F(\xi^1|\theta)$ is distributed normally is not innocuous: the normal distribution has the MLRP property, which implies that higher realizations of ξ^1 imply that a higher θ is more likely.

the decision-making process – I will call this the **Glucose Monitoring Hypothesis**.

Long-term investments are worthless (in terms of adaptive fitness) if the individual dies and is no longer around to reap the benefits of the investment. Because of that, the tradeoff between long-term investments ($a = 1$) and short-term fitness ($a = 0$) is dramatically altered by the survival prospects of the individual. It is therefore intuitive that natural selection would enhance the tendency of those whose long-term survival is compromised to engage in behaviors that generate short-term fitness, at the expense of long-term investments. The question then becomes: how does the Principal determine the relative survival prospects of the Agent? Following the Glucose Monitoring Hypothesis, if blood glucose is a good proxy for how an individual is doing, then the Principal can use that information to asses the value of the individual.[29]

Let γ be the amount of glucose that there is in the bloodstream. I assume that γ is normalized to the relevant units so that $\xi(1) = \gamma \cdot \xi^1$ and $\xi(0) = \xi^0$; with ξ^0, ξ^1 distributed as usual. That means that the fitness-maximizing action is 1 if and only if $\gamma \cdot \xi^1 \geq \xi^0$, i.e. higher γ makes long-term investments more profitable, but glucose is not directly consumed by the Agent. The Principal then chooses a budget $B(\gamma)$ and a utility function $v(\xi^1, \gamma)$, both of which can depend on γ. As the next proposition shows, the model is consistent with the Glucose Monitoring Hypothesis: as γ increases, so does the self-control budget, even though glucose is not consumed.

Proposition 6. *When the Principal's beliefs are well-behaved and trusting, there is a unique Asymptotic Equilibrium with:*

$$v(\xi^1, \gamma) = \frac{1}{\gamma \cdot g(\gamma \cdot \xi^1)} \quad \textit{and} \quad B(\gamma) = K \cdot \mathbb{E}[\xi^1].$$

Note that the budget B does not depend on γ. This is because the Principal's beliefs are

---

[29] Low blood glucose starts a cascade of hormonal and neurophysiological changes, and glucose and energy balance (*homeostais*) are crucial for the survival and thriving of the individual (Williams and Elmquist, 2012). Therefore, it is perfectly plausible that low blood glucose affects self-control indirectly, through neuroendocrine changes that in turn affect the self-control budget B.

trusting, so in the equilibrium the Agent sends messages such that $\mu(m) = m$. Therefore, the Principal only needs to provide the right incentives for the Agent to do so, and these are given by function $v(\xi^1, \gamma) = \frac{1}{\gamma \cdot g(\gamma \cdot \xi^1)}$.

The psychological evidence I have reviewed in the previous sections suggests that people are endowed with a limited amount of self-control which becomes depleted as they exert self-control, irrespectively of the nature of the task.[30] Some psychologists have hypothesized that self-control relies on a physical resource, namely glucose (Gailliot *et al.*, 2007).[31] The present model proposes an alternative explanation for this psychological evidence. The Asymptotic Equilibrium uses glucose in the blood as a source of information, rather than as a physical input: if effortful cognitive tasks deplete glucose or increased tiredness, then the optimal self-control budget will decrease consequently (Proposition 6). Moreover, the model offers a compelling argument as for why this limited reservoir of self-control does not need to be directly tied to any physical resource: it is theoretically possible that the brain keeps track of how the self-control budget B, depending on previous usage as well as other inputs which are monitored (like glucose, but also tiredness or social rejection Baumeister *et al.*, 2005).[32] To conclude, the model offers an explanation as of why the self-control budget does not need to be linked to any physical resource, which is evolutionary plausible and which would support the Glucose Monitoring Hypothesis (Kurzban, 2010).

---

[30] But see Section 2 for the recent controversy on the validity of these results.

[31] Within economics, Alonso *et al.* (2013) have a model of resource allocation in the brain, where a scarce resource (glucose) is allocated to different brain modules as a function of need. They argue that their model could accommodate the observation that exercising self-control impacts and is impacted by performance in other effortful cognitive tasks (Vohs *et al.*, 2014; Pocheptsova *et al.*, 2009).

[32] There is an additional caveat: if a task like the one used in the experiments, that requires self-control, also induces fatigue, and if the self-control budget depends on fatigue, then it will be challenging to disentangle a genuine depletion of the self-control budget (through self-control exertion) from a budget that becomes re-adjusted because one of its inputs (fatigue) has changed. For example, parole judges deny parole more often when they are tired to people with similar backgrounds and sentences (Danziger *et al.*, 2011): one potential explanation is that the judge's self-control budget depletes over time, and becomes restored by a meal and a break; an alternative explanation is that she is simply experiencing physical fatigue, and the self-control budget adjusts dynamically depending on the level of fatigue (as in Proposition 6). The most likely explanation probably involves both mechanisms: the self-control budget becomes depleted both by exerting self-control and by general fatigue (where the latter is a monitored input).

5 Welfare Implications

I believe this model, together with other models on the evolution of preferences (Robson and Samuelson, 2010), if validated by the evidence, has strong normative implications. Rosenquist and Rothschild (2012) argue that we need to make value judgements in order to make normative Economics: saying that smoking, addictions and obesity are detrimental entails a value judgement. However, if we can show that there are modules in our brain that evolved to make us behave *against our own preferences*, then no value judgement seems necessary. The key difference between this paper and more traditional frameworks in Economics is that individual preferences cannot be univocally identified with behavior, as it is traditionally in the revealed preferences paradigm. However, with enough knowledge about the human mind, preferences can be traced back and identified from people's choices, deeds and words (Jimenez-Gomez, 2017). This and other models of the evolution of preferences offer normative support for identifying people's preferences beyond their revealed actions, as well as for the idea that some behaviors are detrimental because they go against the person's own preferences.[33]

5.1 Decoupling choice from welfare

A recent literature is taking seriously the idea that revealed preferences do not always reflect the welfare of the individual (Kahneman *et al.*, 1997; Kahneman and Sugden, 2005; Allcott and Taubinsky, 2015; Chetty, 2015). This literature introduced a distinction between preferences and choice, in the form of experienced and decision utilities. Experienced utility u^{exp} refers to the hedonic experience derive from an action, whereas decision utility u^{dec} refers to the actual neural mechanisms that led to the choice being made. In a broad sense, experienced utility can be identified with preferences (liking), and decision utility with choice (wanting) (Berridge and O'Doherty, 2014). In this paper, the experienced utility of the Agent is given by $u^{exp}(a, \xi^1, \xi^0) = u(a, \xi^1)$, and the decision utility is given by $u^{dec}(a, \xi^1, \xi^0) = u(\hat{a}, \xi^1)$, where $\hat{a} = \mathbb{1}\{\mu(m) \geq \xi^0\}$ is the decision implemented by the Prin-

---

[33] In Jimenez-Gomez (2018) I analyze more generally the evolution of self-control and other biases, which make people choose things that they do not necessarily want.

cipal. Clearly, in this model experienced utility and decision utility do not always coincide.

Suppose that the social planner wants to maximize a weighted average of the utilities from the Agent and the Principal

$$\mathbb{E}\left[\zeta \cdot u(a, \xi^1) + (1 - \zeta) \cdot \xi(a, \xi^1, \xi^0)\right]. \tag{4}$$

Then, it is easy to see that whenever the weight given to the Agent is positive ($\zeta > 0$), the social planner would like to endow the Agent with a larger self-control budget. The reason is that when the budget is $B = K \cdot \mathbb{E}[\xi^1]$, this will result in the maximization of $\xi(a, \xi^1, \xi^0)$. Because the Agent is biased towards action $a = 1$, that means that action $a = 0$ is taken too often, and therefore the maximization of the convex combination of $u(a, \xi^1)$ and $\xi(a, \xi^1, \xi^0)$ involves an increase in the probability of action $a = 1$ being chosen, what is achieved with a larger self-control budget.[34]

5.2 Self-control $\neq$ hyperbolic discounting

In Economics it is usually assumed that people value consumption in the present more than consumption in the future (Frederick *et al.*, 2002; Green and Myerson, 2004). This is modelled through a discount function $D(t)$ which multiplies the utility obtained from consumption at period t, where $D(0) = 1$ (there is no discount in the present) and $D(t)$ is decreasing in t. An exponential discounter has a discount function of the form $D(t) = \delta^t$. However, there is ample evidence that humans are not well described by an exponential discount function (Ainslie, 1975; Frederick *et al.*, 2002; Green and Myerson, 2004).[35] An alternative paradigm is hyperbolic discounting, which is characterized by high discount rates over short horizons and low discounts rate over long horizons (Laibson, 1997). The discount function is usually given by $D(0) = 1$, $D(t) = \beta\delta^t$. There is evidence that humans (Ainslie, 1975) and animals (Louie and Glimcher, 2010; Kim *et al.*, 2008) are better described as hyperbolic discounters, what suggests this is an evolutionarily ancient trait.

---

[34] This reasoning is true for any social welfare function (not just the sum of utilities) that has the Agent's utility as an argument, and is increasing on that argument.

[35] Although see Rubinstein (2003) for a critical take on this evidence.

Within Economics, self-control problems and hyperbolic discounting have often been used as synonyms and conflated. However, I want to emphasize that **self-control and hyperbolic discounting are very distinct phenomena**, with different welfare implications.[36] A lack of self-control refers to the phenomenon by which an individual chooses to act against her own self-interest.[37] Self-control thus requires that the choice be made by the combination of at least two (possibly more) mind modules or mechanisms: in a unitary model of the individual, self-control (and lack thereof) is just not possible. In Economics, Fudenberg and Levine (2006) is an example of a model explicitly assumes such multiplicity of mind modules (or selves, as they are sometimes called).[38] Agents who have self-control issues are often **time inconsistent**.[39] Because of this, people who lack self-control, and who are sophisticated or insightful enough to realize about their lack of self-control, will demand commitment devices.[40] In contrast to the modular view of the mind, models of hyperbolic discounting posit that the individual is a unitary self, which is time inconsistent because of the simple fact that all non-exponential discounters (including hyperbolic ones) are time-inconsistent.[41] Within Neuroeconomics, there is yet no agreement on whether there is a single system Kable (2010, 2013) or two systems McClure *et al.* (2004) responsible for discounting.[42]

---

[36] In the discussion that follows, I use the term "hyperbolic discounting" to include models of genuine hyperbolic discounting as well as those of quasi-hyperbolic discounting such as Laibson (1997).

[37] In the language of my model, self-control refers to action $a = 0$ being chosen, which is always against the Agent self-interest since (in the Asymptotic Equilibrium) $u(1, \xi^1) > u(0, \xi^1)$ for all ξ^1.

[38] Other papers with multiple modules or selves include Bernheim and Rangel (2004), Chatterjee and Krishna (2009) and Ali (2011).

[39] This is the case because preferences expressed for choices to be made in the future are usually influenced by forward-looking (or cold) modules, whereas choices made in "in the heat of the moment" are influenced often by "hot" modules that greatly value immediate gratification (in the relevant context). Therefore, preferences expressed in the past are not reflected in choices made, and hence the agent suffers from time inconsistency.

[40] See Rogers *et al.* (2014) for a recent application of commitment devices.

[41] George Ainslie (see for example Ainslie (2001)) is an exception to this view, as he advocated for both a mind with multiple modules and hyperbolic discounting. (Ainslie, 2001, p. 39-40) writes that we can no longer regard people as having unitary preferences, but rather a variety of contradictory preferences that become dominant at different points because of their timing. He goes as far to identify self-defeating behavior with "just maximizing expected reward, discounted in highly bowed curves".

[42] McClure *et al.* (2004) showed that there are regions involved in immediate rewards (β-regions), and others in delayed rewards (δ-regions), which would lend support to a β-δ quasi-hyperbolic model. However, Kable (2010, 2013) argues that these different areas are not activated by an immediate-delayed dichotomy, but that instead they constitute a single system which modulates valuation.

Irrespectively of the neural basis of these phenomena, Loewenstein (1996) observes that there are two phenomena that models of hyperbolic discounting cannot explain: 1) some types of consumption, such as sweet/fatty foods, or sex, are associated with impulsivity, whereas many others are not (if time discounting was all that mattered, then people would show impulsivity towards those all kinds of things but instead people show more impulsivity when they are hungry, thirsty, or sexually aroused); 2)impulsivity is context-dependent: the smell of a cookie, or re-visiting a place where an addict used to consume a drug, can create a strong impulse to consume (again, hyperbolic discounting cannot account for this).[43] Therefore, the main difference between models of self-control and models of hyperbolic discounting is the existence of multiple selves in the former, with the consequent difference between experienced and decision utility.[44] While both models look similar, and have been used to study similar phenomena, **the normative implications of self-control failures vs. hyperbolic discounting can be drastically different**.

The key normative differences between models of self-control and of hyperbolic discounting arise from the fact that individuals who are subject to self-control problems do things that they don't like to do (according to their experienced utility), whereas hyperbolic discounters's choices are the ones that they like in the moment they make them, but later on they do not. That is, for (sophisticated) hyperbolic discounters, $u^{exp} = u^{dec}$, whereas for individuals with self-control problems, $u^{exp} \neq u^{dec}$. As an illustration, consider a drug addict that today has decided to use a commitment device to prevent herself from consuming the drug tomorrow: she has given you a key to the locker where she stores the drug. The next day she comes back to you and asks for you to give her the key back. Should you?

1. Under the hyperbolic discounting model giving the addict her key back (so she can

---

[43] Of course, it could be that time preferences depend on the visceral state and/or cues, but that will still imply a model of multiple selves.

[44] In the literature of hyperbolic discounting, and depending on the researcher and the model, the Agent is endowed with varying degrees of insight into her time inconsistency. For example, naive agents do not realize that their preferences will change over time, and choose at each period as if their preferences would be constant. At the other extreme, sophisticated agents realize that their preferences will change, and therefore have an incentive to use a commitment device, just as people with self-control problems. Put formally, sophisticated hyperbolic discounters are playing a game against their future "selves", but there is only one "self" (or mind module) in existence, and hence making decisions, at each point in time.

consume the drug) would increase her welfare. This is because today she prefers to consume the drug to not consume it, and yesterday's preferences are irrelevant today. In that model of the world, you should give her the key.[45]

2. Under the self-control model, if we identify the welfare of the addict with the utility of the Agent, then you should not give her the key. The reason is that, although she would *choose* to take the drug ($a = 0$ in the model), she would *prefer* not to take it, as $u(1, \xi^1) > u(0, \xi^1)$.[46]

While this example is extreme, it is designed to clearly illustrate that both models represent different phenomena, and cannot be interchanged at will, especially when it comes to normative implications. Note that the way we treat the different modules of the mind is different from the way we treat different time selves (like present vs. future self): the welfare of present vs. future self is analyzed by whichever welfare criterion we choose, at different points in time; however, in a model of self-control like the one presented in this paper, the self-control conflict is not between present and future self, *but between different modules at the present moment.*[47]

5.3 Evolutionary Mismatch

We live in a period where arguably there are more temptations than ever before. Addictive drugs such as alcohol and tobacco can be legally purchased by adults over a certain age. Sugar and red meat, which were scarce in our evolutionary environment, are now everywhere and can be purchased quite cheaply; moreover being overweight and lack of exercise has been

---

[45] For a simple numerical example, suppose that consuming today has utility $b = 2$, and health costs $c = 3$ tomorrow, not consuming is normalized to 0, $\beta = .5$, and $\delta = .95$. The addict does not want to quit today, because: $b - \beta \times \delta \times c = 2 - .5 \times .95 \times 3 > 0$. But she wants to quit tomorrow, since: $\beta \times \delta \times (b - \delta \times c) = .5 \times .95 \times (2 - .95 \times 3) < 0$. However, when she comes the following day asking for the drug, if you want to maximize her utility you should give back the drug, because that point her utility from the drug is again $2 - .5 \times .95 \times 3 > 0$.

[46] This conclusion also holds when using other popular models of self-control, such as Gul and Pesendorfer (2001) or Fudenberg and Levine (2006).

[47] We need to be careful to avoid conflating the modules responsible of current vs. future utility (see Footnote 42) with the different time selves, i.e. the current vs. future self. This is not hair-splitting: in terms of welfare, the present and future self deserve the same consideration (accounting for a potential difference in weights which takes into account time discounting). However, in terms of welfare, there is no reason why the social planner should put equal weight on all modules: in fact I believe that the social planner should put most, if not all, of the weight on the long-term self, which I have identified with the Agent, and which McClure *et al.* (2004) identify with the lateral prefrontal cortex and posterior parietal cortex.

linked to an increase in the risk of contracting certain diseases such as cancer (Kushi *et al.*, 2012). Non-communicable diseases (such as stroke and heart attack, cancers, chronic lung diseases, etc.) accounted for more than 60% of global deaths in 2008 (Rünger and Wood, 2015). In order to capture this increased availability of temptations, suppose that there is a shift in the distribution of signal ξ^0, so that the new signal is $\hat{\xi}^0 = \rho + \xi^0$, where $\rho > 0$ is a constant. This change happens too fast in the evolutionary time scale, so that v and B are still given by $v(\xi^1) = \frac{1}{g(\xi^1)}$ and $B/K = \mathbb{E}[\xi^1]$. I am agnostic about whether this change is stable enough that the Agent perceives it, in which case I say he is *sophisticated*, or whether the Agent is not aware about this change in the distribution, in which case I say he is *naive*. In this new environment the Agent will fail to resist temptation more often.

Proposition 7. *Irrespectively of whether the Agent is sophisticated or naive, he behaves more impulsively in the new environment ($\hat{\xi}^0$) than in the original environment (ξ^0):*

$$P(a_i = 0|\rho + \xi^0, \xi^1) > P(a_i = 0|\xi^0, \xi^1) \quad \textit{for all } \xi^0,\ \xi^1.$$

The intuition behind Proposition 7 is as follows: when ξ^0 increases to $\hat{\xi}^0$, the Agent needs to exert more self-control *in each task* in order to have $a = 1$ implemented. Because the budget is fixed, that means that it is now "more expensive" to have $a = 1$ implemented for each possible realization of ξ^1, and therefore the probability that $a = 0$ increases across the board. The reader might argue that if the distribution of ξ^0 has changed over time, then the Principal should have changed B as well. The problem with that argument is that gene evolution is (usually) a slow process: humans's genes have not changed fast enough to adapt to the temptations (in the form of alcohol, tobacco and other drugs, fatty and sugary foods, etc., Buss, 2015), which have increased exponentially. Because of that, it seems reasonable to consider that the change in environment $\hat{\xi}^0 = \xi^0 + \rho$ happened faster than our genes could evolve, and therefore that B has remained fixed. Proposition 7 implies that whatever conclusions can be drawn from the present model, will be exacerbated in the current environment, because of an increase in ξ^0. In other words, if we believe that self-control would decrease individual welfare in the original environment (under ξ^0), then it will decrease individual welfare even more due to evolutionary mismatch (under $\hat{\xi}^0$). Because of evolutionary mismatch, we are probably in a point where the Agent is receiving too little self-control budget (as compared to how we were designed in our ancestral environment), to cope with all the temptations of the modern world.[48]

6 Conclusion

This paper sheds light on the origins of temptation and self-control in humans. The evolution of the human brain was subject to constraints. Its great increase in size was most likely due to social competition (those who were better at getting along with others had an evolutionary edge), what generated increased pressure for social performance (by including ξ^1 in the utility function), but due to the fast change of any particular social environment, the natural selection could not observe ξ^1. Due to the modularity of the brain, the human individual could not observe ξ^0 nor have it as an argument in the utility function. Because of these constraints, natural selection could not generate an utility function for humans that was perfectly aligned with the purpose of spreading the genes. These restrictions in brain evolution could be overcome by natural selection by endowing human individuals with a biased utility function. That means that there were occasions when evolutionarily advantageous actions were against the interest of the individual, according to the individual's evolved utility function. The solution to this problem was the evolution of a mechanism that generated a temptation to act against the individual's own interest together with a limited amount of self-control that the individual could use to avoid caving to temptation. The intuition is that most of the time, humans need to exert enough self-control to follow social norms: those are the times when the interests of the individual and their genes are aligned. However, there are occasions when the individual can take an action which is evolutionarily advantageous but individually detrimental (like breaking social norms). The individual has superior information (over natural selection) about the costs of engaging in such action: sometimes it might be relatively costless (if nobody will find out about the transgression), and sometimes it can be very costly (if the transgression can be easily discovered). When the individual is endowed with a limited amount of self-control, the individual will refrain from

---

[48] Firms might be exploiting this fact (Akerlof and Shiller, 2015; Jimenez-Gomez, 2017).

taking the action when it is costly, but not when it is relatively costless. Therefore, natural selection can exploit the informational advantage of the individual by endowing him with a limited amount of self-control, and I showed that this mechanism is (asymptotically) optimal.

The present framework can explain several stylized facts found in the psychological literature on self-control, such as the fact that self-control becomes depleted with usage in the short-run, but grows with exercise on the long-run. Moreover, self-control becomes depleted when glucose levels are low, but glucose is not necessarily consumed to exert self-control. This paper can also help shed light on a recent controversy in the aforementioned literature.[49] It has been argued that refinements of the ego depletion model are secondary to the task of identifying whether there is an actual effect (Carter and McCullough, 2014), and this paper could provide a theoretical framework to confront with the conflicting empirical evidence. Even more, the framework could be used to connect findings from the fields of evolutionary psychology, social psychology and social neuroscience.

The model is also helpful in thinking about normative Economics. While self-control problems have most likely always been detrimental for welfare, this has been exacerbated in recent decades by an abundance of temptations (evolutionary mismatch), and there is ample evidence that in the present day self-control problems are an important source of welfare loss. Temptations can be reduced by using nudges, which are interventions that do not restrict choice but change the environment (Sunstein, 2014; Jimenez-Gomez, 2017), in this case by making tempting items less salient or available; and self-control, especially for those at high risk, can be increased by voluntary programs that use tools from psychotherapy (Blattman *et al.*, 2015). In order to make an accurate welfare analysis of self-control problems, we must first acknowledge the fact that self-control problems and hyperbolic discounting are two distinct phenomena (that share the property of time inconsistency), with very different welfare implications (for example, time-inconsistent hyperbolic discounters should be allowed to break their commitments, whereas those with self-control problems should not). If we

---

[49] See Section 2.

continue to ignore this distinction, our welfare conclusions for policies related to obesity, smoking, alcohol abuse, dietary choices, etc. will be very likely incorrect, and this could have drastic consequences. A clear future research agenda is to study the interaction between self-control and hyperbolic discounting, at the theoretical level and also their neurological underpinnings, in order to be able to make models with better predictive power, as well as to design better policies.

Appendix

PROOF OF PROPOSITION 1. When the Principal's beliefs are η, and we define $\mu(m) = \int \xi^1 \eta(\xi^1|m) d\xi^1$, then the Agent's problem is

$$\max_{(m_i)_{i=1}^K} \sum_{i=1}^K u(0, \xi_i^1) + G(\mu(m_i)) \cdot v(\xi_i^1)$$

$$s.t. \quad \sum_{i=1}^K m_i \leq B.$$

Because G is strictly concave and differentiable, the problem is well defined and the first order conditions for the Agent are sufficient for optimality:[50]

$$g(\mu(m_i))\mu'(m_i)v(\xi_i^1) = \lambda. \tag{5}$$

Let $\alpha(m) = g(\mu(m))\mu'(m)$. The following equation solves the Agent's condition for the Asymptotic Equilibrium:[51]

$$m_i = \alpha^{-1}\left(\frac{\lambda}{v(\xi_i^1)}\right).$$

This guarantees that the Agent is maximizing his expected utility. In order to have an Asymptotic Equilibrium, it must be the case that the Principal's condition is also met, namely:

---

[50] Note that μ is concave and differentiable as well because beliefs are well-behaved.

[51] Since G and μ are both increasing and concave, so is their composition, and therefore the derivative of $G(\mu(m))$, which we have defined as α is decreasing, and hence α^{-1} is well defined.

$$\lim_{K\to\infty} \mathbb{P}\left[(a_i)_{i=1}^K = \arg\max \sum_{i=1}^K \xi(a_i)\right] = 1.$$

But notice that the following events are all identical:

$$\left\{(a_i)_{i=1}^K = \arg\max \sum_{i=1}^K \xi(a_i)\right\} = \{a_i = 1 \Leftrightarrow \xi_i^1 > \xi_i^0 \ \forall i\} =$$

$$= \{\mu(m_i) > \xi_i^0 \Leftrightarrow \xi_i^1 > \xi_i^0 \ \forall i\} = \{\mu(m_i) = \xi_i^1 \ \forall i\} =$$

$$\left\{\alpha^{-1}\left(\frac{\lambda}{v(\xi_i^1)}\right) = \mu^{-1}(\xi_i^1) \ \forall i\right\} =$$

$$\left\{v(\xi_i^1) = \frac{\lambda}{\alpha(\mu^{-1}(\xi_i^1))} \ \forall i\right\}.$$

The last event can be further decomposed into two events

$$\left\{v(\xi_i^1) = \frac{\lambda}{\alpha(\mu^{-1}(\xi_i^1))} \ \forall i\right\} = \left\{v(\xi_i^1) = \frac{c}{\alpha(\mu^{-1}(\xi_i^1))} \ \forall i\right\} \cap \{c = \lambda\},$$

for some constant $c > 0$ (because λ is a positive Lagrange multiplier). Hence, we must have $v(\xi_i^1) = \frac{c}{\alpha(\mu^{-1}(\xi_i^1))}$, and we need to prove that $\lim_{K\to\infty} \mathbb{P}[c = \lambda] = 1$. We have that,

$$B = \sum_{i=1}^K m_i = \sum_{i=1}^K \alpha^{-1}\left(\frac{\lambda}{c}\alpha(\mu^{-1}(\xi_i^1))\right).$$

In the limit, by the Law of Large Numbers, we have that

$$\frac{B}{K} = \mathbb{E}\left[\alpha^{-1}\left(\frac{\lambda}{c}\alpha(\mu^{-1}(\xi^1))\right)\right]. \tag{6}$$

Now, for any B and c, λ is the solution to Equation 6. But, when $\lambda = c$, then we have that

$$\frac{B}{K} = \mathbb{E}\left[\alpha^{-1}\left(\alpha(\mu^{-1}(\xi^1))\right)\right] = \mathbb{E}[\mu^{-1}(\xi^1)]. \tag{7}$$

Therefore, when $v = \frac{c}{\alpha(\mu^{-1}(\xi^1))}$ and $\frac{B}{K} = \mathbb{E}[\mu^{-1}(\xi^1)]$, by the Law of Large Numbers we have that

$$\lim_{K\to\infty} \mathbb{P}\left\{\mathbb{E}[\mu^{-1}(\xi^1)] = \mathbb{E}\left[\alpha^{-1}\left(\frac{\lambda}{c}\alpha(\mu^{-1}(\xi^1))\right)\right]\right\} = \lim_{K\to\infty} P\{c = \lambda\} = 1.$$

This shows that $v = \frac{c}{\alpha(\mu^{-1}(\xi^1))}$ and $\frac{B}{K} = \mathbb{E}[\mu^{-1}(\xi^1)]$ is an Asymptotic Equilibrium. Moreover, v is uniquely determined (up to a positive constant c), and Equation 7 uniquely determines $\frac{B}{K}$ (up to function $\mu(m) = \int \xi^1 \eta(\xi^1|m) d\xi^1$, and therefore up to beliefs $\eta(\xi^1|m)$).

$\square$

PROOF OF PROPOSITION 3. Let $F_K(\xi^1)$ be the empirical distribution of ξ^1 when there are K choices. By the Glivenko-Cantelli theorem, we have that for all $\delta > 0$, there exists a $\bar{K}$ such that for all $K > \bar{K}$, $\sup_{\xi^1} |F_K(\xi^1) - F(\xi^1)| < \delta$ almost surely.

Because the Agent chooses m_i as in Equation 3, that means that the average message sent by the Agent is bounded above by $(1+\delta)\mathbb{E}[\xi^1]$. Therefore, that means that there are a fraction of at most $1 - \frac{1}{1+\delta} = \frac{\delta}{1+\delta}$ tasks where his self-control is exhausted (and receives payoff of at least $u(0,\xi^1)$, since $v(\xi^1) = \frac{1}{g(\xi^1)} > 0$), so the Agent's utility is bounded below by $\mathbb{E}[u(0,\xi^1)] + \frac{\mathbb{E}[G(\xi^1)\cdot v(\xi^1)]}{1+\delta}$. Therefore given $\nu > 0$, we can find δ such that

$$\mathbb{E}[u(0,\xi^1)] + \frac{\mathbb{E}[G(\xi^1)\cdot v(\xi^1)]}{1+\delta} = \mathbb{E}[u(0,\xi^1)] + \mathbb{E}[G(\xi^1)\cdot v(\xi^1)] - \nu,$$

and solving for δ we find:

$$\delta = \frac{\nu}{\mathbb{E}[G(\xi^1)\cdot v(\xi^1)] - \nu}.$$

Therefore, choosing $\bar{K}$ such that for all $K > \bar{K}$, $\sup_{\xi^1 \in \xi^1} |F_K(\xi^1) - F(\xi^1)| < \delta$ almost surely concludes the proof. $\square$

PROOF OF PROPOSITION 4. The Agent's first order conditions are:

$$g(m(\xi_1^1) - \rho(\tau))v(\xi_1^1) = \lambda(\tau),$$

$$g(m(\xi_j^1))v(m(\xi_j^1)) = \lambda(\tau) \qquad \text{for } j > 1.$$

Where $\lambda(\tau)$ is given as the solution to:

$$\rho(\tau) + \sum_{k=1}^{k} g^{-1}\left(\frac{\lambda(\tau)}{v(\xi_k^1)}\right) = B.$$

Because g^{-1} is decreasing in $\lambda(\tau)$, we have that $\lambda(S) > \lambda(C)$. Therefore, since $m_i(\tau) = g^{-1}\left(\frac{\lambda(\tau)}{v(\xi_i^1)}\right)$, we have that $m_i(C) < m_i(S)$ for all $i > 1$, and therefore revealed self-control is larger under C than under S, as we wanted to show. □

PROOF OF PROPOSITION 5. The distribution of $\bar{\xi}^1$ is given by a normal $\mathcal{N}\left(\theta, \frac{\sigma^2}{K}\right)$, with probability density function $\tilde{\phi}$. The normal distribution has the Monotone Likelihood Ratio Property:

$$\frac{d}{d\bar{\xi}^1}\left(\frac{\frac{d\tilde{\phi}}{d\theta}}{\tilde{\phi}}\right) > 0.$$

Let $p_{t+1}(\bar{\xi}^1(t+1)|\bar{\xi}^1(t))$ be the posterior of $\bar{\xi}^1(t+1)$, after having observed $\xi^1(t)$. Using Lemma 2 in Alonso *et al.* (2013), we have that $p_{t+1}(\bar{\xi}^1(t+1)|\bar{\xi}^1(t))$ inherits the MLRP property from $\tilde{\phi}$. Finally, note that

$$\frac{B(t+1)}{K} = \mathbb{E}[\xi^1] = \mathbb{E}[\bar{\xi}^1(t+1)] = \int \bar{\xi}^1(t+1)\ dp(\bar{\xi}^1(t+1)|\bar{\xi}^1(t)).$$

But MLRP implies First Order Stochastic Dominance, so $\int \bar{\xi}^1(t+1)\ dp(\bar{\xi}^1(t+1)|\bar{\xi}^1(t))$ is increasing in $\bar{\xi}^1(t)$, and therefore so is $B(t+1)$. □

PROOF OF PROPOSITION 6. The proof is analogous to that of Proposition 1. When the Principal's beliefs are well-behaved and trusting, the Agent's problem is

$$\max \sum_{i=1}^{K} G(\gamma m_i) v(\xi^1, \gamma),$$
$$\text{s.t.} \sum_{i=1}^{K} m_i \leq B.$$

From the First Order Conditions, the Agent's optimal message is

$$m_i = \frac{1}{\gamma} g^{-1}\left(\frac{\lambda}{\gamma v(\xi^1, \gamma)}\right).$$

Following a similar reasoning to the proof of Proposition 1, and taking into account that the beliefs are trusting (so $\mu(m) = m$), we have that

$$\left\{(a_i)_{i=1}^{K} = \arg\max \sum_{i=1}^{K} \xi(a_i)\right\} = \{a_i = 1 \Leftrightarrow \gamma\xi_i^1 > \xi_i^0 \ \forall i\} =$$

$$= \{\gamma m_i > \xi_i^0 \Leftrightarrow \gamma\xi_i^1 > \xi_i^0 \ \forall i\} = \{m_i = \xi_i^1 \ \forall i\} =$$
$$\left\{\frac{1}{\gamma} g^{-1}\left(\frac{\lambda}{\gamma v(\xi^1, \gamma)}\right) = \xi_i^1 \ \forall i\right\} =$$

$$\left\{v(\xi_i^1, \gamma) = \frac{\lambda}{\gamma g(\gamma \xi_i^1)} \ \forall i\right\}.$$

Therefore, following the same reasoning as in the proof of Proposition 1, we must have $v(\xi_i^1, \gamma) = \frac{c}{\gamma g(\gamma \xi_i^1)}$, and then, when $c = \lambda$:

$$B = \sum_{i=1}^{K} \frac{1}{\gamma} g^{-1}\left(\frac{\lambda}{\gamma v(\xi^1, \gamma)}\right) = \sum_{i=1}^{K} \frac{1}{\gamma} g^{-1}\left(\frac{\lambda \gamma g(\gamma \xi^1)}{c\gamma}\right) = \sum_{i=1}^{K} \xi^1.$$

Therefore choosing $v(\xi_i^1, \gamma) = \frac{c}{\gamma g(\gamma \xi_i^1)}$ and $B/K = \mathbb{E}[\xi^1]$ concludes the proof (where we can normalize $c = 1$).

$\square$

PROOF OF PROPOSITION 7. If the Agent is naive, he still chooses $m_i = \frac{\lambda}{v(\xi^1)}$. Therefore,

$$\mathbb{P}[a = 1|\rho + \xi^0, \xi^1] = \mathbb{P}[\mu(m) > \rho + \xi^0] < \mathbb{P}[\mu(m) > \xi^0] = \mathbb{P}[a = 1|\xi^0, \xi^1].$$

If the Agent is sophisticated, he solves

$$\max \sum_{i=1}^{K} G(\hat{m}_i - \rho) \cdot v(\xi_i^1)$$
$$s.t. \quad \sum_{i=1}^{K} \hat{m}_i \leq B.$$

The optimality conditions are:

$$g(\hat{m}_i - \rho) \cdot v(\xi_i^1) = \hat{\lambda} \implies \hat{m}_i = \rho + g^{-1}\left(\frac{\hat{\lambda}}{v(\xi_i^1)}\right).$$

From the budget constraint, and the fact that $B = K \cdot \mathbb{E}[\xi^1]$ and $v(\xi^1) = \frac{1}{g(\xi^1)}$, we know that

$$\frac{1}{K} \sum_{i=1}^{K} g^{-1}(\hat{\lambda} \cdot g(\xi_i^1)) = \mathbb{E}[\xi^1] - \rho.$$

Let $\tilde{m}_i$ and $\tilde{\lambda}$ be as in the original problem (i.e. when $\rho = 0$). Because $g^{-1}(\lambda \cdot g(\xi^1))$ is decreasing in λ, then we have that $\hat{\lambda} > \tilde{\lambda}$, and therefore that

$$\mathbb{P}[a = 1|\rho + \xi^0, \xi^1] = \mathbb{P}[\rho + g^{-1}(\hat{\lambda} \cdot g(\xi^1)) > \rho + \xi^0] < \mathbb{P}[g^{-1}(\tilde{\lambda} \cdot g(\xi^1)) > \xi^0] = \mathbb{P}[a = 1|\xi^0, \xi^1].$$

□

References

Aghion, P. and Tirole, J. (1997) Formal and Real Authority in Organizations, *The Journal of Political Economy*, **105**, 1–29.

Ainslie, G. (1975) Specious reward: a behavioral theory of impulsiveness and impulse control., *Psychological Bulletin*, **82**, 463.

Ainslie, G. (2001) *Breakdown of Will*, Cambridge University Press.

Akerlof, G. A. and Shiller, R. J. (2015) *Phishing for Phools: The Economics of Manipulation and Deception*, Princeton University Press.

Ali, S. N. (2011) Learning Self-Control, *The Quarterly Journal of Economics*, **126**, 857–893.

Allcott, H. and Taubinsky, D. (2015) Evaluating behaviorally-motivated policy: Experimental evidence from the lightbulb market, *American Economic Review*, **105**, 2501–2538.

Alonso, R., Brocas, I. and Carrillo, J. (2013) Resource allocation in the brain, *Review of Economic Studies*.

Alonso, R. and Matouschek, N. (2008) Optimal delegation, *Review of Economic Studies*, **75**, 259–293.

Baumeister, R. F., Bratslavsky, E., Muraven, M. and Tice, D. M. (1998) Ego depletion: is the active self a limited resource?, *Journal of Personality and Social Psychology*, **74**, 1252.

Baumeister, R. F., DeWall, C. N., Ciarocco, N. J. and Twenge, J. M. (2005) Social exclusion impairs self-regulation., *Journal of Personality and Social Psychology*, **88**, 589.

Baumeister, R. F., Heatherton, T. F. and Tice, D. M. (1994) *Losing control: How and why people fail at self-regulation.*, Academic Press.

Baumeister, R. F. and Tierney, J. (2011) *Willpower: Why Self-Control is the Secret to Success*, Penguin Group US.

Baumeister, R. F., Vohs, K. D. and Tice, D. M. (2007) The Strength Model of Self-Control, *Current Directions in Psychological Science*, **16**, 351–355.

Benhabib, J. and Bisin, A. (2005) Modeling internal commitment mechanisms and self-control: A neuroeconomics approach to consumption-saving decisions, *Games and Economic Behavior*, **52**, 460–492.

Bernheim, B. D. and Rangel, A. (2004) Addiction and cue-triggered decision processes, *American Economic Review*, pp. 1558–1590.

Berridge, K. C. and O'Doherty, J. P. (2014) From experienced utility to decision utility, *Neuroeconomics*, pp. 335–351.

Bisin, A. and Iantchev, E. (2017) Evolutionary Selection of Modular Decision Architectures, *Working Paper*.

Blattman, C., Jamison, J. C. and Sheridan, M. (2015) Reducing crime and violence: Experimental evidence from cognitive behavioral therapy in Liberia, Tech. rep., National Bureau of Economic Research.

Brocas, I. and Carrillo, J. D. (2008) The brain as a hierarchical organization, *The American Economic Review*, **98**, 1312–1346.

Buss, D. M. (2015) *Evolutionary Psychology: The New Science of the Mind, Fifth Edition*, Taylor & Francis.

Carter, E. C. and McCullough, M. E. (2014) Publication bias and the limited strength model of self-control: has the evidence for ego depletion been overestimated?, *Frontiers in Psychology*, **5**, 1–11.

Cartwright, J. (2007) *Evolution and Human Behaviour: Darwinian Perspectives on Human Nature*, Palgrave Macmillan.

Chatterjee, K. and Krishna, R. V. (2009) A "Dual Self" Representation for Stochastic Temptation, *American Economic Journal: Microeconomics*, **1**, 148–167.

Che, Y.-K. and Kartik, N. (2009) Opinions as incentives, *Journal of Political Economy*, **117**, 815.

Chetty, R. (2015) Behavioral Economics and Public Policy: A Pragmatic Perspective, *American Economic Review*, **105**, 1–33.

Danziger, S., Levav, J. and Avnaim-Pesso, L. (2011) Extraneous factors in judicial decisions, *Proceedings of the National Academy of Sciences*, **108**, 6889–6892.

Duckworth, A. L. and Seligman, M. E. (2005) Self-discipline outdoes IQ in predicting academic performance of adolescents, *Psychological science*, **16**, 939–944.

Dunbar, R. and Shultz, S. (2007) Understanding primate brain evolution, *Philosophical Transactions of the Royal Society B: Biological Sciences*, **362**, 649–658.

Epictetus (2008) *Discourses and Selected Writings*, Penguin classics, Penguin Books Limited.

Fodor, J. A. (1983) *The modularity of mind: An essay on faculty psychology*, MIT press.

Frankel, A. (2014) Aligned delegation, *The American Economic Review*, **104**, 66–83.

Frederick, S., Loewenstein, G. and O'donoghue, T. (2002) Time discounting and time preference: A critical review, *Journal of economic literature*, **40**, 351–401.

Freud, S. (1961) The ego and the id.

Fudenberg, D. and Levine, D. K. (2006) A dual-self model of impulse control, *The American Economic Review*, pp. 1449–1476.

Gailliot, M. T. and Baumeister, R. F. (2007) The physiology of willpower: Linking blood glucose to self-control, *Personality and Social Psychology Review*, **11**, 303–327.

Gailliot, M. T., Baumeister, R. F., DeWall, C. N., Maner, J. K., Plant, E. A., Tice, D. M., Brewer, L. E. and Schmeichel, B. J. (2007) Self-control relies on glucose as a limited energy source: willpower is more than a metaphor., *Journal of Personality and Social Psychology*, **92**, 325–36.

Green, L. and Myerson, J. (2004) A discounting framework for choice with delayed and probabilistic rewards., *Psychological bulletin*, **130**, 769.

Gul, F. and Pesendorfer, W. (2001) Temptation and self-control, *Econometrica*, **69**, 1403–1435.

Hagger, M. S. (2010) Self-regulation: An important construct in health psychology research and practice, *Health Psychology Review*, **4**, 57–65.

Hagger, M. S. and Chatzisarantis, N. L. D. (2016) A Multilab Preregistered Replication of the Ego-Depletion Effect, *Perspectives on Psychological Science*, **11**, 546–573.

Haidt, J. (2006) *The happiness hypothesis: Finding modern truth in ancient wisdom*, Basic Books.

Hare, T. A., Camerer, C. F. and Rangel, A. (2009) Self-control in decision-making involves modulation of the vmPFC valuation system, *Science*, **324**, 646–648.

Jackson, M. O. and Sonnenschein, H. F. (2007) Overcoming Incentive Constraints by Linking Decisions, *Econometrica*, **75**, 241–257.

Jimenez-Gomez, D. (2017) Nudging and Phishing: A Theory of Behavioral Welfare Economics, *Working Paper*.

Jimenez-Gomez, D. (2018) Co-Evolution of Consciousness and Biases that Make Humans Behave Against their Own Interest, *Working Paper*.

Kable, J. (2013) Valuation, Intertemporal Choice and Self-Control, in *Neuroeconomics: Decision Making and the Brain*.

Kable, J. W. (2010) Just a little (lateral prefrontal) patience, *Nature Neuroscience*, **13**, 523–524.

Kahneman, D. (2011) *Thinking, fast and slow*, Macmillan.

Kahneman, D. and Sugden, R. (2005) Experienced utility as a standard of policy evaluation, *Environmental and resource economics*, **32**, 161–181.

Kahneman, D., Wakker, P. P. and Sarin, R. (1997) Back to Bentham? Explorations of Experienced Utility, *The Quarterly Journal of Economics*, **112**, 375–406.

Kim, S., Hwang, J. and Lee, D. (2008) Prefrontal Coding of Temporally Discounted Values during Intertemporal Choice, *Neuron*, **59**, 161–172.

Kurzban, R. (2010) Does the brain consume additional glucose during self-control tasks?, *Evolutionary Psychology*, **8**.

Kurzban, R. (2012) *Why Everyone (Else) Is a Hypocrite: Evolution and the Modular Mind*, Princeton University Press.

Kushi, L. H., Doyle, C., McCullough, M., Rock, C. L., Demark-Wahnefried, W., Bandera, E. V., Gapstur, S., Patel, A. V., Andrews, K. and Gansler, T. (2012) American Cancer Society guidelines on nutrition and physical activity for cancer prevention, *CA: A Cancer Journal for Clinicians*, **62**, 30–67.

Laibson, D. (1997) Golden eggs and hyperbolic discounting, *The Quarterly Journal of Economics*, **112**, 443–478.

Livnat, A. and Pippenger, N. (2006) An Optimal Brain Can Be Composed of Conflicting Agents, *Proceedings of the National Academy of Sciences of the United States of America*, **103**, 3198–3202.

Loewenstein, G. (1996) Out of Control: Visceral Influences on Behavior, *Organizational Behavior and Human Decision Processes*, **65**, 272–292.

Louie, K. and Glimcher, P. W. (2010) Separating value from choice: delay discounting activity in the lateral intraparietal area., *The Journal of neuroscience : the official journal of the Society for Neuroscience*, **30**, 5498–507.

Magen, E., Kim, B., Dweck, C. S., Gross, J. J. and McClure, S. M. (2014) Behavioral and neural correlates of increased self-control in the absence of increased willpower, *Proceedings of the National Academy of Sciences*, **111**, 9786–9791.

McClure, S. M., Laibson, D. I., Loewenstein, G. and Cohen, J. D. (2004) Separate Neural Systems Value Immediate and Delayed Monetary Rewards, *Science*, **306**, 503 –507.

McGonigal, K. (2011) *The Willpower Instinct: How Self-Control Works, Why It Matters, and What You Can Doto Get More of It*, Penguin.

Mischel, W. (2014) *The Marshmallow Test: Mastering Self-Control*, Little, Brown.

Muraven, M., Baumeister, R. F. and Tice, D. M. (1999) Longitudinal Improvement of Self-Regulation Through Practice: Building Self-Control Strength Through Repeated Exercise., *Journal of Social Psychology*, **139**, 446–457.

Muraven, M., Tice, D. M. and Baumeister, R. F. (1998) Self-control as a limited resource: Regulatory depletion patterns., *Journal of Personality and Social Psychology*, **74**, 774–789.

Mylovanov, T. (2008) Veto-based delegation, *Journal of Economic Theory*, **138**, 297–307.

Netzer, N. (2009) Evolution of time preferences and attitudes toward risk, *The American Economic Review*, **99**, 937–955.

Oaten, M. and Cheng, K. (2006a) Improved self-control: The benefits of a regular program of academic study, *Basic and Applied Social Psychology*, **28**, 1–16.

Oaten, M. and Cheng, K. (2006b) Longitudinal gains in self-regulation from regular physical exercise, *British journal of health psychology*, **11**, 717–733.

Oaten, M. and Cheng, K. (2007) Improvements in self-control from financial monitoring, *Journal of Economic Psychology*, **28**, 487–501.

Pocheptsova, A., Amir, O., Dhar, R. and Baumeister, R. F. (2009) Deciding without resources: Resource depletion and choice in context, *Journal of Marketing Research*, **46**, 344–355.

Rayo, L. and Becker, G. S. (2007) Evolutionary Efficiency and Happiness, *Journal of Political Economy.*

Rayo, L. and Robson, A. (2017) Biology and the Arguments of Utility, *Working Paper.*

Richerson, P. J. and Boyd, R. (2005) *Not by genes alone: How culture transformed human evolution*, University of Chicago Press.

Robson, A. and Samuelson, L. (2011) The evolution of decision and experienced utilities, *Theoretical Economics*, **6**, 311–339.

Robson, A. J. (2001) Why would nature give individuals utility functions?, *Journal of Political Economy*, **109**, 900–914.

Robson, A. J. and Samuelson, L. (2010) The Evolutionary Foundations of Preferences, in *Handbook of Social Economics*.

Rogers, T., Milkman, K. L. and Volpp, K. G. (2014) Commitment Devices: Using Initiatives to Change Behavior, *JAMA*, **311**, 2065–2066.

Rosenquist, J. N. and Rothschild, C. (2012) A Cautionary Primer, *The Neuroscientific Turn: Transdisciplinarity in the Age of the Brain*, p. 163.

Rubinstein, A. (2003) Economics and Psychology? The Case of Hyperbolic Discounting, *International Economic Review*, **44**, 1207–1216.

Rünger, D. and Wood, W. (2015) Maintenance of Healthy Behaviors: Forming and Changing Habits, in *Behavioral Economics and Public Health*, Oxford University Press.

Samuelson, L. (2004) Information-Based Relative Consumption Effects, *Econometrica*, **72**, 93–118.

Samuelson, L. and Swinkels, J. M. (2006) Information, evolution and utility, *Theoretical Economics*, **1**, 119–142.

Sanfey, A. G., Loewenstein, G., McClure, S. M. and Cohen, J. D. (2006) Neuroeconomics: cross-currents in research on decision-making., *Trends in cognitive sciences*, **10**, 108–16.

Schelling, T. C. (1978) Egonomics , or the Art of Self-Management, *The American Economic Review*, **68**, 290–294.

Smith, A. (1759) *The Theory of Moral Sentiments*, Penguin.

Sunstein, C. R. (2014) *Why Nudge?: The Politics of Libertarian Paternalism*, Yale University Press.

Tangney, J. P., Baumeister, R. F. and Boone, A. L. (2004) High self control predicts good adjustment, less pathology, better grades, and interpersonal success, *Journal of Personality*, **72**, 271–324.

Thaler, R. H. and Shefrin, H. M. (1981) An Economic Theory of Self-Control, *Journal of Political Economy*, **89**, 392–406.

Vohs, K. D., Baumeister, R. F., Schmeichel, B. J., Twenge, J. M., Nelson, N. M. and Tice, D. M. (2014) Making choices impairs subsequent self-control: a limited-resource account of decision making, self-regulation, and active initiative., *Journal of Personality and Social Psychology*, **94**, 883–898.

Williams, K. W. and Elmquist, J. K. (2012) From neuroanatomy to behavior: central integration of peripheral signals regulating feeding behavior, *Nature Neuroscience*, **15**, 1350–1355.

serie
ad

Ivie

Guardia Civil, 22 - Esc. 2, 1º
46020 Valencia - Spain
Phone: +34 963 190 050
Fax: +34 963 190 055

Website: www.ivie.es
E-mail: publicaciones@ivie.es