Choosing and Adjusting

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Abstract

The paper develops a model of individual decision-making in which durable cognitive adjustment complements choice of action and regret may provoke a need to justify committed "errors." Because adjustment is durable, initial positions in consumption (*endowments*) matter for future consumption decisions. Thus the theory provides a unified foundation in primitives for the endowment effect and behaviors traditionally attributed to sunk-cost bias. The model shows that what psychological experiments have typically characterized as reactions to cognitive dissonance may be explained by an adjustment-to-choice mechanism in combination with a choice set restriction or discontinuity. This last finding is key to new public policy approaches with the potential to resolve policy stalemates as well as agent compliance problems in public health and occupational safety. It also forms the basis for a new approach to measuring cognitive dissonance reactions empirically.

Keywords consumer decision-making; endogenous preference; behavioral; escalation of commitment.

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1 Introduction

When we humans act, we tend to adjust to our actions. We buy a home, choose a spouse, or decide to take a position on a political issue. We then – or sometimes in anticipation – get psyched up, rehearse the best qualities of our selected course, get acclimated to the inevitability of what we are doing, and rationalize.

Adjustment efforts may take varying forms. They can be specific and top-of-mind, or broad-based and ambient. A consumer may actively rationalize the additional expense associated with an all-electric vehicle shortly after purchasing a new Tesla. Meanwhile, over several months and almost without being aware of it, the same individual may find he is "growing into" being a Tesla owner, becoming more accustomed to and accepting of the car's various features and thus enjoying them more. Adjustment may occur as an instantaneous and almost imperceptible process, as for example when the purchaser of a roll-on quickly assembles an argument for getting deodorant rather than anti-perspirant. Or it may be extended and manifestly obvious to all, as in the case of marital engagement. The desire to adjust optimally to an action may motivate people to seek resources external to themselves, such as friends' advice, information on the Internet, or persuasive images in television commercials. Whether or not they seek external inputs to aid adjustment, individuals invest limited attention and energy in the process. And while even the smallest purchases engender a modicum of supportive thinking, the bigger the commitment one makes, the harder one endeavors to learn to love it.[1]

There is a substantial amount of experimental evidence on the complementarity of actions and cognitive processes that alter perceptions of actions. Individuals asked to re-rate alternatives following a decision or in anticipation of one increase their ratings of chosen alternatives and in some cases diminish ratings of non-chosen alternatives (Lieberman *et al.* 2001, Kitayama *et al.* 2004, Sharot *et al.* 2010, Wakslak 2012). Studies using functional magnetic resonance imaging (fMRI) indicate changes in preference-related brain activity contemporaneous with the changes in subjects' subjective rating of stimuli accompanying decisions or actions (Sharot *et al.* 2009, Van Veen *et al.* 2009, Izuma *et al.* 2010, Jarcho *et al.* 2011, Qin *et al.* 2011, Kitayama *et al.* 2013).

Festinger's (1962) theory of cognitive dissonance explains some of these phenomena conceptually in terms of individuals preferring their actions to be aligned with their beliefs; when they are not aligned,

[1] Adjustment, as I have defined it, is distinct from search, which has the objective of identifying one's best choice; the purpose of adjustment is to increase utility from a choice one has already determined – or is, in parallel, determining – to be one's best.

the theory contends, people may become uncomfortable and may alter their beliefs to restore a sense of comfort. The tri-component model of attitude also reflects the notion that action moves hand-in-hand with adaptive changes in beliefs and feelings (see, e.g., Grimm 2005). This model has been applied extensively to explain consumer behavior and, as such, has formed the basis for a substantial amount of marketing strategy.

Despite the evidence that people adjust to their actions and its general acceptance by psychologists and marketers, the role of adjustment in decision-making has received little attention from economists. This likely stems from the fact that adjustment nominally involves a change in tastes. Most economists are reluctant to consider changing tastes because they tend to upend traditional approaches to identifying preferences and measuring welfare. Yet the idea that choices not only reflect, but also create, preferences continues to gain currency in the social sciences (Ariely & Norton 2008).

In this paper I offer a theory of individual decision-making in which adjustment complements choice. I circumvent some of the thornier issues associated with taste change by modeling a consumer who obtains utility from an adjustment-augmented commodity. In my framework, adjustive thinking quasi-changes preferences in the sense of altering the consumer's marginal utility for the product; but in the context in which the consumer operates - rationally choosing both a quantity of the product and quantity of adjustment as complements, like peanut butter and jelly – tastes can be said to be fixed. An exogenous parameter representing product quality (or, equivalently, consumer-specific taste for the product) affects the marginal utilities of both the product and adjustment. While product consumption decisions are revisited period-by-period, adjustive thinking creates a durable stock of product-specific attitude that affects the utility from future consumption.[2]

People do not always adjust simply to complement their current and future consumption; sometimes they do so to justify a past decision to themselves. For example, subjects in forced compliance experiments change their beliefs to feel better about actions they took that were incongruent with their beliefs or values (Festinger & Carlsmith 1959). To capture such motivations, I allow regret to play a role in the agent's objective function. To give meaning, in turn, to the notion of regret, I introduce *endowments* – exogenous actions occurring in the initial period of the model prior to the realization of quality/taste. Endowments can represent choices the individual made under uncertainty or subject to a constraint;

[2]The manner in which thinking in the model creates an enduring stock of attitude (adjustment) is similar to the mechanism in Becker's (1965, 1985) model, in which certain present actions create enduring stocks that are complementary with future actions. Becker's complementary stocks explain diverse behaviors that appear prima facie to represent changing tastes, including addiction and the accumulation of human capital (Stigler & Becker 1977, Becker & Murphy 1988). However, Becker's activity-focused theory does not admit cognition as a complement to action and so fails to recognize the role played by adjustment in the utility obtained from consumption activities.

they may in the extreme represent actions forced on the individual. Such actions are suboptimal given the realization of quality, or they may appear so in hindsight. The regret-driven individual attempts to use adjustment to directly rationalize the "endowed" decision by rendering it post-hoc optimal.

The model provides a unified foundation in primitives for a number of phenomena that have been previously treated separately. First, it demonstrates that endowments, independent of other factors (such as regret), increase consumption of the same good at the margin in future periods – an *endowment effect* – because they drag adjustment with them. However, the model predicts that this tendency is unambiguously increased by regret, because the need to justify one's prior action quite generally implicates greater adjustment. Second, the model recognizes escalation of commitment as a pattern of repeated action driven by a motor of ongoing regret. The persistently regretful agent harks back continually to his initial "error," seeking again and again to justify it. His rationalization then drives repeated action of the same kind taken initially. The model's predictions in this regard are consistent with experimental evidence that regret fosters repeat purchase behavior by consumers (Mittelstaedt 1969) and more broadly fit with descriptive accounts of escalation of commitment from the literature (e.g., Staw 1976). Third, the model shows that many instances of what have been described as cognitive dissonance in the literature involve some form of choice set restriction or discontinuity paired with regret. The key mathematical result associated with this is that regret reverses the sign of the marginal effect of product quality on adjustment. Fourth, the model provides a robust rational-agent explanation for a range of marketing practices. In particular it offers an understanding of why advertising, price promotions, and free sampling are observed *even when they do not serve to increase the consumer's information about a product.*

In a paper relevant to the present effort, Eyster (2002) analyzes sunk cost effects using a dynamic decision-making framework in which an agent acts in the present to justify past actions. His model is able to explain scenarios such as Thaler's (1980) classic example of a family that decides to go to a basketball game during a snowstorm, the family noting that they would not have gone had they received the tickets for free rather than purchasing them. Strategic complementarity of the initial action (deciding to purchase the tickets) and a subsequent action that justifies the initial one (attending the game) propels observed sunk-cost behavior.

The adjustment-to-choice model offers an advance over Eyster's approach in cases where a cognitive layer is essential to understanding the mechanism of post-hoc justification. To demonstrate, consider the scenario, described by Akerlof & Dickens (1982), in which individuals face a dissonance-producing decision of whether to work in a hazardous industry and, subsequently, are given the opportunity to purchase safety equipment. Based purely on the complementarity of actions, one would expect the workers to purchase the safety equipment even when the benefits to improved safety do not exceed equipment costs: the adoption of the equipment renders more prudent in retrospect one's decision to work in the industry. Yet, consistent with the anecdotal evidence on safety-related behavior in a range of situations (e.g., motorcycle helmets, headgear for hockey, AIDS testing), workers in such situations typically *avoid* the equipment even when its isolated net benefit is positive. The reason, as described in the discussion on cognitive dissonance in Section 4 of this paper, is that such scenarios involve a discontinuous choice set that induces inconsistency with continuously variable beliefs; the resultant regret precipitates compensatory adjustment that reduces adoption of future behaviors that might have been rational *but for the adjustment*.

Conceiving of thinking as being used to minimize regret from action relates adjustment to the literature on motivated reasoning (see Epley & Gilovich 2016 for a survey). The idea behind motivated reasoning is that certain beliefs are desirable and will be held when it is possible for the individual to hold them rationally. The literature's focus is on what reasoning is feasible and under what circumstances. Adjustment (for the purposes of minimizing regret) may be contextualized as a very specific form of motivated reasoning: the use of complementary thinking to rationalize a previously-chosen intensity of an action. That is, the agent I consider is deciding how much or how little to psych himself up about a previously-committed action as an instrument for minimizing the experienced regret from having made an "error" about the intensity of that action. Given this scope for adjustment, I assume that rationalizations can always be found – simply that it must be costly to invent them – whence the key question becomes not whether one adjusts in a given circumstance, but how much. This proves relevant to determining how much ongoing action will occur.

The rest of this paper is structured as follows. Section 2 lays out a portable model of individual decision-making involving adjustment to choice. Section 3 introduces endowments and regret. Section 4 applies the model to explain the four core phenomena highlighted above: the endowment effect, escalation of commitment, cognitive dissonance reactions, and marketing practices. Section 5 concludes by discussing some possibilities for future work. The Appendix contains proofs of all results.

2 Adjustment to Choice

Consider an individual who consumes over an infinite series of periods, indexed t, extending out from an initial period $t = 0$. He must make two decisions each period: how much $x_t \geq 0$ to consume of a good x, and how much "adjustive" thinking $T_t \geq 0$ to engage in in support of that good.[3] Let us initially assume that the thinking decision and the consumption action decision at t are made simultaneously. The good x is not durable: the consumption decision must be renewed each period and the history of previous consumption does not matter directly for current utility. However, thinking creates a durable stock of adjustment, y_t, according to the process

$$\begin{aligned} y_t &= (1-\sigma)\, y_{t-1} + T_t,\ t > 0 \\ y_0 &= T_0 \end{aligned} \tag{1}$$

This stock of adjustment in a period is, in turn, complementary with the contemporaneous consumption of x.

I formalize the utility of complementary consumption and adjustment using the household production function approach proposed by Becker (1965) to model the allocation of time. Let instantaneous utility u be a function of a "commodity" z the individual consumes and that is, in turn, "produced" using inputs x and y, to wit, $u(z)$ where $z = z(x, y)$. I assume $u(.)$ and $z(.)$ satisfy the following properties:

(A1) The production function $z(.)$ exhibits diminishing returns to x and y and constant returns to scale; that is, $z_x, z_y > 0$, $z_{xx}, z_{yy} < 0$, with z homogeneous of degree one in x and y.

(A2) Marginal utility diminishes in z, $u_{zz} < 0$.

(A3) The elasticity of z_x with respect to y is larger in absolute value than the elasticity of u_z with respect to y, and the elasticity of z_y with respect to x is larger in absolute value than the elasticity of u_z with respect to x; that is, $u_z z_{xy} > -u_{zz} z_x z_y$.[4] This property, when combined with (A1) and (A2), guarantees that consumption and adjustment are mutually complementary in utility, not just in z.

Notice that this specification has the intuitive characteristic that the value of adjustment is related

[3] More broadly, good x might be an activity that could be engaged in at varying levels of intensity.

[4] One example of a utility function that satisfies (A1)-(A3) is the extended Cobb-Douglas formulation, $u(z) = z^{a+b}$, with $z(x, y) = x^{\frac{a}{a+b}} y^{\frac{b}{a+b}}$, for $a, b > 0$, $a + b < 1$. See Appendix.

to the consumption value attached to the goods in question, so that the first unit of adjustment effort expended on a car would have greater payoff, say, than the first unit of such effort invested in a can of anti-perspirant. Homogeneity of the production function ensures that consumption of and adjustment to the good have the same complementary relationship at the margin when both are scaled up proportionally. Meanwhile, diminishing marginal returns to z ensures that, even as consumption and corresponding elaboration are scaled up proportionally, their combination contributes less and less to utility.

It will be convenient to express instantaneous consumption utility as the derived function of the quantities of instantaneous activity and thinking, $u(x,T) \equiv u(z(x,y(T)))$, whence I will also use the shorthand u_x, u_T, u_{xx}, u_{TT}, and u_{xT} to represent $u_z z_x$, $u_z z_y$, $u_z z_{xx} + u_{zz} z_x^2$, $u_z z_{yy} + u_{zz} z_y^2$, and $u_z z_{xy} + u_{zz} z_x z_y$, respectively, where appropriate.

The consumption problem occurs in the context of a broader economy in which there are many goods and activities in which effort can be invested. To focus the analysis, I assume the consumer possesses an invariable, finite supply of effort, K, each period. This effort may be allocated to adjust to good x; or to earn labor income, paid in a numeraire commodity, that may be spent on x or on other consumption activities. The price of x is normalized to one. Each unit of numeraire not spent on x garners one unit of utility (via the other consumption activities). At time $t = \tau$, then, the consumer's preferences are represented by the quasilinear discounted utility function

$$\begin{aligned} &U(x_\tau, x_{\tau+1}, ...; T_\tau, T_{\tau+1}, ...) = \\ &\mu u(x_\tau, T_\tau) + K - x_\tau - T_\tau + \sum_{t=\tau+1}^{\infty} \delta^{t-\tau} \left[\mu u(x_t, T_t) + K - x_t - T_t\right] \end{aligned} \tag{2}$$

where $\mu > 0$ is the good or activity's quality level and $\delta \in (0,1)$ is the consumer's discount rate. The consumer's problem in $t = \tau$ is therefore

$$\max_{T_\tau, x_\tau} (2) \tag{3}$$

Quality is an intrinsic characteristic of the good x and does not vary over time. The variable μ might, alternatively, represent the consumer's exogenous taste for, or attitude toward, the good (i.e., in the traditional "fixed" sense). Under this interpretation, μ is intrinsic *jointly* to the consumer and the good. Under the attitudinal interpretation of μ, the model conceives of a consumer whose attitude comprises fixed and discretionary components. The consumer begins in the initial period $t = 0$ with only her fixed component whereupon, according to the process in (1), she begins to invest in the discretionary component, adjusting to the activity that she is about to commence.

The complementary utility model I have set forth here may be thought of as portraying a consumption process that is like driving a car on a cold day. One can turn the car on and drive it productively without warming up the engine, taking the "fixed" components of the car as given and obtaining utility from those. But one might get better results (e.g., better contemporaneous pick-up, as well as longer life for the engine going forward) if one invests in warming the car up first. Note that the model allows for two extremes with respect to the ongoing process of consumption. With $\sigma = 0$, adjustment does not depreciate at all: once the consumer has finished her initial adjustment to an activity, she is "adjusted," and she does not have to do it again. With $\sigma = 1$, adjustment depreciates completely every period, requiring fresh adjustment every period. For the values of σ in between, the setup conceives of an activity that requires some ongoing discretionary cognitive effort to remain primed, or "psyched up." (Marriage provides a good example: you have to invest in it every day if you want optimal results!)

In intertemporal models, it is common in the literature to model the consumer as a sequence of temporal selves that make choices in a dynamic game with one another (e.g., Pollak 1968, Peleg & Yaari 1973, Goldman 1980, and Laibson 1997). This is the normal approach when preferences are dynamically inconsistent, such that the consumer at t would disagree with the tradeoff decision between consumption in $t+1$ and $t+2$ that a consumer at $t+1$ would make. The preferences given by (2) are not dynamically inconsistent; however, I will use a modified objective that does exhibit dynamically inconsistent preferences when I consider regret in section 3. Therefore I adopt here, and carry forward through subsequent analysis, the approach of modeling the infinite-period consumption problem as an infinite game, with an infinite number of players, or "selves," indexed by their respective periods of control over the consumption and thinking decisions (Laibson 1997). I look for subgame perfect equilibrium (SPE) strategies of this game. In that context, I will let S_t represent the set of feasible strategies in the game for self t. Let $S = \prod_{t=0}^{\infty} S_t$ represent the joint strategy space for all selves.

The following is the main technical result of the core model. The theorem confirms that there is a single equilibrium path involving action and complementary adjustment for a discounted-future-utility-maximizing consumer who simultaneously chooses action and adjustment starting from the very first period.

Theorem 1. *The infinite consumption game in which the consumer at each $t \geq 0$ chooses (x_t, T_t) to solve* (2) *has a unique subgame perfect equilibrium strategy, $s^*(\mu) \in S$, characterized by: (i) a steady-state $(x^*(\mu), y^*(\mu))$ such that $(x_0, T_0) = (x^*(\mu), y^*(\mu))$ and $(x_t, T_t) = (x^*(\mu), \sigma y^*(\mu))$ for all $t > 0$;*

and (ii) $x^*_\mu, y^*_\mu > 0$.

Theorem 1 implies that in world in which product quality is known from the outset, the unique consumption and adjustment path is a steady state in which both depend positively on the level of quality. The consumer engages in adjustive thinking each period at the intensity level needed to maintain steady-state adjustment given its depreciation rate, σ.

3 Endowments

Now let us consider a tweak to the setup: x_0 is fixed exogenously at $\bar{x}_0 > 0$ rather than being set by the consumer contemporaneously with adjustive thinking at $t = 0$. This can represent a number of things. A consumer might have committed to a level of consumption before knowing the good's quality level (or her taste for it). Subsequently, quality is revealed, placing her in the position of deciding how much adjustment to do given her prior consumption commitment and the quality level. Or the consumer might be exogenously endowed with a level of consumption, having received the good as a gift or bequest. Or the individual might somehow have been compelled to take an action independent of her tastes or beliefs. In all these cases, the level $\bar{x}_0$ presents itself at the start of the game before anything else is determined, an existing "fact" to which the consumer must adapt her adjustment level.

I begin by establishing a revised equilibrium existence result:

Lemma 1. *The infinite consumption game in which the consumer at each* $t > 0$ *chooses* (x_t, T_t) *to solve* (2) *and the consumer at* $t = 0$ *chooses* T_0 *given* x_0 *fixed at* $\bar{x}_0$ *to solve* (2) *has a unique subgame perfect equilibrium strategy,* $s^*(\bar{x}_0, \mu) \in S$.

3.1 Equilibrium with Regret

In general, the level of endowed actions will not be consistent with the consumer's realized tastes or the realization of quality and so not on the optimizing steady-state path. That is, $\bar{x}_0 \neq x^*(\mu)$. This gives rise to the possibility that the consumer will feel she erred in having taken the action at its endowed level and will regret her error. She may see herself as responsible and may question her own judgment. Where she is clearly not responsible – having merely acted in a way that was chosen for her by someone else – she may experience incongruence between her values and her action. In both cases, the experience is unpleasant. The consumer acts to minimize such displeasure.

We may think of the experience of regret and the consumer's response to it as a reframing of the consumer's problem. A non-regret-driven consumer chooses and adjusts in order to make the most of her present and future consumption opportunities. A regret-driven consumer instead uses her power to choose and adjust in the present in order to minimize the discrepancy between the path she believes she should have chosen in the past and the one she actually chose. While the first consumer makes her decision while looking forward, the second looks back. It is possible in general that a consumer may embody a little bit of both the forward-looking and the backward-looking individual, whence her decision process takes a hybrid form. The extent to which she acts in a forward-looking or backward-looking way could vary over time, following her moods or other relevant aspects of her situation.

To fix ideas, let us assume the consumer's objective at $t = \tau$ takes the following general form:

$$\max_{T_\tau, x_\tau | \bar{x}_0} U^R(x_\tau, T_\tau; \beta_\tau) = (1 - \omega\beta_\tau)\left\{\mu u(x_\tau, T_\tau) + K - x_\tau - T_\tau + \sum_{t=\tau+1}^{\infty} \delta^{t-\tau}\left[\mu u(x_t, T_t) + K - x_t - T_t\right]\right\}$$
$$+ \omega\beta_\tau\left\{\left[\mu u(\bar{x}_0, T_\tau) + K - \bar{x}_0 - T_\tau\right] - \left[\mu u(x_0^*(T_\tau), T_\tau) + K - x_0^*(T_\tau) - T_\tau\right]\right\} \quad (4)$$

This function weights the quasilinear discounted future utility function in (2) with a second term. That second term in effect revisits the consumer's consumption decision from $t = 0$ in hindsight. It is a strictly non-positive loss function that is minimized, at a value of zero, when the endowed level of consumption turns out to have been the optimizing level *given adjustment* at $t = \tau$. The consumer endeavors through this term, in effect, to manipulate the instrument that she currently has available ($t = \tau$ adjustment) to render her earlier decision ($t = 0$ consumption) post-hoc optimal, acting *as if* through current adjustment she could turn back the clock and somehow enhance the effectiveness of her prior consumption decision.

Here, $\omega \in [0, 1)$ parameterizes the degree of regret that the consumer experiences overall, while $\beta_\tau \in [0, 1)$ reflects the degree to which regret is experienced specifically at $t = \tau$. Thus this form anticipates a consumer who not only experiences immediate displeasure (i.e., in $t = 0$) from having erred, but who continues to experience *lingering* displeasure in later periods and to experience a lingering desire to reduce it through adjustment. The form allows for maximum generality in specifying how regret lingers over time, allowing the model to describe, for example, a person who feels substantial regret for his decision one period, a lot less the next, and then a subsequent resurgence in later periods. Non-lingering regret is nested as the special case $\beta_\tau = 0 \; \forall \tau > 0$, and other interesting special cases such as a simple decay path (i.e., $\beta_\tau = \beta^\tau$) could also be represented.[5]

Note that the preferences represented by (4) are dynamically inconsistent. That is, preferences in period t are inconsistent with preferences in period $t+1$. This occurs as a consequence of regret. The regret-driven part of the consumer cares only about minimizing regret now, in t, as reflected by the second term in the objective. His non-regret-driven self has dynamically consistent preferences and wants to treat all periods the same. Both selves in t anticipate that the $t+1$ self will, to the extent he is regret-driven, care only about minimizing regret in $t+1$; the non-regret-driven self does not view that as a desirable goal. (The regret-driven self totally discounts the future and does not care.) One may check that regret leads to a marginal rate of substitution between periods $t+1$ and $t+2$ from the perspective of the decision-maker at t that does not equal the marginal rate of substitution between those same periods from the perspective of the decision-maker at $t+1$, consistent with the demonstration of dynamic inconsistency proposed by Laibson (1997).[6]

The equilibrium existence result for the regret context depends on complementary restrictions on the convexity of the regret term and the intensity of regret. If the regret term is quite convex, then it must be weighted lightly in the objective for the overall objective to be strictly globally concave. If the regret term is not very convex or is concave, then it may be weighted heavily in the objective. Existence is guaranteed by bounding the convexity above, whence one may obtain an upper bound on regret that guarantees global concavity of the overall objective.

Lemma 2. *Assume $u(z(x,y))$ such that, for any $\bar{x}_0 > 0$, there exists $Z(\bar{x}_0, \mu) < \infty$ where for all T_τ at all $\tau \geq 0$,*

$$\mu u_z z_{EE}(\bar{x}_0, E_\tau) + \mu u_{zz} z_E^2(\bar{x}_0, E_\tau) - \mu u_z z_{EE}(x_0^*(T_\tau), E_\tau)$$
$$-\mu u_{zz} z_E^2(x_0^*(T_\tau), E_\tau) - \mu u_z z_{xE}(x_0^*(T_\tau), E_\tau)\, x_T^* - \mu u_{zz} z_E z_x(x_0^*(T_\tau), E_\tau)\, x_T^* < Z(\bar{x}_0, \mu)$$

Then it follows there exists $\bar{\omega} > 0$ such that for $\omega \in [0, \bar{\omega})$ the infinite consumption game in which the consumer at each $t > 0$ chooses (x_t, T_t) to solve (4) and the consumer at $t = 0$ chooses T_0 given x_0 fixed at $\bar{x}_0$ to solve (4) has a unique subgame perfect equilibrium strategy, $s^*(\bar{x}_0, \mu) \in S$.

[5] I assume the consumer does not experience "meta-regret," that is, regret over experiencing regret. For this reason, because the endowment does not affect utility directly except for the current period, the regret component does not include any terms relating to future periods.

[6] The non-regret-driven self might try to behave strategically with respect to the future regret-driven self, but I will assume for simplicity initially that he assumes his future self will not be affected by regret. One might conceive of such an agent as naïve in the sense of not realizing he will act to minimize regret in the future (see, e.g., Eyster 2002). I discuss relaxing this assumption later on.

3.2 Comparative Statics

With Theorem 1 and Lemmas 1 and 2 as underpinning, two comparative static results relating to adjustive thinking in the initial period set the stage for our application of the model.

Proposition 1.

1. *For a consumer who does not experience regret ($\omega = 0$), adjustive thinking in the initial period increases with quality* (complementary adjustment).

2. *With extreme regret ($\omega = 1$), adjustive thinking decreases with increased quality* (compensatory adjustment).

3. *More generally, $\partial^2 T_0 / \partial \mu \partial \omega < 0$; that is, intensified regret causes adjustive thinking to become increasingly compensatory.*

Proposition 1 establishes that regret reverses the direction of the effect of quality on adjustment in the initial period. The result is intuitive. A higher quality good yields greater benefits to incremental adjustment in consumption utility. Thus, quality "surprises" excite the forward-looking individual, motivating her to invest more in adjusting to the good. I refer to this as *complementary adjustment.* For an individual who is only concerned about minimizing regret, however, unexpected quality is viewed as a threat. It suggests to the individual that she chose *too little* of the good. She is motivated only to reduce this perception, which she achieves by adjusting *less* when quality is higher to offset the surprise. I refer to this phenomenon as *compensatory adjustment.* For cases along the continuum between the extremes of pure regret and pure consumption-utility maximization, a greater weight on regret in the objective implies an increase in the compensatory motive.

The second comparative static result concerns the endowment's effect on initial period adjustment.

Proposition 2. *A larger endowment induces increased adjustive thinking in the initial period (i.e., $\partial T_0 / \partial x_0 > 0$). This tendency increases with the intensity of regret (i.e., $\partial^2 T_0 / \partial x_0 \partial \omega > 0$).*

The more of the good the individual has, the greater the value of adjusting to it. This is true purely from the perspective of consumption utility: if you are going to do more of something, it is all the more important that you love it. But regret implies the same effect: the larger the amount of the endowed good, holding quality constant, the greater the perception that one choose too much of it. This motivates additional compensatory adjustive thinking, so that the amount of the good is justified post hoc by the amount of adjustment the individual later committed to it.

To understand why the endowment's effect on adjustive thinking is always *greater* the greater one's regret, consider a simple thought experiment. We know already that a larger endowment, holding quality constant, increases T_0 when the individual experiences no regret. Now suppose the quality level is increased, ceteris paribus, to the level of quality that would correspond to the endowment if that amount of the good had been chosen with quality known. From Proposition 1, again for the regret-free individual, we know that T_0 would be yet higher. Next, let us suppose the individual is transformed into one who experiences regret, and simultaneously let us reduce the quality level *back* to its previous lower level. Again invoking Proposition 1, we see that T_0 is increased further still, since lower quality results in compensatory adjustment by the regretful individual. The net observation is that a higher endowment, all else equal, results in greater adjustive thinking the more regretful the individual.

4 Analysis

In the following subsections, I consider several applications of the adjustment-to-choice model.

4.1 The Endowment Effect

When a person who is forward-looking adjusts to her choices, a remarkable thing happens when she is endowed with a significant amount of a good. She learns to love it. If adjustment is sufficiently durable, these feelings may carry over into future periods, inducing increased consumption of the good in future periods.

Proposition 3. *(Endowment Effect) Let $(x^*(\mu), y^*(\mu))$ be the unique steady-state equilibrium in consumption and adjustment, and suppose $x_0 > x^*$. Then: (i) the regret-free consumer chooses $y_0 > y^*$; and (ii) if x_0 large enough, as defined implicitly by*

$$\mu u_z z_y \left(x_0, \frac{y^*}{(1-\sigma)^\tau} \right) \quad > \quad \mu u_z z_y (x^*, y^*)$$

then $y_t > y^*$ and $x_t > x^*$ for all $t \leq \tau$.

The endowment effect, under the adjustment model, is a *mere possession* effect. Merely possessing an object motivates thinking to improve attitude toward the object in hand. Durability of the attitude is all that is needed to motivate persistent behavior going forward. Note that this has nothing to do with the honoring of sunk costs: it follows for a "rational" discounted future utility maximizer from a process by which thinking complements action. The adjustment model's explanation of the endowment effect does not rely on loss aversion. Explanations based on loss aversion, while supportive of the observed asymmetry in valuations between people endowed with a good and those not endowed, do not answer the simple question of why parting with something in trade should be viewed as a loss. Unlike the adjustment model, they also cannot explain ownership effects whereby individuals – whether buyers or sellers, and whether what they are trading is their own or not – value objects more when they own an identical item (Morewedge *et al.* 2009).[7]

The adjustment model is consistent with the observation that experienced traders do not exhibit the endowment effect, nor are endowment effects witnessed with money (DellaVigna 2009). Money, as a pure medium of exchange, does not bear being "adjusted to": there is not a material object with respect to which one may, through thinking, improve one's attitude. Similarly, experienced traders are likely to treat un-owned, traded items as mere commodities that they do a business in; thus there is really nothing, in their eyes, to be "adjusted to."[8]

The endowment effect is unambiguously strengthened by regret, as the following result indicates:

Proposition 4. *(Sweet Lemons) Let* $(x^*(\mu), y^*(\mu))$ *be the unique steady-state equilibrium in consumption and adjustment, suppose* $x_0 > x^*$*, and consider a consumer characterized by non-lingering regret* $\beta_\tau = 0\ \forall\tau > 0$ *and* $\beta_0 > 0$ *for* $\omega \in [0,1]$*. Define* $x_{0\tau}(\omega)$ *to be the size of endowment needed to induce this consumer to set* $x_t > x^*$ *for all* $t \leq \tau$*. Then* $\frac{\partial x_{0\tau}(\omega)}{\partial \omega} < 0$.

Put simply, the stronger the consumer's regret, the smaller the endowment it takes to induce an endowment effect in any given future period. The mechanism is through the effect of regret on justification-oriented thinking. The more strongly a person feels the need to justify a past action (because he more intensely regrets it), the more justification he will engage in, creating a larger stock of adjustment that will carry forward further into the future. I call this the "sweet lemons" effect. A regretful consumer chooses a product that later turns out not to live up to expectations; he then tells himself, in effect, that the decision must not have been so bad (i.e., the lemon was "sweet"), because, after all, it motivated him

[7]The trouble is that the lack of conceptual framework for understanding the endowment effect has led to excessive reliance on indications from experimental evidence alone, including a "leap" from the results of the lottery experiments that led to prospect theory to the notion that such experiments also explain what is going on with trades.

[8]Kőszegi & Rabin (2006) describe the trader phenomenon in terms of traders' "rational expectations" that there is a high probability of parting with items they have just acquired. This "reference dependence perspective" is fully consistent with the adjustment theory view of a rational adjuster who will not adjust if she does not expect to own the object.

enough to adjust considerably. This behavior leads naturally to ongoing consumption of the "lemon," motivated by the consumer's regret-driven zeal.

4.2 Escalation of Commitment

A range of psychological evidence suggests that real-life decision-makers exhibit "sunk-cost bias," violating the normative principle that rational agents should not take account of sunk costs in making decisions. In particular, individuals who have previously invested more in a course of action may be more likely to continue it, a phenomenon referred to variously as the "Concorde effect" (Dawkins & Carlisle 1976) or "escalation of commitment" (Staw 1976). As discussed in the introduction, recent behavioral economic models have rationalized such behavior when past actions and present actions are strategic complements. This can occur because agents exhibit a taste for consistency of action (Eyster 2002) or because previously-sunk costs provide a signal of the value of projects to forgetful agents who must consider whether to continue investment in the present period (Baliga & Ely 2011).

The adjustment model offers another basis for making sense of escalation-of-commitment-type behaviors. They can occur if agents who adjust exhibit a lingering desire to achieve a psychological accommodation of prior errors.

Proposition 5. *(Sweet Lemons Redux) Let $(x^* (\mu), y^* (\mu))$ be the unique steady-state equilibrium in consumption and adjustment, suppose $x_0 > x^*$, and consider a consumer characterized by lingering regret such that $\beta_\tau > 0$ for some $\tau > 0$ with $\omega \in (0, 1]$. Then $x_\tau > x^*$.*

Proposition 5 captures basic intuition about the motivations of decision-makers who feel "invested" (in the sunk-cost sense) in a past course of action. They want to do something now will that make it all seem as if it was worthwhile. While a consistent action in the present can have this effect (e.g., à la Eyster), such an action is not *necessary.* In a complementary action-and-adjustment world, what is necessary is that one *believes*, at the end of the day, that the prior action was all worthwhile. This is achieved by rationalization - that is, by adjustment. Indeed, when we observe a decision-maker taking a consistent action, such as Thaler's (1980) family going to the basketball game in the snowstorm, it may well be because the action carries with it, as a complement, the adjustment in cognition that rationalizes the prior decision.

The lingering desire to accommodate prior errors works for under-endowments as well, as recognized by the following proposition:

Proposition 6. *(Sour Grapes) Let* $(x^*(\mu), y^*(\mu))$ *be the unique steady-state equilibrium in consumption and adjustment, suppose* $x_0 < x^*$*, and consider a consumer characterized by lingering regret such that* $\beta_\tau > 0$ *for some* $\tau > 0$ *with* $\omega \in (0, 1]$*. Then* $x_\tau < x^*$*.*

I call this the "sour grapes" proposition because it reflects the situation of the fox in the Aesop parable who sees grapes that are out of his reach and therefore rationalizes that they were sour at not worth his while anyway. Suppose the fox is given the chance the next day to eat the grapes; would the fox pass them up? Proposition 6 indicates that this depends on whether he experiences a lingering desire to rationalize not having gotten the grapes yesterday, as only then would he continue to perceive them as sour and act upon that assumption.

Note the asymmetry between under-endowments and over-endowments in the model when there is no lingering regret. An over-endowment - that is, an endowment of an amount of the activity greater than what would have been chosen with quality known - causes an endowment effect. An under-endowment can be rectified immediately the following period (now that one knows quality and is free to choose the amount of the activity), whence there is no future reduction in consumption, that is, no endowment effect. Lingering regret, however, gets in the way of this correction, causing behavior to be biased downward based on the need to continue to rationalize the downside error from the initial period.

4.3 Cognitive Dissonance

4.3.1 The Model and General Principles

Cognitive dissonance has been defined as what occurs when an individual simultaneously holds two beliefs that are inconsistent (Aronson 2004). The term has been used to characterize a range of observed phenomena typically involving the individual changing his beliefs in response to being compelled to take an action or being faced with a difficult decision. Often subsequent behavior is affected. For example, in the scenario proposed by Akerlof & Dickens (1982) described in the introduction, workers adjust their beliefs about the hazardousness of the industry they choose to work in and, subsequently, their behavior is affected (i.e., they choose not to purchase the safety equipment). Economic manifestations of cognitive dissonance referred to in the literature – other than the failure to take precautions in risky situations – include failure to set aside optimal amounts for retirement, and the observation that increasing the severity of punishments can sometimes increase the likelihood of crime (Akerlof & Dickens 1982, Dickens 1986).

The adjustment model offers an advance in terms of understanding these phenomena. Most such phenomena may be characterized in the model's parlance as involving an endowment of some kind, corresponding regret, and a corresponding adjustment reaction. Perhaps of greatest consequence, the model reveals as an identifying characteristic of the cognitive dissonance mechanism the presence of *a restriction or discontinuity in the choice set.*

To fix ideas, consider in the adjustment model an individual whose objective includes a regret term. Let us suppose that the quantity of the action that may be taken is constrained to lie on the unit internal; thus, say for the initial period, $x_0 \in [0, 1]$. Suppose also that quality μ is known at the outset and is such that the individual's optimizing action is an interior solution $x_0 \in (0, 1)$. Let us define the set $\mathbb{C} \subseteq [0, 1]$ of choice options actually available to the decision-maker. In the case where $\mathbb{C} = [0, 1]$, the individual chooses x_0^* and sets T_0 to optimally adjust to x_0^*. In this situation, he experiences no regret. Put another way, there is no dissonance between the individual's action and his preferences.

Now consider the case of forced compliance, as per the experiments of Festinger & Carlsmith (1959). Forced compliance may be represented in the adjustment model by an individual being compelled to take a greater quantity of action than he would have chosen given its quality level μ. Formally, $\mathbb{C} = [\underline{x}, 1]$ where $1 \geq \underline{x} > x_0^*$. This situation creates the potential for regret: the quantity $\underline{x}$ is "too high" and must be rationalized. To reduce his misgivings, the individual adjusts with greater intensity (as per Proposition 2) to support the endowed action. When asked later, his reports on his comfort with taking the endowed action typically improve relative to early measures; that is, there is an opinion change (Festinger & Carlsmith 1959, p. 203). Given the durability of adjustment, his initial adjustive thinking may decrease misgivings about taking the action in the future, increasing his tendency to engage in it again. The critical characteristic of the scenario that set in motion the cognitive dissonance reaction was a *restriction* in the choice set; had the individual been able to choose his action freely, there would have been no dissonance, no adjustment, and no altered future behavior.

A variation of the phenomenon is provided by the scenario discussed previously of the workers in the hazardous industry. Suppose a particular worker judges the dangers of the industry a priori as neither extreme nor non-existent, such that he would like to participate in the industry workforce but only tentatively or partially (i.e., $x_0^* \in (0, 1)$). Of course, life does not normally permit a worker to be tentative: you have to take a job, or else pass it up. Here, then, $\mathbb{C} = \{0, 1\}$. The choice set exhibits a *discontinuity*, jumping from 0 to 1. So the worker chooses to take the job - his best option of the two available - but experiences dissonance: it is more dangerous than he is comfortable with for a full-time commitment. His response is to engage in adjustive thinking to support his decision to take the job: he convinces himself the job is not as hazardous as people say. Such attitudes tend to persist, whence the dynamic problem arises. If, in the future, the individual is given the opportunity to purchase safety equipment, the option to do so does not look as attractive as it might have before he started the job.

A choice set discontinuity is also at the heart of the "crime and punishment" cognitive dissonance reaction described by Dickens (1986). In an oft-repeated experiment, children are told not to play with a desirable toy. One group is threatened with a severe punishment for disobedience, while another is told to expect a mild punishment. Much later, the children are again put in the room with the toy, but this time without the threat of punishment. It is observed that the children threatened with the severe punishment are more likely to play with the toy than those threatened with the mild punishment. The standard interpretation of these studies is that those threatened with mild punishment had to justify to themselves their decision not to play with the toy.

The adjustment model clarifies the mechanism of this process. The children in the experiment are, in effect, faced with a binary decision: do not play at all, or play (at all) and be subject to a punishment. Thus the choice set is perceived as discontinuous. Were a child to "dabble" in playing with the toy, this would not prevent him from being punished, so it is fair to say it is dominated by playing "all out" and does not represent a viable intermediate option. A child threatened with a severe punishment does not need an intermediate option: he views playing with the toy as "low quality" activity, whence his decision not to play at all is relatively consistent with his preferences. But in the case of the child threatened with a mild punishment, not playing creates significant dissonance and requires adjustment. Hence the subsequent changes in the child's behavior after he chooses initially not to play.

Note that the occurrence of a cognitive dissonance reaction hinges on what the adjustment model characterizes as regret. And the critical role of regret is that, as established by Proposition 1, it reverses the direction of the marginal effect of activity "quality" on engagement in adjustive thinking. Consider again the worker in the hazardous industry, and suppose that worker does not exhibit regret per the model's parlance. The more hazardous the industry, the less such a worker would engage in adjustive thinking to support it (i.e., because hazards reduce the perceived "quality" of working in the industry, there is less benefit to be had from being "psyched up" to work in it). Meanwhile the regret-burdened worker engages in more adjustive thinking the more hazardous the industry is. When safety equipment is later introduced, a non-regret-laden worker sees clearly the low quality of the industry he works in; the regret-laden worker does not and therefore fails to see the value of safety equipment.

4.3.2 Policy Implications

The adverse effect on social welfare of behaviors that stem from cognitive dissonance reactions is well recognized, particularly in areas relating to public health. The adjustment model offers a new potential policy strategy for addressing these. Since choice set discontinuities often give rise to cognitive dissonance, the problem can be solved by offering people continuous choices or otherwise reframing the choice set as continuous.

An area where this approach might be particularly useful is the problem of political polarization. Certain social issues become politically charged and divisive to the point where it becomes virtually impossible to make progress on them. One example is climate change. What has been surprising on this issue – and particularly vexing to those in the scientific community – is that, while a scientific consensus has emerged supporting the notion of a human-caused change in the earth's climate, a similar consensus has not occurred among the general public. While a majority of people accepts the scientific consensus, there remains a significant cluster who are skeptical or deny the veracity of scientific stipulations about the climate. The steady and progressive accumulation of data supporting the climate change hypothesis has not moved these "deniers." Why not? Though the climate stalemate may be attributed to a number of factors, including the presence of entrenched economic interests that lobby the public, cognitive dissonance likely plays an important role. The crux of the problem is that climate change is framed in terms of a discontinuous choice set: you can either accept (fully) that it is real, or else deny it obstinately. There are no other options.

Consider what happens to an individual in the denial camp when fresh information comes to light (such as the record temperatures of 2016) that points more conclusively to global warming. The individual in the past has chosen to deny global warming and, at various junctures, has likely reviewed and reaffirmed his commitment to that position. He has buttressed his position with adjustive thinking – assembling the best arguments and rationalizing – and over time has developed a formidable stock of attitude supporting it. Can this individual react to the new information by developing a more nuanced position on climate change, something on the "grey" scale between full acceptance and full denial? Chances are he would not be able to explain such a position to his friends and co-workers, who would not recognize it as even an option for consideration. Without a role model for doing so (e.g., some respected public figure), he probably would not even be able properly to articulate an intermediate position on the climate to himself. He is left with two choices. He could now choose to "defect" and go over to the climate change camp; but to do so would involve a massive cognitive dislocation and lots of effort. The easier option is to “neutralize” the new information with more adjustive thinking and to remain a denier.

A solution to the climate change stalemate – and to stalemates on other divisive issues, such as gun control – might be to reframe the issue in terms of a continuum of positions. The idea would be to encourage discussion of the issue with greater openness, developing social norms for being receptive to other people’s perspectives. Over time, the hard edges of the debate might soften; this would not only make for more harmonious relations between people with differing views, but also would make it easier for all people to accept new information that might incrementally shift their position. On an aggregate level, progress toward positions aligned with “the facts” would be greatly facilitated. This is, of course, not so easy. When people are used to viewing political debates, such as over climate and guns, in rigid terms, it is not easy to change these frames. Often, it helps to adopt new language for speaking about the debates.[9] Apropos of this challenge, Akerlof & Dickens (1982) note that innovation in a society often originates with outsiders, those who are not familiar by experience with traditional conditions of a situation. Similarly, debates on such issues as climate change cannot easily be advanced by insiders; often it takes newcomers not bound by existing frames to reframe a discussion and take it forward.

4.3.3 Empirical Testing Implications

The recognition that cognitive dissonance reactions arise when the choice set is restricted or discontinuous opens the door to an innovative approach to measuring their occurrence empirically: regression discontinuity designs.[10]

Consider again our unrestricted set of possibilities for action $x_0 \in [0, 1]$, and now let us suppose the propensity to take this action depends on the individual characteristic s, which is a continuous variable.[11] Without loss of generality let us assume $\frac{\partial x_0^*}{\partial s} > 0$. Suppose, as has been assumed all along, that the stock of adjustment y_0 complements x_0, and suppose further that y_0 is measurable either in terms of observable actions by the individual or by a set of attitudes revealed through answers to questions that one could ask the individual.[12] If the de facto choice set is restricted - say, to $\mathbb{C} = \{0, 1\}$ - then one has a natural experiment. Consider individuals whose levels of s places them close to the transitional value of x_0^* at which the individual would switch from choosing 0 to 1, given the restriction. If those persons

[9] See, for example, Tabuchi, Hiroko, “In America’s Heartland, Discussing Climate Change Without Saying ‘Climate Change,’” The New York Times, January 28, 2017.

[10] For a fuller discussion of the regression discontinuity approach, see, e.g., Angrist & Pischke (2008).

[11] More generally, of course, s could be a vector of individual characteristics.

[12] Note that the variables used to measure y_0 are distinguished from the characteristic s in that they are endogenous while s must be convincingly exogenous.

choosing 1 having significantly different values of y_0 from those choosing 0, then we have demonstrated conclusively that *the decision has caused the change in attitude.*

One might develop convincing designs along these lines for demonstrating that one's decision to be a climate denier versus a climate believer actually gives rise to a set of supporting climate-related attitudes, instead of the other way around; or that one's position on gun control influences one's opinions on the risks of gun violence; and on and on. The adjustment model thus paves the way for potential demonstration, across a range of phenomena, of the notion that actions create preferences.

4.4 Marketing Practices

Traditional economic theories of advertising have conceived of two roles for the practice: to provide information about the product, and to persuade consumers to prefer the product. Both propositions have significant limitations. The information theory cannot explain advertisers' costly efforts devoted to crafting message and image in ads otherwise devoid of informational content.[13] The persuasion theory offers no explanation as to why advertising should elicit a response at all from a rational consumer.

The adjustment theory recognizes that rational consumers desire to improve their fit with the products they choose. From this emerges a new primitives-based explanation of persuasive advertising as *facilitating optimal self-persuasion*. In the model, advertising may be introduced as an expenditure that reduces consumers' adjustment costs with respect to the advertised product. This leads to the potential for truly persuasive advertising to influence demand. Moreover, recognized in this way, persuasive advertising is not necessarily wasteful and can actually serve the efficient purpose of enabling consumers to obtain greater satisfaction from their chosen products. Economics has traditionally only perceived informational advertising as non-wasteful.[14]

The adjustment model also makes way for a primitives-based - and arguably more accurate - economic understanding of other marketing practices. The practice of giving free product (e.g., samples, trial-basis services, short-term memberships) has traditionally been viewed in economics as providing an incentive to consumers to learn more about the product. Thus giveaways can be an efficient aid to search in a world of consumers with strictly fixed preferences. Viewed through the lens of adjustment,

[13]The theory *has* offered an explanation of non-substantive advertising as providing a signal that the product is of sufficient quality to warrant a costly advertising expenditure (Nelson 1974). But if the purpose is just to show that money is being spent and the ad is not in some measure intended to be persuasive, why should message and image details matter?

[14]An explanation of advertising closely aligned with my notion of facilitated self-persuasion is offered by Akerlof & Dickens (1982) in their cognitive dissonance paper. They refer to the idea of advertising as helping consumers by furnishing them with an "external justification" for believing that a purchased product meets their needs (p. 317).

giveaways play another role: they establish an *endowment.* The consumer who receives a free one-month membership to a fitness club rationally adjusts to use of the club facilities; because such adjustment is durable, her marginal utility from use of the club is increased in future periods and she is more likely to see the benefit of purchasing a long-term membership. Coupons, discounts, and price promotions all function in a similar way: they create incentives for the consumer to establish an endowment that will lead, through the endowment effect, to future (full-price) purchases. Marketers have long recognized these sorts of benefits and, in fact, are more prone to talk in terms of dynamic "preference-smithing" effects on consumers (e.g., creating a habit, building a relationship) than they are to think in terms of simply providing the consumer with more information as a basis for making an optimal decision.

5 Conclusion

This paper has presented a generally applicable theory of individual decision-making based on adjustment to choice. Rather than reiterate the findings of the model, I will use this section to propose some promising directions for future research focused on applications of the framework.

The present paper's analysis of adjustment was restricted to a partial equilibrium context involving focus on a single product. Extending the adjustment model's approach to a multi-product context would allow for the analysis of *lifestyle* choice - that is, the simultaneous choice of attitudes towards multiple, potentially related product or activity choices (*ensembles*). A general equilibrium model is the proper structure for considering the broader effects of advertising (i.e., in fostering lifestyles, rather than simply stimulating demand for specific products) and other inter-market effects of relevance.

Adding into the adjustment model the possibility of dynamic introduction of new offerings would provide insights into how individuals adjust in a context in which the available options, and not just their quality, is uncertain. The dating process is an example of such an environment. Options appear over time, and the agent can choose to accept one of them or else wait for more to come along. One may conjecture that if the agent anticipates better options, has a high value of being alone, a low discount rate, or a high valuation on the quality (versus quantity) of dating experiences, then it is rational to take no partner in the present period and allocate present adjustive effort to future consumption - a "longing equilibrium." Such a model might explain teenage daydreaming, as well as longing for loved ones away at sea, war, or school, as rational investments.

Equilibrium in differentiated product markets has traditionally been modeled with spatial frameworks such as the seminal "beach" proposed by Hotelling (1929). These models represent product offerings as fixed or endogenous locations along a continuum, and consumers' heterogeneous fixed preferences are similarly represented by location. A given consumer will generally not find an ideal choice among the available products, in that there will not be a product offering at his precise location, whence his utility loss from consuming something less-than-ideal is represented by a "transportation cost" from his location to the location of the nearest product. Introducing adjustment into the differentiated product context would imply a consumer whose location is not fixed, but who "moves closer" to his chosen product, trading off transportation cost against adjustment cost. A model of competition in differentiated products with adjustment to choice would provide for improved predictions regarding the price and market share outcomes accruing to various relevant exogenous factors. It could additionally be quite fruitful to examine the role and effects of advertising in this context. Nagler (2016, 2017) offers exploratory treatments on these issues, but there is more work to be done.

A Appendix

Proof of Theorem 1. The optimization problem is the same every period, so fix $t = \tau$ and consider the problem for self τ of solving (3). This player recognizes that his choice of (T_τ, x_τ) will influence the subsequent choices of future selves. Specifically, his choice of T_τ will influence future decisions because it affects the future stock of elaboration which in turn influences the preferences of future selves; his choice of x_τ has no bearing on future selves' preferences or decisions. A subgame perfect strategy takes account of how the choice of T_τ affects responses in all $t > \tau$ by treating T_t as a function $T_t(T_\tau)$ for all $t > \tau$ when choosing the optimal T_τ.

We observe from (2) that self τ's objective function nests the objective function of each $t > \tau$: one may rewrite (2) as

$$U_\tau \equiv \mu u(x_\tau, T_\tau) + K - x_\tau - T_\tau + \delta U_{\tau+1} \tag{A.1}$$

whence the nesting of future selves' objectives for $t > \tau + 1$ follows by induction. Observe also that T_t for $t > \tau$ appears in self τ's objective function only within U_t. It follows we may write

$$\frac{\partial U_\tau}{\partial T_\tau} = \left.\frac{\partial U_\tau}{\partial T_\tau}\right|_D + \sum_{t=1}^{\infty} \frac{\partial U_\tau}{\partial U_{\tau+t}} \left.\frac{\partial U_{\tau+t}}{\partial T_{\tau+t}}\right|_D \frac{\partial T_{\tau+t}}{\partial T_\tau} \tag{A.2}$$

where the "D" indicates direct effects, not through the choice of T by another self.

For an interior solution $\left.\frac{\partial U_{\tau+t}}{\partial T_{\tau+t}}\right|_D = 0$ for all $t \geq 1$ in (A.2). Thus by the envelope theorem $\frac{\partial U_\tau}{\partial T_\tau} = \left.\frac{\partial U_\tau}{\partial T_\tau}\right|_D$, that is, the overall effect of T_τ on utility is equal to the direct effect, ignoring effects of T_τ through the $T_{\tau+t}$ that are already being optimized by future selves.

With this in mind, we take the FOC of 3 for each τ:

$$\begin{aligned} \mu u_x &= 1 \\ \mu u_y &= 1 \end{aligned}$$

As stated, the problem is the same in every period, whence the FOCs yield the same $(x^*(\mu), y^*(\mu))$ interior solution in all periods $t \geq 0$. It follows that $T_0 = y^*(\mu)$ and $T_t = \sigma y^*(\mu)$ for all $t > 0$. (Note the constant marginal cost of adjustment implies the consumer engages in adjustment in each period t until the level $y^*(\mu)$ is reached, regardless of y_{t-1}.) It is moreover easy to see from the first-order conditions that $x^*_\mu, y^*_\mu > 0$.

We now must show that this interior solution is the unique maximum. We calculate the derivatives of (A.1) needed to evaluate the Hessian with respect to this objective, reflecting the relevant values of (x, y) at which they are evaluated:

$$\begin{aligned}
&\frac{\partial U_\tau}{\partial x_\tau} = \mu u_z z_x (x_\tau, y_\tau) - 1 \rightarrow \frac{\partial^2 U_\tau}{\partial x_\tau^2} = \mu \left(u_z z_{xx} (x_\tau, y_\tau) + u_{zz} z_x^2 (x_\tau, y_\tau) \right) \\
&\frac{\partial U_\tau}{\partial T_\tau} = \mu u_z z_y (x_\tau, y_\tau) + \delta (1-\sigma) \mu u_z z_y (x_{\tau+1}, y_{\tau+1}) + \ldots - 1 \\
&\qquad \rightarrow \frac{\partial^2 U_\tau}{\partial T_\tau^2} = \mu \left(u_z z_{yy} (x_\tau, y_\tau) + u_{zz} z_y^2 (x_\tau, y_\tau) \right) \\
&\qquad\qquad\qquad + \delta (1-\sigma)^2 \mu \left(u_z z_{yy} (x_{\tau+1}, y_{\tau+1}) + u_{zz} z_y^2 (x_{\tau+1}, y_{\tau+1}) \right) + \ldots \\
&\qquad\qquad\qquad\qquad \rightarrow \frac{\partial^2 U_\tau}{\partial T_\tau \partial x_\tau} = \mu \left(u_{zz} z_x z_y (x_\tau, y_\tau) + u_z z_{xy} (x_\tau, y_\tau) \right) \qquad \text{(A.3)}
\end{aligned}$$

To simplify notation, we drop the arguments for $t = \tau$ and show only arguments for $t > \tau$. The Hessian is

$$
\begin{aligned}
|H| &= \mu^2 \left| \begin{array}{cc} u_z z_{xx} + u_{zz} z_x^2 & u_{zz} z_x z_y + u_z z_{xy} \\ u_{zz} z_x z_y + u_z z_{xy} & u_z z_{yy} + u_{zz} z_y^2 + \\ & \delta (1-\sigma)^2 \mu \left(u_z z_{yy} (x_{\tau+1}, y_{\tau+1}) + u_{zz} z_y^2 (x_{\tau+1}, y_{\tau+1}) \right) + \ldots \end{array} \right| \quad \text{(A.4)} \\
&= \left(u_z z_{xx} + u_{zz} z_x^2 \right) \left(u_z z_{yy} + u_{zz} z_y^2 \right) - \left(u_{zz} z_x z_y + u_z z_{xy} \right) \left(u_{zz} z_x z_y + u_z z_{xy} \right) \\
&\quad + \left(u_z z_{xx} + u_{zz} z_x^2 \right) \delta (1-\sigma)^2 \mu \left(u_z z_{yy} (x_{\tau+1}, y_{\tau+1}) + u_{zz} z_y^2 (x_{\tau+1}, y_{\tau+1}) \right) + \ldots \\
&> \left(u_z z_{xx} + u_{zz} z_x^2 \right) \left(u_z z_{yy} + u_{zz} z_y^2 \right) - \left(u_{zz} z_x z_y + u_z z_{xy} \right) \left(u_{zz} z_x z_y + u_z z_{xy} \right) \\
&= u_z^2 z_{xx} z_{yy} + u_z u_{zz} z_x^2 z_{yy} + u_z u_{zz} z_{xx} z_y^2 + u_{zz}^2 z_x^2 z_y^2 - u_{zz}^2 z_x^2 z_y^2 - 2 u_z u_{zz} z_{xy} z_x z_y - u_z^2 z_{xy}^2
\end{aligned}
$$

Given that z is homogenenous of degree one in (x, y), Euler's formula yields $z_x x + z_y y = z$. Differentiating this identity with respect to x yields $z_{xx} x + z_x + z_{xy} y = z_x$, and similarly with respect to y one obtains $z_{xy} x + z_{yy} y + z_y = z_y$. Thus, $z_{xx}/z_{xy} = -y/x = z_{xy}/z_{yy}$, whence $z_{xx} z_{yy} = z_{xy}^2$. Thus the last line of (A.4) simplifies to $u_z u_{zz} z_x^2 z_{yy} + u_z u_{zz} z_{xx} z_y^2 - 2 u_z u_{zz} z_{xy} z_x z_y > 0$. Since $\frac{\partial^2 U}{\partial x_\tau^2} < 0$ and $\frac{\partial^2 U}{\partial T_\tau^2} < 0$, $U_\tau (x_\tau, T_\tau)$ is strictly concave.

This establishes the solution (x_τ^*, T_τ^*) to the first-order conditions as the unique absolute maximum for τ whence, by induction, the strategy this constitutes represents the subgame perfect equilibrium strategy for all $t \geq 0$.

We need finally to dispense with the possibility of a corner solution. We have noted that the unique interior solution is $(x_t^*, y_t^*) = (x^* (\mu), y^* (\mu))$ for all $t \geq 0$, whence $T_t^* = \sigma y^* (\mu)$ for all $t > 0$. A corner solution of $T_1 = 0$ could result if and only if $(1 - \sigma) y_0^* (\mu) > y^* (\mu)$. But this would imply $y_0^* (\mu) > y^* (\mu)$, which is a contradiction of the unique interior solution for $t = 0$. Thus no corner solution will result in $t = 1$. By similar argument, a corner solution in any $t = \tau$ requires $y_{\tau-1}^* (\mu) > y^* (\mu)$, a contradiction of the interior solution for the prior period. By induction, the interior solution is the only solution for all periods.

Proof of Lemma 1. Let (x^*, y^*) represent the steady-state optimum under the unique subgame perfect equilibrium with no endowment, and let $T_0 (\bar{x}_0)$ represent the level of T_0 arising from the first-order condition for T based on $\bar{x}_0$. Because $\bar{x}_0$ can vary relative to the level x^*, $y_0 (\bar{x}_0) = T_0 (\bar{x}_0)$ varies relative to y^* such that it is possible that $(1 - \sigma) y_0 (\bar{x}_0) > y^*$ and, more generally, that $(1 - \sigma)^t y_0 (\bar{x}_0) > y^*$. In each period $t \geq 1$, if $(1 - \sigma)^t y_0 (\bar{x}_0)$ is below the steady-state optimum y^*, then the individual chooses $T_t > 0$, an interior solution. The proof of Theorem 1 establishes that this solution is unique. If $(1-\sigma)^t y_0(\bar{x}_0)$ is at or above that optimal level, there is a corner solution in individual t's optimization at $T_t = 0$.[15] This means that, in our analysis of the choice of T_0, we must account for the possibility of corner solutions for $t \geq 1$ in which $T_t^* = 0$ is the optimizing choice for self $\tau = t$.

Again consider (A.2). Now, in each term following the first term of this expression, the derivatives $\left.\frac{\partial U_{\tau+t}}{\partial T_{\tau+t}}\right|_D$ and $\frac{\partial T_{\tau+t}}{\partial T_\tau}$ for $t \geq 1$ exhibit complementary slackness. Consider again the two cases with respect to $(1-\sigma)^t y_0(\bar{x}_0)$ referenced above. In the former case, $\left.\frac{\partial U_{\tau+t}}{\partial T_{\tau+t}}\right|_D = 0$ and $\frac{\partial T_{\tau+t}}{\partial T_\tau} = -(1-\sigma)^t < 0$ (reflecting the effect of an increase in T_τ on $E_{\tau+t}$ given the depreciation of elaboration); in the latter, $\left.\frac{\partial U_{\tau+t}}{\partial T_{\tau+t}}\right|_D < 0$ and $\frac{\partial T_{\tau+t}}{\partial T_\tau} = 0$. In either case, all the terms except the first in (A.2) are equal to zero. Thus the effect of T_τ on U_τ reduces to T_τ's direct effect with all T_t for $t > \tau$ treated as constants.

In view of this, a trivial variation on the proof of Theorem 1 yields that there exists a unique interior solution $T_0^*(\bar{x}_0)$. If $(1-\sigma) T_0^*(\bar{x}_0) \leq y^*$, then there is a unique subgame perfect equilibrium strategy for all $t \geq 0$ and it is an interior solution. If instead $(1-\sigma)^\tau T_0^*(\bar{x}_0) > y^*$ for all $\tau \leq t$ for some t, then there will be a corner solution $T_\tau^* = 0$ for all $\tau \leq t$ and it is unique, while for all $\tau > t$ there is an interior solution and, as demonstrated in the proof of Theorem 1, it is unique.

Proof of Lemma 2. Let us calculate the derivatives of (4) needed to evaluate the Hessian with respect to this objective, reflecting all relevant values of (x, y) at which they are evaluated:

$$U_x^R = (1-\omega\beta_\tau)(\mu u_z z_x(x_\tau, y_\tau) - 1) \to U_{xx}^R = (1-\omega\beta_\tau)\mu\left(u_z z_{xx}(x_\tau, y_\tau) + u_{zz} z_x^2(x_\tau, y_\tau)\right)$$

$$U_{xT}^R = (1-\omega\beta_\tau)\mu(u_{zz} z_x z_y(x_\tau, y_\tau) + u_z z_{xy}(x_\tau, y_\tau))$$

$$\begin{aligned} U_T^R = (1-\omega\beta_\tau)\Big(&\mu u_z z_y(x_\tau, y_\tau) - 1 + \delta\left\{\left[(1-\sigma) + T'_{\tau+1}(T_\tau)\right]\mu u_z z_y(x_{\tau+1}, y_{\tau+1}) - T'_{\tau+1}(T_\tau)\right\} \\ &+\delta^2\left\{\left[(1-\sigma)^2 + (1-\sigma)T'_{\tau+1}(T_\tau) + T'_{\tau+2}(T_\tau)\right]\mu u_z z_y(x_{\tau+2}, y_{\tau+2}) - T'_{\tau+2}(T_\tau)\right\} + \ldots\Big) \\ &+ \omega\beta_\tau(\mu u_z z_y(\bar{x}_0, y_\tau) - \mu u_z z_y(x_0^*(T_\tau), y_\tau)) \end{aligned}$$

[15] Setting $T_t < 0$ to arrive at E^* does not make sense, because it would be costly to reduce T and only would reduce the value of complementary consumption.

$$U^R_{TT} = (1-\omega\beta_\tau)\Bigg(\mu u_z z_{yy}(x_\tau, y_\tau) + \mu u_{zz} z_y^2 (x_\tau, y_\tau)$$
$$+ \delta \left\{ \left[(1-\sigma) + T^{'}_{\tau+1}\right]^2 \left[\mu u_z z_{yy}(x_{\tau+1}, y_{\tau+1}) + \mu u_{zz} z_y^2 (x_{\tau+1}, y_{\tau+1})\right] \right\}$$
$$+\delta^2 \left\{ \left[(1-\sigma)^2 + (1-\sigma) T^{'}_{\tau+1} + T^{'}_{\tau+2}\right]^2 \left[\mu u_z z_{yy}(x_{\tau+2}, y_{\tau+2}) + \mu u_{zz} z_y^2 (x_{\tau+2}, y_{\tau+2})\right] \right\} + \ldots \Bigg)$$
$$+ \omega\beta_\tau \left[\mu u_z z_{yy}(\bar{x}_0, y_\tau) + \mu u_{zz} z_y^2 (\bar{x}_0, y_\tau)\right.$$
$$\left. -\mu u_z z_{yy}(x_0^*(T_\tau), y_\tau) - \mu u_{zz} z_y^2 (x_0^*(T_\tau), y_\tau) - \mu u_z z_{xy}(x_0^*(T_\tau), y_\tau) x_T^* - \mu u_{zz} z_y z_x (x_0^*(T_\tau), y_\tau) x_T^*\right]$$

where $x_0^*(T_0)$ arises implicitly as the solution to $\mu u_z z_x(x_0^*, y_0) = 1$. (Thus terms $\mu u_z z_x(x_0^*(T_0), y_0) x_T^* - x_T^*$ drop out of the parentheses on the bottom line of U_T^R, as do a "1" and "-1".)

We suppose first that $(1-\sigma) y_{\tau-1} < y_\tau^*$, such that the solution arising from the first-order condition is an interior solution and candidate unique solution. Note, in this case, that all the $T^{'}_t$ terms above are constants that either take a value of zero or $-(1-\sigma)^{t-\tau}$. The value taken by each of these terms follows from the form of the state equation (1) and depends specifically on the size of the base value of T_τ, which determines in turn whether each T_t is a corner or interior solution. Suppose first that T_τ is relatively small; then the depreciated value of elaboration $(1-\sigma) y_\tau$ will be less than the optimizing value of $y_{\tau+1}$, whence there will be an interior solution for $T_{\tau+1}$ such that $T^{'}_{\tau+1}(T_\tau) = -(1-\sigma)$. It follows that $T^{'}_{\tau+t}(T_\tau) = 0$ for all $t > 1$. If, however, T_τ is a bit larger but not too large, $(1-\sigma) y_\tau$ will be large enough to push $T_{\tau+1}$ to a corner solution at zero; T_τ would then be large enough that changes in its value would influence the choice of T in the following period, $\tau+2$, whence $T^{'}_{\tau+2}(T_\tau) = -(1-\sigma)^2$ and $T^{'}_{\tau+t}(T_\tau) = 0$ for all $t > 2$. And so on. It can be shown therefore that each squared expression in square brackets in U^R_{TT} is nonnegative; more precisely, they take the value $(1-\sigma)^t$ up to a threshold t and zero thereafter. Overall, the sum of the curly bracketed terms within the non-regret component of U^R_{TT} (i.e., the portion that is weighted by $1-\omega\beta_\tau$), which we shall refer to as "NR" for convenience, is unambiguously negative. The regret component (weighted by $\omega\beta_\tau$), which we shall refer to as "R", is ambiguously signed.

Dropping the arguments for $t=\tau$ to simplify notation, the Hessian may be written

$$
\begin{aligned}
|H| &= \mu^2 \begin{vmatrix} (1-\omega\beta_\tau)\left(u_z z_{xx} + u_{zz} z_x^2\right) & (1-\omega\beta_\tau)\left(u_{zz} z_x z_y + u_z z_{xy}\right) \\ (1-\omega\beta_\tau)\left(u_{zz} z_x z_y + u_z z_{xy}\right) & (1-\omega\beta_\tau)\left[\mu u_z z_{yy} + \mu u_{zz} z_y^2 + NR\right] + \omega\beta_\tau R \end{vmatrix} \\
&= \mu^2 (1-\omega\beta_\tau)^2 \left[\left(u_z z_{xx} + u_{zz} z_x^2\right)\left(\mu u_z z_{yy} + \mu u_{zz} z_y^2\right) - \left(u_{zz} z_x z_y + u_z z_{xy}\right)^2 + \left(u_z z_{xx} + u_{zz} z_x^2\right) NR\right] \\
&\quad + \mu^2 (1-\omega\beta_\tau)\,\omega\beta_\tau \left(u_z z_{xx} + u_{zz} z_x^2\right) R
\end{aligned}
$$

This takes the sign of

$$
\begin{aligned}
&(1-\omega\beta_\tau)\left[\left(u_z z_{xx} + u_{zz} z_x^2\right)\left(\mu u_z z_{yy} + \mu u_{zz} z_y^2\right) - \left(u_{zz} z_x z_y + u_z z_{xy}\right)^2 + \left(u_z z_{xx} + u_{zz} z_x^2\right) NR\right] \\
&+\omega\beta_\tau \left(u_z z_{xx} + u_{zz} z_x^2\right) R
\end{aligned}
\tag{A.5}
$$

The proof of the Theorem showed that $\left(u_z z_{xx} + u_{zz} z_x^2\right)\left(\mu u_z z_{yy} + \mu u_{zz} z_y^2\right) - \left(u_{zz} z_x z_y + u_z z_{xy}\right)^2 > 0$, whence it follows that the entire portion of (A.5) weighted by $1-\omega\beta_\tau$ is positive. It is therefore sufficient for signing the entire expression positive, given ω sufficiently small, that R be bounded above.

Proof of Proposition 1. Let's write the version of (4) for $\tau = 0$:

$$
\begin{aligned}
\max_{T_0|\bar{x}_0} U^R(\bar{x}_0, T_0) = (1-\omega\beta_0)\left\{\mu u(\bar{x}_0, T_0) + K - \bar{x}_0 - T_0 + \sum_{t=1}^{\infty} \delta^t \left[\mu u(x_t, T_t) + K - x_t - T_t\right]\right\} \\
+\, \omega\beta_0 \left\{\left[\mu u(\bar{x}_0, T_0) + K - \bar{x}_0 - T_0\right] - \left[\mu u\left(x_0^*(T_0), T_0\right) + K - x_0^*(T_0) - T_0\right]\right\}
\end{aligned}
\tag{A.6}
$$

Take the first-order condition with respect to T_0, using (A.3):

$$
\begin{aligned}
&(1-\omega\beta_0)\Big(\mu u_z z_y(\bar{x}_0, y_0) - 1 + \delta\left\{\left[(1-\sigma) + T_1'(T_0)\right]\mu u_z z_y(x_1, y_1) - T_1'(T_0)\right\} \\
&\qquad + \delta^2\left\{\left[(1-\sigma)^2 + (1-\sigma)T_1'(T_0) + T_2'(T_0)\right]\mu u_z z_y(x_2, y_2) - T_2'(T_0)\right\} + \ldots\Big) \\
&\qquad\qquad + \omega\beta_0\left\{\mu u_z z_y(\bar{x}_0, y_0) - \mu u_z z_y\left(x_0^*(T_0), y_0\right)\right\} = 0
\end{aligned}
\tag{A.7}
$$

where, as mentioned above, $x_0^*(T_0)$ arises implicitly as the solution to $\mu u_z z_x(x_0^*, y_0) = 1$. (Thus terms $\mu u_z z_x\left(x_0^*(T_0), y_0\right) x_T^* - x_T^*$ drop out of the second braces, as do a "1" and "-1".) (In the extreme case $\beta_0 = 1$, y_0^* is set for given $\bar{x}_0$ by implicit solution to $\mu u_z z_x(\bar{x}_0, y_0^*) = 1$ as the "justifying" value of y_0. We'll return to this.) We recall that all terms $T_\tau'(T_0)$ are constants. Totally differentiating (A.7) and using D_1, D_2, N_{11}, and N_{12} to represent respective bracketed terms yields

$$\begin{aligned}
&\left[(1-\omega\beta_0)\left\{\mu u_z z_{yy}(\bar{x}_0,y_0)+\mu u_{zz}z_y^2(\bar{x}_0,y_0)+\delta\left[(1-\sigma)+T_1^{'}(T_0)\right]^2\left[\mu u_z z_{yy}(x_1,y_1)+\mu u_{zz}z_y^2(x_1,y_1)\right]+\ldots\right\}\right.\\
&\quad+\omega\beta_0\left\{\mu u_z z_{yy}(\bar{x}_0,y_0)+\mu u_{zz}z_y^2(\bar{x}_0,y_0)\right.\\
&\left.\left.-\mu u_z z_{yy}(x_0^*(T_0),y_0)-\mu u_{zz}z_y^2(x_0^*(T_0),y_0)-\mu u_z z_{xy}(x_0^*(T_0),y_0)x_T^*-\mu u_{zz}z_y z_x(x_0^*(T_0),y_0)x_T^*\right\}\right]dT_0\\
&=-\left[(1-\omega\beta_0)\left\{u_z z_y(\bar{x}_0,y_0)+\delta\left[(1-\sigma)+T_1^{'}(T_0)\right]u_z z_y(x_1,y_1)+\ldots\right\}\right.\\
&\quad\left.+\omega\beta_0\left\{u_z z_y(\bar{x}_0,y_0)-u_z z_y(x_0^*(T_0),y_0)\right\}\right]d\mu\\
&\iff(1-\omega\beta_0)D_1+\omega\beta_0 D_2=-(1-\omega\beta_0)N_{11}-\omega\beta_0 N_{12}
\end{aligned}\tag{A.8}$$

This yields, using Cramer's rule, for $\omega=0$:

$$\frac{\partial T_0}{\partial\mu}=-\frac{N_{11}}{D_1}=-\frac{u_z z_y(\bar{x}_0,y_0)+\delta\left[(1-\sigma)+T_1^{'}(T_0)\right]u_z z_y(x_1,y_1)+\ldots}{\mu u_z z_{yy}(\bar{x}_0,E_0)+\mu u_{zz}z_y^2(\bar{x}_0,y_0)+\delta\left[(1-\sigma)+T_1^{'}(T_0)\right]^2\cdot\left[\mu u_z z_{yy}(x_1,y_1)+\mu u_{zz}z_y^2(x_1,y_1)\right]+\ldots}>0\tag{A.9}$$

For $\omega=1$ and $\beta_0=1$ - the case of extreme regret in the initial period - we can totally differentiate $\mu u_z z_x(\bar{x}_0,y_0^*)=1$:

$$\begin{aligned}
\left[\mu u_z z_{xy}(\bar{x}_0,y_0^*)+\mu u_{zz}z_x z_y(\bar{x}_0,y_0^*)\right]dT_0 &= -\left[u_z z_x(\bar{x}_0,y_0^*)\right]d\mu\\
\rightarrow\frac{\partial T_0}{\partial\mu} &= -\frac{u_z z_x(\bar{x}_0,y_0^*)}{\mu u_z z_{xy}(\bar{x}_0,y_0^*)+\mu u_{zz}z_x z_y(\bar{x}_0,y_0^*)}<0
\end{aligned}$$

recalling that, by assumption, $u_z z_{xy}>-u_{zz}z_y z_x$. To understand what happens in between we apply Cramer's rule to (A.8) for general ω and then differentiate with respect to ω:

$$\begin{aligned}
\frac{\partial T_0}{\partial\mu} &= -\frac{(1-\omega\beta_0)N_{11}+\omega\beta_0 N_{12}}{(1-\omega\beta_0)D_1+\omega\beta_0 D_2}\\
\rightarrow\frac{\partial^2 T_0}{\partial\mu\partial\omega} &= -\beta_0\frac{\left[(1-\omega\beta_0)D_1+\omega\beta_0 D_2\right](N_{12}-N_{11})-\left[(1-\omega\beta_0)N_{11}+\omega\beta_0 N_{12}\right](D_2-D_1)}{\left[(1-\omega\beta_0)D_1+\omega\beta_0 D_2\right]^2}
\end{aligned}\tag{A.10}$$

Recognizing that (A.10) takes the sign of the numerator, let us evaluate the numerator. This can be simplified as follows, prior to substitutions:

$$
\begin{aligned}
&-\left[(1-\omega\beta_0) D_1+\omega\beta_0 D_2\right](N_{12}-N_{11})+\left[(1-\omega\beta_0) N_{11}+\omega\beta_0 N_{12}\right](D_2-D_1) \\
&\qquad =-(1-\omega\beta_0) D_1 N_{12}+(1-\omega\beta_0) D_1 N_{11}-\omega\beta_0 D_2 N_{12}+\omega\beta_0 D_2 N_{11} \\
&\qquad\quad -(1-\omega\beta_0) D_1 N_{11}+(1-\omega\beta_0) D_2 N_{11}-\omega\beta_0 D_1 N_{12}+\omega\beta_0 D_2 N_{12} \\
&\qquad =-(1-\omega\beta_0) D_1 N_{12}+\omega\beta_0 D_2 N_{11}+(1-\omega\beta_0) D_2 N_{11}-\omega\beta_0 D_1 N_{12} \\
&\qquad =-D_1 N_{12}+D_2 N_{11}
\end{aligned}
$$

Substitution back yields

$$
\begin{aligned}
&-\left\{\mu u_z z_{yy}(\bar{x}_0,y_0)+\mu u_{zz} z_y^2(\bar{x}_0,y_0)+\delta\left[(1-\sigma)+T_1^{'}(T_0)\right]^2\left[\mu u_z z_{yy}(x_1,y_1)+\mu u_{zz} z_y^2(x_1,y_1)\right]+\ldots\right\} \\
&\quad\cdot\left\{u_z z_y(\bar{x}_0,y_0)-u_z z_y(x_0^*(T_0),y_0)\right\}+\left\{\mu u_z z_{yy}(\bar{x}_0,y_0)+\mu u_{zz} z_y^2(\bar{x}_0,y_0)-\mu u_z z_{yy}(x_0^*(T_0),y_0)\right. \\
&\qquad\left.-\mu u_{zz} z_y^2(x_0^*(T_0),y_0)-\mu u_z z_{xy}(x_0^*(T_0),y_0)\, x_T^*-\mu u_{zz} z_y z_x(x_0^*(T_0),y_0)\, x_T^*\right\} \\
&\qquad\qquad\cdot\left\{u_z z_y(\bar{x}_0,y_0)+\delta\left[(1-\sigma)+T_1^{'}(T_0)\right] u_z z_y(x_1,y_1)+\ldots\right\}
\end{aligned}
$$

We evaluate this at $\mu=\bar{\mu}$, the value of μ at which the endowment $\bar{x}_0$ would have resulted if $(\bar{x}_0, T_0)$ were chosen simultaenously with μ known, that is, the value of μ for which $x_0^*(T_0)=\bar{x}_0$. In this context, $\partial^2 T_0/\partial\mu\partial\omega$ tells us how regret influences the adjustment effect of an increment to quality relative to the "expectations baseline" that would have resulted in the observed endowment. Thus the second term in curly braces is zero. This leaves us with

$$
\begin{aligned}
&\mu u_z\left\{u_z z_{yy}(\bar{x}_0,y_0)+u_{zz} z_y^2(\bar{x}_0,y_0)-u_z z_{yy}(x_0^*(T_0),y_0)\right. \\
&\qquad\left.-u_{zz} z_y^2(x_0^*(T_0),y_0)-u_z z_{xy}(x_0^*(T_0),y_0)\, x_T^*-u_{zz} z_y z_x(x_0^*(T_0),y_0)\, x_T^*\right\} \\
&\qquad\qquad\cdot\left\{u_z z_y(\bar{x}_0,y_0)+\delta\left[(1-\sigma)+T_1^{'}(T_0)\right] u_z z_y(x_1,y_1)+\ldots\right\}
\end{aligned}
$$

The second and fourth terms cancel at $x_0^*(T_0)=\bar{x}_0$, as do the first and third. We are left with

$$
\mu u_z\left\{-u_z z_{xy}(x_0^*(T_0),y_0)\, x_T^*-u_{zz} z_y z_x(x_0^*(T_0),y_0)\, x_T^*\right\}\cdot\left\{z_y(\bar{x}_0,y_0)+\delta\left[(1-\sigma)+T_1^{'}(T_0)\right] z_y(x_1,y_1)+\ldots\right\}<0
$$

because $u_z z_{xy} > -u_{zz} z_y z_x$. ${\partial^2 T_0}/{\partial\mu\partial\omega}$ takes the same sign, whence ${\partial^2 T_0}/{\partial\mu\partial\omega} < 0$. Additionally this uses an expression for x_T^* which comes from totally differentiating $\mu u_z z_x (x_0^*, y_0) = 1$:

$$\begin{aligned}\left[\mu u_{zz} z_x^2 (x_0^*, y_0) + \mu u_z z_{xx} (x_0^*, y_0)\right] dx_0 &= -\left[\mu u_z z_{xy} (x_0^*, y_0) + \mu u_{zz} z_x z_y (x_0^*, y_0)\right] dT_0 \\ \to x_T^* &= -\frac{u_z z_{xy} (x_0^*, y_0) + u_{zz} z_x z_y (x_0^*, y_0)}{u_z z_{xx} (x_0^*, y_0) + u_{zz} z_x^2 (x_0^*, y_0)} > 0 \qquad \text{(A.11)}\end{aligned}$$

We have shown that, without regret ($\omega = 0$), adjustment is complementary with quality given the endowment, whereas with extreme regret ($\omega = 1$) it is *compensatory* for such quality. We have now observed that, as the degree of regret increases, it causes adjustment to become increasingly compensatory.

Proof of Proposition 2. Let us again totally differentiate (A.7), defining new bracketed terms N_{21}, N_{22}:

$$\begin{aligned}&\Bigg[(1-\omega\beta_0)\left\{\mu u_z z_{yy} (\bar{x}_0, y_0) + \mu u_{zz} z_y^2 (\bar{x}_0, y_0) + \delta \left[(1-\sigma) + T_1^{'} (T_0)\right]^2 \left[\mu u_z z_{yy} (x_1, y_1) + \mu u_{zz} z_y^2 (x_1, y_1)\right] + \dots\right\} \\ &\quad + \omega\beta_0 \left\{\mu u_z z_{yy} (\bar{x}_0, y_0) + \mu u_{zz} z_y^2 (\bar{x}_0, y_0)\right. \\ &\left. -\mu u_z z_{yy} (x_0^* (T_0), y_0) - \mu u_{zz} z_y^2 (x_0^* (T_0), y_0) - \mu u_z z_{xy} (x_0^* (T_0), y_0) x_T^* - \mu u_{zz} z_y z_x (x_0^* (T_0), y_0) x_T^*\right\}\Bigg] dT_0 \\ &= -\left[(1-\omega\beta_0)\left\{\mu u_z z_{xy} (\bar{x}_0, y_0) + \mu u_{zz} z_x z_y (\bar{x}_0, y_0)\right\} + \omega\beta_0 \left\{\mu u_z z_{xy} (\bar{x}_0, y_0) + \mu u_{zz} z_x z_y (\bar{x}_0, y_0)\right\}\right] dx_0 \\ &\iff (1-\omega\beta_0) D_1 + \omega\beta_0 D_2 = -(1-\omega\beta_0) N_{21} + \omega\beta_0 N_{22} \qquad \text{(A.12)}\end{aligned}$$

This yields, using Cramer's rule, for $\omega = 0$:

$$\frac{\partial T_0}{\partial x_0} = -\frac{N_{21}}{D_1} = -\frac{\mu u_z z_{xy} (\bar{x}_0, y_0) + \mu u_{zz} z_x z_y (\bar{x}_0, y_0)}{\mu u_z z_{yy} (\bar{x}_0, y_0) + \mu u_{zz} z_y^2 (\bar{x}_0, y_0) + \delta \left[(1-\sigma) + T_1^{'} (T_0)\right]^2 \cdot \left[\mu u_z z_{yy} (x_1, y_1) + \mu u_{zz} z_y^2 (x_1, y_1)\right] + \dots} > 0$$

because $u_z z_{xy} > -u_{zz} z_y z_x$. For $\omega = 1$ and $\beta_0 = 1$ - the case of extreme regret in the initial period - we can totally differentiate $\mu u_z z_x (\bar{x}_0, y_0^*) = 1$:

$$\begin{aligned}\left[\mu u_z z_{xy} (\bar{x}_0, y_0^*) + \mu u_{zz} z_x z_y (\bar{x}_0, y_0^*)\right] dT_0 &= -\left[u_z z_{xx} (\bar{x}_0, y_0^*) + u_{zz} z_x^2 (\bar{x}_0, y_0^*)\right] dx_0 \\ \to \frac{\partial T_0}{\partial x_0} &= -\frac{u_z z_{xx} (\bar{x}_0, y_0^*) + u_{zz} z_x^2 (\bar{x}_0, y_0^*)}{\mu u_z z_{xy} (\bar{x}_0, y_0^*) + \mu u_{zz} z_x z_y (\bar{x}_0, y_0^*)} > 0\end{aligned}$$

To see what happens as regret intensifies, let us apply Cramer's rule to (A.12) for general ω and then differentiate with respect to ω:

$$\begin{aligned}
\frac{\partial T_0}{\partial x_0} &= -\frac{(1-\omega\beta_0)\,N_{21}+\omega\beta_0 N_{22}}{(1-\omega\beta_0)\,D_1+\omega\beta_0 D_2} \\
\rightarrow \frac{\partial^2 T_0}{\partial x_0 \partial \omega} &= -\beta_0 \frac{[(1-\omega\beta_0)\,D_1+\omega\beta_0 D_2]\,(N_{22}-N_{21})-[(1-\omega\beta_0)\,N_{21}+\omega\beta_0 N_{22}]\,(D_2-D_1)}{[(1-\omega\beta_0)\,D_1+\omega\beta_0 D_2]^2}
\end{aligned} \tag{A.13}$$

Recognizing that the sign of (A.13) takes on the sign of the numerator, let us evaluate the numerator:

$$-[(1-\omega\beta_0)\,D_1+\omega\beta_0 D_2]\,(N_{22}-N_{21})+[(1-\omega\beta_0)\,N_{21}+\omega\beta_0 N_{22}]\,(D_2-D_1)=-D_1 N_{22}+D_2 N_{21}$$

Substitution back yields

$$\begin{aligned}
&-\Big\{\mu u_z z_{yy}(\bar{x}_0,y_0)+\mu u_{zz} z_y^2(\bar{x}_0,y_0)+\delta\Big[(1-\sigma)+T_1^{'}(T_0)\Big]^2\left[\mu u_z z_{yy}(x_1,y_1)+\mu u_{zz} z_y^2(x_1,y_1)\right]+\dots\Big\} \\
&\cdot\{\mu u_z z_{xy}(\bar{x}_0,y_0)+\mu u_{zz} z_x z_y(\bar{x}_0,y_0)\}+\big\{\mu u_z z_{yy}(\bar{x}_0,y_0)+\mu u_{zz} z_y^2(\bar{x}_0,y_0)-\mu u_z z_{yy}(x_0^*(T_0),y_0) \\
&\quad -\mu u_{zz} z_y^2(x_0^*(T_0),y_0)-\mu u_z z_{xy}(x_0^*(T_0),y_0)\,x_T^*-\mu u_{zz} z_y z_x(x_0^*(T_0),y_0)\,x_T^*\big\} \\
&\qquad \cdot\{\mu u_z z_{xy}(\bar{x}_0,y_0)+\mu u_{zz} z_x z_y(\bar{x}_0,y_0)\}
\end{aligned}$$

The second and fourth bracketed expressions - N_{22} and N_{21} - are equal and clearly positive. So let us sum the terms that multiply them and evaluate:

$$\begin{aligned}
&-\mu u_z z_{xy}(x_0^*(T_0),y_0)\,x_T^*-\mu u_{zz} z_y z_x(x_0^*(T_0),y_0)\,x_T^*-\mu u_z z_{yy}(x_0^*(T_0),y_0) \\
&\quad -\mu u_{zz} z_y^2(x_0^*(T_0),y_0)-\delta\Big[(1-\sigma)+T_1^{'}(T_0)\Big]^2\left[\mu u_z z_{yy}(x_1,y_1)+\mu u_{zz} z_y^2(x_1,y_1)\right]+\dots
\end{aligned}$$

Let's evaluate just the first four terms, substituting (A.11):

$$\begin{aligned}
&-\left[\mu u_z z_{xy}(x_0^*(T_0),y_0)+\mu u_{zz} z_y z_x(x_0^*(T_0),y_0)\right]\left[-\frac{u_z z_{xy}(x_0^*(T_0),y_0)+u_{zz} z_x z_y(x_0^*(T_0),y_0)}{u_z z_{xx}(x_0^*(T_0),y_0)+u_{zz} z_x^2(x_0^*(T_0),y_0)}\right] \\
&\quad -\mu u_z z_{yy}(x_0^*(T_0),y_0)-\mu u_{zz} z_y^2(x_0^*(T_0),y_0) \\
&=\mu\left[u_z z_{xy}(x_0^*(T_0),y_0)+u_{zz} z_y z_x(x_0^*(T_0),y_0)\right]^2\left[\frac{1}{u_z z_{xx}(x_0^*(T_0),y_0)+u_{zz} z_x^2(x_0^*(T_0),y_0)}\right] \\
&\quad -\mu u_z z_{yy}(x_0^*(T_0),y_0)-\mu u_{zz} z_y^2(x_0^*(T_0),y_0)
\end{aligned}$$

Multiply through by $-u_z z_{xx}(x_0^*(T_0), y_0) - u_{zz} z_x^2(x_0^*(T_0), y_0)$ and the sign is the same. We'll remove the arguments to make it simpler:

$$
\begin{aligned}
&-\mu\left[u_z z_{xy} + u_{zz} z_y z_x\right]^2 + \mu u_z^2 z_{xx} z_{yy} + \mu u_z u_{zz} z_x^2 z_{yy} + \mu u_z u_{zz} z_{xx} z_y^2 + \mu u_{zz}^2 z_x^2 z_y^2 \\
&= -\mu\left[u_z^2 z_{xy}^2 + u_{zz}^2 z_y^2 z_x^2 + 2u_z u_{zz} z_{xy} z_y z_x\right] + \mu u_z^2 z_{xx} z_{yy} + \mu u_z u_{zz} z_x^2 z_{yy} + \mu u_z u_{zz} z_{xx} z_y^2 + \mu u_{zz}^2 z_x^2 z_y^2 \\
&= \mu\left[-u_z^2 z_{xy}^2 - u_{zz}^2 z_y^2 z_x^2 - 2u_z u_{zz} z_{xy} z_y z_x + u_z^2 z_{xx} z_{yy} + u_z u_{zz} z_x^2 z_{yy} + u_z u_{zz} z_{xx} z_y^2 + u_{zz}^2 z_x^2 z_y^2\right] \\
&= \mu\left[-2u_z u_{zz} z_{xy} z_y z_x + u_z u_{zz} z_x^2 z_{yy} + u_z u_{zz} z_{xx} z_y^2\right] \\
&= -\mu u_z u_{zz}\left[2z_{xy} z_y z_x - z_x^2 z_{yy} - z_{xx} z_y^2\right] = -\mu u_z u_{zz}\left[2\sqrt{z_{xx} z_{yy}}\, z_y z_x - z_x^2 z_{yy} - z_{xx} z_y^2\right] \\
&= -\mu u_z u_{zz}\left[z_x\sqrt{-z_{yy}} + z_y\sqrt{-z_{xx}}\right]^2 > 0
\end{aligned}
$$

because, due to homogeneity of z, $z_{xx} z_{yy} = z_{xy}^2$. Thus $\partial^2 T_0 / \partial x_0 \partial\omega > 0$.

Proof of Proposition 3. We use the first-order conditions without regret in the case of an endowment x_0. As noted in the proof of Lemma 1, $(1-\sigma)\, y_0\left(\bar{x}_0^1\right) = y^*$ defines the threshold of a corner solution for adjustive thinking in $t = 1$, where $\bar{x}_0^1$ gives the level of the endowment that corresponds to this threshold. At the threshold itself, the unique interior solution that obtains for $t > 0$ remains unaffected, thus $(x_t, y_t) = (x^*, y^*)$ for $t \geq 1$ even when $(x_0, y_0) = \left(\bar{x}_0^1, \frac{y^*}{1-\sigma}\right)$. $\bar{x}_0^1$ is defined implicitly by the first-order condition with respect to T,

$$
\begin{aligned}
\mu u_z z_y\left(\bar{x}_0^1, \frac{y^*}{1-\sigma}\right) + \delta(1-\sigma)\,\mu u_z z_y(x_1, y_1) + \ldots &= 1 \\
\Rightarrow \mu u_z z_y\left(\bar{x}_0^1, \frac{y^*}{1-\sigma}\right) + \delta(1-\sigma)\,\mu u_z z_y(x^*, y^*) + \ldots &= 1
\end{aligned}
$$

All the terms of the first-order condition except the first are identical when $(x_0, y_0) = (x^*, y^*)$, whence we can write

$$
\mu u_z z_y\left(\bar{x}_0^1, \frac{y^*}{1-\sigma}\right) = \mu u_z z_y(x^*, y^*) \tag{A.14}
$$

Now consider the threshold of a corner solution for adjustive thinking in $t = 2$, defined by corresponding expression $(1-\sigma)^2\, y_0\left(\bar{x}_0^2\right) = y^*$. Given the depreciation rate of adjustment, $y_1 = \frac{y^*}{1-\sigma}$. Therefore, because the process is the same every period, there is an expression identical to (A.14) that defines $\bar{x}_1^2$, such that $\bar{x}_1^2 = \bar{x}_0^1$. Using the first-order condition with respect to T,

$$\begin{aligned} \mu u_z z_y \left(\bar{x}_0^2, \frac{y^*}{(1-\sigma)^2} \right) + \delta (1-\sigma) \mu u_z z_y (x_1, y_1) + \ldots &= 1 \\ \Rightarrow \mu u_z z_y \left(\bar{x}_0^2, \frac{y^*}{(1-\sigma)^2} \right) + \delta (1-\sigma) \mu u_z z_y (x^*, y^*) + \ldots &= 1 \end{aligned}$$

whence we can write

$$\mu u_z z_y \left(\bar{x}_0^2, \frac{y^*}{(1-\sigma)^2} \right) = \mu u_z z_y (x^*, y^*) \tag{A.15}$$

By induction, the level of the endowment that corresponds to the threshold of a corner solution for adjustive thinking in $t = \tau$ is defined implicitly by

$$\mu u_z z_y \left(\bar{x}_0^\tau, \frac{y^*}{(1-\sigma)^\tau} \right) = \mu u_z z_y (x^*, y^*)$$

Properties (A1)-(A3) imply complementarity of x and y in utility. Thus, $x_0 > \bar{x}_0^\tau$ implies $y_\tau > y^*$, which in turn implies $x_\tau > x^*$, which is what we sought to show.

Proof of Proposition 4. The proof of Proposition 3 establishes that for the no-regret case there exists a threshold endowment level for every τ that is defined implicitly by $(1-\sigma)^\tau y_0 (\bar{x}_0^\tau) = y^*$ and by the no-regret first-order condition with respect to T. Proposition 2 establishes the manner in which the first-order condition for T changes with regret, whereby $\partial^2 T_0 / \partial x_0 \partial \omega > 0$. From the tautology $(1-\sigma)^\tau y_0 (\bar{x}_0^\tau) = y^*$ it then follows from $\partial^2 T_0 / \partial x_0 \partial \omega > 0$ that $\frac{\partial x_{0\tau}(\omega)}{\partial \omega} < 0$.

Proof of Proposition 5. Consider first the extreme regret case $\beta_\tau = \omega = 1$. It is clear from analysis of (4) that $x_0 > x^*$ implies $y_\tau > y^*$. Now instead suppose $\beta_\tau > 0$ with $\omega \in (0, 1]$. We consider two cases. Suppose first that $(1-\sigma)^\tau y_0 (x_0) > y^*$. Then $y_\tau > y^*$ for $\beta_\tau = 0$, whence by complementarity of x and y, it follows that $x_\tau > x^*$ for $\beta_\tau = 0$. As we have already established that $y_\tau > y^*$ in the extreme regret case, then $y_\tau > y^*$ also when $\beta_\tau > 0$ with $\omega \in (0, 1]$, and we are done. Suppose instead that $(1-\sigma)^\tau y_0 (x_0) \leq y^*$. Then $y_\tau = y^*$ for $\beta_\tau = 0$. But since $y_\tau > y^*$ in the extreme regret case, it follows also that $y_\tau > y^*$ for $\beta_\tau > 0$, whence by complementarity of x and y, $x_\tau > x^*$, and we are done.

Proof of Proposition 6. Consider first the extreme regret case $\beta_\tau = \omega = 1$. It is clear from analysis of (4) that $x_0 < x^*$ implies $y_\tau < y^*$. Now instead suppose $\beta_\tau > 0$ with $\omega \in (0, 1]$. It is obvious that $(1-\sigma)^\tau y_0(x_0) < y^*$. This means $y_\tau = y^*$ for $\beta_\tau = 0$. But since $y_\tau < y^*$ in the extreme regret case, it follows also that $y_\tau < y^*$ for $\beta_\tau > 0$, whence by complementarity of x and y, $x_\tau < x^*$, and we are done.

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