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Relativity, Rank, and the Utility of Income*

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Abstract

Relative utility has become an important concept in several disjoint areas of economics. We present a cardinal model of income utility based on the supposition that agents care about their rank in the income distribution, and that utility is subject to adaptation over time. Utility levels correspond to the Leyden Individual Welfare Function while utility differences yield a version of the prospect theory value function, thereby providing a new and shared derivation of each. We offer an explanation of some long-standing paradoxes in the well-being literature, and an insight into the links between relative comparisons and loss aversion.

JEL Classification: D60; D31; D81; I31
Keywords: relative utility; individual welfare function; rank; adaptation; prospect theory; well-being.

1. Introduction

The idea that utility is relative, or reference-dependent, has recently permeated several areas of economic thought. The supposition that outcomes are judged relative to socially determined benchmarks such as societal averages (social-comparison) is the oldest form of relativism, dating back to the Greek philosophy of Epicurus and the Stoics, and in the economics literature to Veblen (1899). Empirical evidence of social-comparison in economics is found in the context of income satisfaction (Clark and Oswald, 1996; Van Herwaarden *et al.*, 1977) and in subjective well-being (SWB) within countries (Blanchflower and Oswald,

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2004; Luttmer, 2005; McBride, 2001).[1] Social-comparison can be used to explain aspects of, amongst other things, SWB data (Easterlin, 2001a), savings behaviour (Duesenberry, 1949), and the desire for conformity (Clark and Oswald, 1998). There are important consequences for economic policy, with the case for economic growth becoming less clear and the case for progressive taxation stronger (Boskin and Sheshinki, 1978).

However, social-comparison appears to be only one prevalent form of relativism. Rather, as noted as early as Marshall (1890, p. 86), people also engage in comparison with their own past performance (self-comparison). Kapteyn *et al.* (1980) and Van der Stadt *et al.* (1985) present evidence for self-comparison in the context of income satisfaction, while Clark (1999) provides evidence from job satisfaction data. McBride (2001) finds evidence for both self- and social-comparison in data from the 1994 General Social Survey. Otherwise puzzling economic phenomena are also consistent with self-comparison. For instance, it can explain the evidence of Frank and Hutchens (1993) and Loewenstein and Sicherman (1991) that people prefer an increasing income profile to a decreasing profile, even if both have the same undiscounted payoff, and therefore the increasing profile the lower present discounted value. Frederick and Loewenstein's (1999) review of adaptation contains many further examples. Self-comparison plays a prominent role in several literatures, most notably consumption (under the name of habit formation). Significant theoretical contributions to this literature include Campbell and Cochrane (1999) and Constantinides (1990).

An implication of self-comparison is that utility is dependent upon the rate of change in income, not only the level of income (see Hsee and Abelson, 1991). A consequence is that the same level of income can yield different levels of utility, depending upon the level of previous income. Second, the impulse response function of utility in response to an income shock will initially over-shoot its long-run level. This effect, a lagged adaptation of utility to income shocks, is widely observed. Di Tella *et al.* (2005) cannot reject the null hypothesis of full adaptation to income after 4 years. Clark *et al.* (2003) report varying degrees of adaptation of SWB to marriage, divorce and unemployment. Few doubt that winning a lottery or losing a limb initially provoke euphoria or despair. However, what evidence we have suggests that long-run well-being is much less influenced (Brickman *et al.*, 1978; Oswald and Powdthavee, 2006). Third, if adaptation to all determinants of SWB is complete, as supposed by some psychologists, humans may simply be trapped on a 'hedonic treadmill' (Brickman and Campbell, 1971).

The literature on non-expected utility theory also embraces the idea that lottery outcomes are judged relative to a reference level, with this being a feature of its principal theory: (cumulative) prospect theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992). Although not formally identified, the conventional interpretation of the reference level in this

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[1] Other disciplines have long studied social-comparison. In sociology, the relative deprivation theory of Runciman (1966) assumes that people compare themselves with others, and feel relatively deprived when others have what they desire. In social psychology, social-comparison is repeatedly shown to influence SWB (e.g. Brickman and Bulman, 1977; Emmons and Diener, 1985).

literature is the status quo position. However, Kőszegi and Rabin (forthcoming) explore a version of the model that identifies the reference level with the prior expectation of an outcome.

The various literatures on income satisfaction, SWB, and non-expected utility theory contain a number of independent approaches to the form of the income utility function. Two examples are the Individual Welfare Function (IWF) of Van Praag (1968, 1971) and the value function of prospect theory. Despite similar assumptions on the cardinality of utility across these literatures, so far little attention has been paid to possible linkages among concepts. Second, despite the fact that self- and social-comparison are typically found within the same domains, theoretical work has tended to focus exclusively on only a single form of relativism.

We attempt to build a model of cardinal utility based upon the two notions of self- and social-comparison. It is argued that social-comparison arises from a concern for ranked position in the income distribution. Self-comparison generates a process of adaptation to income over time. For analysis of utility levels we show that a special case of the model coincides with the IWF of Van Praag (1968, 1971). Second, we show that the model offers an explanation of well-known paradoxes in the literature on national and international well-being. We contrast our account of these paradoxes with those of Easterlin (2001a). Third, when we analyse the first difference of utility between consecutive periods we establish a version of the value function of prospect theory. Our value function is 'reference-contingent' in the sense that it is different for each reference level of income. We show how loss aversion may be generated by a concern for relative income.

The plan of the paper is as follows: Section 2 motivates the main economic and psychological concepts behind our approach. Section 3 presents the model. In Section 4 we analyse the Leyden IWF, paradoxes in the literature on SWB, and the value function of prospect theory. In Section 5 we calibrate a version of the model to assess the particular form of reference-contingency implied by our value function, and the extent of loss aversion. Section 6 concludes.

2. Relative Utility

2.1. *Reference Levels*

In a well-known contribution, Van Praag (1968) begins from the supposition that people have a lower (worst) income level $Y_{\min}$ and an upper (best) income level $Y_{\max}$, with $U(Y_{\min}) = 0$ and $U(Y_{\max}) = 1$.[2] Agents are taken to compare income levels relative to these two extreme levels.

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[2] The same idea is used by Dhillon and Mertens (1999) in their 'relative utilitarian' social welfare function. Parducci's (1963) range-frequency theory is also based on two reference levels and a bounded $[0, 1]$ satisfaction scale.

Our point of departure from Van Praag's approach is his assumption that the upper and lower reference levels are fixed and abstract 'best' and 'worst' levels. Instead, we reinterpret the lower reference level as corresponding to a particular verbal label, for instance, the level of income that would be said to be 'minimum', assuming this amount to be less than current income. Similarly, we reinterpret the upper reference level as the level of income that would be said to be 'very good', or 'excellent', assuming this to be greater than current income. A small but growing literature studies the empirical properties of income levels that correspond to particular verbal labels. This literature must be evaluated with caution, since some inter-personal differences must surely reflect idiosyncratic variations in semantic expression. Nevertheless were variation purely random, we would not expect to observe the systematic relations with own income we now describe.

The Leyden group of economists have over many years employed the Income Evaluation Question, in which people are asked to state income levels that they perceived as 'sufficient', 'bad', etc. Their results are supportive of relativity in utility. For instance, the income level perceived 'sufficient' or 'good' has an elasticity with current income of around 0.6 (Van Herwaarden *et al.*, 1977; Van Praag, 1993; Van Praag and Van der Sar, 1988). Similar results are found for 'minimum' income by Stutzer (2003, 2004) and for 'get along' income by Rainwater (1974). Time-series data from Gallup Polls conducted since 1946 display a positive inter-temporal elasticity between mean 'get along' income and mean disposable income that is estimated at 0.6 by Kilpatrick (1973) and at unity by Rainwater (1974, 1994).

A common finding in these studies is that mean 'minimum' or 'sufficient' income is less than mean household income for the sample. This suggests that most households are above their perceived 'sufficient' or 'minimum' level. The mean income level deemed 'good' or 'very good' exceeds mean household income for the sample. This is consistent with the upper and lower reference levels lying respectively above and below current income.

2.2. *Modelling Self- and Social-Comparison*

Following the lead of Gilboa and Schmeidler (2001), we argue that the two reference levels, which we collectively term the frame of reference, reflect the processes of self- and social-comparison.[3] We model differences in the frame of reference across people using the concept of social-comparison. We use self-comparison as a means to model the dynamics of the frame of reference over time. Two approaches in the literature propose why people might optimally desire social information. The first (e.g. Samuelson, 2004) stresses informational advantages, while the second (e.g. Cole *et al.*, 1992, 1995, 2001) stresses the importance of status or rank in determining access to non-market goods such as mates.

Recent experimental and empirical results provide support for the importance of rank position. For instance, Brown *et al.* (2005) find that income satisfaction exhibits rank

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[3] Gilboa and Schmeidler (2001) also argue that expectations should be taken into account. For instance, an individual might have higher income aspirations if they are expecting the economy to boom, relative to if they are expecting a slump. However, for simplicity, we do not develop this aspect here.

dependence in questionnaire data of UK employees. Evidence from Whitehall studies of British civil servants suggests that rank is protective against a wide range of human diseases (Marmot, 2004; Marmot *et al.*, 1984). Frank (1985b) offers a neurobiological account of such results, emphasising the relationship between relative position and the neurotransmitter serotonin. Psychologists have been aware of the role of rank in satisfaction judgements since Parducci's (1963, 1965) range-frequency theory, which models the satisfaction of a given income from within a contextual set of other incomes as a compromise between its ordinal rank in the contextual set (frequency component) and its magnitude relative to the minimum and maximum incomes in the contextual set (range component). A growing literature in economics considers the implications of a concern for rank on human behaviour and economic policy (e.g. Becker *et al.*, 2005; Frank, 1985a; Layard, 1980; Robson, 1992). We follow these authors in modelling relative income as the relative rank of an income in the income distribution.

Precursors in the economic literature on self-comparison emphasise the role of recency: more recent events are more important to the current frame of reference. Psychologists, however, also note the disproportionate influence of extreme experiences in framing the perception of subsequent events. Tversky and Griffin (1991) and Kahneman and Varey (1991) note that experiences have a direct (endowment) effect on well-being, but also an indirect (contrast) effect, through the changed evaluation of subsequent events. The contrast effect is argued to dominate the endowment effect for extreme experiences. This leads Myers (1992, p. 63) to argue that if extremely good experiences are rare, people might actually be better off without them.

Psychologists refer to the prolonged use of past extreme stimuli as bounds against which to evaluate current stimuli as end-anchoring. Several studies uncover direct evidence of end-anchoring using responses to discrete shifts in the range of a stimulus (Haubensak, 2000, 2001; Parducci, 1992, 1995; Tomassi, 2001). Our approach attempts to model both the end-anchoring and recency dimensions to self-comparison.

3. A Model of the Utility of Income

3.1. *Experienced Utility*

Suppose we have an infinity of agents. Let each agent's period t income be denoted $Y_t > 0$, where periods are discrete and $t = 1, ..., T$. In period t, each agent possesses an endogenous upper reference level $H_t^E \geq Y_t$ and an endogenous lower reference level $0 < L_t^E \leq Y_t$.[4] Following Kahneman *et al.* (1997) we define experienced utility as the *ex-post* hedonic quality associated with a given income level within a given income distribution. We suppose

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[4] To our knowledge, the idea of endogenising both reference levels is new. In a different context, March (1988) offers a model of adaptive risk preferences featuring a fixed lower reference level and an endogenous upper reference level. Versions of his model are employed in the behavioural literature on management decision-making (see e.g. Shapira, 1995; Sullivan and Kida, 1995).

that experienced utility reflects the balance of current income relative to that perceived 'sufficient' and that perceived 'good'. This gives us experienced utility as

$$U^E\left(Y_t, L_t^E, H_t^E\right) \equiv \frac{Y_t - L_t^E}{H_t^E - L_t^E}. \tag{1}$$

Were the reference levels fixed experienced utility would be linear in income. However, as the frame of reference adjusts endogenously with income, experienced utility is typically non-linear in income. Following Van Praag (1968) we take $U^E(\cdot)$ to be cardinally measurable.[5]

An obvious objection to this formulation is that it neglects entirely the possibility of absolute utility. However, to keep the model simple we shall ignore the possibility of absolute utility, even though we believe it to exist. International studies of SWB reliably document a threshold of average national income above which average national income is uncorrelated with average national well-being. The value of this threshold is estimated at \$5,000 (in 1995, PPP) by Frey and Stutzer (2002). A similar figure is suggested by Murray (1988) and Diener and Diener (1995, Fig. 1). Since most citizens of developed countries lie above this threshold, our model may be a reasonable approximation in such cases.

Individual incomes evolve according to a stochastic income accumulation equation. In every period $t = 1, ..., T$ each agent's income is subject to a random income shock ε_t with mean $\mu \geq 0$ and variance σ^2. These parameters, and the income accumulation equation are assumed to be known by all agents. The income accumulation equation and income shock implicitly define a long-run income density. At time t we denote this $f_t(Y)$, and its distribution function we denote as $F_t(Y)$. The distribution function is a relative rank that assigns the highest income unity, and the lowest income zero. We shall use the term 'relative income' to refer to $F(Y)$.

The role of social-comparison is summarised by the construction in each period of two 'relative indicator levels' (RILs), which we denote by the pair $\left(l_t^E, h_t^E\right)$, where $0 < l_t^E \leq Y_t$ and $h_t^E \geq Y_t$. The RILs for period t summarise an agent's absolute and relative income position at time t, but contain no information from before time t. We formalise this by defining $\left(l_t^E, h_t^E\right)$ as functions of absolute and relative income:

$$l_t^E = l\left(Y_t, F_t\left(Y_t\right)\right); \qquad h_t^E = h\left(Y_t, F_t\left(Y_t\right)\right).$$

For point-in-time phenomena, the reference levels L_t and H_t can be assumed equivalent to l_t and h_t. However, as we shall model the value function of prospect theory as a through-time phenomenon, we must allow for the frame of reference at time t to be influenced by events occurring before time t. We therefore introduce the process of self-comparison, in a manner that emphasises the importance to the frame of reference of extreme events. Suppose each agent is able to store information in working memory information from the present period

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[5] The technical assumption we require is that of cardinal measurability and unit comparability. This is the coarsest measurability condition that enables the application of a utilitarian social welfare function.

and the previous n periods. At time t, the memory set containing all present and past information known to the agent is given by $I_t = \left\{l_t^E, l_{t-1}^E, ..., l_{t-n}^E, h_t^E, h_{t-1}^E, ..., h_{t-n}^E\right\}$. The frame of reference is constructed from the memory set as

$$L_t^E = \min\left(l_t^E, l_{t-1}^E, ..., l_{t-n}^E\right); \qquad H_t^E = \max\left(h_t^E, h_{t-1}^E, ..., h_{t-n}^E\right).$$

As $n \to \infty$ an agent remembers every previous RIL and is not subject to adaptation effects. If $n = 0$ an agent is said to adapt instantaneously. When $n > 0$ a RIL may never be adopted as a reference level if it is always overshadowed by other, more extreme, RILs in the memory set.

Holding relative income constant, we endow experienced utility with monotonicity in absolute income. Sufficient conditions for this are that $\frac{\partial l_t^E}{\partial Y_t}|_{F_t(Y_t)=c} < 1$ and $\frac{\partial h_t^E}{\partial Y_t}|_{F_t(Y_t)=c} < 1$. As a necessary condition, at least one of these inequalities must hold. However, we make no assumption that experienced utility is monotonic in absolute income if relative income is not held constant. If an agent receives a positive income shock, but one that is sufficiently small that relative income falls, then experienced utility may fall.

Second, holding absolute income constant, we suppose experienced utility is increasing in relative income. Sufficient conditions for this are that $\frac{\partial l_t^E}{\partial F_t(\cdot)}|_{Y_t=c} < 0$ and $\frac{\partial h_t^E}{\partial F_t(\cdot)}|_{Y_t=c} < 0$. As a necessary condition, at least one of these inequalities must hold. Third, in light of the evidence on income levels that correspond to verbal labels we suppose that, holding relative income constant, the RILs $\left(l_t^E, h_t^E\right)$ are increasing in absolute income: $\frac{\partial l_t^E}{\partial Y_t}|_{F_t(Y_t)=c} > 0$, $\frac{\partial h_t^E}{\partial Y_t}|_{F_t(Y_t)=c} > 0$.

3.2. *Decision Utility*

Again following Kahneman *et al.* (1997) we introduce the notion of decision utility, which refers to the *ex-ante* expectation of experienced utility. We do this to consider concepts such as the value function of prospect theory, which is a decision utility used to choose between risky prospects. We model decision utility by supposing the agent predicts experienced utility in period t at $t-1$ under the Cournot assumption that the income distribution at $t-1$ is fixed. We have then that

$$U^D\left(Y_t, L_t^D, H_t^D\right) \equiv \frac{Y_t - L_t^D}{H_t^D - L_t^D}. \tag{2}$$

where

$$\begin{aligned} l_t^D &= l\left(Y_t, F_{t-1}\left(Y_t\right)\right); \qquad & L_t^D &= \min\left(l_t^D, l_{t-1}^E, ..., l_{t-n}^E\right); \\ h_t^D &= h\left(Y_t, F_{t-1}\left(Y_t\right)\right); \qquad & H_t^D &= \max\left(h_t^D, h_{t-1}^E, ..., h_{t-n}^E\right). \end{aligned}$$

Clearly, only if the income distribution does not change between periods, i.e. $F_{t-1}(\cdot) = F_t(\cdot)$, does the Cournot assumption actually obtain, in which case decision and experienced utility coincide. More generally, for a given absolute income Y, our restrictions imply the following inequalities must hold:

$$l_t^E \geq l_t^D \Leftrightarrow h_t^E \geq h_t^D \Leftrightarrow F_{t-1}(Y) \geq F_t(Y). \tag{3}$$

3.3. *A Simple Model*

We now outline a simple and tractable specification of the model that we shall consider in what follows. First, we specify the formation of the RILs $l(\cdot)$ and $h(\cdot)$ as

$$\begin{aligned} l(Y, F(Y)) &= Y - g(Y) F(Y), \\ h(Y, F(Y)) &= Y + g(Y)[1 - F(Y)], \end{aligned}$$

where $g(Y)$ is a positive-valued and increasing function $0 < g(Y) < Y$ defined for all $Y > 0$ with $0 < g'(Y) < 1$.[6] Note that $g(Y)$ can be interpreted as the difference between h_t^E and l_t^E since $h(\cdot) - l(\cdot) = g(Y)$. Two examples illustrate some possibilities for $g(Y)$. First, $g(Y)$ can be assumed to grow linearly in income, in which case $g(Y) = \lambda Y$, where $0 < \lambda < 1$. Concavity can be introduced by setting $g(Y) = \log(1 + Y)$.

Second, we suppose $n = 1$. This choice is sufficient to allow for adaptation effects, without encumbering the analysis with additional lagged variables. These two assumptions lead to a model with utility functions given by (1) and (2), with

$$\begin{aligned} l_t^E &= Y_t - g(Y_t) F_t(Y_t); & L_t^E &= \min\left(l_t^E, l_{t-1}^E\right); \\ h_t^E &= Y_t + g(Y_t)[1 - F_t(Y_t)]; & H_t^E &= \max(h_t^E, h_{t-1}^E); \\ l_t^D &= Y_t - g(Y_t) F_{t-1}(Y_t); & L_t^D &= \min\left(l_t^D, l_{t-1}^E\right); \\ h_t^D &= Y_t + g(Y_t)[1 - F_{t-1}(Y_t)]; & H_t^D &= \max(h_t^D, h_{t-1}^E). \end{aligned}$$

4. Analysis

4.1. *Leyden IWF*

The Leyden IWF (Van Praag, 1968) identifies the income utility function as coinciding with the log-normal distribution function. To analyse this idea, we first define the notion of steady-state at time t to be the case where the income shock is 'turned off', such that all agents receive a shock $\varepsilon_t = 0$. In this case it holds that $F_t(Y) = F_{t-1}(Y)$ for all agents. While not intended to be realistic, steady-state is the easiest state of the model to analyse, since both the effects of an agent's own past income and the effect of changes in other agents' incomes are abstracted from. We are then in a position to state our first Proposition (all proofs being in the Appendix).

Proposition 1. Suppose:

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[6] The condition $g(Y) < Y$ is sufficient to ensure that $l(\cdot)$ is always positive. The condition $g'(\cdot) < 1$ guarantees that $\left(l_t^E, h_t^E\right)$ are increasing in absolute income, holding relative income constant.

i) Incomes evolve according to Gibrat's Law (Gibrat, 1931):

$$Y_t = (1 + \varepsilon_t) Y_{t-1},$$

with $Y_0 = 1$ *for all agents.*

ii) ε_t *is iid across agents and drawn from a normal distribution (truncated to guarantee* $\log Y_t$ *always exists) with mean* $\mu \geq 0$ *and variance* σ^2*.*

Then steady-state experienced utility is approximately the log-normal distribution function:

$$U^E \left(Y_t, L_t^E, H_t^E | \varepsilon_t = 0\right) = \frac{1}{\sigma\sqrt{2\pi t}} \int_{-\infty}^{\log\ Y_t} e^{-\frac{(z-\mu t)^2}{2\sigma^2 t}} \mathrm{d}z.$$

If we are prepared to rely on asymptotic theory, the income shock in Proposition 1 may be generalised to any *iid* shock with finite mean and variance. Proposition 1 is easily understood when it is realised that steady-state experienced utility is simply

$$U^E \left(Y_t, L_t^E, H_t^E | \varepsilon_t = 0\right) = F_t \left(Y_t\right).$$

The two requirements of the Proposition merely guarantee that the distribution function of income is log-normal. Note that since experienced and decision utilities coincide in steady-state, Proposition 1 also holds for decision utilities. This parallels the treatment of Van Praag and Ferrer-i-Carbonell (2004) who define both a decision and experienced version of the IWF, both of which are log-normal.

Despite the similarities, there are notable differences between our model and the Leyden IWF. First, in our model experienced utility only coincides exactly with the log-normal distribution function in the special case that the model is in steady-state. Nevertheless, results from the calibrated model in Section 5 suggest that the log-normal distribution function is a close approximation to experienced utility after allowing for plausible amounts of income growth. Consistent with this, Leyden authors find empirical support for the log-normal formulation (e.g. Van Praag, 1971; Van Praag *et al.*, 1978; Van Praag and Kapteyn, 1973).

Second, Van Praag's (1968) derivation of the IWF is based on a two-stage budgeting process, in which the consumer first allocates money across commodity groups and subsequently within each commodity group. By examining a commodity group containing a large number of commodities, and employing a number of restrictive assumptions, the author invokes the central limit theorem to obtain the desired result. Several aspects of this approach are the subject of a critique by Seidl (1994). In contrast, our derivation emphasises that experienced utility takes the form of the distribution function of income. The log-normal form emerges as a consequence of its close approximation to empirically observed income distributions. In this respect our model is more similar with the preference formation theory of Kapteyn (1977) and a cognitive model of utility by Kornienko (2004).

Third, the approaches differ in interpretation of μ and σ. In our model (μ, σ) are summary properties of the entire income distribution. Conversely, Leyden authors interpret (μ, σ) as psychological parameters specific to the individual. The parameter μ is perceived as a 'want' parameter, while σ is interpreted as a measure of welfare sensitivity.

4.2. *Subjective Well-Being*

SWB is a broad notion of utility, and its determinants need not be economic in nature. Nevertheless, income appears as an important explanatory variable in studies of well-being, such that we feel it possible to extend our model to that literature. Easterlin (2001a) identifies three apparently paradoxical findings that permeate existing research on SWB within and across countries. First, the cross-section finding: well-being is positively related to income within countries (Argyle, 1999; Easterlin, 1974, 1995, 2001b). Second, the time-series finding: at least for developed countries, as the income of a nation rises, SWB typically remains unchanged (Blanchflower and Oswald, 1999; Diener and Oishi, 2000; Easterlin 1974, 1995; Kenny, 1999). Third, people typically think that their well-being will improve in the future, and that their present well-being is higher than in the past (Cantril, 1965; Lipset and Schneider, 1987). To these we add a fourth effect, evidence for which we have already presented, that the well-being yielded by an given income level depends upon the level of prior income.

While a standard increasing income utility function can easily accommodate the cross-section effect, it struggles to deal with the conjunction of the cross-section and time-series effects. The third finding appears to contradict the second, since if everyone's well-being is rising over time, so ought to be average national well-being. The fourth finding is inconsistent with the standard income utility function since it implies that the same income level can, in different circumstances, yield different levels of utility.

The experienced utility function (1) and associated restrictions guarantee that experienced utility is increasing in relative income. Therefore, the cross-section finding within countries is generated in the standard economic manner. Second we turn to Easterlin's time-series finding. To examine this, we define the utilitarian average of experienced utility (social welfare) as

$$W^E \equiv \int U^E\left(Y_t, L_t^E, H_t^E\right)\ dF_t\left(Y_t\right).$$

It is well-known that social welfare is constant in a model in which experienced utility is proportional to the distance between an agent's income and the mean income. However, the notion of rank also possesses such a zero-sum property since one person's increase in rank must come at the expense of another's decrease. This idea underpins the following Proposition on steady-state social welfare:

Proposition 2. *Steady-state social welfare is independent of the mean and variance of the income distribution, taking a value of precisely* $\frac{1}{2}$.

Given Proposition 2 there can be no time trend in average steady-state experienced utility. However, the presence of income growth can prevent the model from entering steady-state, thereby holding social welfare above the steady-state level. Importantly however, income *growth* rates affect only social welfare *levels*. In the case of a country with long-run growth rates fluctuating around a balanced path growth rate, as would appear to characterise most major economies (Landon-Lane and Robertson, 2002), the model predicts no systematic time trend in social welfare. The only circumstance in which average well-being exhibits a time-trend is if growth rates themselves are increasing or decreasing over time: positive well-being trends are associated with accelerating income growth.

It may be instructive to compare our explanation of these two findings to that of Easterlin (2001a). Rather than have all agents begin with the same income, Easterlin argues that agents begin with different incomes but similar reference levels. Therefore, at the beginning of the life-cycle there is a positive association between income and well-being. Second, he argues that the frame of reference moves one-for-one with increases in income, such that well-being always remains at its original level. The possibility of such one-for-one adjustment in our account is ruled out by the assumption $g'(\cdot) > 0$.

Easterlin guarantees the absence of time trends in average well-being by forcing each individual agent's well-being to be constant over time irrespective of the time-path of absolute and relative income. We, however, allow individual well-being to change over time as a function of absolute and relative income, but place a zero-sum restriction only on the aggregate. Second, Easterlin's account rules out trends in average well-being entirely, while our model predicts a circumstance under which they can exist.

We now turn to Easterlin's third finding. To analyse this we relax the assumption of steady-state. We retain the assumption of a common shock at time t, though now we allow it to be non-zero. Changes in income rank remain abstracted from, for relative income is unchanged at time t for all agents: $F_{t-1}(Y_{t-1}) = F_t(Y_t)$. We then have Proposition 3:

PROPOSITION 3. *If the common income shock is positive (incomes are growing over time), then the (ex-ante) decision utility of an income level* Y_t *always exceeds the (ex-post) experienced utility*:

$$U^D\left(Y_t, L_t^D, H_t^D\right) > U^E\left(Y_t, L_t^E, H_t^E\right).$$

Proposition 3 offers an account of why people tend to believe they will be happier in the future than at present, yet appear to get no happier according to aggregate data. Although essentially the explanation offered by Easterlin himself, from the formalisation it is now apparent that what differentiates the notions of decision and experienced utility is the 'positional' externality discussed extensively in Frank (1985a, 1997). Positional externalities are the negative externality that an increase in one agent's income imposes on the income utility of all other agents. The mechanism here is the dependence of each agent's frame of reference on rank in the income distribution. Decision utility fails to take positional externalities into account, and therefore exceeds experienced utility whenever they are present.

Finally, we turn to the fourth finding on the effects of own income. To isolate the role of self-comparison we again suppose that at time t all agents receive a common income shock. We then have the following Proposition:

PROPOSITION 4. *Experienced utility is above its steady-state level in the period after an increase in income and below its steady-state level in the period after a decrease in income*:

$$U^E\left(Y_t, L_t^E, H_t^E | \varepsilon_t \gtrless 0\right) \gtrless U^E\left(Y_t, L_t^E, H_t^E | \varepsilon_t = 0\right).$$

Proposition 4 is an immediate consequence of adaptation to income shocks. The lower reference level takes a period to adjust to an increase in income, so utility initially lies above the steady-state level. In the case of a decease in income it is the upper reference level that takes a period to adjust.

4.3. *Prospect Theory*

We now extend our model to the behavioural literature on decision-under-risk. Here the appropriate notion of utility is that of decision utility: to evaluate a gamble in advance requires an ex-ante prediction of the experienced utility corresponding to each payoff. Prospect theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992) is the dominant descriptive model of decision-under-risk, and is used to explain a number of economic phenomena, including the endowment effect (Kahneman *et al.*, 1990; Knetsch, 1989), the equity premium puzzle (Benartzi and Thaler, 1995), and consumption smoothing (Bowman *et al.*, 1999).

As applied to income, prospect theory defines a value function $V^{KT}(\Delta Y; Y_R)$ endowed with the following properties (Figure 1). First, the carriers of utility are argued to be changes in income (ΔY) around an exogenous reference income Y_R. Outcomes $\Delta Y \geq 0$ are termed gains, and outcomes $\Delta Y < 0$ are termed losses. Kahneman and Tversky (1979) describe the value function as being like a book, with each page describing $V^{KT}(\cdot)$ at a different reference income, though they fail to formally develop this point. We term this book-like property reference-contingency. Second, utility is steeper in the loss domain than in the gain domain $\left(\frac{\partial V^{KT}(-\Delta Y; Y_R)}{\partial \Delta Y} > \frac{\partial V^{KT}(\Delta Y; Y_R)}{\partial \Delta Y} \text{ for all } \Delta Y > 0\right)$, which they term loss aversion. Third, marginal utility is a decreasing function in distance from the reference income (diminishing sensitivity). Diminishing sensitivity implies that the utility of income is concave for gains and convex for losses. The conjunction of loss aversion and diminishing sensitivity implies a kink-point at the reference income level.

In principle a standard concave utility function $U(Y)$ can be used to construct a reference-dependent utility function given by

$$U^R(\Delta Y; Y_R) \equiv U(Y_R + \Delta Y) - U(Y_R).$$

By the (strict) concavity of $U(\cdot)$ we have that $\frac{\partial U^R(-\Delta Y; Y_R)}{\partial \Delta Y} > \frac{\partial U^R(\Delta Y; Y_R)}{\partial \Delta Y}$ for all $\Delta Y > 0$, so $U^R(\cdot)$ exhibits loss aversion. However, $U^R(\cdot)$ cannot generate diminishing sensitivity, for it is everywhere concave. When agents evaluate gambles in which they stand to lose a large percentage of their income (the case of ruin), absolute utility of income would likely dominate relative concerns. Arguably, in these cases where absolute utility effects are likely to be strong, the concavity of the absolute utility function can account for loss aversion: we do not need a theory of relative utility to explain loss aversion for those sufficiently near the ruin point. The puzzle is to explain loss aversion in agents far from the ruin point where we suppose absolute effects to be weak. To address this issue we therefore focus on the relative component of the value function, though we comment on the effects of including an absolute component.[7]

To simplify some aspects of the problem we suppose the frame of reference is scaled in income. This implies $g(Y) = \lambda Y$, where $0 < \lambda < 1$. Let us now introduce our 'value' function $V[\cdot]$, which is simply the first difference between the decision utility of income in period t (the period $t-1$ prediction of experienced utility in period t) and experienced utility in period $t-1$:

$$V(\cdot) \equiv U^D(Y_t, L_t^D, H_t^D) - U^E(Y_{t-1}, L_{t-1}^E, H_{t-1}^E).$$

Since both $U^D(\cdot)$ and $U^E(\cdot)$ are bounded on the unit interval, the value function is bounded on the interval $[-1, 1]$. As the value function is everywhere non-decreasing in ε_t and bounded, it can be shown that as $\varepsilon_t \downarrow -1$ the value function is convex and converging to linear. Similarly, as $\varepsilon_t \to \infty$ the value function is concave and converging to linear. Proposition 5 states that we can always have the value function concave for small $\varepsilon_t \geq 0$, though the possibility of a convex region for some intermediate values of ε_t exists:

PROPOSITION 5. *Suppose* $\varepsilon_t \geq 0$, *then there exists a* $\lambda \in (0, 1)$ *such that the value function is concave at* $\varepsilon_t = 0$. *Conditional on parameter values, the value function may either be concave throughout the gain domain or may contain a convex interval.*

Now suppose that $\varepsilon_t < 0$. Proposition 6 states that for negative income shocks the value function is initially convex, though again the possibility of a concave interval for some intermediately large negative shock exists:

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[7] Köbberling and Wakker (2005) propose am alternative definition of loss aversion according to which $U^R(\cdot)$ displays loss aversion if and only if $\lim_{\Delta Y \uparrow 0} \frac{\partial U^R(\Delta Y; Y_R)}{\partial \Delta Y} > \lim_{\Delta Y \downarrow 0} \frac{\partial U^R(\Delta Y; Y_R)}{\partial \Delta Y}$. If $U(\cdot)$ is a smooth concave absolute utility function then $U^R(\cdot)$ does not satisfy this condition and our argument no longer holds. However, our relative component of the value function is kinked by construction, and therefore always satisfies this alternative definition of loss aversion without recourse to absolute utility.

Proposition 6. *Suppose $\varepsilon_t < 0$, then there exists a $\lambda \in (0,1)$ such that the value function is convex as $\varepsilon_t \uparrow 0$. Conditional on parameter values, the value function may either be convex throughout the loss domain or may contain a concave interval.*

In tandem, Propositions 5 and 6 imply a kink-point at the reference level of income. While Kahneman and Tversky's (1979) formalisation of the value function does not contain either a concave region in the loss domain or a convex region in the gain domain, the authors nevertheless note (p. 279) that such regions are possible. They emphasise the possibility of concave regions for large losses, since such losses 'often necessitate changes in lifestyle'. Concavity for large losses is not a feature of the relative component of the value function, but does emerge if a concave absolute component is also allowed for. Near the ruin point the relative component of the value function is approximately linear so the concavity of the absolute component is likely to dominate. More generally, the addition of a concave absolute component reduces the likelihood of observing convex regions for gains, and increases the likelihood of observing a concave region in the loss domain.[8]

A difference between our value function and that of prospect theory is that when individual income is evolving the value function does not intersect the origin. In particular, if $\varepsilon_{t-1} > 0$ the value function intersects below the origin, and if $\varepsilon_{t-1} < 0$ it intersects above the origin. The reason for this is that income utility is initially above or below its long-run (steady-state) level after a change in income. The effect being captured is the lagged process of adaptation to the income change at time $t-1$.

Several sources of loss aversion can be identified within the model. The first arises from the asymmetric effect on rank of income gains and losses. The upper tail of the log-normal density is decreasing in income so in the neighbourhood of any income level, there exist more agents with lower incomes than those with higher incomes. Therefore, the loss of rank associated with a fall in income exceeds the gain in rank associated with an equivalent rise in income. This observation is reversed for individuals in the lower tail, leading to the prediction that loss aversion from relative concerns is systematically weaker for such agents relative to those in the upper tail.[9]

A second source of loss aversion arises when the mean of the income distribution is growing over time. In this case the income shock required to maintain a constant level of experienced utility is strictly positive due to the presence of positional externalities: to stand still is to fall behind. Since gains and losses are judged against the income growth rate rather

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[8] When experienced utility corresponds to a weighted average of a concave absolute component and a relative component, the resulting function is of the Friedman-Savage form (Friedman and Savage, 1948) for some intermediate values of the weighting parameter. This parallels earlier derivations of the Friedman-Savage formulation by Gregory (1980) and Robson (1992).

[9] Friedman (1989) offers a derivation of the value function of prospect theory using Leland's (1988) notion of approximate expected utility. His account also emphasises the role of a positively skewed income distribution in the widespread generation of loss aversion.

than zero, absolute losses are magnified when translated into relative losses, while absolute gains are correspondingly diminished in relative terms.

A third source is inherent in the particular form of path dependence implied by the dynamics of the frame of reference. When incomes are growing over time positive income shocks are more prevalent than negative shocks. In our model, agents habituate to receiving positive shocks, making negative shocks more painful when they arrive.[10] To see this, note that when successive income shocks alternate in sign only a single reference level adjusts. The frame of reference does not shift, but stretches. However, when successive income shocks are of the same sign the frame of reference shifts contemporaneously. Consequently, alternating income shocks have a greater contemporaneous impact on utility than do same-sign shocks. If the incidence of positive shocks exceeds that of negative shocks then negative shocks are more likely be of alternate sign to the previous shock than are positive shocks.

Model complexity is such that these effects do not summarise easily into a simple theoretical statement. Rather, the incidence of loss aversion depends in a complex way on all the model parameters. Much the same can be said for the implied form of reference-contingence. We therefore analyse these issues in a calibration of the model in the next section.

5. Calibration

Here we perform a calibration of the model. The parameters μ and σ are fitted to data from Incomes Data Services on the distribution of UK gross weekly earnings of full-time employees for April 2002. All income amounts are in Pounds Sterling. The median and mean of the log-normal density are defined as $\rho_t \equiv e^{\mu t}$ and $\phi_t \equiv e^{\mu t + (\sigma^2 t)/2}$ respectively. From these we estimate $\mu t = 5.95$ and $\sigma\sqrt{t} = 0.62$. We decompose μt by assuming a long run income growth rate of 2.5% ($\mu = 0.025$), which implies $t = 238$, and $\sigma = 0.0402$. The conclusion of a large body of work by the Leyden group of economists into 'minimum' income suggests an elasticity of the lower reference level with current income of $\eta_{l_t Y_t} = 0.6$. Since $\eta_{l_t Y_t}$ is not constant in our model, we evaluate it at the modal income, in which case $\lambda = 0.63$. Evaluating instead at the mean income yields $\lambda = 0.46$ and similar outcomes obtain.

Figures 2-4 depict the value function for different reference levels of income. Each is drawn for ε_{t-1} set at the mean value of 0.025. Although the value function intersects below the origin, the effect appears almost indiscernible.

The results suggest a widespread finding of loss aversion for incomes in the upper tail of the income distribution. As the reference level of income increases, so does the range of ε_t for which loss aversion holds. Therefore relative effects generate loss aversion for those far from the ruin point, where absolute utility effects may be weak. There appear to be failures of

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[10] The psychological notion of habituation refers to the decreasing response of an organism to a repeated stimulus. This differs slightly from adaptation, which instead refers to a maintained stimulus (Thompson and Spencer, 1966).

loss aversion at low reference income levels, and more generally for very large shocks relative to income. However, it is at these lower incomes that absolute utility would be expected to generate loss aversion were we to include an absolute component.

Turning to reference-contingency, Figures 2-4 show that in a neighbourhood on either side of the reference level, non-linearity is decreasing with the reference income. That is, the regions of significant curvature in the value function become more distant from the reference level as income increases. This appears to be consistent with Kahneman and Tversky (1979) who speculated that $V(\cdot)$ becomes more linear as the reference income increases. However, the kink at the reference level of income becomes more pronounced with increases in the reference income due to the increasing strength of loss aversion. There is an unfortunate absence of empirical research on reference-contingence against which to evaluate these theoretical predictions (Schmidt, 2003).

How do small variations in the other parameters alter our findings? As regards loss aversion, the effect of increasing ε_{t-1} is to increase the incidence of loss aversion, while decreasing ε_{t-1}, or allowing it to be negative, decreases the incidence of loss aversion. Lowering λ has the effect of introducing progressively stronger thresholds into the value function. In these cases, $V(\cdot)$ is initially steep around the reference income level, before flattening quickly in a region of high curvature. However, there are no substantial changes in respect of loss aversion.

Finally, the occurrence of convex (concave) regions in the gain (loss) domain is severely limited. For this calibration, a convex interval in the gain domain only exists for reference incomes less than approximately £35, which accounts for less than 0.01% of the population. A concave interval in the loss domain emerges only for reference incomes greater than around £7000, which again affects less than 0.01% of the population. Thus, in the overwhelming majority of cases, we find the principle of diminishing sensitivity to hold.

6. Conclusion

This paper has presented a model of cardinal utility based upon the two psychological notions of self- and social-comparison. We have argued that such a model can go some way to reconciling the Leyden IWF, time-series and cross-sectional findings on SWB, and the value function of prospect theory, within a single conceptual framework. In our model, utility reflects the distribution of income because agents care about their ranked position in the income distribution. Utility approximating the log-normal distribution function emerges because empirical income distributions are often approximately log-normal.

We have offered an account of apparent paradoxes in well-being data without supposing that individuals must have constant utility over the life-cycle. Instead we show how the zero-sum properties of a rank lead naturally to constant average well-being for constant rates of income growth. A testable prediction of the model is that time-trends in well-being should emerge in periods with accelerating or de-accelerating economic growth rates.

We argue that the value function of prospect theory corresponds to the transition dynamics of income utility around its steady-state level. These dynamics are driven by stochastic shocks to the income process. Different from Kahneman and Tversky's (1979) formalisation of the value function, our value function is explicitly contingent on the reference level of income at which it is drawn, since it describes the first difference of a utility function defined on income levels. More empirical work on the nature of the reference-contingency is needed before the merits of the model in this respect can be assessed.

However, our model is only a relatively modest beginning in attempting to explain the phenomena we have discussed. An important development will be to recast the model in the maximising framework common to economic analysis more generally. However, a better economic understanding of behavioural features such as adaptation will be required before such a development is feasible. Nevertheless, we hope to have shown what such a model might be able to achieve.

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Appendix

Proof of Proposition 1. Let $Y_0 = 1$ and $Y_t = (1+\varepsilon_t)Y_{t-1}$, where ε_t is *iid* across agents and has a truncated normal distribution on the interval $(-1, \infty)$. Then $\log Y_t$ is approximately truncated normal on the interval $(-t, \infty)$ with mean μt and variance $\sigma^2 t$. Thus Y_t is truncated log-normal on the interval (e^{-t}, ∞). Since in steady-state $U^E\left(Y_t, L_t^E, H_t^E | \varepsilon_t = 0\right) = F_t\left(Y_t\right)$, the result follows.

Proof of Proposition 2. Using the definition of social welfare: $W^E|_{\varepsilon_t=0} = \int U_t\left(Y_t\right) dF_t\left(Y_t\right) = \int F_t\left(Y_t\right) dF_t\left(Y_t\right) = \frac{1}{2}$.

Proof of Proposition 3. We have $F_{t-1}\left(Y_{t-1}\right) = F_t\left(Y_t\right)$ so $\frac{\partial l_t^E}{\partial \varepsilon_t} \gtrless 0 \Leftrightarrow \frac{\partial h_t^E}{\partial \varepsilon_t} \gtrless 0 \Leftrightarrow \varepsilon_t \gtrless 0$. Suppose $\varepsilon_t \geq 0$, then $U^E\left(\cdot\right) = \frac{Y_t - l_{t-1}^E}{h_t^E - l_{t-1}^E}$ and $U^D\left(\cdot\right) = \frac{Y_t - l_{t-1}^E}{h_t^D - l_{t-1}^E}$. Since $Y_t > l_t^E \geq l_{t-1}^E$ it follows that $U^D\left(\cdot\right) > U^E\left(\cdot\right) \Leftrightarrow h_t^E > h_t^D$. As all incomes are increasing it follows that $\frac{\partial F_t(Y)}{\partial t} < 0$, so $F_t\left(Y_t\right) < F_{t-1}\left(Y_t\right)$. Then $h_t^E > h_t^D$ follows from (3) in the text. Now suppose $\varepsilon_t < 0$ then $U^E\left(\cdot\right) = \frac{Y_t - l_t^E}{h_{t-1}^E - l_t^E}$ and $U^D\left(\cdot\right) = \frac{Y_t - l_t^D}{h_{t-1}^E - l_t^D}$. Since $l_t^E > l_t^D$, from (3) we have that $U^D\left(\cdot\right) > U^E\left(\cdot\right) \Leftrightarrow h_{t-1}^E > Y_t$. This holds as $h_{t-1}^E > Y_{t-1} > Y_t$.

Proof of Proposition 4. We have $F_{t-1}\left(Y_{t-1}\right) = F_t\left(Y_t\right)$ so $\frac{\partial l_t^E}{\partial \varepsilon_t} \gtrless 0 \Leftrightarrow \frac{\partial h_t^E}{\partial \varepsilon_t} \gtrless 0 \Leftrightarrow \varepsilon_t \gtrless 0$. If $Y_t > Y_{t-1}$ experienced utility is given by $U^E\left(\cdot | \varepsilon_t > 0\right) = \frac{Y_t - l_{t-1}^E}{h_t^E - l_{t-1}^E}$. If $Y_t > Y_{t-1}$ then experienced utility is $U^E\left(\cdot | \varepsilon_t = 0\right) = \frac{Y_t - l_t^E}{h_t^E - l_t^E}$. So $U^E\left(\cdot | \varepsilon_t > 0\right) > U^E\left(\cdot | \varepsilon_t = 0\right) \Leftrightarrow h_t^E > Y_t$, and the r.h.s. holds by the definition of h_t^E. If $Y_t < Y_{t-1}$ we have $U^E\left(\cdot | \varepsilon_t < 0\right) = \frac{Y_t - l_t^E}{h_{t-1}^E - l_t^E}$. Then $U^E\left(\cdot | \varepsilon_t = 0\right) > U^E\left(\cdot | \varepsilon_t < 0\right) \Leftrightarrow h_t^E < h_{t-1}^E$, which holds for $\varepsilon_t < 0$.

Proof of Proposition 5. Noting that $\frac{\partial^2 V(\cdot)}{\partial \varepsilon_t^2} = \frac{\partial^2 U(\cdot)}{\partial \varepsilon_t^2}$, assume $\varepsilon_t \geq 0$ then $U^D\left(Y_t, L_t^D, H_t^D\right) = \frac{Y_t - l_{t-1}^E}{h_t^D - l_{t-1}^E}$. It follows that

$$\frac{\partial^2 U}{\partial \varepsilon_t^2} = \frac{1}{\left(h_t^D - l_{t-1}^E\right)^3} \left\{ 2 \frac{\partial h_t^D}{\partial \varepsilon_t} \left[\left(Y_t - l_{t-1}^E\right) \frac{\partial h_t^D}{\partial \varepsilon_t} - \left(h_t^D - l_{t-1}^E\right) \frac{\partial Y_t}{\partial \varepsilon_t} \right] - \left(h_t^D - l_{t-1}^E\right) \left(Y_t - l_{t-1}^E\right) \frac{\partial^2 h_t^D}{\partial \varepsilon_t^2} \right\}.$$

Using

$$\begin{aligned} \frac{\partial h_t^D}{\partial \varepsilon_t} &= Y_{t-1} \left\{ 1 + \lambda - \lambda \left[F_{t-1}\left(Y_t\right) + \left(1 + \varepsilon_t\right) \frac{\partial F_{t-1}\left(Y_t\right)}{\partial \varepsilon_t} \right] \right\}, \\ \frac{\partial^2 h_t^D}{\partial \varepsilon_t^2} &= -\lambda Y_{t-1} \left[2 \frac{\partial F_{t-1}\left(Y_t\right)}{\partial \varepsilon_t} + \left(1 + \varepsilon_t\right) \frac{\partial^2 F_{t-1}\left(Y_t\right)}{\partial \varepsilon_t^2} \right], \end{aligned}$$

we may write this in the form $\lambda \left(\frac{Y_{t-1}}{h_t^D - l_{t-1}^E}\right)^3 \left(a_1 \lambda^2 + b_1 \lambda + c_1\right)$ where

$$c_1 = -2 \left(1 - F_{t-1}\left(Y_t\right) + \varepsilon_t \frac{\partial F_{t-1}\left(Y_t\right)}{\partial \varepsilon_t} \right) + \varepsilon_t^2 (1 + \varepsilon_t) \frac{\partial^2 F_{t-1}\left(Y_t\right)}{\partial \varepsilon_t^2}.$$

Ignoring the trivial root $\lambda = 0$, the remaining two roots are $\lambda_{1+} = \frac{-b_1+\sqrt{b_1^2-4a_1c_1}}{2a_1}$ and $\lambda_{1-} = \frac{-b_1-\sqrt{b_1^2-4a_1c_1}}{2a_1}$. Concavity requires that $\lambda \in [\lambda_{1-}, \lambda_{1+}]$ if $\lambda_{1+} > \lambda_{1-}$, and $\lambda \geq \lambda_{1-}$ if $\lambda_{1-} > \lambda_{1+}$. There exists a $0 < \lambda < 1$ such that these conditions hold if $\lambda_{1-} < 0$ and $\lambda_{1+} > 0$. Both conditions are satisfied if $c_1 < 0$. We have that at $\varepsilon_t = 0$, $c_1 = -2\left(1 - F\left(Y_t\right)\right) < 0$ for all finite Y, which completes the proof.

Proof of Proposition 6. If $\varepsilon_t < 0$ then $U^D\left(Y_t, L_t^D, H_t^D\right) = \frac{Y_t-l_t^D}{h_{t-1}^E-l_t^D}$. In this case

$$\frac{\partial^2 U}{\partial \varepsilon_t^2} = \frac{1}{\left(h_{t-1}^E-l_t^D\right)^3}\left\{2\frac{\partial l_t^D}{\partial \varepsilon_t}\left[\left(h_{t-1}^E - l_t^D\right)\frac{\partial Y_t}{\partial \varepsilon_t} - \left(h_{t-1}^E - Y_t\right)\frac{\partial l_t^D}{\partial \varepsilon_t}\right] - \left(h_{t-1}^E - l_t^D\right)\left(h_{t-1}^E - Y_t\right)\frac{\partial^2 l_t^D}{\partial \varepsilon_t^2}\right\}.$$

Using $\frac{\partial l_t^D}{\partial \varepsilon_t} = \frac{\partial h_t^D}{\partial \varepsilon_t} - \lambda Y_{t-1}$ and $\frac{\partial^2 l_t^D}{\partial \varepsilon_t^2} = \frac{\partial^2 h_t^D}{\partial \varepsilon_t^2}$, we can write this as $\lambda\left(\frac{Y_{t-1}}{h_{t-1}^E-l_t^D}\right)^3\left(a_2\lambda^2 + b_2\lambda + c_2\right)$, where $c_2 = c_1 + 2$. Convexity requires that $\lambda \in [\lambda_{2+}, \lambda_{2-}]$ for $\lambda_{2-} > \lambda_{2+}$ and $\lambda \geq \lambda_{2+}$ for $\lambda_{2+} > \lambda_{2-}$, where λ_{2+} and λ_{2-} are defined analogous to λ_{1+} and λ_{1-} above. The conditions $\lambda_{2-} > 0$ and $\lambda_{2+} < 0$ ensure that for all agents there exists a $0 < \lambda < 1$ such that $V(\cdot)$ is convex. Both conditions are satisfied if $c_2 > 0$. Then $\lim\limits_{\varepsilon_t \uparrow 0} c_2 = 2F_{t-1}\left(Y_t\right) > 0$ for $Y > 0$, which completes the proof.