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Loneliness and mood-influenced returns on health-dependent active-time: a conceptualisation

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Abstract
This paper incorporates loneliness into the mood influenced health-investment theory developed by Caputo and Levy (2012). The expanded model takes the individuals' active time to be dependent on health and considers its allocation to a broader set of activities. A two-direction relationship between loneliness, mood and, subsequently, health is considered. The possibility of a vicious cycle is highlighted. Loneliness adversely affects the individual's overall state of mood and, in turn, the deterioration of mood adversely affects health and; as the mood-influenced return on interaction is diminished; intensifies loneliness. The deterioration of health lengthens rest-time. The lower returns and the shortened active-time reduce interaction. The reduced interaction intensifies loneliness, and so on and so forth.

Key words: Loneliness; Mood; Health; Wealth; Survivability; Dynamic Time Allocation

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1. Introduction

Loneliness is a personal state marked by a sense of undesired social isolation and accompanied by a feeling of sadness. Its prevalence has been intensified in recent decades. Cacioppo and William (2008) have estimated that approximately twenty percent of the people living in the United States feel lonely. A similar percentage can be expected in other western countries. Living alone is highly correlated with loneliness. Yet the increase in the number of single-person households does not provide a complete explanation of the prevalence of loneliness. This is because living alone is neither a necessary condition, nor necessarily a cause, for loneliness. In many cases, living alone is a direct result of the same factors that cause loneliness, or an indirect result of those factors through personal acceptance of loneliness as a permanent state. Interrelated factors such as technological change, materialism, secularism, cultural change, loss of social cohesion and trust, family breakdown and suburbization have been indicated by Putnam (1995), McPherson, Smith-Lovin and Brashears (2006) and Cacioppo and William (2008) as determinants of loneliness. Cacioppo and Hawkley (2010) have argued that loneliness adversely affects people's mental and physical health. Loneliness might lead to depression and depression might lead to a deterioration of physical health and suicide. Holt-Lunstad et al. (2015) have found that loneliness increases the likelihood of mortality by approximately twenty-six percent.

Despite the said prevalence and adverse effects on life, the conceptualisation of loneliness has not been a focus of behavioural economic and health economic studies. This paper attempts to fill this void by incorporating loneliness and its interrelationships with mood and mental and physical health (health henceforth) into the model of mood-influenced physical investment in personal health developed by Caputo and Levy (2012). The expansion of this model also takes the individuals' active time to be endogenous and dependent on the individual's health and deals with its allocation to a broader set of activities than the original one. The expanded model presents a circular relationship between loneliness, mood and, subsequently, health and highlights the possibility of the following vicious cycle. Loneliness adversely affects the individual's overall state of mood. In turn, the deterioration of mood adversely affects health and also the returns on social interaction. The deterioration of health lengthens rest-time. The shortened active-time and the lower returns on social interaction reduce the time allocated to social interaction. The diminished social interaction intensifies loneliness, and so on and so forth. A suicide might be committed to end the misery stemming from this vicious cycle.

Yet there are outlets to which the shortened active-time can be channelled, before the returns on taking these outlets are excessively impacted, that may prevent entrapment in the aforesaid vicious cycle of deteriorating mood and health, diminishing returns on interaction, diminishing active-time, diminishing interaction and intensifying loneliness. Already three decades ago Byrne and Byrne (1993) have published a review of a large body of research that lends support to the claim that regular exercising improves the individual's mood directly and also indirectly through its health-improving effect. The improvement in health also lengthens active-time. Other outlets are learning and producing. Learning increases human capital, and the increment in human capital generates a chain reaction of greater employability, productivity, income, wealth, consumption and utility and, consequently, better mood, with income and the ensuing factors being further enhanced by time spent on producing.

The objective of this paper is to construct a conceptual framework for a preliminary discussion of the possibility of entrapment in, or escape from, a vicious cycle of deteriorating mood, health and loneliness and to set the stage for empirical investigations of this issue. The Caputo-Levy pioneering model of mood-influenced personal investment in health is the natural corner stone.

It is expanded to include loneliness and the possible interrelationship between this mental state and mood within a broader, more comprehensive, framework of dynamic allocation of time along an uncertain endogenous lifespan. In the expanded model, time is allocated to interacting, learning, exercising and producing goods. In addition to the individual's degree of loneliness, the expansion considers two state variables that are essential to generating and protecting income, wealth and life: human capital and the quality of the physical environment. The expansion also adds environmentally generated and self-inflicted catastrophes to the individual's set of flow variables, and time invested in interacting and learning to the individual's set of control variables. The expansion divides the individual's production and consumption into those of an environmentally dirty good and an environmentally clean good. Another added feature is a distinction between active-time and rest-time, with both depending on the individual's state of health.

A graphical summary of the expanded and modified Caputo-Levy model is presented in Figure 1. As reflected by the number of out-going and in-coming arrows and by its position as the last post that funnels the nexus of direct and indirect effects into the argument of the postulated objective — maximum expected lifetime happiness — mood is also pivotal in the present analysis of the dynamics of individual's time allocation. This state variable is defined as the background feeling of a person (Thayer, 1996). Consistent with empirical findings, the in-coming and out-going arrows indicate a wide range of factors affecting, and/or being affected by, this background feeling.

Loneliness is recognised by the psychological and health literature; and also by the social capital literature stemming from Bourdieu (1986); as an important determinant of individuals' mood and, subsequently, happiness. Putnam (1995, 2000) has argued that lack of interpersonal interaction adversely affects happiness. His argument is congruent with Maslow's (1954) and Schultz's (1966) argument that people have a need for inclusion and affection, and with Berne's (1964) claim that interactions are attempts to satisfy this need. The individual's level of loneliness can be reduced by the individual's investment in intimate relationships and other types of interpersonal and social interactions, generally being referred to henceforth as interacting. Time allocated to interacting is time unspent in producing goods and, thereby, direct generation of income. The forgone income can be offset by the positive effects of interacting. Interacting can also indirectly improve the individual's human capital; and, subsequently, employment and investment opportunities; through the positive effects of a moderated level of loneliness on mood and, in turn, on health and the returns on time allocated to learning. Yet, the extent of the positive effects of interacting depends on the individual mood. Due to sadness and/or anger and aggressiveness, the return on interacting with other people while being in a bad state of mood is taken to be lower than the return on interacting with the same people while being in a good state of mood.

The rate of return on interacting may further depend on personal characteristics such as extrovertedness, introvertedness, appearance, age and gender. The effects of these characteristics are embedded in the size of some of the model's parameters. The rate of return on interacting may also depend on socioeconomic status. Levy (2009a) has focused on the effect of economic status and offered an index of connectivity. He has argued that sincere interpersonal communication, hence the individual's social capital, is sensitive to economic status disparities. Consequently, he has suggested that the individual's happiness-wealth relationship can be depicted by an inverted U-shaped curve. In agreement with Levy (2009a), the flowchart in Figure 1 displays that the individual's loneliness might be alleviated by the

individual's material wealth up to a critical level of material wealth and then aggravated. The proposed formal model takes that critical level to be the average material wealth in the society.

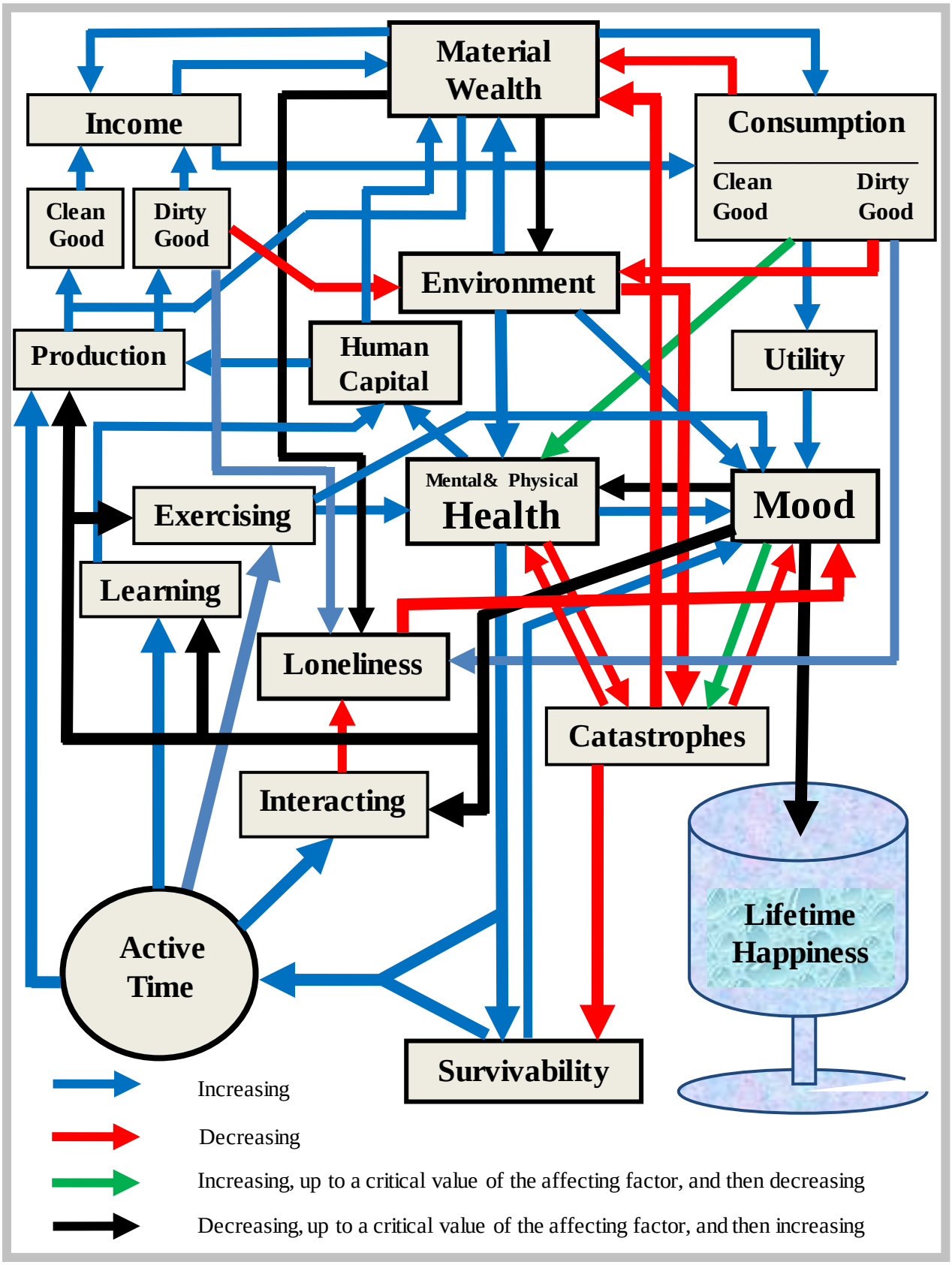

Figure 1. The dynamics of the individual's time allocation and state

The expansion of the Caputo-Levy model also considers the possible interrelationships between people's wealth and health and the state of their natural environment. Environmental degradation can gradually damage people's material wealth, health and, subsequently, productivity (Levy, 2009b). It can also do so abruptly and strongly — catastrophes (Weitzman 2009, 2011). In turn, economic activity and accumulation of material wealth can affect people's physical environment in several ways. The environmental Kuznets curve (*cf*., Shafik and Bandyopadhyay, 1992; Selden and Song, 1994; Grossman and Krueger, 1995) suggests that at low levels of material wealth the negative effect of the growing scale of production and consumption on a physical environment is dominant. Beyond a critical level of material wealth, the positive effects of the introduction of cleaner production inputs and processes and the changes in the composition of consumption bundles in favour of cleaner goods may dominate the negative effect of the scale of economic activity on the physical environment. This argument is supported by the affluence (also known as post-materialism) hypothesis (Inglehart, 1995, 1997), which suggests that, beyond a critical level of wealth, the environmental degradation might be moderated by intensified concerns for the environment.

In the expanded model, people derive utility from consuming two goods: a dirty good and a clean good. The production and also the consumption of the dirty good harm the environment. The said goods are not perfect substitutes. Each person is a producer of at least one of these goods and a price taker. Productivity increases with good mood and decreases with bad mood. In addition to working time, production is a function of material wealth and human capital. The elasticities of production with respect to these inputs reflect that it is easier to produce the dirty good. Human capital is acquired through learning. It is also increased by improvements in personal health.

Due to the open access nature of the environment; the atmosphere, in particular; moderation of free-riding and improved cooperation are conducive to mitigating environmental degradation. Connectivity can moderate free-riding by strengthening mutual responsibility and thereby cooperation. Humans are taken to be alert social creatures. That is, each person's production and consumption are observed and excessive production and consumption of the dirty good (say, beyond the average) by one person lead to her loss of empathy and, in turn, connectivity, which intensifies her feeling of loneliness. This potential loss of empathy moderates the extent of ignoring self-imprinted footstep on the environment and leads to a production and consumption combinations of the dirty good and the clean good that are less harmful to the natural environment.

The inclusion of the state of the physical environment in the model leads to a modification of the individual's hazard/survival equation. The present expansion of the Caputo-Levy model incorporates a flow variable denoted as catastrophes. In agreement with Weitzman (2009, 2011), Figure 1 suggests that a deterioration in the state of the environment leads to catastrophes. In turn, catastrophes affect the individual's states of health, mood, material wealth and survivability. Figure 1 also suggests that catastrophes can also be self-inflicted. They can be caused by the individual's states of health and mood. Performing tasks in bad health can lead to accidents. A bad state of mood can lead to loss of control and reckless behaviour and, consequently, accidents and determines their severity.

Mood affects personal choices and actions and is affected by their outcomes (Thayer, *ibid*) Good (bad) mood leads to positive (negative) returns on interacting. Good (bad) mood is also conducive to (adversely affecting) learning, working and exercising. People's mood may improve (deteriorate) with a positive (negative) changes in their level of utility from

consumption of the aforesaid goods and also with positive (negative) changes in their states of health, connectivity, environment and survivability.

The next section provides a formal presentation of the expanded and refined model with explicit functional forms that can facilitate a preliminary discussion and future assessments of parameters and numerical simulations of life-profiles for people endowed with different capacities to connect, learn, work and exercise, different sensitivities to changes in their mood, and different concerns for the state of their environment.

2. Formal presentation

With state variables denoted by capital letters and flow variables by lower cases the expanded model's variables are:

$t \in (0,T)$ - a continuous time index with T indicating the physiological upper bound on human lifespan;

$L(t)$ - the individual's level of loneliness at t;

$M(t) \in (0,1)$ - the individual's mood at t, with $M(t) \in (0,0.5)$ indicating bad mood and $M(t) \in (0.5,1)$ good mood (which is analytically more convenient than $M < 0$ for bad mood and $M > 0$ for good mood in the Caputo-Levy model);

$H(t) \in (0,1)$ - the individual's health at t;

$K(t)$ - the individual's material wealth (financial and physical capital) at t;

$I(t)$ - the individual's human capital at t;

$E(t)$ - the quality of the individual's physical environment at t, $E(t) \in (0, E_{\max})$, with $E_{\max}$ denoting the ideal natural environment from humans' perspective;

$P(t)$ - the individual's probability of dying by t, $\lim_{t \to T} P(t) = 1$;

$a(t)$ - active-time (fraction of the time not allocated to rest) at t;

$n(t)$ - the fraction of the active-time allocated by the individual to interacting at t;

$\ell(t)$ - the fraction of the active-time allocated by the individual o learning at t;

$x(t)$ - the fraction of the active-time allocated by the individual to exercising at t;

$w_d(t)$ - the fraction of the active-time allocated by the individual to producing the dirty good at t;

$w_c(t) = a(t) - \ell(t) - x(t) - n(t) - w_d(t)$ - the fraction of the active-time allocated by the individual to producing the clean good at t;

$y_d(t)$ - the individual's potential production of dirty good at t; that is, the quantity of the dirty good produced had the individual's active-time at t been fully allocated to producing this good ($w_d(t) = a(t)$);

$y_c(t)$ - the individual's potential production of clean good at t; that is, the quantity of clean good produced had her active-time at t been fully allocated to producing this good ($w_c(t) = a(t)$);

$c_d(t)$ - the individual's consumption of the dirty good at t, with $\hat{c}_d(t)$ denoting the individual's healthiest level of consumption of dirty good;

$c_c(t)$ - the individual's consumption of the clean good at t, with $\hat{c}_c(t)$ denoting the individual's healthiest level of consumption of dirty good;

p_c(t) - the price of the clean good relative to the price of the dirty good (numeraire),

$u(c_d(t), c_c(t))$ - the individual's utility at t from consumption, a jointly concave function in the quantities consumed of the dirty good and clean good at t; and

$z(t)$ - the severity of catastrophes experienced by the individual at t.

With all scalars taken to be non-negative and denoted by Greek letters, the model's equations are as follows.

The rate of change of the individual's state of loneliness is taken to be given by:

$$\frac{\dot{L}(t)}{L(t)} = \theta_0(t-\hat{t}) - \left(\frac{1+\theta_1[M(t)-0.5]}{1+\theta_2[K(t)-\bar{K}(t)]^2}\right) n(t)^{\theta_3} + \theta_4[y_d(t)-\bar{y}_d] + \theta_5[c_d(t)-\bar{c}_d]. \quad (1)$$

Consistent with empirical findings, the first term in equation (1) suggests that up to a personally critical age ($\hat{t} \geq 0$) loneliness tends to decrease in the passage of time and then increase. The underlying rationale is as follows. In early stages of life, loneliness is moderated by higher ability and inclination to adjust to changing fashions, culture and technology, by enrolment in schools, by affiliation to service and work places and by forming intimate relationships, partnership and family. In later stages, loneliness is intensified by decreasing ability and inclination to adjust to changing fashion, culture and technology, by a loss of contact with childhood and adolescence friends, by the passing away of senior members of the family of origin, by separation and divorce, by a loss of proximity to children, and by the passing away of siblings and cousins, old friends and, in particular, partners. The feeling of loneliness might be firstly and drastically intensified by the passing away of parents. In some languages (e.g., Hebrew), the word used to describe the state of being orphan is also used to describe strong feelings of being lonely. It is therefore possible that $\hat{t}$ might be smaller for a person born to relatively old parents than for a person born to young parents. Being more capable of working through their feelings in solitary and emotionally less dependent on interaction, introverts are less susceptible to the effects of the said losses than extroverts. It is therefore assumed that θ_0 is smaller for introverts than for extroverts.

As regards the second term in equation (1), it is assumed that the positive marginal effect of interaction on loneliness is diminishing and in a lower rate for altruists than for egoists: $0 < \theta_3 < 1$ and is larger for altruists. The ratio in that term suggests that the effect of interaction on loneliness is further influenced by mood and wealth. The numerator suggests that being in a good mood ($M(t) \in (0.5,1)$) increases the rate of return on interacting, whereas being in a bad mood ($M(t) \in (0,0.5)$) renders interacting less effective in alleviating the individual's feelings of loneliness. The effect of mood on the return on interacting is considered to be larger for anxious people than for calm people. Hence, a larger value of θ_1 is assigned for anxious people than for calm people. It is suggested that $0 < \theta_1 < 2$. In other words, interacting always moderates loneliness, even under extreme bad mood (M=0).

Following Levy (2009a), the denominator in the said ratio suggests that the effect of interacting on loneliness is weakened by the deviation of the individual's wealth from the average wealth in the society ($\bar{K}$), but at a rate moderated by the above-the-average-rich person's modesty and below-the-average-poor person's pride. That is to say, the adverse influence of wealth on the effectiveness of interaction in reducing loneliness, θ_2, is smaller for people concealing the state of their material wealth than for people advertising the state of their wealth.

It is further assumed that polluting the environment beyond the average leads to loss of empathy. The third and the fourth terms in equation (1) display that people's loneliness intensifies at a rate that increases with their production and consumption of the dirty good beyond the average levels in their society, $\bar{y}_d$ and $\bar{c}_d$.

The rate of change of the individual's state of health is given by:

$$\frac{\dot{H}(t)}{H(t)} = \left(\frac{E(t)/E_{\max}}{1+\alpha_2[c_d(t)-\hat{c}_d]^2+\alpha_3[c_c(t)-\hat{c}_c]^2} \right) \left(\frac{1}{1-\alpha_4[M(t)-0.5]} x(t) \right)^{\alpha_1} + \alpha_5 K(t)^{\alpha_5} + \alpha_6[M(t)-0.5] - \frac{\alpha_7 + z(t)}{T-t} \quad .(2)$$

With the assumption of $0<\alpha_1<1$, equation (2) suggests that the individual's health diminishingly increases with exercising and at a rate that is intensified by being in a good mood and by the quality of the environment and reduced by being in a bad mood and by deviations from healthiest combination of consumption of clean good and dirty good, $(\hat{c}_c, \hat{c}_d)$. This equation also suggests that, due to affordability of better medical care, the rate of change of the individual's health increases with her wealth, and that a good (bad) mood also improves (deteriorates) health directly. The $\alpha_7/(T-t)$ in the last term represents the catastrophes-free adverse effect of ageing on health, and the addition of $z(t)$ to the numerator indicates that ageing is accelerated by the severity of accidents experienced at t.

The motion equation of the individual's human capital is taken to be:

$$\dot{I}(t) = \lambda_0 H(t)^{\lambda_1} \left(\frac{1}{1-\lambda_2[M(t)-0.5]} \ell(t) \right)^{\lambda_3} - \lambda_4 I(t), \; 0<\lambda_1,\lambda_2,\lambda_3<1. \quad (3)$$

This equation suggests that learning and health increase human capital and that being in good (bad) mood improves (hinders) learning; in other words, the return on time allocated to learning increases (decreases) with good (bad) mood.

A loss of control can lead to an accident. Control is weakened by experiencing a bad mood. Poor health and environment can also lead to catastrophes. Consequently, equation (4) suggests that the severity of the catastrophes experienced at t increases with the deterioration of the individual's mood, state of health and environment:

$$z(t) = \frac{\psi_0 - \psi_1[M(t)-0.5]}{\psi_2 H(t) + \psi_3[E(t)/E_{\max}]} \quad (4)$$

where, ψ_1 is large for a moody person and, in particular, for a person with manic depression (bipolar disorder).

The hazard function suggests that the probability of dying at t ($\dot{P}(t)$), if the individual did not die by t ($1-P(t)$), increases with age and with the severity of the catastrophes experienced at t and decreases with the state of the individual's health at t:

$$\frac{\dot{P}(t)}{[1-P(t)]}=\frac{[1+z(t)]/(T-t)}{1+H(t)^{\varphi}}. \tag{5}$$

Active-time is lengthened by health. With the rest-time under perfect health ($H=1$) denoted by a scalar, $0<\sigma<1$, and with active time increasing linearly (for simplicity) in health, the individual's fraction of active-time at any instance t is:

$$a(t)=(1-\sigma)H(t). \tag{6}$$

Equation (7) suggests that the individual's material wealth increases at every instance t by the saving generated from the individual's return on material wealth and revenues from producing the dirty and clean goods, and depreciates at a rate that intensified by the deviation of the quality of the natural environment from the ideal one and by catastrophes:

$$\begin{aligned}\dot{K}(t)=&rK(t)+w_d(t)y_d(t)\\&+p_c\underbrace{[(1-\sigma)H(t)-\ell(t)-x(t)-n(t)-w_d(t)]}_{w_c(t)}y_c(t)\\&-c_d(t)-p_c(t)c_c(t)-\left(\frac{\delta}{1-[1-E(t)/E_{\max}]}+z(t)\right)K(t)\end{aligned} \tag{7}$$

where, $0<\delta<1$ is a fixed material wealth depreciation rate in the ideal natural environment.

Equations (8) and (9) suggest that the individual's potential productions of the dirty good and the clean good increase with her human capital, material capital and quality of the environment, and that being in good (bad) mood enhances (hinders) work-performance:

$$y_d(t)=\left(\frac{A_d}{1-\eta_0[M(t)-0.5]}\right)I(t)^{\eta_1}K(t)^{\eta_2}E(t)^{\eta_3} \tag{8}$$

$$y_c(t)=\left(\frac{A_c}{1-\eta_0[M(t)-0.5]}\right)I(t)^{\eta_4}K(t)^{\eta_5}E(t)^{\eta_6} \tag{9}$$

with $A_c<A_d$, $0<\eta_4<\eta_1<1$, $0<\eta_5<\eta_2<1$ and $0<\eta_6<\eta_3<1$ suggesting that it is easier to produce the dirty good than the clean good and with $0<\eta_0<2$ being larger for a moody person than for a calm person and with A_d and A_c being larger for diligent people than for less diligent ones.

Equation (10) suggests that the change in the individual's natural environment at any instance is given by the difference between the recovery of her natural environment, which is approximated by a logistic function, and the footstep imprinted by the individual's production and consumption and the aggregate footstep of the rest of the inhabitants ($\Delta(t)$), over which she has a negligible control:

$$\dot{E}(t) = \underbrace{\gamma_0 E(t)[1 - E(t)/E_{\max}]}_{\text{logistic natural environmental recovery}} - \underbrace{[\gamma_1 w(t) y_d(t) + \gamma_2 c_d(t)]}_{\text{own footstep}} - \Delta(t) \ . \tag{10}$$

Utility is generated from consuming the dirty good and clean good. With these goods assumed to be substitutes, the utility function is specified as:

$$u(t) = c_c(t)^{\xi} + \upsilon c_d(t)^{\xi} \tag{11}$$

with the regular assumption of $0 < \xi < 1$, and where $\upsilon = 1$ for an environmentally insensitive person and $0 \le \upsilon < 1$ for an environmentally sensitive one ($\upsilon = 0$ for a strict environmentalist).

Equation (12) suggests that people's mood deteriorates with the intensification of their loneliness and severity of catastrophes experienced. It further suggests that people's mood improves (deteriorates) with a positive (negative) changes in their level of exercising and utility derived from consumption and also with positive (negative) changes in their states of health, environment and prospects of survivability. Note that it is suggested that exercising has a direct improving effect on mood (Byrne and Byrne, 1993; Bartholomew, Morrison and Ciccolo, 2005) and indirect effect through its contribution to health. The rate of change of the individual's mood is taken to be a weighted average of the rates of change of the aforesaid flow and state variables:

$$\begin{aligned} \frac{\dot{M}(t)}{M(t)} = & -\beta_1[\dot{L}(t)/L(t)] - \beta_2[\dot{z}(t)/z(t)] + \beta_3[\dot{x}(t)/x(t)] \\ & + \beta_4[\dot{u}(t)/u(t)] + \beta_5[\dot{H}(t)/Ht)] + \beta_6[\dot{E}(t)/E(t)] \\ & - \beta_7\{\dot{P}(t)/[1 - P(t)]\} \end{aligned} \tag{12}$$

where, β_1 is larger for extroverts than for introverts, β_6 is larger for an environmentally concerned person than for a less concerned one, and

$$\dot{u}(t) = \kappa[c_c(t)^{\xi-1}\dot{c}_c(t) + \upsilon c_d(t)^{\xi-1}\dot{c}_d(t)]. \tag{13}$$

3. Mood, wellbeing and expected lifetime-happiness maximization

Utility maximisation is the criterion commonly used by economists for analysing rational choice. It has been suggested by Caputo and Levy (2012) and reiterated in this paper that the state of mood is a broader measure of personal wellbeing than the flow of utility. In addition

to being responsive to the individual's utility from consumption, the individual's mood is affected by the states of the individual's loneliness, health and environment and by the individual's prospects of survival. Furthermore, mood is more naturally linked to the theme of this paper — loneliness — than utility. Mood is also more in line with contemporary approaches to measuring wellbeing, such as the method used in the World Happiness Reports 2012-2017 (Helliwell, Layard and Sachs, 2017), than utility. Being a state variable and defined as the individual's background feeling, mood is an inter-temporarily more robust, and clinically more comprehensive, measure than utility for assessing the instantaneous changes in the individual's wellbeing. For all these reasons, the following sum of the discounted returns on mood is a more relevant and comprehensive lifetime measure of wellbeing than the commonly used Ramsey's (1928) sum of the discounted instantaneous utilities:

$$V(t) \equiv \int_0^t e^{-\rho t} \mu[M(t) - 0.5] d\tau \tag{14}$$

where, μ indicates a symmetric (for simplicity) rate of return on the individual's mood (in terms of happiness) and $\rho \geq 0$ the individual's rate of time preference (impatience).

Similar to Caputo and Levy (2012), rational people may choose the allocation of their health-dependent active-time to producing, learning, interacting and exercising and their consumption of clean good and dirty good to maximize the expected sum of the discounted instantaneous returns on their state of mood over their uncertain and dependent lifetime, subject to the motion equations of their loneliness, mood, health, human capital, material wealth, environment and survivability. The said expected sum of the discounted instantaneous returns on the state of the individual's mood is henceforth considered to be the individual's expected lifetime happiness. As the individual time of death is unknown *a-priori*, $V(t)$ is random. The expected lifetime happiness is:

$$\begin{aligned} E\left[V(t)\right] &\equiv \int_0^T \dot{P}(t) V(t) dt = \int_0^T \dot{P}(t) \left[\int_0^t e^{-\rho\tau} \mu[M(\tau) - 0.5] d\tau \right] dt \\ &= \int_\tau^T e^{-\rho(t-\tau)} \mu[M(t) - 0.5][1 - P(t)] dt \end{aligned} \tag{15}$$

and the rational decision problem is:

$$\max_{x(\cdot), n(\cdot), \ell(\cdot), w(\cdot), c_c(\cdot), c_d(\cdot)} \int_\tau^T e^{-\rho(t-\tau)} \mu[M(t) - 0.5][1 - P(t)] dt \tag{16}$$

subject to the state equations and production, accidents and utility functions (1) – (13).

4. Complexity, intuition, inclination and some concluding remarks

With six control variables and eight state variables the said optimal control problem is too complex for a derivation of the necessary and sufficient conditions for maximum expected lifetime happiness and for a subsequent analysis of the properties of the optimal trajectories of the control and state variables. Complexity might render choices to be made by intuition. Intuition might be affected by inclination and inclination by personality. In the context of the proposed model, people can be classified by different combinations of characteristics that

affect: i. the returns on the active-time allocated to interacting, learning, producing and exercising; ii. the returns on resources allocated to the production and consumption of the dirty good and clean good; and iii. the severity of accidents. These characteristics are anxiousness (large $\theta_1, \alpha_4, \alpha_6, \lambda_2, \eta_0, \psi_1$) vis-a-vis calmness (small $\theta_1, \alpha_4, \alpha_6, \lambda_2, \eta_0, \psi_1$), altruism (large θ_3) vis-a-vis egoism (small θ_3), extrovertedness (large θ_0 and β_1) vis-a-vis introvertedness (small θ_0 and β_1), high intelligence (λ_3 close to 1) vis-a-vis low intelligence (λ_3 close to 0), high work-efficiency (large A_d and A_c) vis-a-vis low work-efficiency (small A_d and A_c), large natural athletic capacity (α_1 close to 1) vis-a-vis small natural athletic capacity (α_1 close to 0), green orientation (large β_6 and small υ) vis-a-vis non-green orientation (small β_6 and large υ), youth (small τ) vis-a-vis advanced age (large τ), and patience (small ρ) vis-a-vis impatience (large ρ).

All other factors held constant, people endowed with characteristics less suitable for interacting — introverts — might be inclined to invest more time in learning, producing and/or exercising than people endowed with more suitable characteristics for interacting, extroverts. Nonetheless, introverts can gain appreciation and affection and enjoy lower degrees of isolation and loneliness by improving their environmental image — producing and consuming smaller than the average quantities of the dirty good. In agreement with the expressive behaviour theory (Hillman, 2011), even non-true-green people may do so, if loneliness has a strong negative effect on their mood.

The inclination to be trapped in an intensifying loneliness/bad-mood might increase with age and decrease with intrinsic intelligence, work efficiency, athletic capacity and green orientation. With these characteristics being equal, inherently anxious, immodest, extrovert egoists are, perhaps, the most likely to be trapped in an intensifying loneliness/bad-mood vicious cycle once a bad mood is experienced. In addition to strong negative returns on interacting and a strong feedback effect of the subsequent intensification of loneliness on their mood, the adverse effects of the bad mood on their returns on the three other possible activities (learning, exercising and producing), which could have directly and/or indirectly improve their mood, are amplified by their degree of anxiousness. Inherently anxious, immodest, extrovert egoists are, perhaps, some of the most likely people to commit a suicide. Conversely, inherently calm, modest, introvert altruists are the least likely to be trapped in an intensifying loneliness/bad-mood vicious cycle.

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