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Environmental Concern and Rational Production, Consumption and Rehabilitation

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Utility from consumption might be spoiled by the degradation of the environment. The incorporation of a direct dependency of utility on the state of the environment through environmental concern and the incorporation of the effects of production pollution and rehabilitative investment on the environment into a lifetime utility maximization model imply that a minimal degree of impatience is necessary for an interior steady state to exist. This steady state is unique, approachable along a path with damped oscillations of consumption and rehabilitative investment, and characterized by a larger production than in the steady state without environmental concern.

1. Introduction

Is the satisfaction of electricity consumers in China and India lessened by the adverse effect of their carbon-dioxide emitting power plants on the environment? Is the pleasure of Australians from the consumption facilitated by exporting coal to China and India diminished by this export's contribution to global warming? More generally, is the satisfaction from consumption adversely affected by the environmental damage caused by human activity? What are the implications of such an adverse effect for the optimal consumption, investment in rehabilitating the environment, capital stock and output?

The major environmental concern surveys - the Health of the Planet Survey (HOP), the World Values Survey (WVS) and the International Social Survey Program (ISSP) – agree that environmental concern has globally risen, but disagree on the association of environmental concern with affluence. Analyzing the responses in twenty-four countries to the HOP survey, Riley Dunlap, George Gallup and Alec Gallup (1993) have found that nine out of the fourteen items that measure environmental concern are negatively correlated with GNP per capita. This finding suggests that environmental concern is universal rather than confined to rich countries. Using the WVS, Ronald Inglehart (1995, 1997) has found strong support for environmental protection in rich countries and also in poor countries facing severe environmental problems. Consequently, he has argued that the rise in environmental concern in poor countries is due to severe problems of air and water pollution, whereas in rich country it is due to a post-materialism increased attention to non-economic values. Riley Dunlap and Angela Mertig (1997) have claimed that the negative correlation found in the HOP survey between environmental concern and GNP per capita implies that affluence is not a prerequisite for support for environmental protection. In contrast, the analyses of the responses to the ISSP surveys have not rejected the hypothesis of a positive relationship between environmental concern and affluence. In particular, Andreas Diekmann and Axel Franzen (1999) have found a high correlation between an index of priority for the environment and GNP per capita in the ISSP 1993 survey. Using both the ISSP 1993 and the ISSP 2003 surveys, Axel Franzen (2003) has also found that residents in wealthier nations express greater concern for the global condition of the environment, but the increase in real GDP per capita between 1993 and 2000 did not lead to a further increase in environmental concern.

In view of these empirical findings, the assumption underlying the theoretical analysis presented in this paper is that the representative agent of every society values the environment and has non negligible degree of concern about the adverse effect of his production pollution on the environment. Furthermore, based on the responses to the ISSP surveys, which include questions on willingness to pay and priority for environment versus the economy, the proposed analysis employs the assumption that the representative agent's concern about the environment directly affects his instantaneous utility from consumption. Namely, the representative agent's satisfaction from current consumption is spoiled by the degradation of the environment engendered by his production. Having some degree of environmental concern also implies that the representative agent is not myopic. Consequently, the theoretical analysis assumes that the representative agent's environmental concern also indirectly affects his instantaneous utility from consumption by diverting resources from current consumption to investment in rehabilitating the environment.

With these assumptions, the paper analyzes the effect of environmental concern on the interrelationship between consumption and investment in the environment for a rational representative agent within the conceptual framework of lifetime utility maximization. The analysis reveals that a minimal degree of impatience is necessary for an interior steady state to exist. In which case, the interior steady state is unique, asymptotically stable and approachable along a path displaying damped oscillations of consumption and investment in the environment. The analysis also reveals that the optimal stationary output of an environmentally concerned representative agent is larger than that of an environmentally unconcerned representative agent. The analysis leading to these conclusions is structured as follows.

Section 2 adds concern for the environment to the representative agent's instantaneous utility from consumption. The environmental concern augmented instantaneous utility function is used in Section 3 for expanding the prototype representative agent's lifetime-utility-maximization model attributed to Frank Ramsey (1928). As the value of the environment for an environmentally concerned agent is not negligible, the expansion also includes an environmental state equation, which describes the instantaneous improvement in the representative agent's environment as the difference between his instantaneous environmental investment and his instantaneous production pollution. The allocation of resources to investment in the environment is taken into account by the capital state equation. The existence and uniqueness of the steady state, the possibility of convergence to steady state, and the stationary output level are investigated in section 4.

2. Environmental concern and instantaneous utility

The assumption that the instantaneous utility of an environmentally concerned agent from consumption is spoiled by a degradation of the environment is formally represented as follows. Let $E_t \in \mathbb{R}$ indicate the quality of the environment and $c_t \in \mathbb{R}_+$ the agent's level of consumption at time *t*, then $(c_t, E) \succ (c_t, E_t - \Delta)\ \forall c_t$ for an environmentally concerned agent as long as $\Delta > 0$. An analytically convenient modification of the standard instantaneous utility function $u(c_t)$ for representing the agent's environmental concern is:

$$\tilde{u}_t = E_t{}^{\beta} u(c_t)\,,\ 0 \le \beta \le 1. \tag{1}$$

The agent's degree of concern about the state of the environment is reflected by β. The affluence hypothesis suggests that β increases with the agent's income. However, in view of the disagreement between the analyses of the HOP, WVS and ISSP surveys on the association between environmental concern and GNP per capita, β is henceforth assumed to be independent of the agent's income. For an environmentally unconcerned agent $\beta = 0$ (i.e., $\lim_{\beta \to 0} \partial\tilde{u} / \partial c = du / dc$), whereas for a fully concerned agent $\beta = 1$. It is unlikely that all the members of the society are environmentally unconcerned. Nor it is likely that they are all fully concerned. Hence, the representative agent is taken to be partially concerned. Namely, he is assumed to have $0 < \beta < 1$.

Partial concern can lead to diversion of some resources from current consumption and capital investment to investment in rehabilitating the environment. Having a continuous and twice differentiable instantaneous utility function with $u(0) = 0$, $u' > 0$ and $u'' < 0$, the representative agent is willing to forego a maximal fraction $\varepsilon = 1 - u^{-1}(((E_t - \Delta) / E_t)^{\beta} u(c_t)) / c_t$ of his current consumption for maintaining his current environment E_t than living in a degraded one $E_t - \Delta$.[1] For instance, with $u_t = c_t^{\gamma}$ and $0 < \gamma < 1$, $\varepsilon = 1 - ((E_t - \Delta) / E)^{\beta / \gamma}$. This fraction increases with the potential degradation of the environment and with ratio of the representative agent's degree of environmental concern to his elasticity of utility with respect to consumption.

3. Rational choice

The representative agent is assumed to be rational and, being environmentally concerned, non-myopic. As in the prototype lifetime utility maximizing model, he is infinitely lived, has a time consistent preferences reflecting a degree of impatience ($\rho > 0$), and has a lifetime utility *U*, which is measured by an additively separable function. In the present analysis, $U = \int_0^{\infty} e^{-\rho t} E(t)^{\beta} u(c(t)) dt$. In addition to production, consumption and investment in capital stock, the representative agent can invest in the environment (e.g., planting trees, recycling, and collecting and safely burying some of his carbon dioxide emissions). He chooses the joint trajectory of consumption and investment in his

[1] $\{E^{\beta} u((1-\varepsilon)c) = (E - \Delta)^{\beta} u(c)\} \Rightarrow \{(1-\varepsilon)c = u^{-1}((E - \Delta) / E)^{\beta} u(c))\}$.

environment that maximize $\int_0^{\infty} e^{-\rho t} E(t)^{\beta} u(c(t))dt$ subject to the motion equations of his capital stock and state of the environment.

For environmentally concerned agents, the shadow value of the environment is positive. The representative agent's environment is degraded by the pollution (damage, more generally) generated by his production process. The representative agent's environment is improved in a rate, *g*, which is concavely increasing in his investment (s) in rehabilitation. That is,

$$\dot{E}(t) = g(s(t))E(t) - wf(k(t)) \tag{2}$$

where f indicates (with $f' > 0$ and $f'' < 0$) the representative agent's instantaneous production and w is, for simplicity, a fixed production-polluting rate. The rate of environmental improvement is assumed to be diminishingly rising in *s*: $g' > 0, g'' < 0$ and, in the absence of better ideas, $g''' = 0$.

The representative agent's investment in environmental rehabilitation modifies the prototype motion equation of capital as follows:

$$\dot{k}(t) = f(k(t)) - c(t) - s(t) - (\delta + n)k(t) \tag{3}$$

where, as in the prototype model, δ is the capital depreciation rate, and n is the representative agent's regeneration rate.

The present value Hamiltonian associated with the partially environmentally concerned representative agent's optimal control problem (with the time index omitted for convenience) is:

$$H = e^{-\rho t} E^{\beta} u(c) + \lambda_1 [f(k) - c - s - (\delta + n)k] + \lambda_2 [g(s)E - wf(k)] \tag{4}$$

where $\lambda_1 > 0$ and $\lambda_2 > 0$ are the shadow prices of the partially environmentally concerned representative agent's stock of capital and quality of the environment, respectively. The Hamiltonian is concave in the control variables *c* and *s* and (recalling that $0 < \beta < 1$) in the state variable *E*. Since $\lambda_1 > -\lambda_2 w$, the Hamiltonian is also concave in *k*. Consequently, the Mangasarian's theorem on the sufficiency of the Pontryagin's maximum principle conditions is valid. These conditions include the adjoint equations:

$$\dot{\lambda}_1 = -\frac{\partial H}{\partial k} = -(\lambda_1 + \lambda_2 w) f'(k) + (\delta + n)\lambda_1 \tag{5}$$

$$\dot{\lambda}_2 = -\frac{\partial H}{\partial E} = -\beta e^{-\rho t} E^{\beta - 1} u(c) - \lambda_2 g(s) \tag{6}$$

the optimality conditions:

$$\frac{\partial H}{\partial c} = e^{-\rho t} E^{\beta} u'(c) - \lambda_1 = 0 \tag{6}$$

$$\{\frac{\partial H}{\partial s} = -\lambda_1 + \lambda_2 g'(s) E = 0\} \Rightarrow \{\lambda_2 = \lambda_1 / (g'(s)E)\} \tag{7}$$

and the transversality condition:

$$\lim_{t \to \infty} H(t) = 0\,. \tag{8}$$

The differentiation of the optimality conditions with respect to time and, subsequently, the substitution of the adjoint equations for $\dot{\lambda}_1$ and $\dot{\lambda}_2$, of the optimality conditions for λ_1 and λ_2, and of the right-hand side of the state-equation (2) for $\dot{E}$ lead to the following motion equations of the partially environmentally concerned representative agent's consumption and rehabilitative investment:

$$\dot{c} = \frac{[1 + w/(g'(s)E)] f'(k) - (\rho + \delta + n) + \beta[g(s) - wf(k)/E]}{-u''(c)/u'(c)} \tag{9}$$

$$\dot{s} = \frac{[1 + w/(g'(s)E)] f'(k) - (\delta + n) - \beta g'(s) u(c)/u'(c) - wf(k)/E}{-g''(s) g'(s)}\,. \tag{10}$$

(See the Appendix for a detailed derivation.)

4. Steady state: existence, uniqueness, convergence and output

Equations (9) and (10) are the golden rules for a society of partially environmentally concerned lifetime-utility maximizing agents. In addition to the discrepancy between the marginal product of capital and the user cost of capital, the advocated instantaneous changes in consumption and rehabilitative investment are affected by the full price of the society's product $[1 + w/(g'(s)E)]$ (a numéraire representing the output's market price plus the ratio of the environmental damage rate to the rehabilitation rate), the society's degree of concern about the environment (β), and the rate of change of its environment $[g(s) - wf(k)/E]$. The investigation of this set of golden rules leads to the following propositions about the existence and uniqueness of the steady state of consumption and investment in the environment, about the possibility of convergence to this steady state, and about the steady-state output level.

PROPOSITION 1 (Existence and uniqueness): If, and only if, $\rho > (1-\beta)wf(k_{ss})/E_{ss} + \beta g(\bar{s})$, there exists a unique, interior steady-state combination of consumption and rehabilitative investment (with $s_{ss} = \bar{s}$) for a partially environmentally concerned society. (See the Appendix for proof.)

PROPOSITION 2 (Convergence): From any initial point there is a convergence to the interior steady state of a partially environmentally concerned society along a clockwise spiral of consumption and investment in the environment. (See the Appendix for proof.)

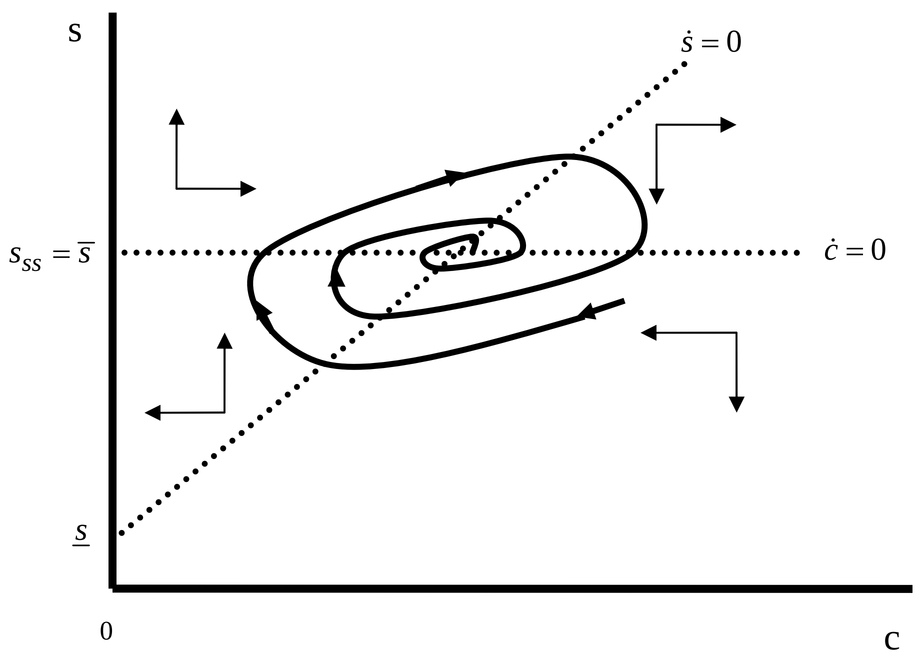

Figure 1. Damped oscillations of consumption and rehabilitative investment

PROPOSITION 3 (Stationary production): The optimal stationary output of a partially environmentally concerned society is larger than that of an environmentally unconcerned society with identical rates of time preference, regeneration and capital depreciation and identical production process.

The underlying rationale for proposition 3 is as follows. In steady state, the value of the marginal product of capital is equal to the user cost of capital for a partially environmentally concerned society as well as for an environmentally unconcerned society. While both have the same user cost of capital $(\rho+\delta+n)$ and the same production process (f), they have different assessments of the full price of their identical products. For the environmentally unconcerned society, the full price of the product is equal to a market price (a numéraire), which does not internalize the environmental damage. For a partially environmentally concerned society, the full price of the product also includes the ratio of the pollution generated by its production (w) to the environmental improvement ($g'(s_{ss})E_{ss}$) that can be generated by its investment in rehabilitating the environment. Due to its higher assessment of the product's full price, *ceteris paribus*, the stationary capital stock and production of the partially environmentally concerned society are larger than that of an environmentally unconcerned society.

5. Conclusion

Partial environmental concern, manifested in this paper by $0<\beta<1$ and positive shadow value of the quality of the environment ($\lambda_2>0$), directly affects utility by spoiling satisfaction from consumption and also indirectly by diverting resources from consumption and investment in production capacity to investment in rehabilitating the environment. As displayed by the phase-plane diagram, the joint transition of consumption and investment in the environment for a society of partially environmentally concerned lifetime-utility maximizers is along a clockwise converging spiral where a period of rising consumption and rehabilitative investment is followed by a period of rising consumption and decreasing rehabilitative investment, a period of decreasing consumption and rehabilitative investment, a period of decreasing consumption and rising rehabilitative investment, and so on. However, the existence of an interior steady state depends on the society's rate of time preference being larger than a critical level, $[(1-\beta)wf(k_{SS})/E_{SS}+\beta g(\bar{s})]$, which can be interpreted as the society's lack of full concern $(1-\beta)$ about the proportion of the environment damage $(wf(k_{SS})/E_{SS})$ engendered by its production plus the instantaneous rate of improvement of the environment $(g(\bar{s}))$ weighted by the society's degree of environmental concern (β). Due to its higher evaluation of its product's full price, *ceteris paribus*, the stationary production of the partially environmentally concerned society is larger than that of an environmentally unconcerned, but otherwise identical, society. Despite its larger production, the stationary environment of the partially concerned society is better than that of an environmentally unconcerned society due to investing in rehabilitation.

The analysis has focused on the utility aspects of environmental concern. Extensions of the model may include possible adverse effects of environmental degradation on production inputs and, in turn, on production. In particular, labor health and, consequently, labor productivity can be adversely affected by pollution, and land productivity can be reduced by acid rain, dust storm, floods, fire, winds and extreme temperatures.

APPENDIX

Derivation of the golden rules (9) and (10)

By differentiating the optimality condition (6) with respect to t the following singular control equation is obtained:

$$e^{-\rho t}\beta E^{\beta-1}u'(c)\dot{E}-\rho e^{-\rho t}E^{\beta}u'(c)+e^{-\rho t}E^{\beta}u''(c)\dot{c}-\dot{\lambda}_1=0 \tag{A1}$$

and in recalling equations (4) and (7):

$$\begin{aligned}&e^{-\rho t}\beta E^{\beta-1}u'(c)\dot{E}-\rho e^{-\rho t}E^{\beta}u'(c)+e^{-\rho t}E^{\beta}u''(c)\dot{c}\\&+\lambda_1\{1+w/g'(s)E\}f'(k)-(\delta+n)\lambda_1=0\end{aligned} \tag{A2}$$

Recalling (6):

$$\begin{aligned}&e^{-\rho t}\beta E^{\beta-1}u'(c)\dot{E}-\rho e^{-\rho t}E^{\beta}u'(c)+e^{-\rho t}E^{\beta}u''(c)\dot{c}\\&+e^{-\rho t}E^{\beta}u'(c)\{[1+w/g'(s)E]f'(k)-(\delta+n)\}=0\end{aligned} \tag{A3}$$

Dividing by $e^{-\rho t}E^{\beta}u'(c)$:

$$\beta E^{-1}\dot{E}-(\rho+\delta+n)+[u''(c)/u'(c)]\dot{c}+[1+w/g'(s)E]f'(k)=0\,. \tag{A4}$$

Hence,

$$\dot{c}=\frac{[1+w/g'(s)E]f'(k)-(\rho+\delta+n)+\beta\dot{E}/E}{-u''(c)/u'(c)}\,. \tag{A5}$$

By differentiating the optimality condition (7) with respect to t the following singular control equation is obtained:

$$-\dot{\lambda}_1+\dot{\lambda}_2g'(s)E+\lambda_2g'(s)\dot{E}+\lambda_2Eg''(s)\dot{s}=0\,. \tag{A6}$$

Recalling (4) and (5):

$$\begin{aligned}&(\lambda_1/\lambda_2+w)f'(k)-(\delta+n)\lambda_1/\lambda_2\\&-[\beta e^{-\rho t}E^{\beta-1}u(c)/\lambda_2+g(s)]g'(s)E+g'(s)\dot{E}+Eg''(s)\dot{s}=0\end{aligned} \tag{A7}$$

By (7) and (6):

$$\lambda_2=e^{-\rho t}E^{\beta}u'(c)/g'(s)E \tag{A8}$$

and

$$\lambda_1/\lambda_2=g'(s)E\,. \tag{A9}$$

Hence,

$$\begin{aligned}&[g'(s)E+w]f'(k)-(\delta+n)g'(s)E\\&-\{\beta g'(s)u(c)/u'(c)+g(s)\}g'(s)E+g'(s)\dot{E}+Eg''(s)\dot{s}=0\end{aligned} \tag{A10}$$

Dividing both sides by $g'(s)E$:

$$[1+w/g'(s)E]f'(k)-(\delta+n) \\ -\{\beta g'(s)u(c)/u'(c)+g(s)\}+\dot{E}/E+g''(s)g'(s)\dot{s}=0 \tag{A11}$$

Hence,

$$\dot{s}=\frac{[1+w/g'(s)E]f'(k)-(\delta+n)-\beta g'(s)u(c)/u'(c)-g(s)+\dot{E}/E}{-g''(s)g'(s)}. \tag{A12}$$

From (2),

$$\dot{E}/E=g(s)-wf(k)/E \tag{A13}$$

and hence:

$$\dot{c}=\frac{[1+w/g'(s)E]f'(k)-(\rho+\delta+n)+\beta[g(s)-wf(k)/E]}{-u''(c)/u'(c)} \tag{A14}$$

$$\dot{s}=\frac{[1+w/g'(s)E]f'(k)-(\delta+n)-\beta g'(s)u(c)/u'(c)-wf(k)/E}{-g''(s)g'(s)}. \tag{A15}$$

Proof of Proposition 1

From (9), the isocline $\dot{c}=0$ is given by:

$$[1+w/g'(s)E]f'(k)-(\rho+\delta+n)+\beta[g(s)-wf(k)/E]=0. \tag{A16}$$

This isocline is represented by a horizontal line in the *c*-*s* plane.

From (10), the isocline $\dot{s}=0$ is given by:

$$[1+w/g'(s)E]f'(k)-(\delta+n)-\beta g'(s)u(c)/u'(c)-wf(k)/E=0. \tag{A17}$$

By total differentiation:

$$-[wf'(k)/g'(s)^2E+\beta u(c)/u'(c)]g''(s)ds-\beta g'(s)[1-u(c)u''(c)/u'(c)]dc=0 \tag{A18}$$

and hence:

$$\left.\frac{ds}{dc}\right|_{\dot{s}=0}=-\frac{\beta g'(s)[1-u(c)u''(c)/u'(c)]}{[wf'(k)/g'(s)^2E+\beta u(c)/u'(c)]g''(s)}>0. \tag{A19}$$

Recalling that $u(c)/u'(c)=0$ for $c=0$ and (A17), the intercept $(0,\underline{s})$ of the isocline $\dot{s}=0$ should satisfy:

$$[1+w/g'(\underline{s})E]f'(k)-(\delta+n)-wf(k)/E=0 \tag{A20}$$

which implies:

$$g'(\underline{s}) = \frac{wf'(k)/E}{(\delta+n)+wf(k)/E-f'(k)}. \tag{A21}$$

From (A16), the intercept $(0,\overline{s})$ of the isocline $\dot{c}=0$ should satisfy:

$$[1+w/g'(\overline{s})E]f'(k)-(\rho+\delta+n)+\beta[g(\overline{s})-wf(k)/E]=0 \tag{A22}$$

which implies:

$$g'(\overline{s}) = \frac{wf'(k)/E}{(\rho+\delta+n)+\beta wf(k)/E-\beta g(\overline{s})-f'(k)}. \tag{A23}$$

Recalling the assumptions that $f'(k)>0$ and $g'(s)>0$, the denominators on the right-hand sides of (A21) and (A23) are positive. Recalling further that $g''(s)<0$, $\underline{s}<\overline{s}$ for any given combination of *k* and *E*, consequently for the relevant one (k_{SS}, E_{SS}), if:

$$(\delta+n)+wf(k_{SS})/E_{SS}-f'(k_{SS})<(\rho+\delta+n)+\beta wf(k_{SS})/E_{SS}-\beta g(\overline{s})-f'(k_{SS}) \tag{A24}$$

or, equivalently, if:

$$\rho>(1-\beta)wf(k_{SS})/E_{SS}+\beta g(\overline{s}). \tag{A25}$$

Recalling that the isocline $\dot{c}=0$ is horizontal whereas the isocline $\dot{s}=0$ is upward sloped, if the inequality (A25) holds, the intercept of the isocline $\dot{s}=0$ is smaller than that of the isocline $\dot{c}=0$ and hence these isoclines intersect one another and do so only once. Their intersection defines a unique, interior steady state with $s_{SS}=\overline{s}$.

Proof of Proposition 2

By differentiating (9):

$$\frac{d\dot{c}}{ds} = \frac{-wf'(k)g''(s)/g'(s)^2E+\beta g'(s)}{-u''(c)/u'(c)}>0 \tag{A26}$$

which explains the direction of the horizontal arrows in the four phases in Figure 1.

By differentiating (10):

$$\frac{d\dot{s}}{dc} = \frac{-\beta g'(s)[1-u(c)u''(c)/u'(c)]}{-g''(s)g'(s)}<0 \tag{A27}$$

which explains the direction of the vertical arrows in the four phases displayed in Figure 1. The combinations of the horizontal and vertical arrows reveal that the steady state is either a spiral point or a centre. The particular nature of the steady state can be found by computing the trace of the Jacobian (state-transition) matrix of the linearized (9) and (10) equation system at the steady state. The elements on the main diagonal of this matrix are:

$$J_{11} = \frac{dA}{dc}(ss) = \{1 + w / g'(s_{ss})] f'(k_{ss}) - (\rho + \delta + n)\} \frac{-u''(c_{ss})^2 + u'''(c_{ss}) u'(c_{ss})}{[-u''(c_{ss})]^2} \qquad \text{(A28)}$$

$$J_{22} = \frac{dB}{ds} = \{1 + w / g'(s_{ss})] f'(k_{ss}) - (\delta + n)\} \frac{-g''(s_{ss})^2 + g'''(s_{ss}) g'(s_{ss})}{[-g''(s_{ss})]^2} . \qquad \text{(A29)}$$

Recalling (A5),

$$[1 + w / g'(s_{ss})\} f'(k_{ss}) - (\rho + \delta + n) = 0 \qquad \text{(A30)}$$

and hence $J_{11} = 0$.

From (A30),

$$[1 + w / g'(s_{ss})\} f'(k_{ss}) - (\delta + n) = \rho > 0 \qquad \text{(A31)}$$

which implies that $J_{22} = -\rho$ as long as $g''' = 0$. Since $trJ = -\rho$ and $\rho > 0$ for an agent with a time preference, the joint trajectory of c and s is a converging spiral. The interior steady state is asymptotically stable and approachable along a clockwise spiral displaying oscillations of consumption and investment in the environment.

Proof of Proposition 3

In view of equation (2):

$$g(s_{ss}) - wf(k_{ss}) / E_{ss} = 0 \qquad \text{(A32)}$$

which in conjunction with equation (9) implies that the value of the stationary marginal product of capital is equal to the user cost of capital:

$$[1 + w / (g'(s_{ss}) E_{ss})] f'(k_{ss}) = (\rho + \delta + n) . \qquad \text{(A33)}$$

Consequently, the stationary marginal product of the partially environmentally concerned representative agent is given by:

$$f'(k_{ss}) = \{(\rho + \delta + n) / [1 + w / g'(s_{ss}) E_{ss}]\} . \qquad \text{(A34)}$$

Since $1 + w / g'(s_{ss}) E_{ss} > 1$, $f'(k_{ss}) < (\rho + \delta + n)$.

In the case of environmentally unconcerned agents, $\beta = 0$ and also $\lambda_2 = 0$ (i.e., the shadow value of the environment is negligible). Consequently, the stationary marginal product of a lifetime utility maximizing environmentally unconcerned representative agent is given (as in the prototype Ramsey model) by:

$$f'(\tilde{k}_{ss}) = (\rho + \delta + n). \tag{A35}$$

Since $1 + w / g'(s_{ss}) E_{ss} > 1$, $\{(\rho + \delta + n) / [1 + w / g'(s_{ss}) E_{ss}]\} < (\rho + \delta + n)$. Therefore, $f'(k_{ss}) < f'(\tilde{k}_{ss})$. Recalling that $f'' < 0$, $k_{ss} > \tilde{k}_{ss}$ and hence $f(k_{ss}) > f'(\tilde{k}_{ss})$.

References

Diekmann, Andreas, and Axel Franzen (1999), “The Wealth of Nations and Environmental Concern”, *Environment and Behavior* 31: 540– 49.

Dunlap, Riley E., George H. Gallup, and Alec M. Gallup (1993), “Of Global Concern: Results of the Health of the Planet Survey”, *Environment* 35(7– 15): 33–39.

Dunlap, Riley E., and Angela G. Mertig (1997), “Global Environmental Concern: An Anomaly for Postmaterialism”, *Social Science Quarterly* 78: 24– 29.

Franzen, Axel (2003), “Environmental Attitudes in International Comparison: An Analysis of the ISSP Surveys 1993 and 2000”, *Social Science Quarterly* 84(2): 297-308.

Inglehart, Ronald (1995), “Public Support for the Environmental Protection: Objective Problems and Subjective Values in 43 Societies”, *PS: Political Science & Politics* 28: 57– 72.

Inglehart, Ronald (1997), *Modernization and Postmodernization: Cultural, Economic, and Political Change in 43 Societies*. Princeton, N.J.: Princeton University Press.

Ramsey, Frank (1928), “A mathematical theory of saving”, *Economic Journal* 38: 543-559.