Green lifestyles and social tipping points

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Overview

A model of consumption behaviour with environmental damage, driven by *descriptive social norms* and *personal norms*.

- social interactions, building on Brock - Durlauf (2001 REStud, 2003 AER);
- discrete choice in a dynamic setting, like Brock-Hommes (1997 Etca, 1998 JEDC).
- warm-glow, or psychological well-being: see Andreoni (1989 JPE, 1995 QJE);
- insights from social psychology (*GLAMURS* EU FP7: Green Lifestyles, Alternative Models and Upscaling Regional Sustainability);

The model

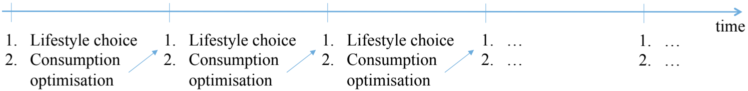
- A large population of consumers;
- a consumption good that causes environmental damage;
- two alternative lifestyles, **green** and **brown**:
  - *green* behaviour *internalises one's consumption damage*,
  - *brown* behaviour *internalises less - or nothing.*
- random utility ⇒ discrete choice distribution;
- repeated choices and switching behaviour.
- bifurcations give *social tipping points*

Lifestyle as a behavioural choice

At each time t there is a *two stages* individual decision:

(1) **discrete choice**: individuals choose a *green* lifestyle, fraction x, or a *brown* lifestyle, fraction $1-x$;

(2) **consumption optimisation**: for each behavioural choice (*green* and *brown*) individuals optimise the demand level.



Utility

Agents $i = 1, \ldots, n$ utility is

$$W_i = U_i - pq_i - D_i + G_i + I_i.$$

Basic model version:

$$U_i(q_i) = vq_i - \frac{\eta q_i^2}{2},$$

$$D(Q) = \delta \sum_{i=1}^{n} q_i = \delta Q.$$

$$G_i = \begin{cases} \gamma & \text{if green} \\ 0 & \text{if brown} \end{cases}$$

$$I_i = \begin{cases} \rho x & \text{if green} \\ \rho(1-x) & \text{if brown.} \end{cases}$$

Stage 2: individual demand

First order condition for individual i

$$U_i'(q_i) - p(x) - \delta_i = 0$$

Greens internalise more, with $\delta_g > \delta_b$:

$$q_b^*(x) = \frac{v - \delta_b - p(x)}{\eta} \quad \text{and} \quad q_g^*(x) = \frac{v - \delta_g - p(x)}{\eta},$$

Total demand is

$$\begin{aligned} Q^*(p,x) &= n\Big[x q_g(x) + (1-x) q_b\Big] \\ &= \frac{n}{\eta}\left[v - p(x) - \delta_b - (\delta_g - \delta_b)x\right]. \end{aligned}$$

With supply $S(p) = sp$, $s > 0$, we get an equilibrium price

$$p^*(x) = \frac{v - \delta_b - (\delta_g - \delta_b)x}{1 + \eta\frac{s}{n}}.$$

Behaviours and consumption

If more individuals adopt a green lifestyle, $x \uparrow$, we have

$$p \downarrow, \quad Q \downarrow, \quad q_i \uparrow$$

But what drives the dynamics of x, that is lifestyles adoption?

Stage 1: discrete choice

Random utility $W(\omega_i, \mathbf{Z}_i) + \epsilon_i(\omega_i)$, choice $\omega_i = 1, 0$ for *green*, *brown*, deterministic factors $\mathbf{Z}_i$, and random shocks $\epsilon_i(\omega_i)$. Stage 1 decision is

$$\max_{\omega_i \in \{0,1\}} W(\omega_i, \mathbf{Z}_i) + \epsilon_i(\omega_i).$$

If the difference $\epsilon_i(1) - \epsilon_i(0)$ is *logit* distributed (McFadden 1981, Brock and Durlauf 2001) the fraction x of *green* choices $\omega_i = 1$ is:

$$x(x') = Pr(\omega_i = 1; x') = \frac{e^{\beta W_g(x')}}{e^{\beta W_g(x')} + e^{\beta W_b(x')}} = \frac{1}{1 + e^{\beta \Delta W(x')}} \quad (1)$$

$\Delta W = W_b - W_g$ the difference of *brown* and *green* deterministic utility, $\beta \in [0, \infty)$ is the *intensity of choice*, an inverse measure of ϵ variance.

- $\beta \to \infty$ (rational limit): $x = 0$ (all *brown*), $x = 1$ (all *green*) are equilibria;
- $\beta \to 0$ (infinite noise variance): decisions split equally, $x = \frac{1}{2}$.

Evolutionary dynamics of behaviours

The equilibrium value x is a *fixed point*, $x(\hat{x}) = \hat{x}$, which corresponds to *consistency of beliefs.*

We assume individuals evaluate utility using the previous realised value of the fraction of behaviours, $\hat{x} = x_{t-1}$, a frequently made assumption (Hommes, 2006).

The probability distribution of discrete choice becomes

$$x_t = \frac{1}{1 + e^{\beta \Delta W(x_{t-1})}} \equiv f(x_{t-1}), \tag{2}$$

and f is a revision protocol of behaviours.

Comparing lifestyles

The discrete choice utility is

$$W_i = \begin{cases} W_b = U(q_b^*) - p^*(x)q_b^*(x) - \delta Q^*(x) + \rho(1-x) \\ W_g = U(q_g^*) - p^*(x)q_g^*(x) - \delta Q^*(x) + \gamma + \rho x. \end{cases}$$

Hence, after substituting the equilibrium price $p^*(x)$

$$\Delta W(x) = \lambda + \rho(1-2x), \tag{3}$$

with $\lambda = \zeta - \gamma$ measuring relative attractiveness of lifestyles, net of warm-glow γ, and $\zeta = \frac{\delta_g^2 - \delta_b^2}{2\eta} > 0$. We notice that $\frac{\partial \Delta W(x)}{\partial x} < 0$.

Examples of choice distribution

A simple 1-dim. dynamical system with possible tipping points

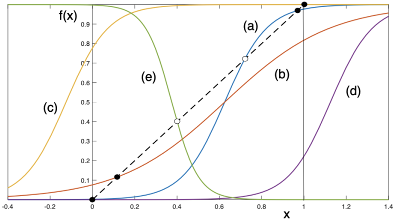


Figure: Examples of distribution $f(x)$. Dots on the 45^o-line are equilibria, stable (black dot), or unstable (empty dot). Cases: a) Increasing f with two stable equilibria and one unstable equilibrium. b) Increasing f with $f' < 1$ everywhere and one stable equilibrium. c) and d) Increasing f with a flex point $x^F \notin [0,1]$ and one stable equilibrium. e) Decreasing f with one equilibrium, which is not stable because $f'(x^*) < -1$ at the equilibrium x^*.

Some results

Part I: Let $f(x)$ be upward sloping $\Rightarrow$ *positive feedback* of choices:

(i) There always exists at least one stable equilibrium.

(ii) Sufficient conditions for a unique stable equilibrium are either $|\Delta W'(x)| \leq 4/\beta \ \forall x \in [0,1]$ or flex point $x^F \notin [0,1]$.

(iii) If there is a fixed point $x^* \in [0,1]$ s.t. $f'(x^*) > 1$, then x^* is not stable, but there exist two stable equilibria, a brown equilibrium with $x^* = x_b^* < 1/2$ and green equilibrium with $x^* = x_g^* > 1/2$.

Part II: (smooth) effects from change in parameters on equilibrium x^*,

(iv) $\beta \uparrow$ or $\rho \uparrow \Rightarrow$ reduce green choices x^* if $x^* < \frac{1}{2}$ and increase x^* if $x^* > \frac{1}{2}$, i.e. equilibria are reinforced.

(v) increasing $\zeta = \frac{\delta_g^2 - \delta_b^2}{2\eta} \Rightarrow$ always reduce green choices x^*.

But *critical* values exist where effects are not smooth...

Social tipping points

Consider the model above, and let $\mathbf{k}$ *be a vector of parameters. For a stable equilibrium of the model* x^**, a set of parameters values* $\mathbf{k} = \mathbf{k}_b$ *can always be found such that*

$$\left| \lim_{\mathbf{k} \to \mathbf{k}_b} \frac{\partial x^*}{\partial \mathbf{k}} (x; \mathbf{k}) \right| = \infty. \tag{4}$$

It is always possible to find a parameter configuration where a tangent bifurcation at $f'(x^*) = 1$ *occurs. This entails a transition from two stable equilibria to one stable equilibrium.*

We call $(x^*; \mathbf{k}_b)$ *a* ***social tipping point*** *of this population.*

Social tipping points, graphically

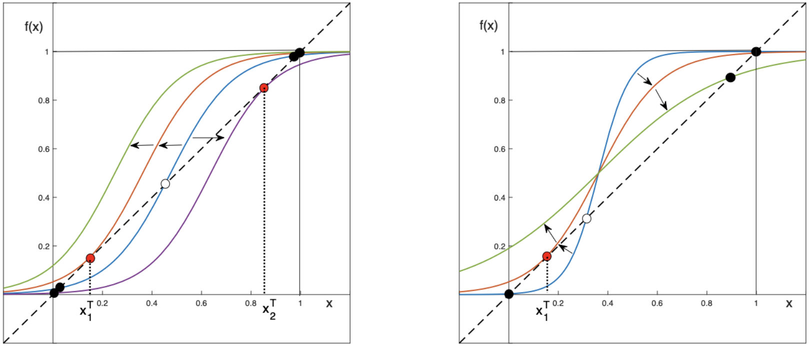


Figure: Illustration of tipping points from two tangent bifurcations. In the left panel tipping points (x_1^T and x_2^T) originate from a shift of the map f. In the right panel a tipping point (x_1^T) is from a decreasing parameter β.

Instances of social tipping points

If critical (bifurcation) values are reached, the equilibrium fraction x^* of choices changes abruptly

- if $\lambda = \frac{\delta_g^2 - \delta_b^2}{2\eta} - \gamma$ is lowered (e.g. warm-glow $\gamma \uparrow$, or $\delta_b \uparrow$) the 'brown' equilibrium $x_1^* < \frac{1}{2}$ may disappear;
- if λ is increased (e.g. with δ_g increasing) the green equilibrium $x_2^* > \frac{1}{2}$ may disappear;
- if β or ρ are lowered, either equilibrium may disappear, which one depending on λ.

The effect of relative attractiveness λ

For an equilibrium $x = x^*$

$$\frac{\partial x}{\partial \lambda} = \frac{\beta x(1-x)}{2\rho\beta x(1-x) - 1}$$

which indicates the following **social tipping points**

$$x_1^T = \frac{1 - \sqrt{1 - \frac{2}{\rho\beta}}}{2}, \quad x_2^T = \frac{1 + \sqrt{1 - \frac{2}{\rho\beta}}}{2},$$

and λ's critical (tangent bifurcation) values.

$$\lambda_1^T = \frac{1}{\beta} \ln \left(\frac{1 + \sqrt{1 - \frac{2}{\rho\beta}}}{1 - \sqrt{1 - \frac{2}{\rho\beta}}} \right) - \rho \sqrt{1 - \frac{2}{\rho\beta}}$$

$$\lambda_2^T = \frac{1}{\beta} \ln \left(\frac{1 - \sqrt{1 - \frac{2}{\rho\beta}}}{1 + \sqrt{1 - \frac{2}{\rho\beta}}} \right) + \rho \sqrt{1 - \frac{2}{\rho\beta}} = -\lambda_1^T,$$

The effect of behavioural parameters β and ρ

We study other parameters in a similar way. In particular, the effect of β on an equilibrium value $x^* = f(x^*)$ is expressed by

$$\frac{\partial x^*}{\partial \beta} = \frac{x(1-x)\Delta W}{2\rho\beta x(1-x)-1} = \frac{\Delta W}{\beta}\frac{\partial x^*}{\partial \lambda}, \tag{5}$$

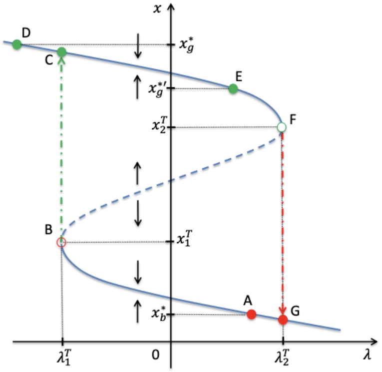
while the effect of ρ is expressed by

$$\frac{\partial x^*}{\partial \rho} = \frac{\beta x(1-x)(1-2x)}{2\rho\beta x(1-x)-1} = (1-2x^*)\frac{\partial x^*}{\partial \lambda}. \tag{6}$$

Effects of β and ρ are explained with effects from λ. However, β and ρ are difficult to alter, while λ is more of a policy channel.

Saddle-node bifurcations as social tipping points

Long run equilibria of the fraction of green choices x for different values of the parameter λ in a scenario with multiple equilibria



Arrows are field lines of the basins of attraction for x. Bifurcation values λ_1^T and λ_2^T are reported, as well as tipping points x_1^T and x_2^T.

Counterintuitive effects on consumption

Increasing warm glow γ, social interactions ρ and rationality β have opposed effects on total consumption Q and individual consumption q_g, q_b in equilibrium.

- warm glow γ: always $\frac{\partial Q}{\partial \gamma} < 0$ and $\frac{\partial q_i}{\partial \gamma} > 0$, with $i = b, g$;
- rationality β, and social interactions ρ: for $\phi = \beta, \rho$:
  $\frac{\partial Q}{\partial \phi} > 0$ while $\frac{\partial q_i}{\partial \phi} < 0$ in a brown equilibrium ($x_1^* < 1/2$),
  $\frac{\partial Q}{\partial \phi} < 0$ while $\frac{\partial q_i}{\partial \phi} > 0$ in a green equilibrium ($x_2^* > 1/2$).

How is possible that consumption f.i. increase at individual level, and decrease at aggregate level? It is thanks to a shift in behaviours, a flow of choices from brown to green!

State-dependent warm-glow (1)

Warm-glow dependent on relative consumption:

$$W_i = \begin{cases} W_g = U(q_g) - pq_g - \delta Q + G + \rho x & \text{if } \textit{green} \\ W_b = U(q_b) - pq_b - \delta Q + \rho(1-x) & \text{if } \textit{brown.} \end{cases}$$

$$G = -\gamma(q_g - \langle q \rangle) = \gamma(1-x)(q_b - q_g).$$

A *composition* effect, $1-x$, and a *scale* effect, $q_b - q_g$:

Stage 2 f.o.c. now gives the demand levels

$$q_b(x) = \frac{v - \delta_b - p(x)}{\eta} \quad \text{and} \quad q_g(x) = \frac{v - \delta_g - p(x) - \gamma}{\eta}.$$

It is like greens internalise consumption damage more, by the quantity γ, for the warm-glow derived from doing 'better' than others.

State-dependent warm-glow (2)

The discrete choice of stage 1 is now:

$$\Delta W \equiv W_b - W_g = \zeta' + \rho(1-2x) - \gamma(1-x)\frac{\delta_g + \gamma - \delta_b}{\eta},$$

where $\zeta' = \zeta + \frac{\gamma(2\delta_g+\gamma)}{2\eta}$ and $\zeta = \frac{\delta_g^2 - \delta_b^2}{2\eta}$.

Now there is a *critical level of the intensity of social interactions*

$$\overline{\rho} = \gamma\frac{\delta_g + \gamma - \delta_b}{2\eta}$$

such that choices show a *positive feedback* for $\rho > \overline{\rho}$, and a *negative feedback* for $\rho < \overline{\rho}$, with possible *periodic dynamics*.

Dynamics and equilibria

There are different regimes dictates by social interactions:

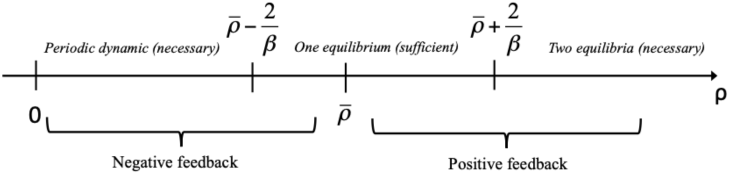


Figure: Different dynamics scenarios for the endogenous warm-glow model.

If social influence is very weak choices change in stable periodic orbits: if it is moderate, they converge to a unique equilibrium; if it is strong, they converge to a green or to a brown equilibrium.

Time series simulations

Examples in three different scenarios:

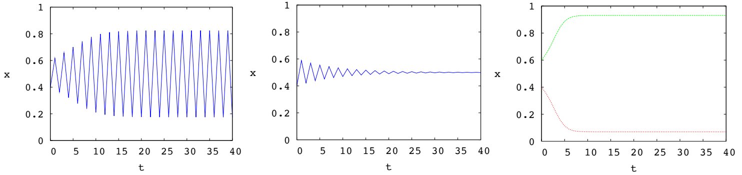


Figure: Simulated share of green choices x_t. Left: $\rho = 1.2$ periodic dynamics. Centre: $\rho = 1.4$ unique equilibrium. Right: $\rho = 3$, two equilibria selected by $x_0 = 0.4$ (brown) and $x_0 = 0.6$ (green). Here $\beta = 3$, $\delta_g = 2$, $\delta_b = 0.1$, $\gamma = 2.1$, $\eta = s = 1$, $N = 1000$, $v = 2$

A tipping point from increasing warm-glow

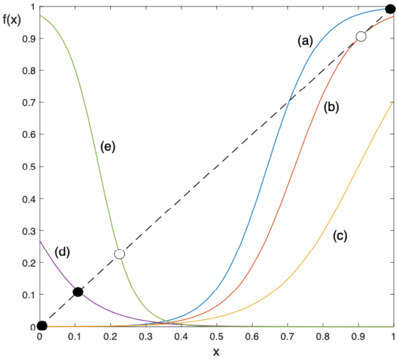


Figure: Examples of map $f(x)$ for different intensity of endogenous warm-glow. (a) $\gamma = 0$, (b) $\gamma = 0.68$, (c) $\gamma = 1.5$, (d) $\gamma = 4$, (e) $\gamma = 5$. The dots on the 45^o-line indicate stable (filled dot) and unstable (circled dot) equilibria. Case (b) is a tangent bifurcation that represents a social tipping point. Other parameters are $\beta = 1$, $\rho = 7$, $\delta_g = 2$, $\delta_b = 0$, $\eta = 1$.

Conclusions

- Any tipping point can be implemented, virtually, including 'desirable' ones leading to a jump in green choices;
- we can see such 'green' tipping points literally as *sustainability* ***phase*** *transitions*;
- behavioural dimensions such as β, ρ, γ may be difficult to control, but others like perceived damage δ's could be seen as policy channels