Radical Climate Policies

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- Energy transition – an example of a switch from one equilibrium to another.
- Policy change designed to bring 'marginal' changes to an equilibrium may not be sufficient for this shift
- How should we think about this? What should policy look like?
- Literature: Nyborg et al., Smulders and Zhou, an der Meijden and Smulders, Besley and Persson, ...
- This paper:
    - Set out simple model to address these questions
    - Ingredients not new – objective is to get people thinking in non-marginal terms and about moving from a "bad" to a "good" equilibrium rather than getting a "bad" outcome a bit cleaner:
        - In particular: setting carbon tax = social cost of carbon may not be optimal or sufficient to bring about required change
- Leverage positive feedback effects/strategic complementarities, temporary "big push" versus need to do less due to positive feedback effect and network effects

Model ingredients and plan of the talk

- Multiple equilibria arise because of complementarities – such as positive reciprocal externalities:
    - Peer effects: - imitation, social norms
    - Network effects: - installation of infrastructure
    - Learning/ knowledge spillovers: - increasing returns not internalized in firms
    - Clustering and agglomeration
    - Thick market effects
- Talk largely based on peer effects:
    - Basic static model
        - Policy: Amplification effects/ Pigouvian taxes/ switching effects.
    - Dynamic model:
        - Switching as an investment
        - History vs expectations.

A static model:

One activity – e.g. 'motoring' – can be done with good x (clean, EV) or good y (dirty, ICE vehicle).

Household CES preferences: elasticity of substitution, σ; Elasticity of demand for 'motoring' ϵ

Prices, p_x and p_y, and preference parameters, a_x and a_y.

Price index for motoring, $P = \left(a_x p_x^{1-\sigma} + a_y p_y^{1-\sigma}\right)^{1/(1-\sigma)}$.

Demand for x, y: $x = a_x p_x^{-\sigma} P^{\sigma-\epsilon}$ and $y = a_y p_y^{-\sigma} P^{\sigma-\epsilon}$.

Production: price at unit cost, c_x, c_y, ad valorem tax/subsidies t_x and t_y: $p_x = t_x c_x$ and $p_y = t_y c_y$.

(NB: discrete choice interpretation with heterogenous consumers – Frechet distribution, etc.)

Externalities: Depend on aggregate quantities, denoted X and Y.

- ***Global warming externality***: Good x is perfectly clean: damage function $K_Y[Y] \geq 0$, increasing in Y.
- ***Preference externalities***: household preferences depend on aggregate sales $a_x[X, Y]$ and $a_Y[Y, X]$.
- ***Production externalities***: economies of scale and learning effects which are external to the firm but internal to the type of good produced, $c_x[X]$, and $c_y[Y]$, especially for X as clean is not a mature market.
- ***N.b.***: $c_y' \geq 0$ (running out of scarce fossil fuel), but more important $c_x{}' < 0$.

Equilibrium with peer effects (preference externalities):

Unit measure of consumers, proportion purchasing *x*, $\Pi_x \equiv X/(X+Y)$

Preference parameters: $a_x[X,Y] = a[\Pi_x]$, $a_y[Y,X] = a[1-\Pi_x]$,

- preferences depend on proportions, Π_x and $1-\Pi_x$ ➔ focus on switching behaviour
- Preferences are symmetric; common function $a[.]$, with arguments for each good Π_x, $1-\Pi_x$.
- Output levels have been entered in physical units: comparable?

Equilibrium: household choices equal to aggregate, so

$$\frac{x}{x+y} = \frac{a_x p_x^{-\sigma} P^{\sigma-\epsilon}}{\{a_x p_x^{-\sigma} P^{\sigma-\epsilon} + a_y p_y^{-\sigma} P^{\sigma-\epsilon}\}} = \Pi_x = \frac{a[\Pi_x](t_x c_x)^{-\sigma}}{a[\Pi_x](t_x c_x)^{-\sigma} + a[1-\Pi_x]\left(t_y c_y\right)^{-\sigma}}.$$

values of Π_x that solve this equation?

Hold the price of good *y* at its equilibrium value, $t_y c_y$, vary Π_x, and ask what values of price, $\tilde{p}_x$, solve

$$\Pi_x = \frac{a_x[\Pi_x](\tilde{p}_x)^{-\sigma}}{a[\Pi_x](\tilde{p}_x)^{-\sigma} + a[1-\Pi_x]\left(t_y c_y\right)^{-\sigma}}.$$

- Values $\tilde{p}_x$ are inverse demand curve:

willingness to pay for *x*, as a function of relative supply of the good, Π_x.

Figure 2a: Preferences with peer effects

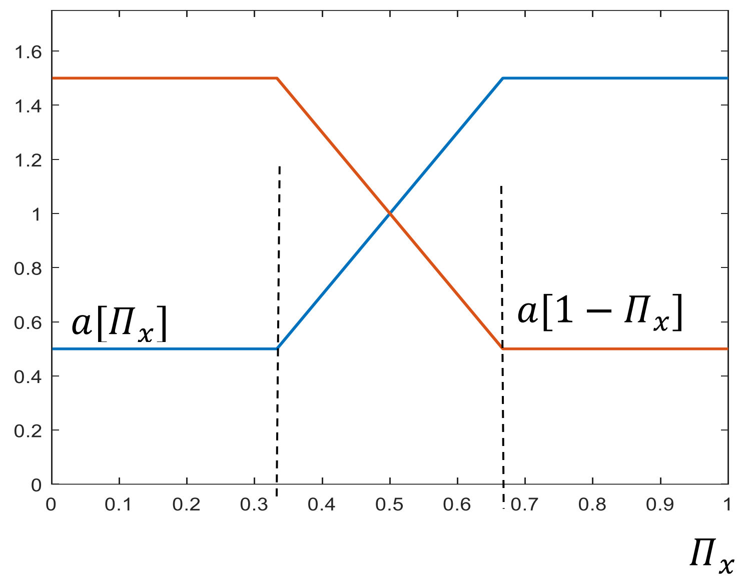
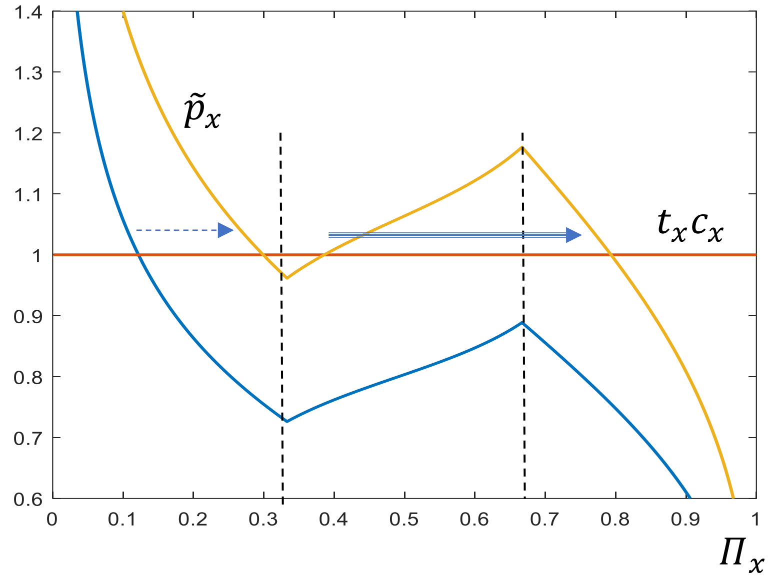


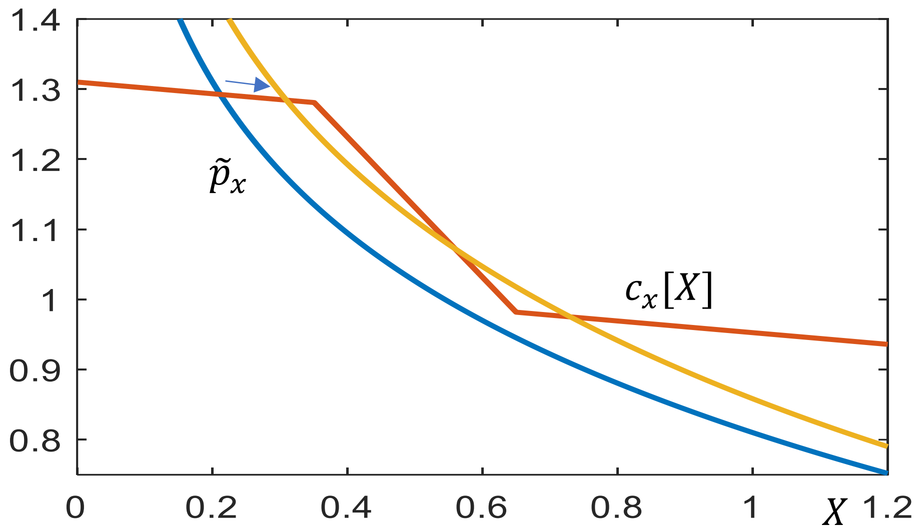
Figure 2b: Unit cost and demand curves, $\tilde{p}_x$



- Blue demand curve: unique equilibrium with low X output, high Y and hence pollution.
- Subsidise x or tax y, shifts $\tilde{p}_x$ upwards: yellow curve, 3 equilibria, middle unstable
- Higher subsidy shifts up the yellow line, so increases x, Π_x until tipping point where low x equilibrium destroyed.

External economies of scale in production:

- Switch off peer effects in demand (i.e. making the demand parameters a_x and a_y constant),
- Unit cost in the clean sector decreases with total output, $c_x'[X] \leq 0$. $\gamma_x = Xc_x'[X]/c_x[X] \leq 0$
- The blue demand curve supports a unique equilibrium while the yellow curve supports 3 equilibria

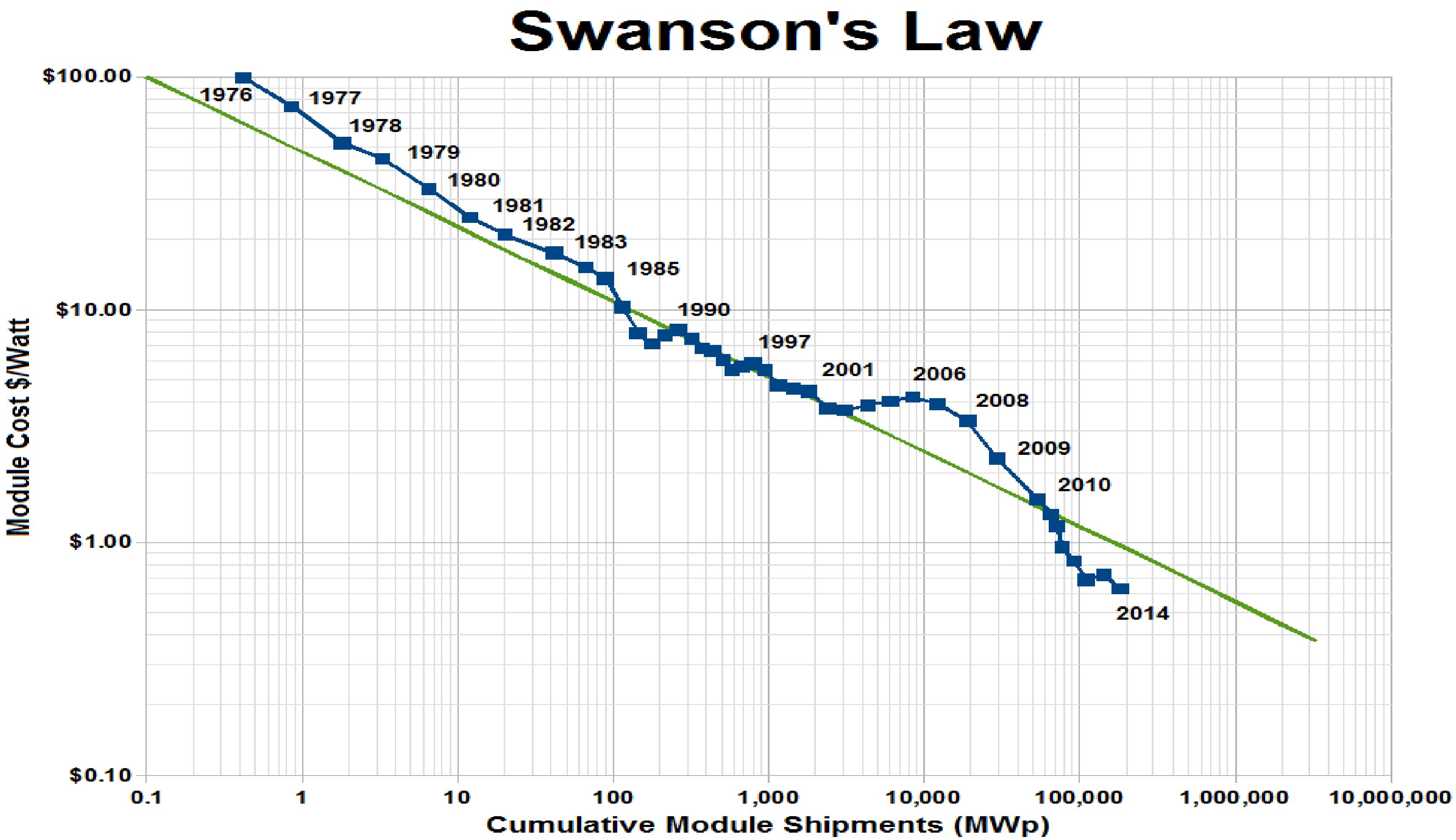


NB: Weak increasing returns everywhere ➔ ***amplification*** effect of policy

- Given shift in demand curve (→) brings larger quantity change if increasing returns $\gamma_x < 0$ (or peer effects)
- Amplification ➔ quantity target can be achieved with *smaller* tax instrument ***vs*** need *larger* tax instrument to destroy the low equilibrium!
- Tension between effects around a given equilibrium ***vs*** shifting between equilibria

Evidence for learning by doing

Cost solar panels drops 20% for every doubling of cumulative shipped volume



Tax and subsidy policies: MARGINAL CHANGE

How do taxes and subsidies change output, pollution, and welfare (consumer surplus plus income including net rebates minus pollution damage) around a particular equilibrium?

- Peer effect: $a_x[X], a_y[Y]$ and hence $\hat{a}_x = \alpha_x \hat{X}, \hat{a}_y = \alpha_y \hat{Y}$, $\alpha_x \equiv X a_x'[X]/a_x[X]$.
- Elasticity of unit costs wrt output: $\gamma_x \equiv X c_x'[X]/c_x[X] < 0$,

Output change wrt to taxes $\hat{X} = \dfrac{-\sigma \hat{t}_x + (\sigma - \epsilon)\left[\mu \hat{t}_x + (1-\mu)\hat{t}_y\right]}{1 - \alpha_x + \gamma_x[\sigma(1-\mu) + \epsilon\mu]}$, $\hat{Y} = \dfrac{-\sigma \hat{t}_y + (\sigma - \epsilon)\left[\mu \hat{t}_x + (1-\mu)\hat{t}_y\right]}{1 - \alpha_y}$

Numerator, from demand curve (μ is market share of x): Denominator (< 1), is amplification effect.

Locally optimal taxes: Pigouvian (1st best): $t_x - 1 = \gamma_x < 0$, $t_y - 1 = K_y'/c_y > 0$.

Constrained: $t_x = 1$ $t_y - 1 = \frac{K_y'}{c_y} + \gamma_x \frac{c_x}{c_y}\frac{dX}{dY} > \frac{K_y'}{c_y} > 0$.

$t_y = 1$ $t_x - 1 = \gamma_x + \frac{K_y'}{c_y}\frac{dY}{dX} < \gamma_x < 0$.

1: Pigouvian subsidy on clean to capture learning by doing but Pigouvian tax on dirty

2: If cannot tax dirty for political or other reasons, subsidy on clean must be larger

3: Locally optimal tax/ subsidy policy unchanged by peer effects, if these are purely expenditure switching.

4: Amplification: Peer effects and/or increasing returns ➔

- Need lower value of policy instruments to hit a target for output/emissions.
- Unit change in a policy instrument towards its locally optimal value brings greater utility gain

Tax and subsidy policies: TIPPING POINTS

- Example: peer preferences; no increasing returns; pollution externality
- Vary t_y with: constrain $t_x = 1$: pollution damage, $K_y'/c_y = 0.2$ (so Pigouvian tax $t_y = 1.2$)

Figure 5a: *Y*-sector tax & *X*-sector output.

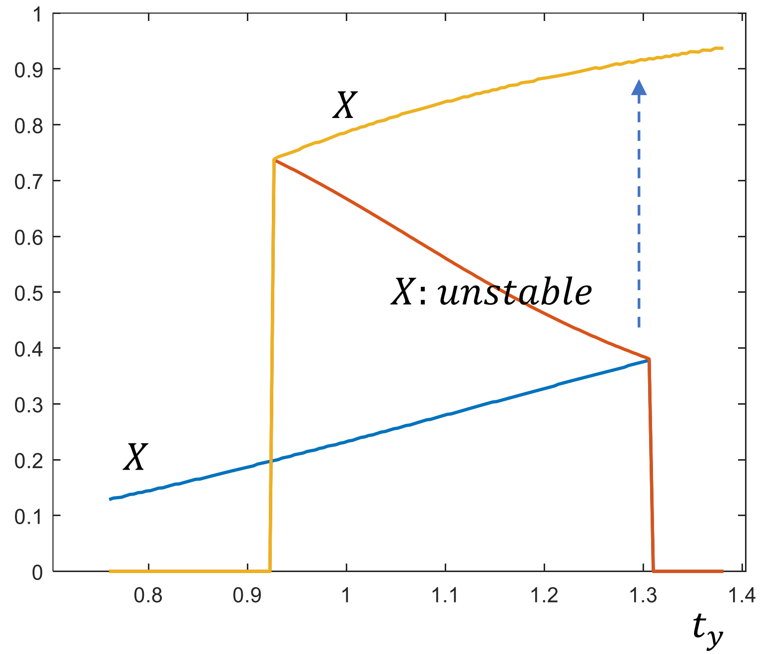
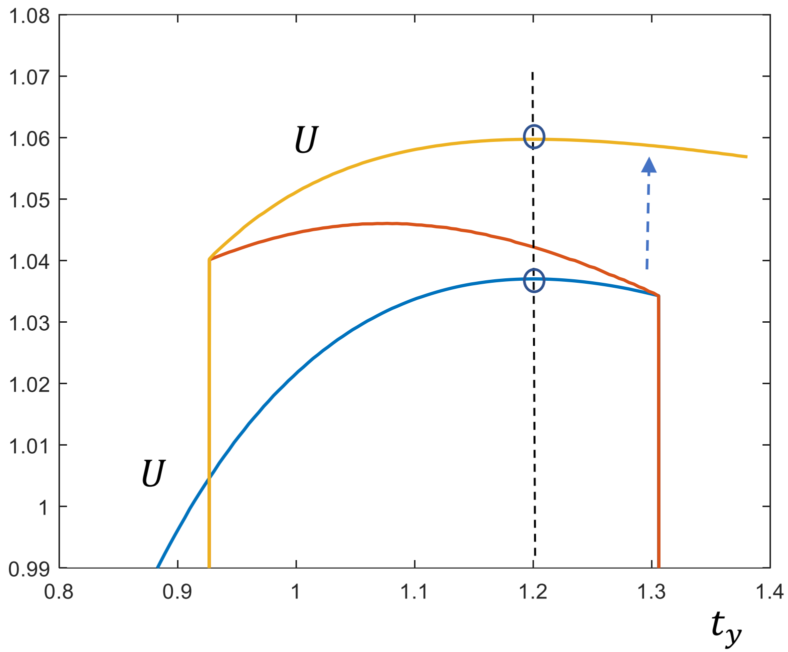


Figure 5b: *Y*-sector tax & utility



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Utility maximisation requires a tax high enough to flip from the dirty equilibrium (blue line) to the clean equilibrium (yellow). In this example the dirt tax exceeds the Pigouvian rate.

- Vary t_x with: $t_y = 1.2$, so Pigouvian tax on pollution in place.

Figure 6a: *X*-sector tax & *X*-sector output.

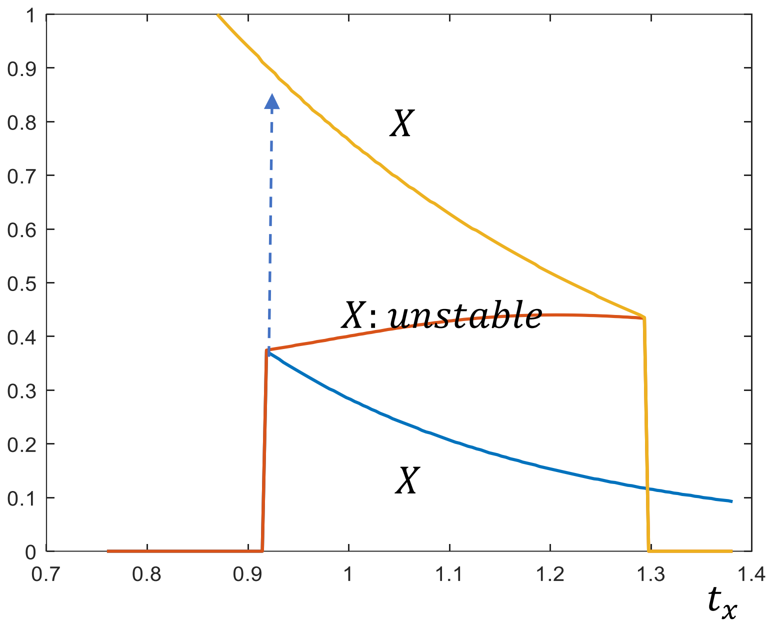
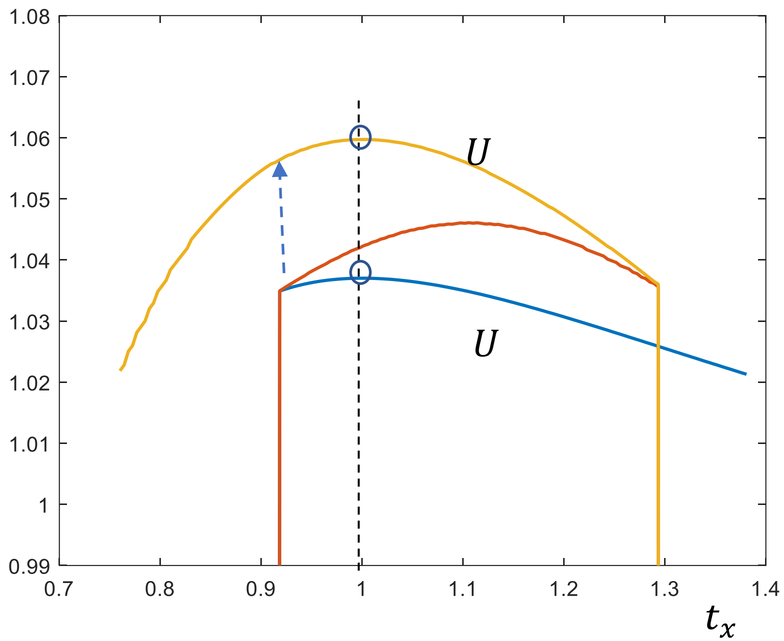


Figure 6b: *X*-sector tax & utility.



Dirty output is subject to the Pigouvian tax, but it takes a subsidy to the clean good to flip the economy from the dirty equilibrium to the clean equilibrium.

Earlier studies

van der Meijden and Smulders (2022): "Factor-eliminating technical change in the energy transition" also has 3 equilibria

- Technological breakthroughs needed in hard-to-abate sectors to increase substitution possibilities
- So weight of fossil fuel in production function becomes endogenous
- Temporary carbon tax can shift economy from low to high decarbonisation equilibrium; permanent carbon tax affects share of decarbonised sectors in clean equilibrium
- FETCH and clean DTC are complements

Smulders and Zhou (2022): self-fulfilling prophecies in green also has 3 equilibria in DTC model where clean and dirty goods are good substitutes:

- multiple transition paths
- Need a coordination device in addition to Pigouvian carbon tax

Delfgauw and Swank (2023): The Gasoline climate trap also multiple equilibria

Besley and Persson (2023): political economy framework to understand commitment problems: socialisation of preferences, political system cannot commit to future policies, strategic complementarities leading to a climate trap, need grand coalition of visionary politicians, business leaders and people in society to shift from bad to good equilibrium

Dynamics:

Switch is an investment – so forward-looking choice.

Framework for analysing role of expectations and time profile of policy – History vs Expectations (Krugman)

- X, Y are stocks of each type of motor vehicle in use at each date, $X + Y = 1$
- Π_x the proportion of the stock that are X, $\Pi_x = X/(X+Y) = X$.
- Vehicle dies with probability δ each instant.
- Choose to replace with either X or Y.

Preferences depend on the stock of each type:

- Flow benefit of holding a type x vehicle at date $t = a(\Pi_x(t))$; type y, $a\big(1 - \Pi_x(t)\big)$
- The present value (PV) of the utility of a purchase made at date t is $u(x,t), u(y,t)$.

  $u(x,t) = \int_t^\infty a\big(\Pi_x(s)\big)\, e^{-\rho(s-t)} ds,$ $u(y,t) = \int_t^\infty a\big(1 - \Pi_x(s)\big)\, e^{-\rho(s-t)} ds$

- The value of purchasing X relative to Y is

$$V = \int_t^\infty \{a\big(X(s)\big) - a\big(1 - X(s)\big)\} e^{-\rho(s-t)} ds,$$

- Change in value:

$$\dot{V} = \rho V - \{a(X) - a(1 - X)\}.$$

Evolution of stocks, X, Y:

- Purchase a new vehicle when old has depreciated. Prices, $\pi = p_x(1 - s_x) - p_y$
- Switching cost c: switch type Y to X with probability $f_{yx} = \Phi(V - \pi - c)$, $or = (V - \pi + G - c)/2G$

  switch type X to Y with probability $f_{xy} = 1 - \Phi(V - \pi + c)$, $or = (\pi - V + G - c)/2G$
- Rationalise by heterogeneous prefs. for X in the population: distributed normal (Φ), or uniform [-G, G].
- Change in stock of type X: $\dot{X} = \{X f_{xx} + Y f_{yx} - X\}\delta = \{f_{yx} - X(f_{xy} + f_{yx})\}\delta$

Simplify:

- Linear peer effects $a(X) = A + \alpha(X - 1/2)$, $a(1 - X) = A + \alpha(1/2 - X)$
- Uniform distribution of preferences, and $\pi = 0$ (but use normal distribution for simulations)

Two equation linear system

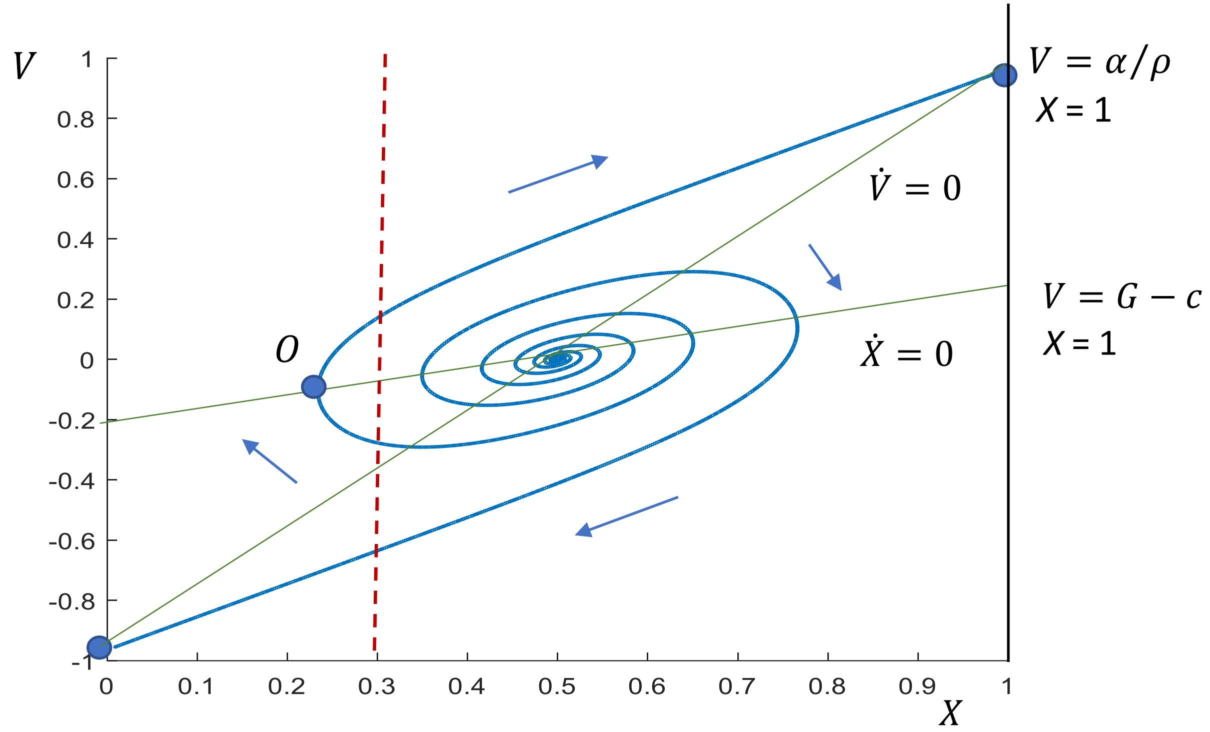
$$\dot{V} = \rho V - \alpha(2X - 1)$$

$$\dot{X} = \{V + (2X - 1)(c - G)\}\delta/2G$$

Stationary points:

- Interior equilibrium: $X = 1/2$, $V = 0$
- If $\alpha/\rho > G - c$, also 2 edge equilibria: $X = 1$, $V = \alpha/\rho$; $X = 0$, $V = -\alpha/\rho$;
- Interpretation: α/ρ is perpetual value of V once all stock is green and of type x (X = 1)

Dynamic behaviour: Interior equilibrium unstable (complex eigen-values, real part > 0)



If start at X = 0.3, then 3 rational expectations paths.

- Low V: go to dirty equilibrium, stalled green transition ($X \rightarrow 0$)
- High V: monotonic path to clean equilibrium, successful green transition ($X \rightarrow 1$)
- Intermediate V: non-monotonic path to clean equilibrium ($X \rightarrow 1$): Little economic sense?

Point O indicates lowest value of X from which economy can reach the clean equilibrium

- For green transition, want to make this range large and subsequent transition fast.

Qualitative dynamics:

Weak peer effects: saddle-point dynamics, so relative value of green technology V jumps while share of green renewables X is predetermined. Only an interior solution. Not our concern here.

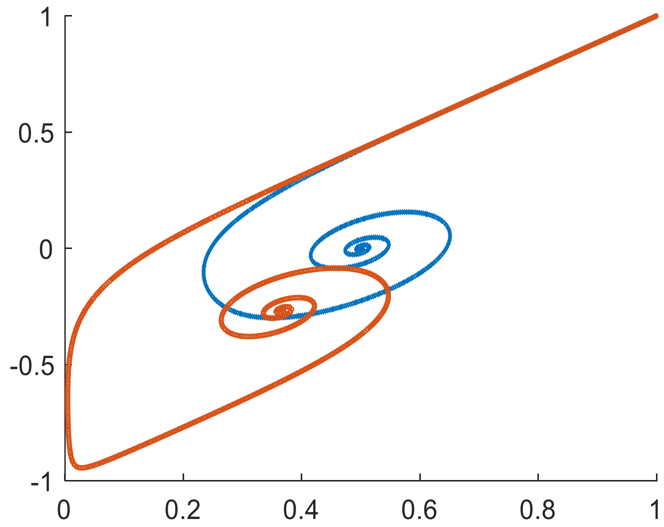
Intermediate peer effects: unstable & eigenvalues have zero imaginary parts, so for all X_0 less than a critical value there is a unique monotonic adjustment path to the brown boundary steady state and ***else*** there is a unique monotonic adjustment path to the green boundary steady state.

Strong peer effects: unstable with complex eigenvalues, so either cyclical adjustment to brown boundary state if X_0 less than a low critical value, or cyclical adjustment to green boundary state if X_0 more than a high critical value, or two cyclical adjustment paths originating from the same X_0, one towards the brown and one towards the green steady state (the "overlap", cf. Krugman, 1991). One can talk up expectations and shift the economy towards the green equilibrium.

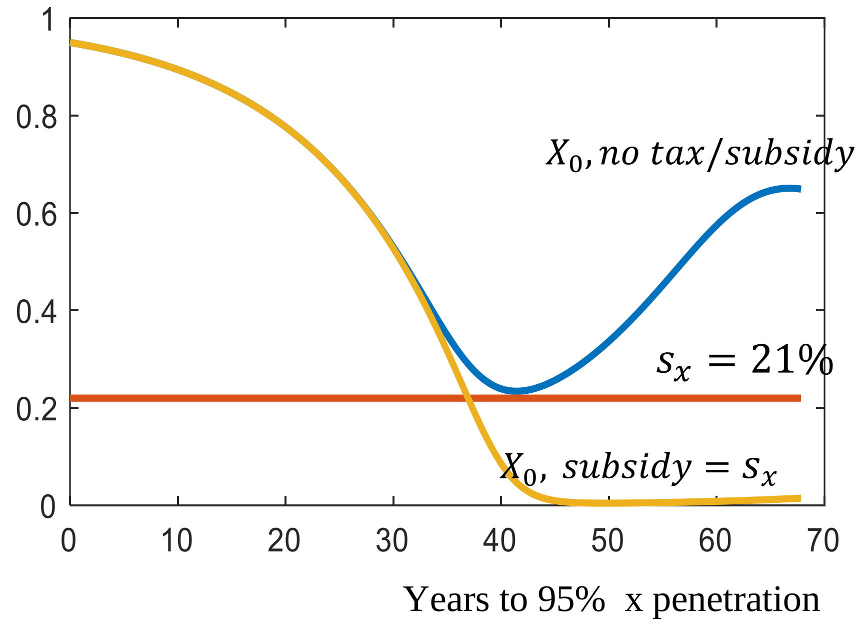
Tax/ Subsidy policies: Stretching the overlap to create a path to the clean equilibrium even when initial share of renewables X_0 is low

1) ***Flat*** subsidy to green *x* (equivalently tax on dirty *y*) for duration of the transition, zero thereafter $\rightarrow$ Blue lines: no policy: other colours, subsidy to green good *x.*

Path on X – V space

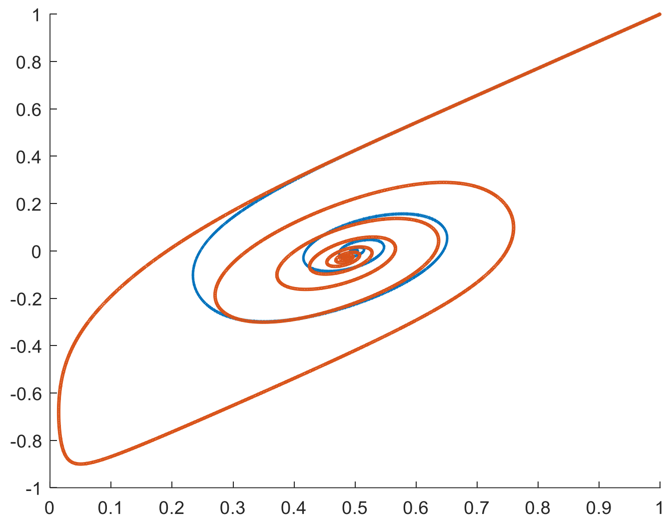


Initial X and subsidy rate as function of 'years' to transition (= 95% of stock green). r=0.025, δ = 0.075



2) ***Front-loaded*** subsidy to *x* (equivalently tax on *y*) for duration of the transition, zero thereafter $\rightarrow$ Blue lines: no policy: other colours, subsidy to *x.*

Path on X – V space



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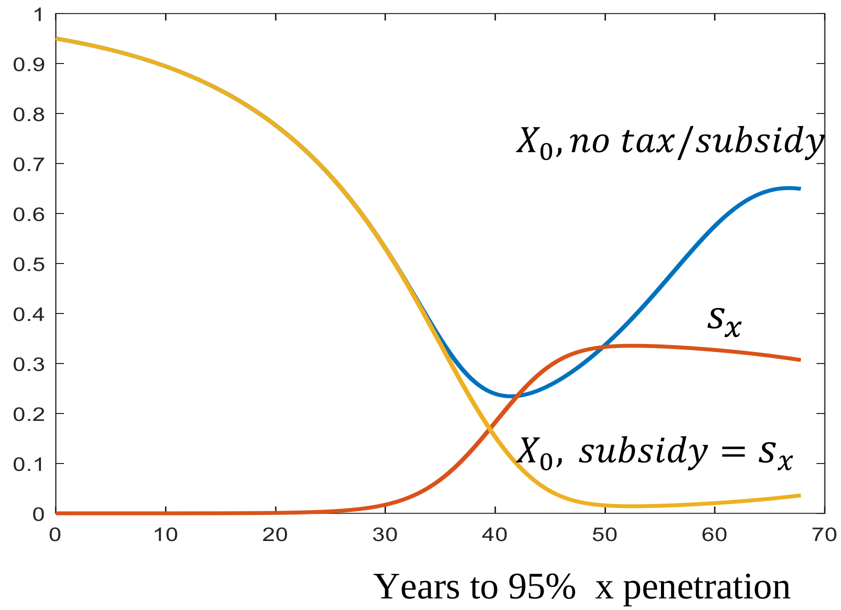

Front loading subsidy is less costly than flat subsidy. Both (at appropriate levels) can stretch the overlap so that successful transition is feasible for any X_0. Neither speeds up the transition much: need faster depreciation (scrappage) to achieve this.

Transformative climate policies: a broader review

Political, social, and technological tipping points

- How to engineer a quick and sudden transition to a net-zero economy?
- Low tariff of 2-5% of climate club can set it off (Nordhaus)

Social norms

- Punctuated equilibria and evolutionary games
- Self-enforcing social norms (Young, Weibull)

Amplification via networks

- Direct policy at key players in network (Ballister et al.)

Sensitive intervention points

- Interventions that kick the system so initial change is amplified by feedback effects that give an outsized effect (Farmer et al.)

Radical climate policies

Scientists warn about 9 irreversible climate tipping points getting more imminent with global warming

- melting Greenland and Antarctic Ice Sheet, loss of Arctic Sea ice, thawing permafrost, Gulf Stream, etc.

What society and policy makers need to exploit are:

- Social tipping points (peer effects, Extinction Rebellion and other grass root movements)
- Technological tipping points (based on exploitation of learning by doing embodied in Wright's and Swanson's law; alternatively via directed technical change)
- Political tipping points (e.g., Nordhaus' climate clubs)
- Network effects

Relies on positive feedback effects or strategic complementarities

Need for more radical, transformative policies (e.g., renewable energy subsidies) which can be done sector by sector. Social and technological interventions can encourage a tilt in the desired direction. A policy that triggers social, technological, and political tipping points and leverages networks can radically accelerate the green transition.

Are current integrated assessment models fit for purpose?

Concluding comments

- Climate tipping points not just in physical space, but also in socio-economic space
- Occur because of other 'market failures' that create multiple equilibria.
  - BUT: Marginal analysis – even if it includes these market failures – does not give the right answer.
  - Need to explicitly recognise that policy should not always be based on local optima around a low-level equilibrium.
  - Not sufficient to just set carbon tax = social cost of carbon
- Policy to switch between equilibria: applicable in many contexts:
  - Other technological transitions
  - Regional disparities and low-level traps
  - Different phases of a growth path – 'creative destruction'
- TO DO
  - Technical extensions: e.g. uncertainty, option value of waiting
  - Going behind the 'reduced form' of this paper
  - Political economy
  - Quantification