The Carbon Bubble
Climate Policy in a Fire Sale Model of Deleveraging

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Introduction

- In 1996, EU Governments set a global temperature target of 2°C above pre-industrial level, confirmed by subsequent climate agreements e.g. IPCC (2014)
- Meeting this target is much more closely related to cumulative carbon emissions rather than rates of emission
- $\Rightarrow$ a "carbon budget" of allowable emissions, of $\sim 20\% - 50\%$ of current reserves, whilst the rest is "unburnable carbon"
- But capital markets positively value fossil fuel reserves
  - Stranded assets $\rightarrow$ reduced market values
  - Reduced value of collateral $\rightarrow$ breakdown of credit relationships
  - No credit $\rightarrow$ less investment in alternative energy infrastructure
- Issue first raised by Carbon Tracker Initiative (2011) and subsequently highlighted by Bank of England, Carney (2014)

In this paper

- What we do
  - We address the implications of climate policy upon macroeconomic stability
  - Given frictional financial markets, climate policy can induce a depression with consequent negative impacts upon welfare and alternative energy infrastructure investment
  - We examine macroeconomic policy responses that can mitigate the effects of implementing climate policy
- How we do it
  - Dynamic simulations
  - Using an augmented macroeconomic model with financial frictions

    Kiyotaki and Moore (1997), Cordoba and Ripoll (2004)
  - In which we impose a cumulative carbon emissions limit

    Allen et al. (2009)

Findings

- Welfare ($= PV(NNP)$) seems to be related to investment in alternative energy infrastructure over period while still have fossil fuels available
- Both are maximised using policy. Various policies are analysed and all these policies have value in the model.
- A sudden "bursting of the carbon bubble" without any offsetting policy is likely to be sub-optimal. The policy response to climate change must pay cognisance to the impact that it will have on investors' balance sheets.

The Model

Extension of Kiyotaki and Moore's (1997) full Credit Cycles model

- Discrete and infinite time
- 3 goods
  - investment goods, Z^H and Z^L, depreciating at rate $1-\lambda$

    interpret as carbon emitting and zero carbon energy infrastructure respectively
  - durable asset K, no depreciation, fixed aggregate amount $\bar{K}$

    interpret as other capital
  - non durable commodity, can be consumed or invested. One unit of energy infrastructure costs ϕ units of commodity
- 2 competitive markets
  - asset: 1 unit of the durable asset is exchanged for q_t units of the commodity
  - credit: 1 unit of the commodity at date t is exchanged for R_t units of the commodity at date $t+1$

Agents

2 types of risk-neutral agents

- mass 1 of entrepreneurs $\rightarrow \max_{\{x_s\}} E_t \left[\sum_{s=t}^{\infty} \beta^{s-t} x_s \right]$
- mass m of savers $\rightarrow \max_{\{x'_s\}} E_t \left[\sum_{s=t}^{\infty} \beta'^{s-t} x'_s \right]$

Assumption A: $\beta < \beta'$ i.e. savers are relatively patient

- Savers use a decreasing returns to scale technology

$$y'_t = \Psi(k'_{t-1}) = (\bar{K} - \nu) k'_{t-1} - \frac{1}{2} m (k'_{t-1})^2 + Const$$

- In equilibrium, savers are unconstrained and entrepreneurs will be credit constrained. $\Rightarrow$ savers' discount factor determines market interest rate i.e. $R_t = R = 1/\beta'$

Entrepreneurs

- Real output: two possible Leontief technologies

  Leontief assumption is straight from Kiyotaki and Moore (1997), but Hassler et al. (2012) suggests energy inputs and other factors of production have extremely low elasticity of substitution, at least in short run.

$$F_i(k_{t-1}, z^i_{t-1}) = (a^i + c) \times \min(k_{t-1}, z^i_{t-1}) \qquad i = \{L, H\}$$

- Private return

$$\begin{aligned} y^H(k_{t-1}, z^H_{t-1}) &= (a^H - \tau + c) \min(k_{t-1}, z^H_{t-1}) \\ y^L(k_{t-1}, z^L_{t-1}) &= (a^L + \delta\varsigma + c) \min(k_{t-1}, z^L_{t-1}) \end{aligned}$$

- where:
  - Assumption B: $a^H > a^L$
  - $c \equiv$ untradeable output which must be consumed
  - $\tau \equiv$ carbon tax, $\varsigma \equiv$ zero carbon subsidy
  - $0 < \delta < 1 \equiv$ subsidy induced distortion

    Credit constraints $\Rightarrow$ sub-optimally low capital. A subsidy therefore moves economy towards first best. Want optimal zero subsidy in steady state, so introduce productivity destroying distortion.

Budget constraints

Financial Accelerator

- Kiyotaki and Moore (1997) uses only fixed capital as collateral, so entrepreneurs face a borrowing constraint
$$b_t \leq \frac{q_{t+1} k_t}{R}$$
- This leads to an equation of motion for capital used by entrepreneurs that exhibits a financial accelerator
$$k_t = \frac{1}{q_t + \phi - \frac{q_{t+1}}{R}} \left[(q_t + \lambda\phi + a) k_{t-1} - R b_{t-1} + g_t \right]$$
where $a = a^H - \tau = a^L + \delta\varsigma$ (i.e. policy here is such that entrepreneurs are indifferent w.r.t. technology).
- At the end of period t, the net worth of an entrepreneur is given by the expression in the square brackets.
- A proportional increase in both q_t and q_{t+1} raises demand for capital. A rise in q_t increases entrepreneur net worth and a rise in q_{t+1} strengthens the value of collateral, outweighing price-increase induced reductions in demand.

Aggregate Equations of Motion

Mkt Clearing Assumptions

- Capital in entrepreneurial sector,

$$K_t = (1-\pi)\lambda K_{t-1} + \frac{\pi}{q_t + \phi - \frac{q_{t+1}}{R}} \times \left[\left(q_t + \phi\lambda + a \right) K_{t-1} - RB_{t-1} + \frac{\gamma_t \tau - (1-\gamma_t)\varsigma}{1+m} K_{t-1} \right]$$

- Where $\gamma_t \equiv$ share of entrepreneurs using z^H at t, and $\pi \equiv$ share of entrepreneurs able to invest each period.
- Debt held by entrepreneurial sector,

$$B_t = q_t(K_t - K_{t-1}) + \phi(K_t - \lambda K_{t-1}) + RB_{t-1} - aK_{t-1} - \frac{\gamma_t \tau - (1-\gamma_t)\varsigma}{1+m} K_{t-1}$$

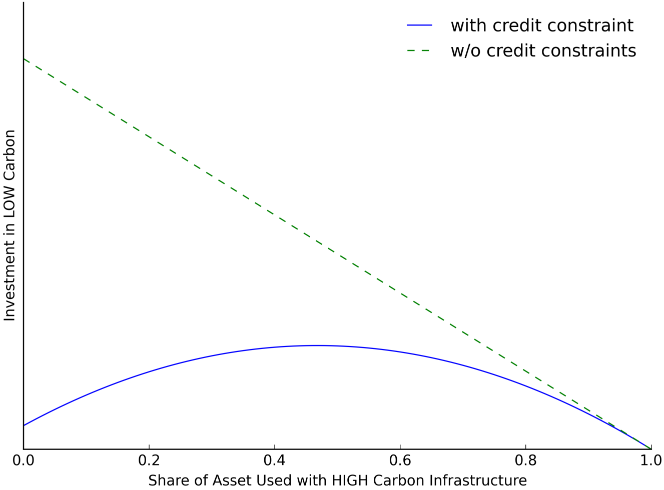
- Capital price, $q_t = \frac{q_{t+1}}{R} + K_t - \nu$

Steady State Equilibria

There exists a continuum of steady state equilibria, $(q^\star, K^\star, B^\star)$, indexed by $\gamma \in [0,1]$ and $a \in [a^L, a^H]$, where

$$
\begin{aligned}
B^\star &= \frac{\phi\lambda - \phi + a + \frac{\gamma\tau - (1-\gamma)\varsigma}{1+m}}{R-1} K^\star \\
K^\star &= \frac{R-1}{R} q^\star + \nu \\
q^\star &= \frac{R}{R-1} \frac{\pi\left(a + \frac{\gamma\tau - (1-\gamma)\varsigma}{1+m}\right) - \phi(1-\lambda)(1-R+R\pi)}{\pi\lambda + (1-\lambda)(1-R+R\pi)}
\end{aligned}
$$

Implication: SS zero carbon investment can be higher if allow high carbon investment



Calibration

- $\beta = \beta' - \epsilon$ for infinitesimal $\epsilon > 0$ chosen so that $PV(NNI)$ is social welfare function
- R & λ chosen so that periods interpreted as quarters
- *Const* chosen to equalise steady state consumption of individual savers and entrepreneurs
- $a^H = 1$ normalisation, and δ chosen so that optimal steady state subsidy is zero (i.e. $a = a^L$ and $\tau = a^H - a^L$)
- Current energy mix suggests $\gamma_0 = 0.8$ and $a^L = 0.9$
- Use initial carbon emitting energy infrastructure value $=$ 4.5% of total global capital value as calibration target

  loosely based on Dietz et al. (2016) and EIA (2016)
- For $2^o C$ target, Carbon Tracker Initiative (2013): up to "80% of listed companies' current reserves cannot be burnt", IEA (2012): "no more than one-third of proven reserves of fossil fuels can be consumed". In value terms, assume 50% of initial carbon emitting energy infrastructure can be used.

Calibration

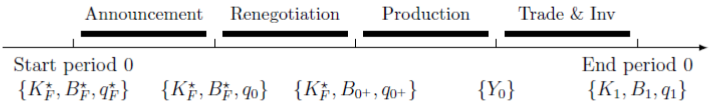
- i.e. Carbon Bubble will be modelled as the write off (implemented using $\lambda_H < \lambda$) of carbon emitting energy infrastructure representing 2.25% of total global capital value.
- The Financial Crisis of 2008-09 was triggered by loss of value associated with sub-prime mortgage assets. These had value of perhaps 0.9% of total global capital value (Hellwig (2009))
- Use the Financial Crisis, modelled in the same way as Carbon Bubble, as calibration target
- This 0.9% value write off precipitated dynamics in which global output fell 6% below trend, and global asset values fell by around 20%
- This allows us to generate a calibration for the model

Parameters

Dynamic Simulations

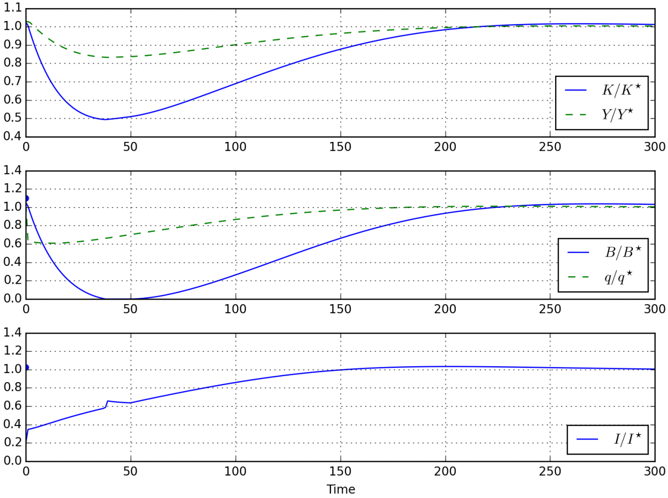
▸ Algorithm ▸ Default

- At $t = 0$, social planner
  - privately observes total carbon budget, $\bar{S} = 50\% \times S_0 = \frac{0.5\gamma K_0}{1-\lambda}$
  - forbids high-carbon investment



- Policy instruments (analysed separately)
  - planner takes some share of entrepreneurs' debt, ω, funded through lump sum taxes, τ^G, i.e. $B'_{0+} = (1-\omega)B_{0+}$ and $B_0^G = \omega B_{0+}$, where $B_t^G = (1+m)\tau^G \frac{\beta}{1-\beta}(1-\beta^{25-t})$
  - planner implements a zero carbon subsidy, $\varsigma_0 > 0$, $\varsigma_t = \max(0, \varsigma_0 \times (25-t)/25)$
  - planner announces some carbon budget $\hat{S} > \bar{S}$

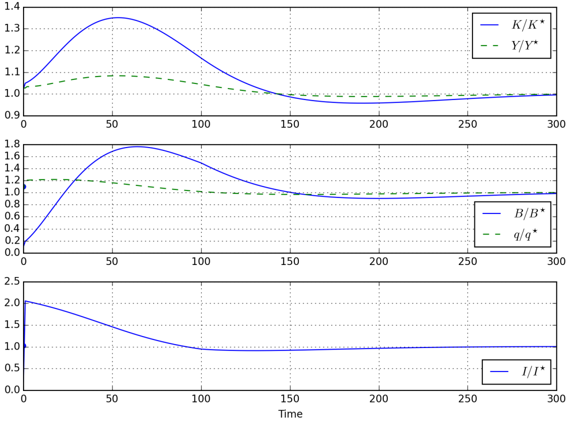
No Policy



1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
50
100
150
200
250
300
$K/K^\star$
$Y/Y^\star$
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
$B/B^\star$
$q/q^\star$
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
$I/I^\star$
Time

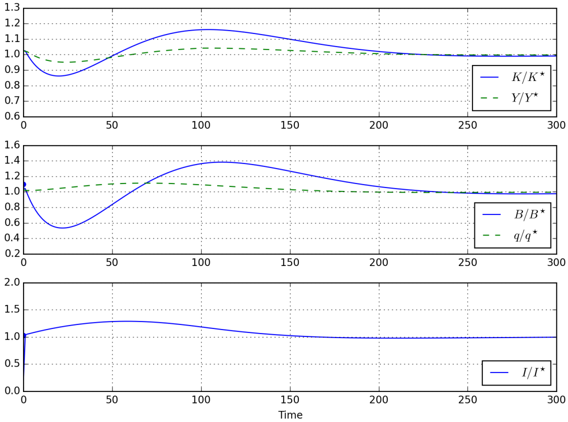
Tax-Funded Transfer of Entrepreneur's Debt

Optimal ω is 90% $\Rightarrow$ +5.2% welfare (entrepreneurs +73%, savers −11%), & cumulative I^L over 200 periods is +50%. NB optimal ω without Carbon Bubble is 60% $\Rightarrow$ +0.6% welfare.



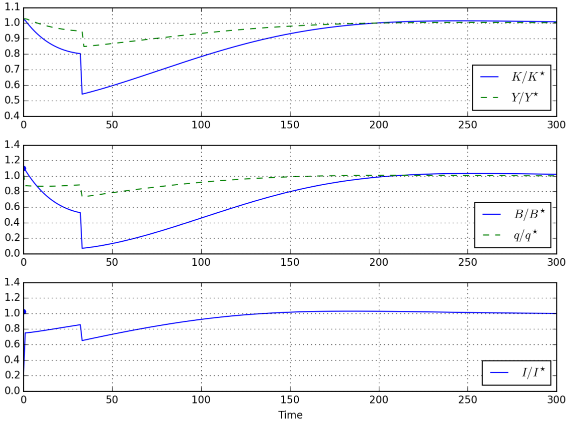
Subsidy

Optimal ς_0 is 45% $\times$ a^L $\Rightarrow$ +3% welfare (entrepreneurs +49%, savers −7%), & cumulative I^L over 200 periods is +40%.



Deception

Optimal $\hat{S}$ is 72% $\times$ S_0 $\Rightarrow$ +2% welfare (entrepreneurs +17%, savers +0%), & cumulative I^L over 200 periods is +12%.



Conclusions

- Carbon Bubble introduced by Carbon Tracker Initiative (2011) as warning to investors: protect your portfolio
- We incorporate Carbon Bubble in macro-financial model $\Rightarrow$ go beyond this warning to investors and consider appropriate macroeconomic policy to accompany Carbon Bubble
- $\Rightarrow$ cannot ignore balance sheet effects of writing off high carbon assets on investment in zero carbon replacement infrastructure
- Without policy, full “bursting of the carbon bubble” could lead to deep recession, depriving green technology of investment when it’s most needed, and causing large welfare losses
- Macroeconomic policy likely effective, and must pay cognisance to the impact that climate policy will have on investors’ balance sheets

Thank you!

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Appendix: Budget Constraints

For an entrepreneur using capital together with carbon emitting energy infrastructure

$$q_t(k_t - k_{t-1}) + \phi(k_t - \lambda k_{t-1}) + Rb_{t-1} + (x_t - ck_{t-1}) + \tau k_{t-1}$$
$$= a^H k_{t-1} + b_t + g_t$$

For capital used together with zero-carbon energy infrastructure

$$q_t(k_t - k_{t-1}) + \phi(k_t - \lambda k_{t-1}) + Rb_{t-1} + (x_t - ck_{t-1})$$
$$= a^L k_{t-1} + \delta\varsigma k_{t-1} + b_t + g_t$$

For savers

$$q_t(k_t' - k_{t-1}') + Rb_{t-1}' + x_t' = \Psi(k_{t-1}') + b_t' + g_t$$

For the government

$$\tau\gamma K_t - \varsigma(1-\gamma_t)K_t = (1+m)g_t$$

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Appendix: Market Clearing Conditions

- Market Clearing Conditions

$$K_t + K_t' = \bar{K} \tag{1a}$$

$$B_t + B_t' = 0 \tag{1b}$$

$$X_t + I_t^H + I_t^L + X_t' = Y_t + Y_t' \tag{1c}$$

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Appendix: Assumptions

- $\Psi'\left(\frac{\bar{K}}{m}\right) < \frac{\pi\left(a^L+\frac{\gamma\tau}{1+m}\right)-\phi(1-\lambda)(1+R\pi-R)}{\pi\lambda+(1-\lambda)(1-R+R\pi)} < \Psi'(0)$
- $a^H > a^L > (1-\lambda)\phi$
- $\pi > \frac{R-1}{R}$
- $c > \frac{1-\beta R\lambda(1-\pi)}{\beta R[\pi\lambda+(1-\lambda)(1-R+R\pi)]}\left(\frac{1}{\beta}-1\right)(a^L+\lambda\phi)$
- $\lim_{s\to\infty} E_t(R^{-s}q_{t+s}) = 0$

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Appendix: $I_L^\star$

- $I_t^L = (1-\gamma)\phi(K_t - \lambda K_{t-1})$
- In steady state:

$$
\begin{aligned}
I^{L\star} &= (1-\gamma)\phi(1-\lambda)K^\star \\
&= (1-\gamma)\phi(1-\lambda)\times \\
&\quad \left\{ \frac{\pi\left[a + \frac{\gamma\tau - (1-\gamma)\varsigma}{1+m}\right] - \phi(1-\lambda)(1-R+R\pi)}{\pi\lambda + (1-\lambda)(1-R+R\pi)} + \nu \right\}
\end{aligned}
$$

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Appendix: Possibility of Default

- Non-existence of solution for large negative shock in KM
- Allow entrepreneurs to default
- In KM, the shock hits the economy once the farmers have already taken their labor input decisions
  - even if tradable output is not collaterizable, debt repayments can be collected against both assets and output
  - farmers always choose to honor their debt completely
- Here, entrepreneurs already know the value of the shock before they had input labor
  - after a negative shock, the value of the debt is above the net worth of the collateral and, given that default is costless, entrepreneurs always have the incentive to renegotiate

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Appendix: Shooting Algorithm

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- By combining the laws of motion together with the land market equilibrium condition, we can find (K_t, B_t, q_{t+1}) as function of (K_{t-1}, B_{t-1}, q_t)
- $q_{t+1} = R(q_t - u(K_t)) = R(q_t - K_t + \nu)$
- System of "transition equations" than we can iterate
- When the shock hits, land price jumps in response to the shock and entrepreneurs experience a loss on their landholdings
- But for large T, $q_T = q^\star$
- Guess the initial variation in land price given the shock and then iterate the economy forward through time to see if it converges again to the steady state
  - If the level of land price eventually explodes, the initial guess is revised downward
  - If it is forever smaller then the initial guess is revised upward
  - "Guess and check" procedure is repeated until the land price is close to the steady state

Appendix: Parameters

Parameters Values

R	1.01	λ	0.975	π	0.015	ν	0.225
$\bar{K}$	5.26	ϕ	24	a^H	1	a^L	0.9
γ_0	0.8	m	2.71	c	0.9	$Const$	3.90

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