Modeling Cyclical Growth

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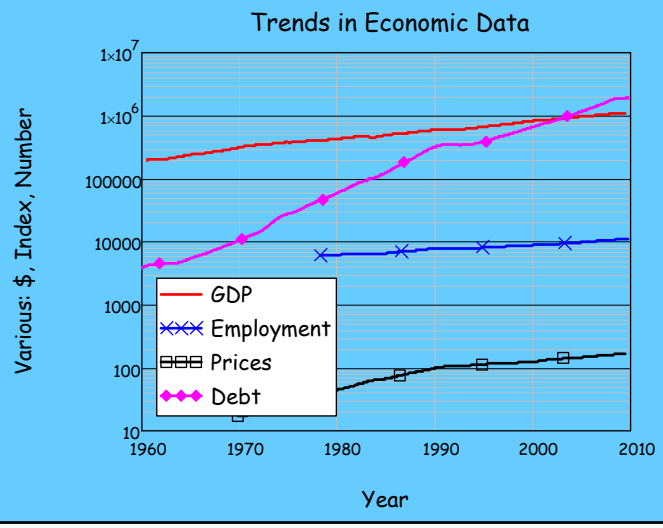
The Project

- UNEP specification of non-equilibrium economic model
  - Linked to CSIRO bio-physical model
- My brief:
  - Take single sectoral model of cycles (Keen 1995 etc.)
  - Single sectoral model of credit (Keen 2009 etc.)
  - Combine into multi-sectoral cyclical model of credit and production
    - ***Never previously done***
      - Previous attempts at dynamic "IO" input-output (multi-sectoral) models generally failed
        - Fatal instabilities—negative prices etc.
      - No previous attempts to model multisectoral ***monetary*** dynamics

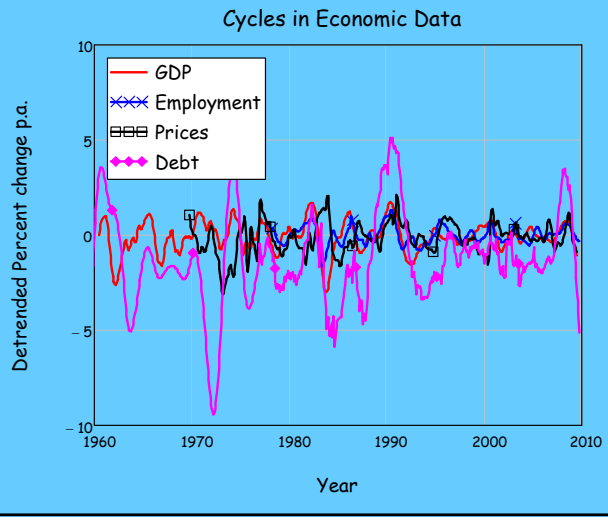
Trends in economic data

- Growth the norm in market economies...



Cycles in economic data

- As are cycles...
  - Previous data, de-trended:



Conventional economic models

- "Neoclassical" General Equilibrium models
  - Focus on trend
  - Ignore cycles
  - Ignore money
  - Presume system is
    - In equilibrium unless "shocked"
    - Will return to equilibrium after "exogenous shock"
      - Yet models have "dual instability" dilemma
        - Prices or quantities or both ***must*** be unstable
    - Effectively a barter system
      - Money only affects relative prices & inflation
- Cycles assumed to be caused by *noneconomic* factors
  - Agriculture/weather/sunspots… (meteors?)

Conventional economic models

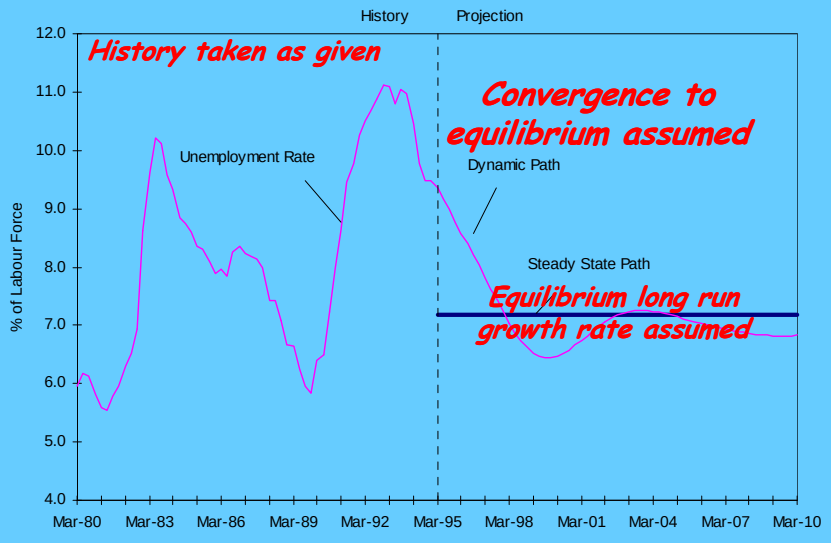
- "The capitalistic economy is stable, and absent some change in technology or the rules of the economic game, the economy converges to a constant growth path with the standard of living doubling every 40 years."
  - Edward C. Prescott (Nobel Prize 2004 for Real Business Cycle Theory), 1999
- "As … discussed in … "The Dynamic General Equilibrium Model," the model features a representative household [***i.e., one only!***] that chooses paths of consumption, leisure, and investment to maximize utility. *The paths of TFP and population are exogenously given, and the agent has perfect foresight over their values*. We start the model at date T_0 = 1980 and let time run out to infinity…" Conesa 2007

Conventional economic models

- "The model could be described as broadly new Keynesian in its dynamic structure **but with an equilibrating long run.**
- Activity is demand determined in the short run but supply determined in the long run…
- **The model will eventually return to a supply determined equilibrium growth path in the absence of demand or other shocks."**
  - Australian Treasury TRYM Model (2001)
- Cycles treated as exogenous to model of economy…

Conventional economic models

- E.g. unemployment in Australian Treasury TYRM model



Conventional economic models

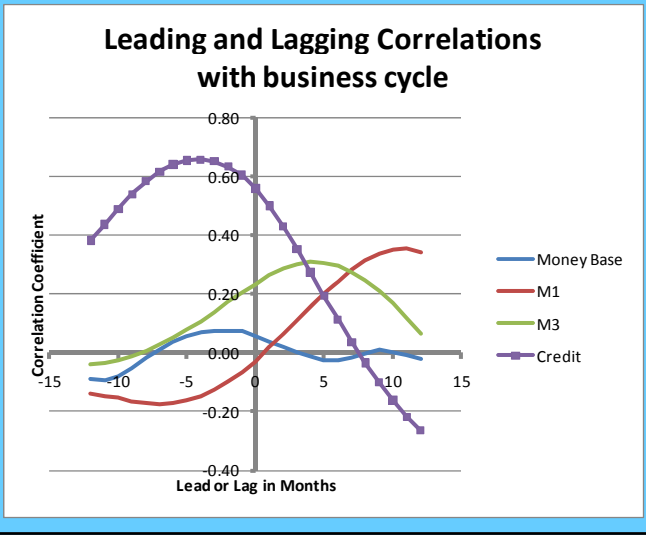
- Treatment of money and debt
  - In general, money ignored
    - "One thing which has not changed over the past five years is the philosophy underpinning the model.
    - It remains small, highly aggregated, empirically based, **and non-monetary in nature**." Australia's RBA (2005)
    - Money "neutrality" assumed
      - Affects price level but not real output
  - Universally, private debt ignored
- Versus empirical data...

Endogenous Money

- "The fact that the transaction component of real cash balances (M_1) moves contemporaneously with the cycle
- while the much larger nontransaction component (M_2) leads the cycle
- suggests that credit arrangements could play a significant role in future business cycle theory.
- *Introducing money and credit into growth theory in a way that accounts for the cyclical behavior of monetary as well as real aggregates is an important open problem in economics*."
  - Kydland and Prescott (1990, p. 15. Emphasis added)
- 1990 analysis confirmed by more recent data
  - E.g., leads and lags for Australia 1954-2009:

Endogenous Money

- Credit leads cycle with significant correlation
- All other variables lag or have low correlations:



Key role of private debt

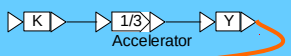
- "Our tests produce a clear story about short-term financing decisions in response to earnings and investment…
  - The leverage and debt regressions then confirm that, for dividend payers, ***debt is indeed the residual variable in financing decisions***.
  - Like dividend payers, non-payers primarily ***use debt to absorb short-term variation in earnings and investment***." (Fama & French 2000; emphases added)

Objectives for our economic model

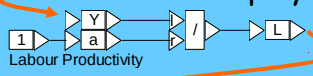
- Non-equilibrium
  - Economy itself inherently & endogenously cyclical
  - Model had to represent this
- Multi-sectoral
  - Many non-neoclassical endogenous cycle models
  - But none to date were multi-sectoral
- Explicitly monetary
  - Key role of money & debt shown in data
  - Incorporate interplay of debt, money and cycles
- 3 key foundations
  - Goodwin "Growth Cycle" model (1967)
  - Minsky "Financial Instability Hypothesis"
  - Graziani "Circuit Theory" model of credit creation

Foundations (1) Cycles: Goodwin's "Growth Cycle"

- Capital K determines output Y via the accelerator:

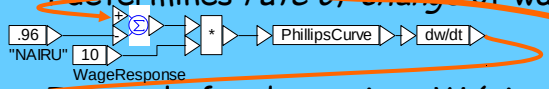


- Y determines employment L via productivity a:

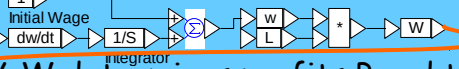


- L determines employment rate l via population N:

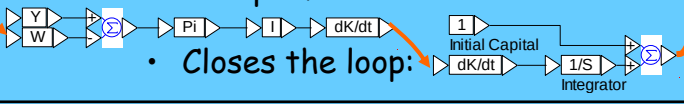
- l determines rate of change of wages w via P.C.



- Integral of w determines W (given initial value)



- Y-W determines profits P and thus Investment I…

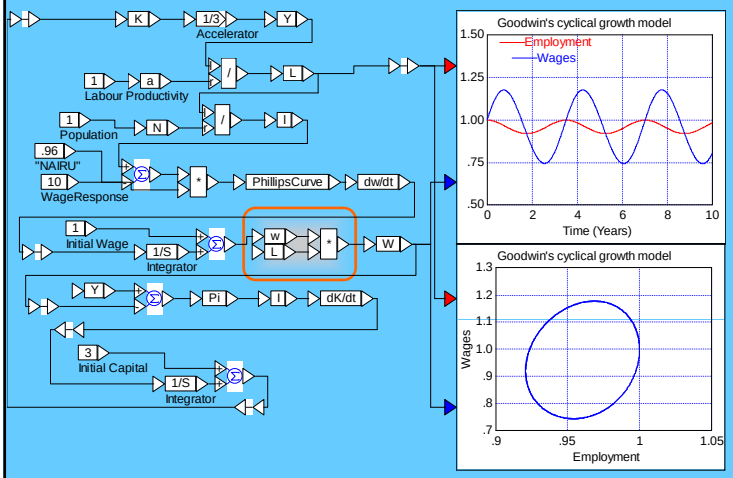


- Closes the loop:

Foundations (1) Cycles: Goodwin's "Growth Cycle"

- Goodwin's"Lokta-Volterra" model generates cycles:

Goodwin01B.vsm



- Cycles caused by ***essential*** nonlinearity:
- Wage rate times employment
- Behavioural nonlinearities not needed for cycles;
- Instead, restrain values to realistic levels

Foundations (2) Debt: Minsky's "FIH"

- Only theory that predicts this financial crises:
  - "it is necessary to have an economic theory which makes great depressions one of the possible states in which our type of capitalist economy can find itself." (*Can "It" Happen Again? A Reprise*)
- Time-&-debt-aware model:
  - Economy in historical time
  - Debt-induced recession in recent past
  - Firms and banks conservative re debt/equity, assets
  - Only conservative projects are funded
    - Recovery means most projects succeed
  - Firms and banks revise risk premiums
    - Accepted debt/equity ratio rises
    - Assets revalued upwards…

Foundations (2) Debt: Minsky's "FIH"

- Period of tranquility causes expectations to rise…
  - "Stability—or tranquility—in a world with a cyclical past and capitalist financial institutions is destabilizing." (*The Financial Instability Hypothesis: A Restatement*)
- Self-fulfilling expectations
  - Decline in risk aversion causes increase in investment
    - Investment expansion causes economy to grow faster
  - Asset prices rise
    - speculation on assets profitable
  - Increased willingness to lend increases money supply
    - Money supply endogenous money, not under Fed control
      - Riskier investments enabled, asset speculation rises
- The emergence of "Ponzi" financiers
  - Cash flow less than debt servicing costs
  - Profit by selling assets on rising market
  - Interest-rate insensitive demand for finance

Foundations (2) Debt: Minsky's "FIH"

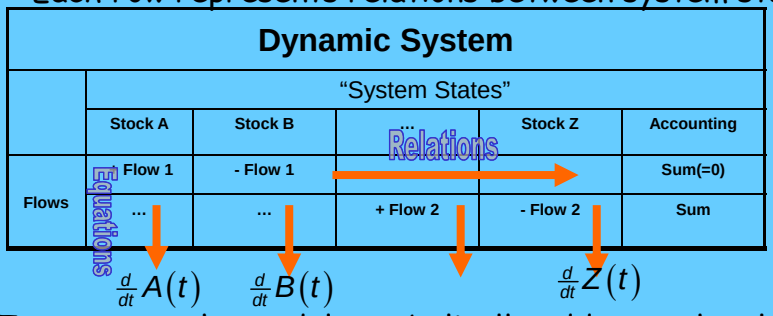
- Eventually:
  - Rising rates make conservative projects speculative
  - Non-Ponzi investors sell assets to service debts
  - Entry of new sellers floods asset markets
  - Rising trend of asset prices falters or reverses
- Ponzi financiers go bankrupt:
  - Can no longer sell assets for a profit
  - Debt servicing on assets far exceeds cash flows
- Asset prices collapse, increasing debt/equity ratios
- Endogenous expansion of money supply reverses
- Investment evaporates; economic growth slows
- Economy enters a debt-induced recession
  - Back where we started…

Foundations (3): Endogenous money

- Fundamental Endogenous Money insight
  - "Loans create Deposits"
    - Reverse of "Money Multiplier" model
- Suggested directly modeling bank credit creation via account dynamics
  - Simple model of "Wicksellian" pure credit economy
    - No government sector or fiat money (yet)
    - Explicitly monetary model
    - "Double-entry book-keeping" meets symbolic math

Foundations (3): Endogenous money

- New methodology for dynamic modelling
  - Table where each column represents a stock
  - Each row represents relations between system states…



- To generate the model, symbolically add up each column
  - Sum of column is differential equation for stock
    - Continuous time, not "discrete" time
    - *Strictly* monetary model of *pure credit* multi-commodity production economy developed…

Foundations (3): Endogenous money

- Input system as table:

$S_2 :=$

"Type"	0	1	−1	−1	0
"Account"	"Bank Reserves"	"Firm Loan"	"Firm Deposit"	"Worker Deposit"	"Bank Income"
"Account"	$B_R(t)$	$F_L(t)$	$F_D(t)$	$W_D(t)$	$B_I(t)$
Interest flows: bank<—>firm					
Wage flows: firm—>workers					
Interest flows: bank—>workers					
Consumption flows: bank & workers—>firms					
Debt repayment flows: firms—>bank					
Reserve relending flows: bank—>firms					
New Money/Debt flows: bank<—>firms					

- Symbolic substitutions for placeholders above:
- E.g., A is "loan interest rate times outstanding debt"

$$A = r_L \cdot F_L(t)$$

- Time lags used for behavioural variables

Foundations (3): Endogenous money

- Simple code develops mode automatically:

Over to Mathcad...

```
SystemODEs(x) :=
  Functions ← submatrix(x, 2, 2, 1, cols(x) − 1)
  Equations ← submatrix(x, 3, rows(x) − 1, 1, cols(x) − 1)
  for i ∈ 0.. cols(Functions) − 1
    E_i ← (d/dt) Functions_i = Σ Equations^⟨i⟩
  return E
```

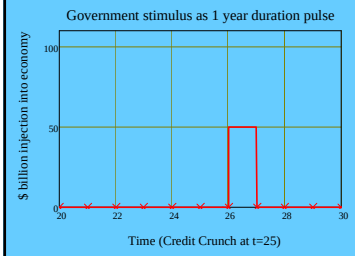
$$\text{SystemODEs}(S_2) \rightarrow \begin{bmatrix} \frac{d}{dt}B_R(t) = \frac{F_L(t)}{\tau_L} - \frac{B_R(t)}{\tau_R} \\ \frac{d}{dt}F_L(t) = \frac{B_R(t)}{\tau_R} + \frac{F_D(t)}{\tau_M} - \frac{F_L(t)}{\tau_L} \\ \frac{d}{dt}F_D(t) = r_D \cdot F_D(t) - r_L \cdot F_L(t) + \frac{B_I(t)}{\tau_B} + \frac{B_R(t)}{\tau_R} + \frac{F_D(t)}{\tau_M} - \frac{F_L(t)}{\tau_L} + \frac{W_D(t)}{\tau_W} + \frac{F_D(t)\cdot(s-1)}{\tau_S} \\ \frac{d}{dt}W_D(t) = r_D \cdot W_D(t) - \frac{W_D(t)}{\tau_W} - \frac{F_D(t)\cdot(s-1)}{\tau_S} \\ \frac{d}{dt}B_I(t) = r_L \cdot F_L(t) - r_D \cdot F_D(t) - r_D \cdot W_D(t) - \frac{B_I(t)}{\tau_B} \end{bmatrix}$$

Modelling a Credit Crunch

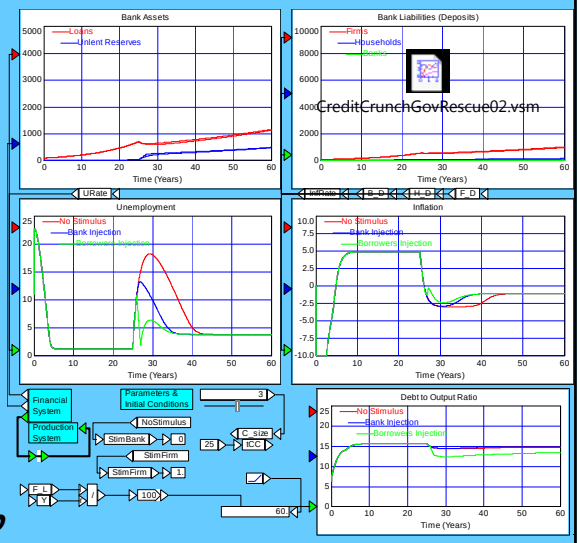
- Simple production model linked to financial flows
  - Output is Labour times productivity $Q = a \cdot L$
  - Labour is Money Wages flow divided by Money Wage rate $L = \frac{1-s}{\tau_s} \cdot \frac{F_D}{W}$
  - Wage set by Phillips curve unemployment-money wage change function $\frac{1}{W} \cdot \frac{d}{dt} W = P_h\left(\frac{L}{N}\right)$
  - Price (necessary link between $ accounts and physical output) lagged convergence to markup over monetary cost of production $\frac{d}{dt} P = \frac{1}{\tau_P} \cdot \left(P - \frac{W}{a \cdot (1-s)} \right)$
- Single sectoral model generates stable dynamics
- Can be used to consider some policy questions
  - But no cycles as yet
- Policy example—stimulus to overcome credit crunch

Modelling a Credit Crunch

- What's better? Stimulus to lenders or debtors?



- Injected into either B_R (Bank Reserves) or F_D (Firm Deposits) in simulation
- ***Stimulus far more effective if given to debtors***



Producing a multi-sectoral nonequilibrium model

- Minsky model
  - Goodwin cycles
  - Debt "ratchets up" of in series of cycles
    - With "Ponzi lending", tends towards Depression
  - But implicit money only (debt to GDP ratio)
- Graziani model
  - Explicit money
  - Monetary determination of equilibrium output
  - But no cycles
- Blending two models ***necessitates*** multi-sectoral model
  - Capital sector for purchases of investment goods
  - Easily built using "Table to Dynamic Model" technology

A Multi-sectoral monetary model

- More complicated table (2 sector version shown here):

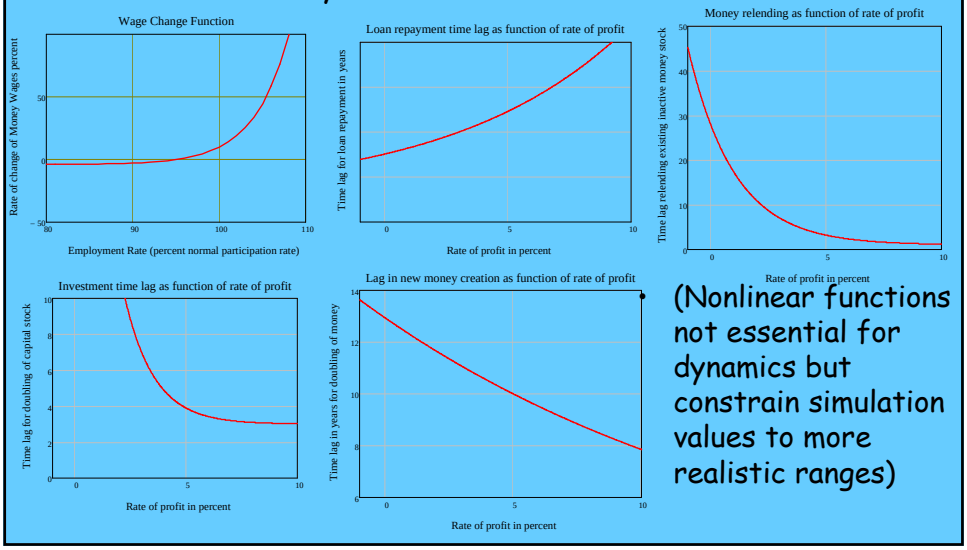
$$S_1 := \begin{bmatrix}
\text{"Type"} & 0 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & -1 & 0 \\
\text{"Name"} & \text{"BR"} & \text{"K1 L"} & \text{"K2 L"} & \text{"C1 L"} & \text{"C2 L"} & \text{"K1 D"} & \text{"K2 D"} & \text{"C1 D"} & \text{"C2 D"} & \text{"W D"} & \text{"B I"} \\
\text{"Symbol"} & B_R(t) & F_{LK1}(t) & F_{LK2}(t) & F_{LC1}(t) & F_{LC2}(t) & F_{DK1}(t) & F_{DK2}(t) & F_{DC1}(t) & F_{DC2}(t) & W_D(t) & B_I(t) \\
\text{"Compounding Debt"} & 0 & A & B & C & D & 0 & 0 & 0 & 0 & 0 & 0 \\
\text{"Deposit Interest"} & 0 & 0 & 0 & 0 & 0 & E & F & G & H & 0 & -(E + F + G + H) \\
\text{"Investment"} & 0 & 0 & 0 & 0 & 0 & -I + (J + K) & -J + (I + L) & -K & -L & 0 & 0 \\
\text{"Wages"} & 0 & 0 & 0 & 0 & 0 & -M & -N & -O & -P & M + N + O + P & 0 \\
\text{"Intersectoral Demand"} & 0 & 0 & 0 & 0 & 0 & -Q & -R & -S + (Q + T) & -T + (R + S) & 0 & 0 \\
\text{"Interest Workers"} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & U & -U \\
\text{"Pay Interest"} & 0 & -V & -W & -X & -Y & -V & -W & -X & -Y & 0 & V + W + X + Y \\
\text{"Consumption"} & 0 & 0 & 0 & 0 & 0 & -Z & -AA & -AB + \left(Z + AC + \frac{AD + AE}{2}\right) & -AC + \left(AA + AB + \frac{AD + AE}{2}\right) & -AD & -AE \\
\text{"Repay Loans"} & AF + AG + AH + AI & -AF & -AG & -AH & -AI & -AF & -AG & -AH & -AI & 0 & 0 \\
\text{"Recycle Reserves"} & -(AJ + AK + AL + AM) & AJ & AK & AL & AM & AJ & AK & AL & AM & 0 & 0 \\
\text{"New Money"} & 0 & AN & AO & AP & AQ & AN & AO & AP & AQ & 0 & 0
\end{bmatrix}$$

- Capital and Consumer Goods Sectors
  - All sectors in 2 halves to force recording of intra-sectoral monetary purchases
- Investment & inter-sectoral demand
- Time lags are time-varying functions of rate of profit rather than constant parameters

$$\begin{pmatrix} I \\ J \\ K \\ L \end{pmatrix} := \overrightarrow{\begin{bmatrix} F_{Deposits} \div \begin{pmatrix} \tau_{pr}(pr_K(t)) \\ \tau_{pr}(pr_K(t)) \\ \tau_{pr}(pr_C(t)) \\ \tau_{pr}(pr_C(t)) \end{pmatrix} \end{bmatrix}} \rightarrow \begin{pmatrix} \frac{F_{DK1}(t)}{\tau_{pr}(pr_K(t))} \\ \frac{F_{DK2}(t)}{\tau_{pr}(pr_K(t))} \\ \frac{F_{DC1}(t)}{\tau_{pr}(pr_C(t))} \\ \frac{F_{DC2}(t)}{\tau_{pr}(pr_C(t))} \end{pmatrix}$$

A Multi-sectoral monetary model

- More complex financial model results
  - Constrained by nonlinear behavioural relations



(Nonlinear functions not essential for dynamics but constrain simulation values to more realistic ranges)

A Multi-sectoral monetary model

- Allied to lagged Goodwin growth cycle production model
  - Investment minus Depreciation determines Capital

$$\frac{d}{dt}K_{K1}(t) = \frac{F_{DK1}(t)}{\tau_{pr}(pr_K(t)) \cdot P_{K1}(t)} - \gamma \cdot K_{K1}(t)$$

  - Output function of capital stock $\frac{d}{dt}Q_{K1}(t) = \frac{-1}{\tau_{QK}} \cdot \left[Q_{K1}(t) - \frac{1}{v_K} \cdot (K_{K1}(t)) \right]$
  - Employment function of output $\frac{d}{dt}L_{K1}(t) = \frac{-1}{\tau_{LK}} \cdot \left(L_{K1}(t) - \frac{Q_{K1}(t)}{a_K(t)} \right)$
- Model of financially driven cyclical economy
  - Simulations shown here lead to sustained cycles
    - (No speculative debt in model as yet)
- Overall system very complex
  - But easily simulated in modern software
  - Scales indefinitely (more sectors easily added)

A Multi-sectoral monetary model

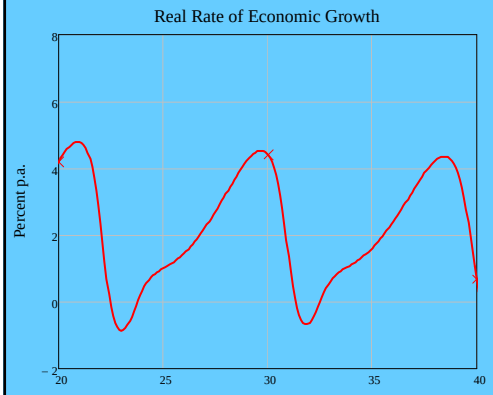
- Model requires minimum of
  - *4n+3* financial ODEs
  - *2n* Loan & *2n* Deposit
  - Bank Income
  - Bank Reserves
  - Household Deposit
- *5n* sectoral equations
  - capital, output, labour, prices, productivity
- 1 population equation
- 40 ODEs in this 4 sector model

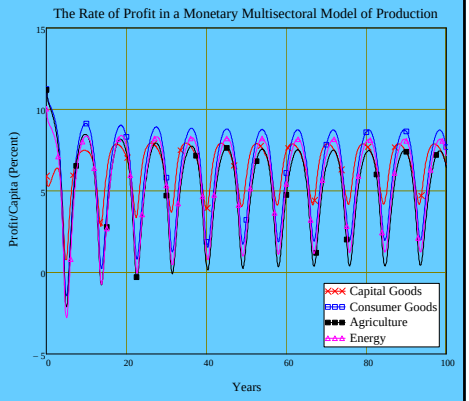
A Multi-sectoral monetary model

- Notional Sectors in system shown here:
  - Capital Goods
  - Consumer Goods
  - Agriculture
  - Energy
- Generates complex endogenous cycles in income shares, output, credit, employment—just like actual economy
  - No need for "exogenous shocks"
    - Though can also be added in future
- Not yet fitted to empirical data
  - But ***qualitative*** behaviour of model matches "stylised facts" of (credit-driven) business cycle

A Multi-sectoral monetary model of production

- Endogenous cycles…

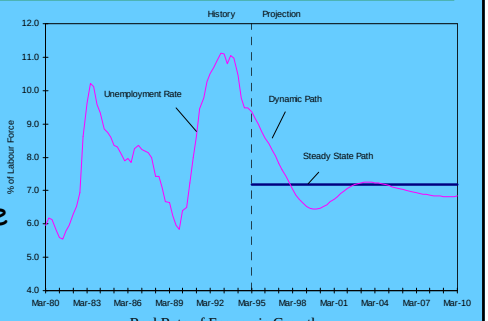


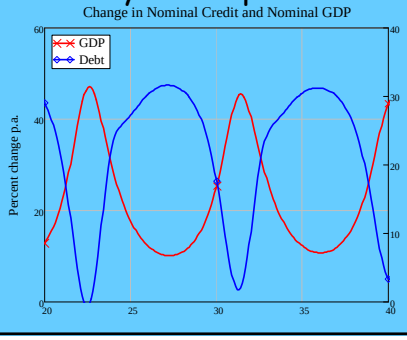


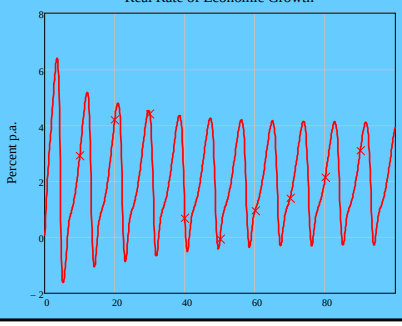
- Cycles similar to stylised facts of business cycle
  - Long accelerating boom
  - Sudden slump
  - Tepid recovery before next boom

A Multi-sectoral monetary model of production

- With equilibrium models
  - History cyclical
  - The future equilibrium…
- With non-equilibrium model, projections look like history
  - Cycles in past & future

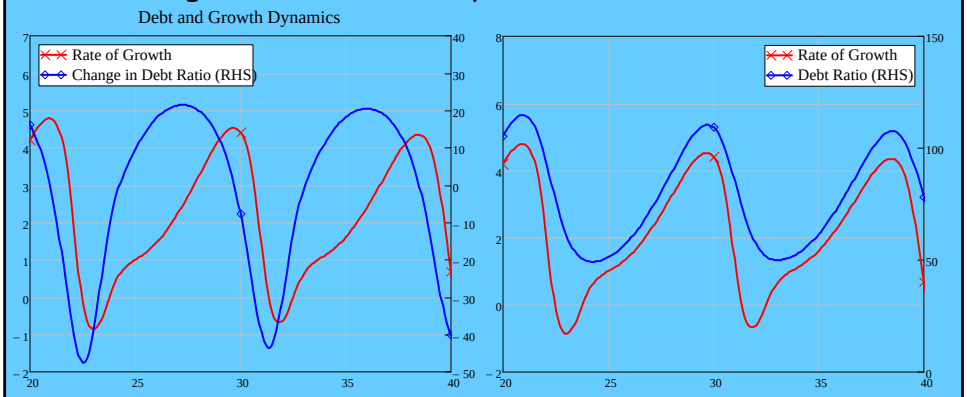






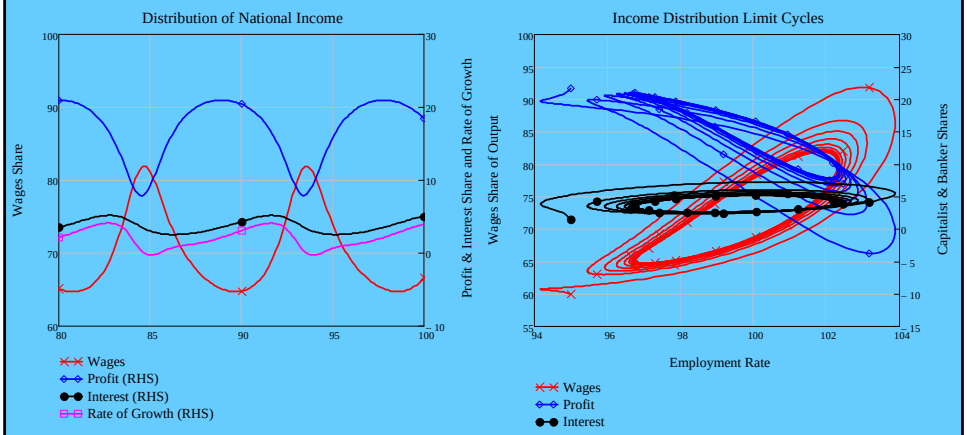
A Multi-sectoral monetary model of production

- Crucial role of credit
  - Change in credit leads cycle



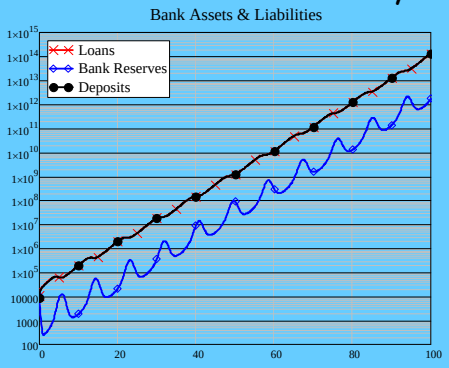
A Multi-sectoral monetary model of production

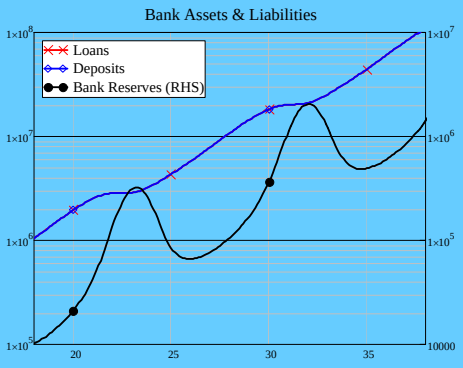
- Income distribution cycles…



A Multi-sectoral monetary model of production

- Crucial role of monetary variables





- Simulation show here generates "stable instability"
  - Cycles but not breakdown
- Different parameters can generate
  - Convergence to stability; or
  - Financial collapse (Great Depression)

A Multi-sectoral monetary model of production

- Crucial characteristic that cycles are endogenous
  - General ***Disequilibrium*** as hallmark of a good model
- "Instability is an observed characteristic of our economy.
- For a theory to be useful as a guide to policy for the control of instability, the theory must show how instability is generated.
- The abstract model of the neoclassical synthesis cannot generate instability..."
  - (Minsky, "Can "It" Happen Again? A Reprise")

Future development of model

- First "meteorological" model of capitalism
  - Causal dynamics rather than equilibrium assumptions
  - Realistic non-equilibrium multi-sectoral production
  - Designed for rising realism/complexity over time
- Parameter calibration of nonlinear, disequilibrium model
  - Two approaches to data fitting feasible
    - Fit functions and selected empirical data
    - Fit overall model and generate realistic nonlinear functions, lags, etc. from that
- Develop to generate alternative scenarios
  - *All will include cyclical, non-equilibrium future*
- Enable automatic generation of higher-dimensional multisectoral models