Nelson and Winter-like models of industrial dynamics as a starting point

ETIC PhD course

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Main contents

- **1. Nelson and Winter,s start-up of evolutionary modelling**
  - In growth theory and industrial dynamics
- **2. The basic set-up of the model**
- **3. Specification of a simple NewlWin model**
  - With some details
- **4. NelWin and the art of computer simulation**
  - Through a worked-out example
- **5. Starting an evaluation...**

1. Nelson and Winter,s start-up of evolutionary modelling

Nelson and Winter made precise Schumpeterian causation through an evolutionary synthesis including:

- 1. Behavioural patterns and their transmission.
- 2. Creation of new behavioural patterns.
- 3. Different types of selection mechanisms.

More specifically, they combined:

- 1. Simon’s work on rules and satisficing behaviour.
- 2. Nelson’s and other ‘Schumpeterian’ work on invention and innovation.
- 3. Alchian’s and Winter’s work on ‘natural selection’.

The structure of Nelson and Winter: *An Evolutionary Theory of Economic Change* (Harvard UP, 1982)

- Part I: Overview and Motivation
- <u>Part II: Organization-Theoretic Foundations of Economic Evolutionary Theory</u>
- Part III: Textbook Economics Revisited
- <u>Part IV: Growth Theory</u>
- <u>Part V: Schumpeterian Compatition</u>
- Part VI: Economic Welfare and Policy
- Part VII: Conclusion

Some modelling tasks of Nelson and Winter

Growth theory

- Solow presented data on economic growth in the US and ‘explained’ it by

  $Q_t = A_t K_t^a L_t^b$ where the movement of A is exogeneous

- N&W gives a ’better’ (more ‘realistic’) explanation by simulating an evolutionary process where firms are innovation and imitating. Thus there is an endogenous movement of A based on the micro level:

  $$Q_{jt} = A_{jt} K_{jt}$$

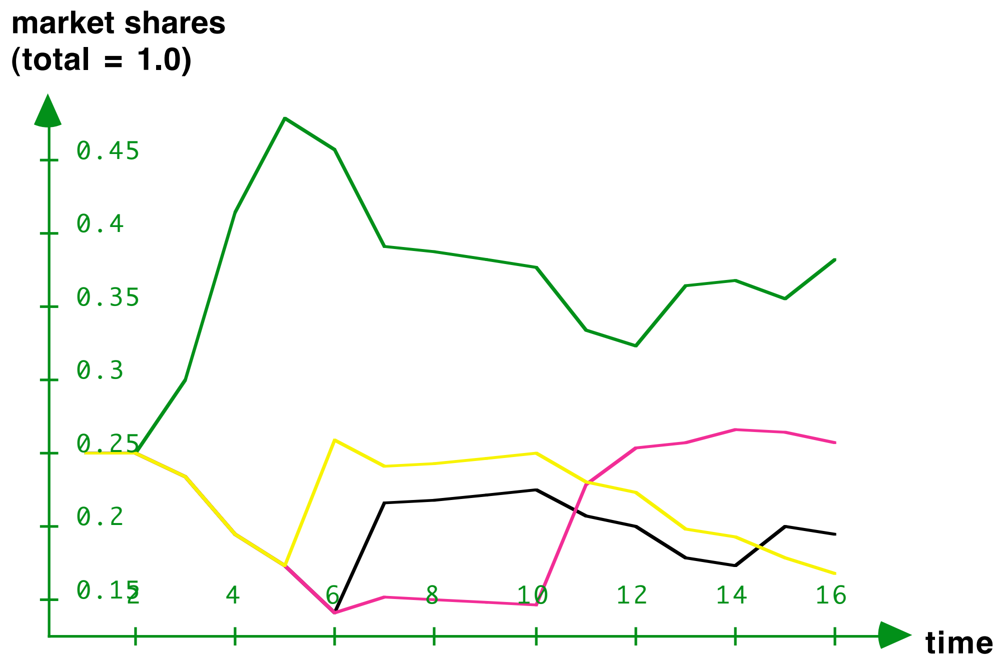
  $$Q_t = \sum_{j=1}^{n} Q_{jt}$$

Industrial dynamics

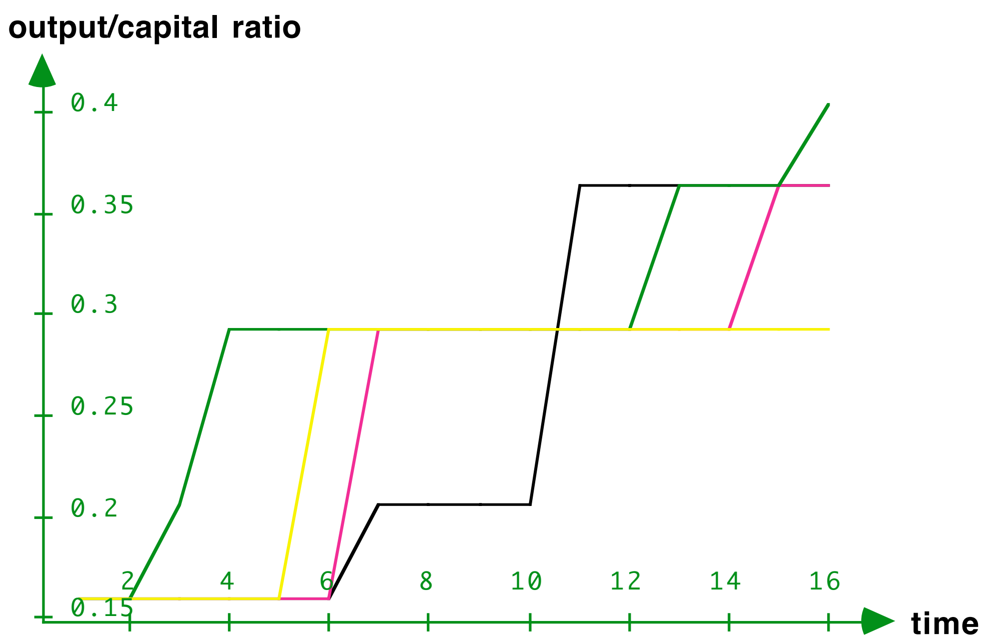
- The evolutinary growth model translates easily to a model of Schumpeterian competition within an industry that produces a homogenous product. Here are many uses of the evolutionary model, e.g.
  - Within each industry there is normally a survival of firms with different strategies with respect to innovation and imitation. Show this with an evolutionary simulation model and estimate the parameters
  - Give an evolutionary explanation of the size distribution of firms of industries under different technological regimes
  - Explain why the role of external finance is often limited in simple industrial dynamics and specify conditions under which it is important
  - Make a ‘history-friendly’ evolutionary model of the stylised development of the automobile industry and the computer industry

The productivity race in NelWin models

Market shares



Productivity levels



The Nelson and Winter family of simulation models

– Simulation models from Nelson and Winter (1982)

I. Growth models **(see Silverberg/Verspagen, 1995)**

- (1) NelWin76
  - – presented in ch. 9: ‘An Evolutionary Model of Economic Growth’
  - - reproduces Solow’s growth data in a more ‘realistic’ way than through Solow’s own growth model)

II. Models of industrial dynamics **(see Andersen, 1996)**

- (2) NelWin77
  - – presented in ch. 12: ‘Dynamic Competition and Technical Progress’
  - - analyses the competition between innovators and imitators in a process of 'Schumpeterian competition' (Schumpeter Mark II)
- (3) NelWin78
  - – presented in ch. 13: ‘Forces Generating and Limiting Concentration under Schumpeterian Competition’
  - - analyses how concentration and macroproductivity is influenced by the conditions of innovation and imitation, and by investment strategies
- (4) NelWin82
  - – presented in ch. 14: ‘The Schumpeterian Tradeoff Revisited’
  - - analyses the trade-off between static efficiency and dynamic efficiency (based on some degree of market power)
- (5) NelWin84
  - – presented in Winter (1984): ‘Schumpeterian Competition in Alternative Technological Regimes’

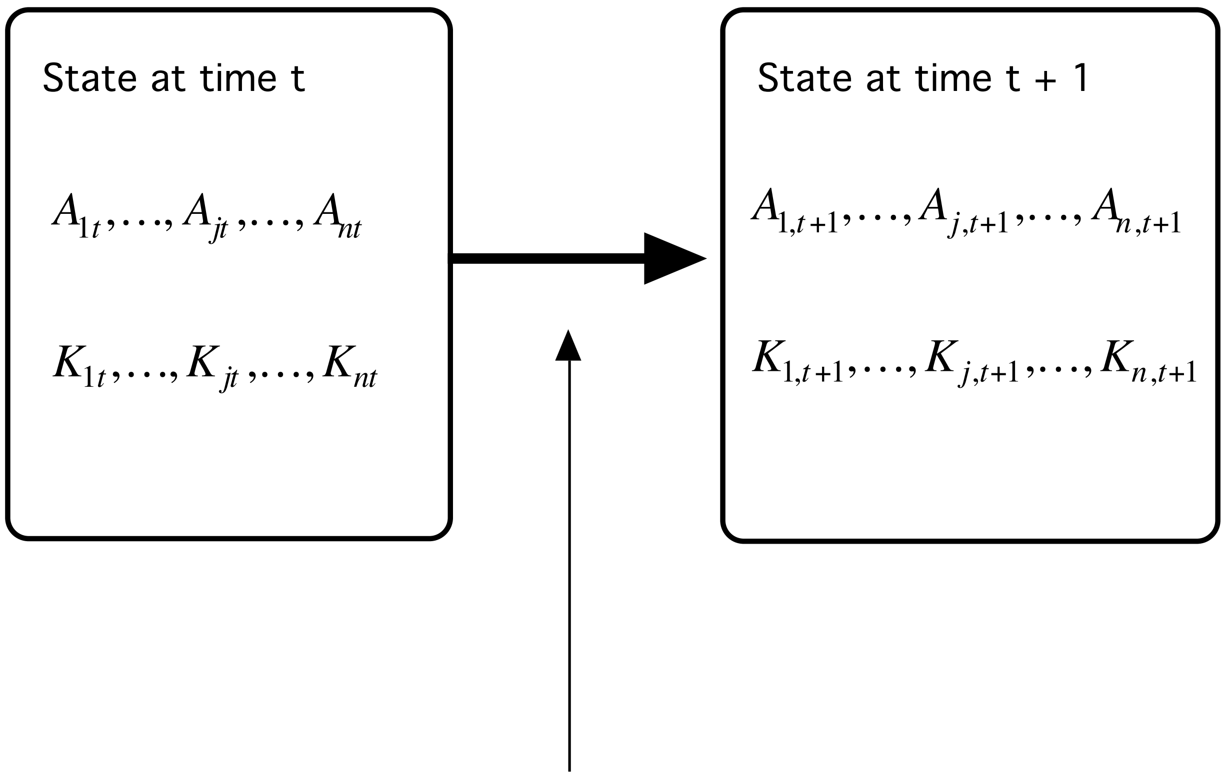
Core assumptions

NelWin modelling is typically using the following assumptions:

- 1. The agents (firms and organisations) can never be perfectly informed and they have (at best) to optimise locally rather than globally.
- 2. The normal decision-making of firms is bound to routines or rules, and it is influenced by institutions (also implemented ad routines of e.g. banks)
- 3. Firms are to some extent able to imitate the rules of other firms, to learn for themselves and to create novelty.
- 4. The firm's processes of imitation and innovation are often characterised by significant degrees of cumulativeness and path-dependence, but they may also be determined by the exogenous movement of science.
- 5. The interactions between the firms are typically made in disequilibrium situations, and the result is successes and failures of firms and their underlying routines.
- 6. The processes of change occurring in a context described by the above assumptions and characteristics are non-deterministic, open-ended and often irreversible.
- 7. The tools of standard economics can often help to discuss potential equilibria of the evolutionary process, but they may easily distract attention from the core task - to understand the manifold questions about disequilibrated processes

2. The basic set-up of the model

Basic specification:



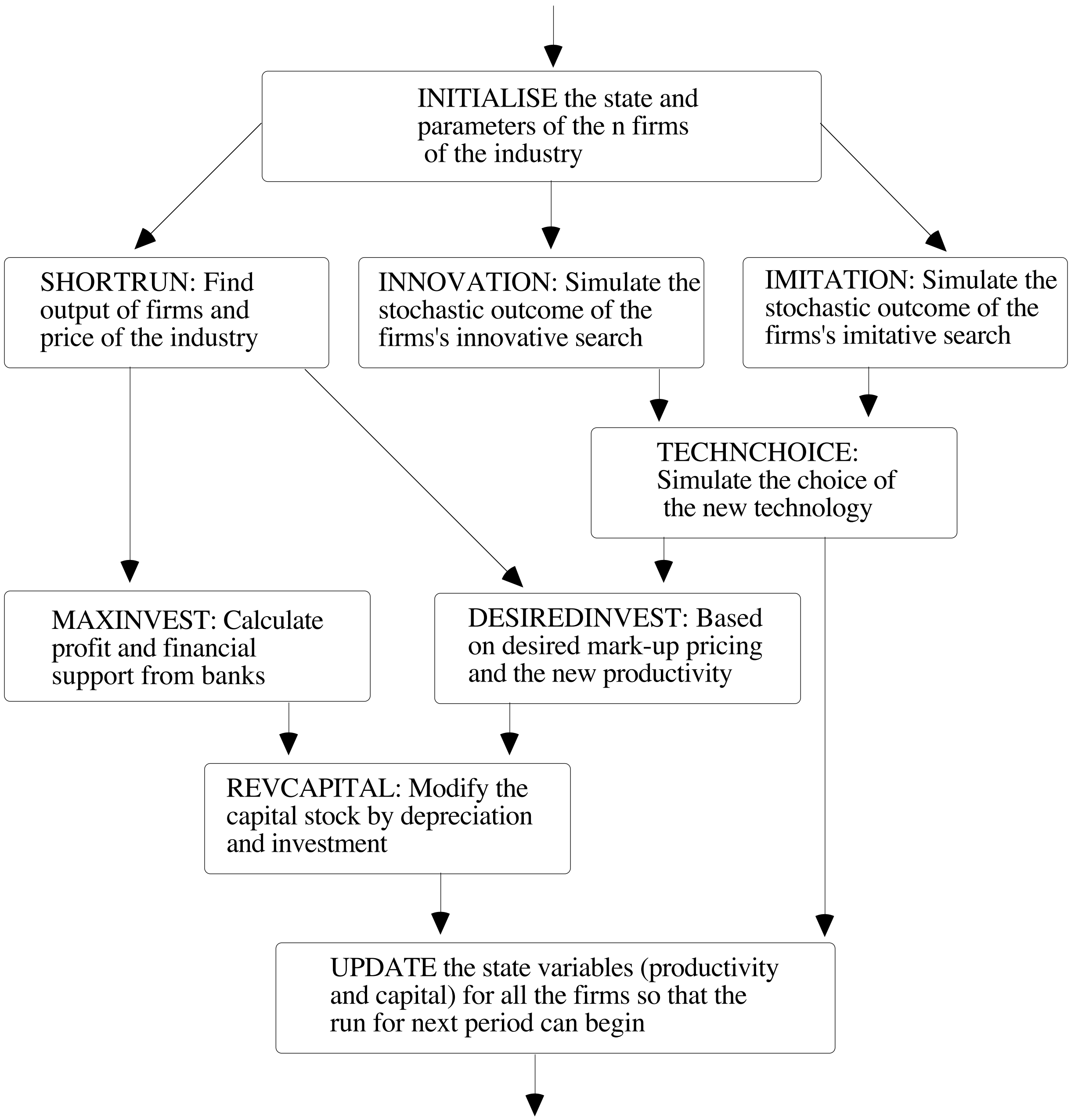
Complex transition rule with stochastic change of A
and deterministic change of K
Determined by a lot of decision 'routines'
(parameters), e.g. R&D intensity per unit of capital,
capacity utilisation etc.

Extending the model by introducing new evolving variables

- E.g. R&D intensity in the model by Silverberg and Verspagen

The transition rules implemented as a NelWin simulation model

The basic procedures in a NelWin model:



Main elements of the NelWin model (I)
SHORTRUN

The demand side

- The simplest possible assumption is normally chosen:
  - consumers always pays the same sum (D) for the goods of the industry
    - Recently an interest is emerging in more interesting - even evolving - specification of demand is being researched

Short-term supply

- In the short term the firm's A and K is given
- Production is determined by the firm's fixed capacity ulitisation role (e.g. full capacity utilisation)
- Since the firm operate under constant returns to scale, it produces $Q=AK$
  - On this basis we find in a simplistic way the costs of the firm
- Total supply is found by simple aggragation of the firms' output

Market price

- The market always clears, so that the total supplied quantity is sold
- The market price in each period is then simple $P = D/Q$
- Given this price, the firms can calculate their profits

Main elements of the NelWin model (II) MAXINVEST, DESIREDINVEST, REVCAPITAL

Desired investment

- Determined by the actual mark-up of price over costs and the desired mark-up that is determined by the firm's market share (if low market share, no mark-up pricing)

Financial constraint

- The firm has a financial constraint determined by internal and external funds. The finance is determined by the profits. If they are positive, they are multiplied with a factor larger than one.

Investment at fixed capital costs

Physical capital decrease gradually due to simple depreciation.

Main elements of the NelWin model (III)
INNOVATION, IMITATION, TECHNOCHOICE

R&D and productivity evolution

- Capital productivity is determined by firm-specific knowledge
- Innovation and imitation are the result of R&D activities
- The R&D intensity of a firm (per unit of capital) is determined by a fixed rule (but it is easy to let it evolve - see Winter, Silverberg)

Research gives proportional probabilistic results in two steps

- First, it is determined whether the firm will have a result (accoding to a Poisson process)
- Second, the productivity of the result is found
  - In the case of imitation it is best-practice technology
  - In the case of innovation the result is drawn from a normal distribution
  - Mean value either the level of general science or the productivity level of the sucessful firm

Comments

- The issue of innovation is rather well thought out
- The issue of imitation is more dubious.
  - Later Nelson and Winter participated in the Yale survey that demonstrated that imitation is often nearly as complicated as innovation.
  - NelWin also uses a primitive innovation and diffusion approach. But diffusion includes innovative problems.

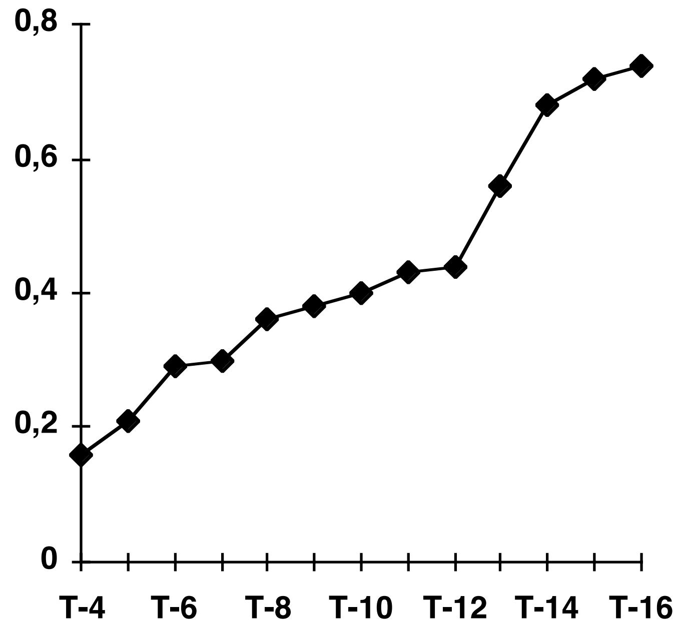
The concept of search spaces

R&D is considered as search in a search space

- Simplistic search space – basically search for production algorithms (disembodied production techniques) measured in one or two dimentions
- Algorithms are measured by capital productivity (the output/capital ratio). Techniques are ordered and named by integer numbers.

The evolution can most easily be studied if we introduce a discretely organised search space

- The search landscape has steep hills where there is a big jump from one technology to the next.
- This means that the probability that a firm will manage the jump is much smaller than for smooth parts of the landscape…



- A more interesting search space is presented in NelWin76 (the growth model).
  - Here a techniques are characterised by their capital productivity as well as its labour productivity. Firms have a somewhat more complex task when they choose between two technologies (including factor prices).

3. Specification of a simple NelWin model (I)

1. Initialisation, period 1 (and 0)

$K_{j1} = K^{\text{INIT}}$ (physical capital stock)

$A_{j1} = A^{\text{INIT}}$ (capital productivity)

$c_j = r + \delta + v + r_j^{\text{IM}} + r_j^{\text{IN}}$ (misc. costs per unit of capital)

<u>if</u> $\mathit{ScienceBased} = \text{true}$

<u>then</u> $\mu_0^{\text{IN}} = A^{\text{INIT}}$ (mean value for innovative draws)

2. SHORTRUN: Short-run market process, period t

$Q_{jt} = A_{jt} K_{jt}$ (individual outputs)

$Q_t = \sum_{j=1}^{n} Q_{jt}$ (total output)

$s_{jt} = Q_{jt} / Q_t$ (markets shares)

$P_t = D / Q_t$ (market price)

$\pi_{jt} = P_t A_{jt} - c_j$ (individual profits per unit of capital)

Specification of a simpel NewWin model (II)

3. IMITATION, period t

$A_t^{\text{MAX}} = \max(A_{jt})$ (best - practice tecnnique)

$R_{jt}^{\text{IM}} = r_j^{\text{IM}} K_{jt}$ (size of imitative R & D)

$\lambda_{jt}^{\text{IM}} = d^{\text{IM}} R_{jt}^{\text{IM}}$ (average number of imi draws for Poisson process)

$N_{jt}^{\text{IM}} = \text{Poisson}(\lambda_{jt}^{\text{IM}})$ (actual number of imi draws in period t)

if $N_{jt}^{\text{IM}} > 0$ then $A_{jt}^{\text{IM}} = A_t^{\text{MAX}}$

else $A_{jt}^{\text{IM}} = 0$ (outcome of imi R & D in period t)

4. INNOVATION, period t

$R_{jt}^{\text{IN}} = r_j^{\text{IN}} K_{jt}$ (size of innovative R & D)

$\lambda_{jt}^{\text{IN}} = d^{\text{IN}} R_{jt}^{\text{IN}}$ (average number of inno draws for Poisson process)

$N_{jt}^{\text{IN}} = \text{Poisson}(\lambda_{jt}^{\text{IN}})$ (actual number of inno draws in period t)

if $N_{jt}^{\text{IN}} = 0$ then $A_{jt}^{\text{IN}} = 0$

else FindResult (find outcome of inno R & D in period t)

if $ScienceBased$ = true then $\mu_{jt}^{\text{IN}} = A_{jt}$ (mean value for cumulative technology)

else $\mu_t^{\text{IN}} = (1+g)\mu_{t-1}^{\text{IN}}$ (mean value for science - based technology)

for i from 1 to x do $N_{jt}^{\text{IN}} = \text{Normal}(\mu_{jt}^{\text{IN}}, \sigma)$ (outcome of successes in inno R & D)

$A_{jt}^{\text{IN}} = \max(A_{ijt}^{\text{IN}})$ (overall outcome of successes)

Specification of a simpel NelWin model (III)

5. TECHNOCHOICE: Selection and implementation of techniques, period t

$$A_{j,t+1} = \max(A_{jt}, A_{jt}^{\mathrm{IM}}, A_{jt}^{\mathrm{IN}}) \quad \text{(technique for period } t+1)$$

- Problems:
  - Do firms have precise knowledge?
  - Will a given technique improve over time?
  - Can a new technique be implemented immediately?

6. MAXINVEST, DESIREDINVEST, REVCAPITAL: Change in physical capital, period t

$$\delta = \text{fixed rate of depreciation}$$

$$m_{j,t+1}^{\mathrm{EXPECT}} = \frac{P_t A_{j,t+1}}{c_j} \quad \text{(markup expected in next period)}$$

$$m_{j,t+1}^{\mathrm{DESIRE}} = \frac{\eta - s_{jt}}{\eta - 2s_{jt}} \quad \text{(markup desired in next period)}$$

$$\text{if } m_{j,t+1}^{\mathrm{DESIRE}} \le m_{j,t+1}^{\mathrm{EXPECT}} \text{ then } I_{jt}^{\mathrm{DESIRE}} > 0$$

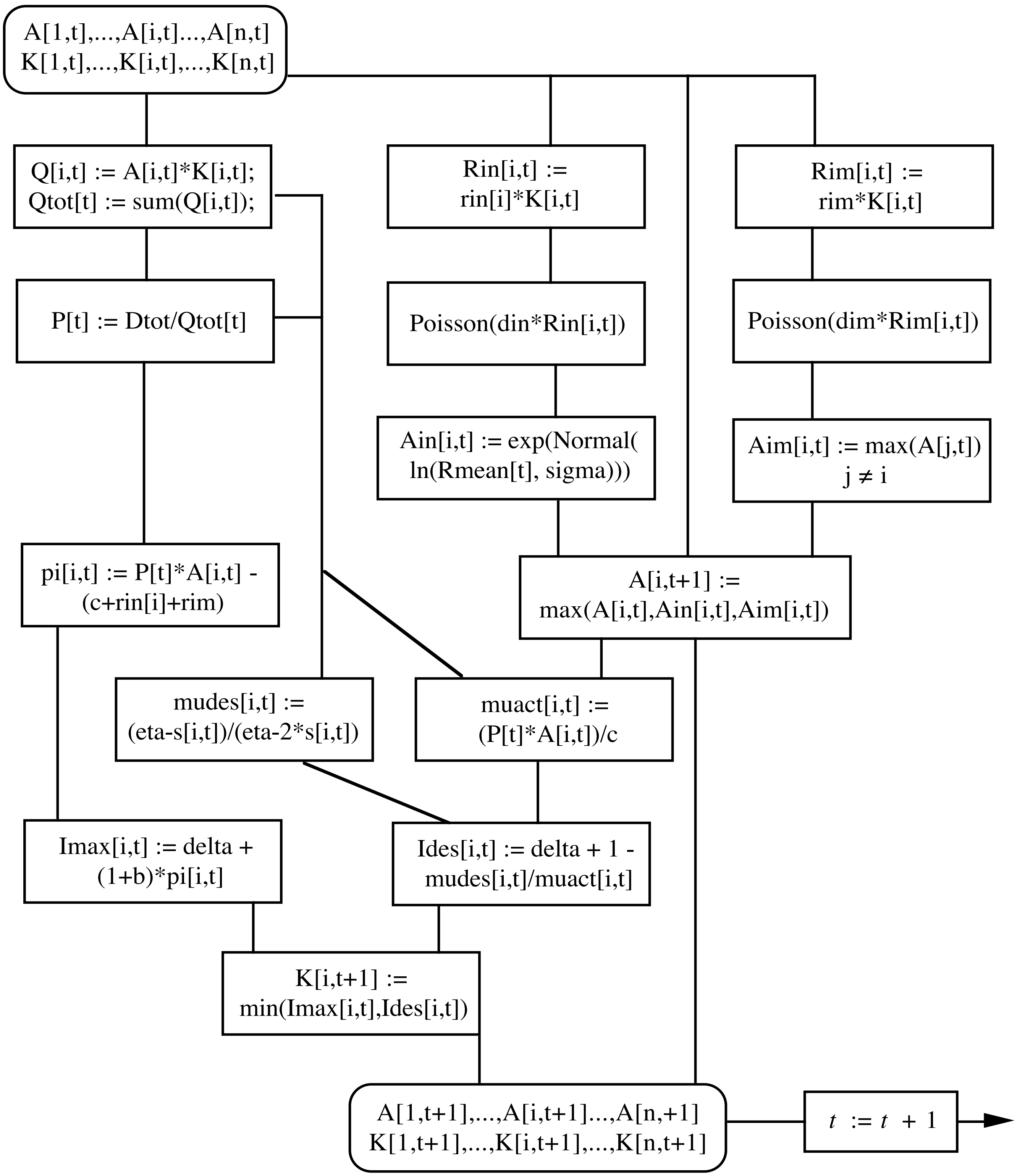
$$\text{else } I_{jt}^{\mathrm{DESIRE}} = 0 \quad \text{(full specification of desired invest elsewhere)}$$

$$I_{jt}^{\mathrm{MAX}} = \delta + (1+b)\pi_{jt} \quad \text{(financial constraint based on bank rule } b)$$

$$I_{jt} = \max[0, \min(I_{jt}^{\mathrm{DESIRE}}, I_{jt}^{\mathrm{MAX}})] \quad \text{(actual investment)}$$

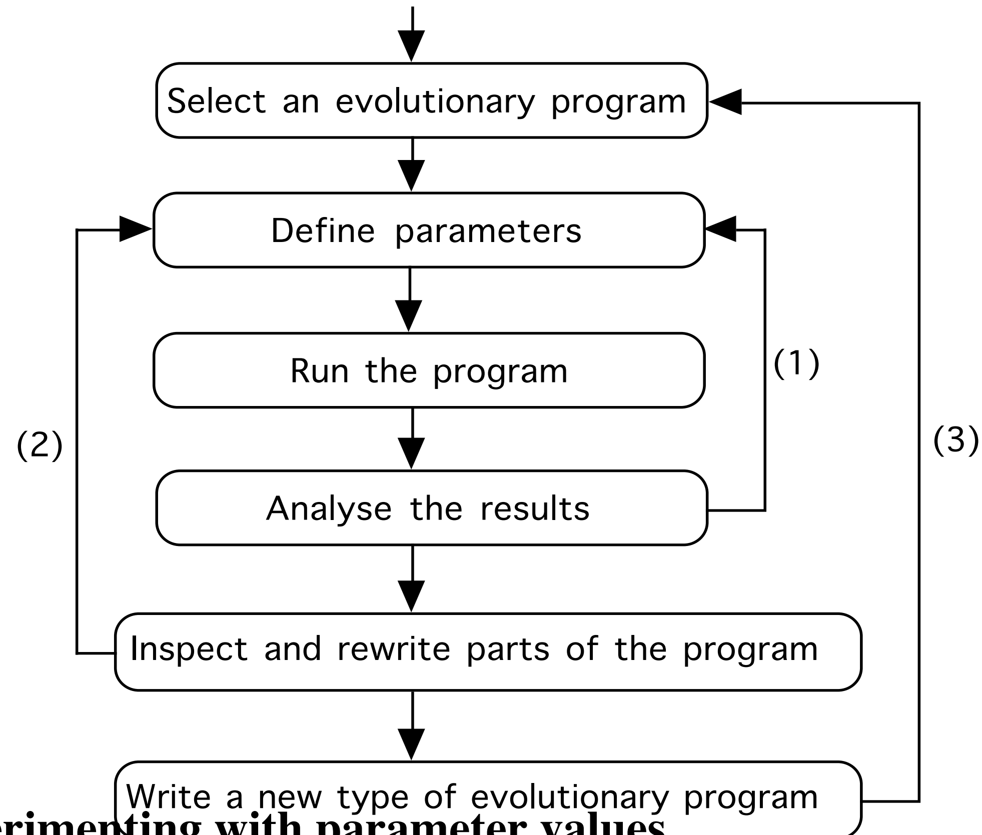
$$K_{i,t+1} = K_{jt}(I_{jt} + 1 - \delta) \quad \text{(physical capital in period } t+1)$$

Overview over a possible specification



4. NelWin and the art of computer simulation

The structure of ambitious computer lab exercises



(1) Experimenting with parameter values

How does the model work? -> systematic experiments

I think I know how it works -> test hypotheses

Correct evolutionary explanation? -> empirical validation

(2) Experimenting with program components

Often parameters are hidden in program lines

Even larger blocks of the program should be considered as parameters

Too many simultaneous changes may give a meaningless model

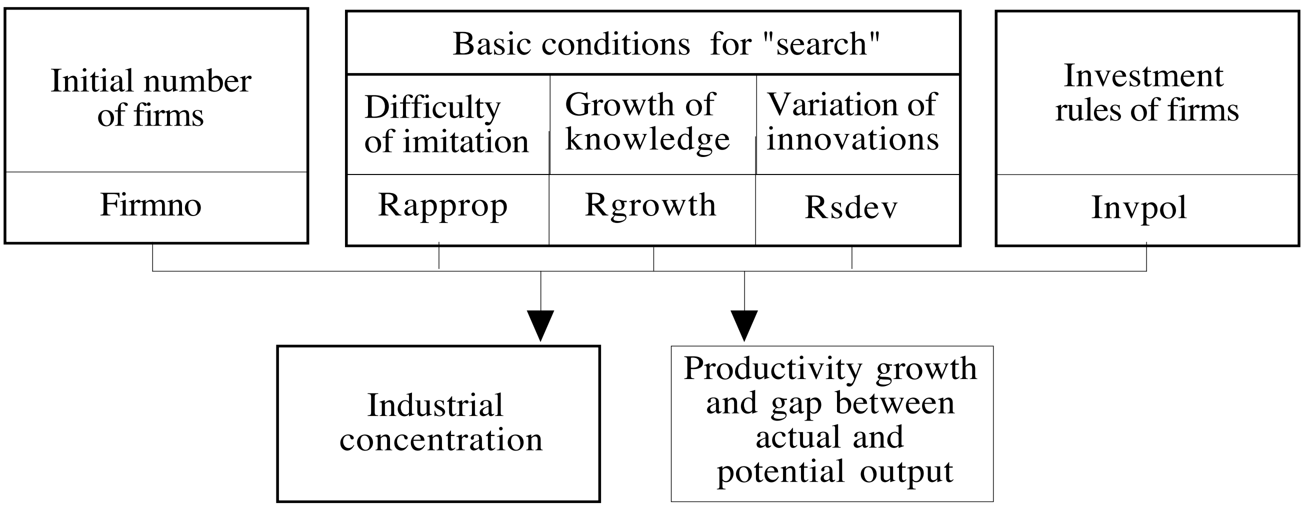
(3) Producing new models from old ones

New models are often developed from old ones - although the model history is seldom published

After the experiments with an initial prototype, the model and the program should be redesigned from scratch

Ad 1. A worked-out example of parameter experiments - using NelWin78

The causal structure:



Measurement of dependent variables:

- **industrial concentration by the Herfindahl index of the market shares:**

$$H_t = \sum_{i=1}^{n} s_{it}^2 ,$$

the reciprocal shows the number of equally sized firms that have the same Herfindahl index as the actual industry

- **average productivity**
- **gap between actual and potential production**

$$Q_t^{\text{gap}} = \frac{\sum_{i=1}^{n} A_{it} K_{it}}{\sum_{i=1}^{n} A_t^{\max} K_{it}},$$

Definition of independent variables (0=low, 1=high):

(1) Firmno = the initial number of firms

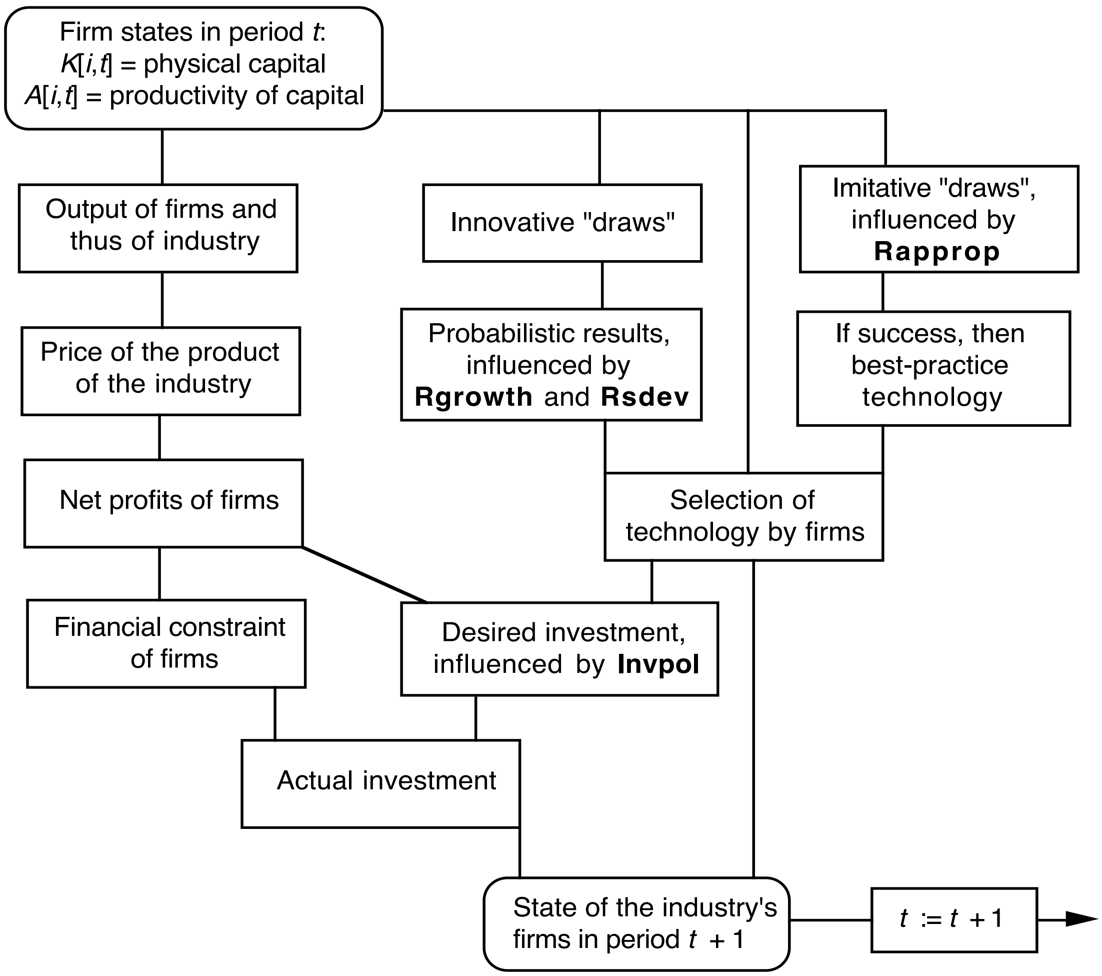
(2) Rapprop = the approproability of innovations or the difficulty of imitation

(3) Rgrowth = the exogeneously given growth in the mean productivity of innovations

(4) Rsdev = the spread of the actual innovations around this mean

(5) Invpol = the aggressiveness by which a productivity advantage is followed up by expansion of production capacity.

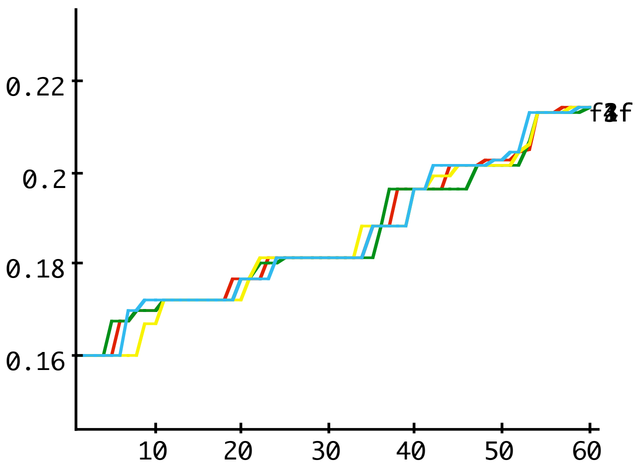
Relating to the structure of NelWin78



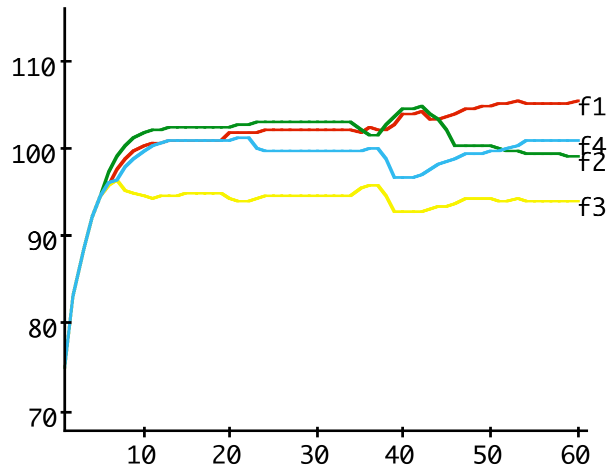
Firm-level results (I)

Firm variables for a typital Nelson and Winter simulation - with easy imitation

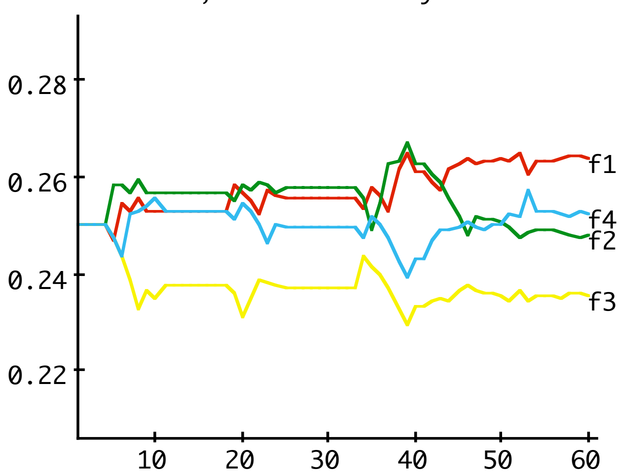
Productivity, imitation easy



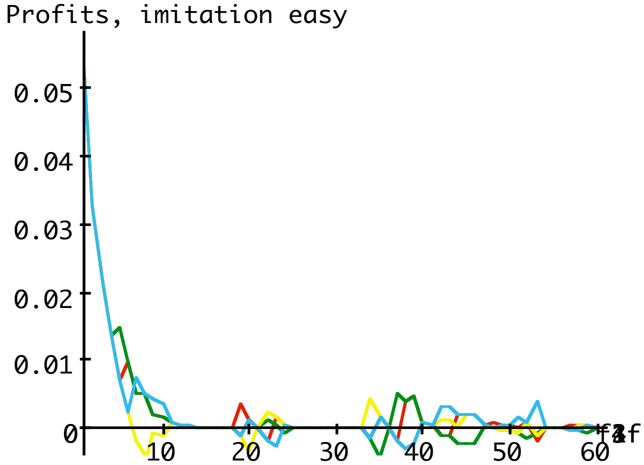
Capital, imitation easy



Market shares, imitation easy



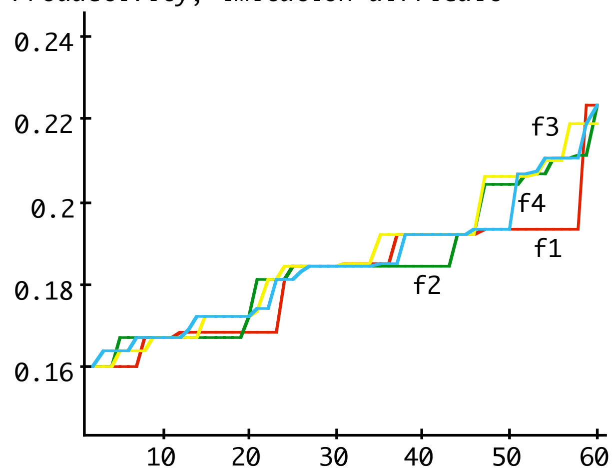
Profits, imitation easy



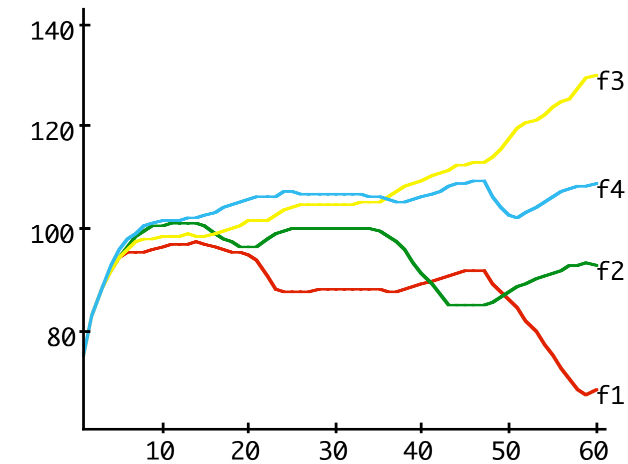
Firm-level results (II)

Firm variables for a typital Nelson and Winter simulation - with difficult imitation

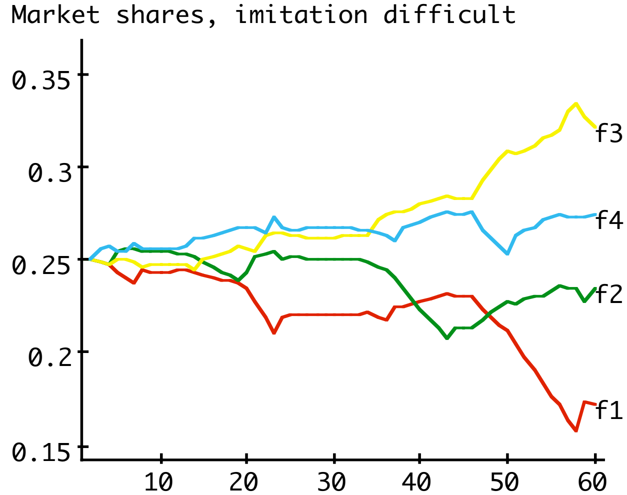
Productivity, imitation difficult



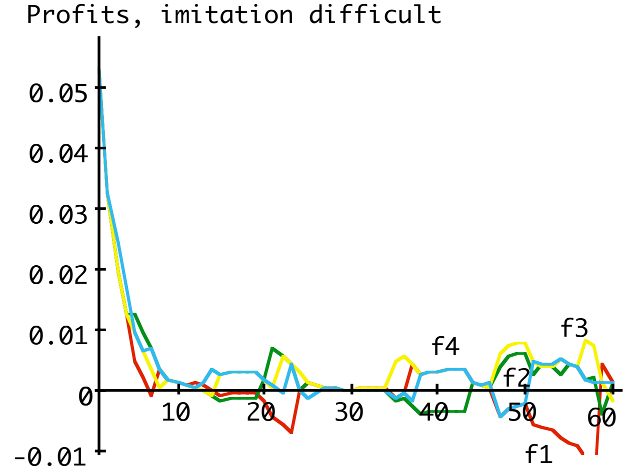
Capital, imitation difficult



Market shares, imitation difficult

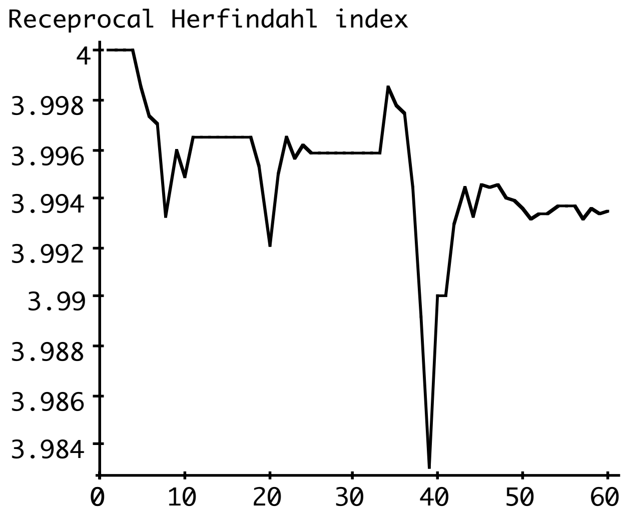


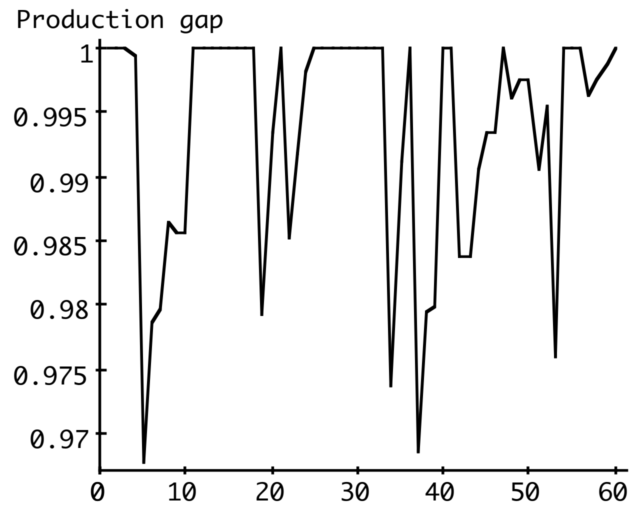
Profits, imitation difficult



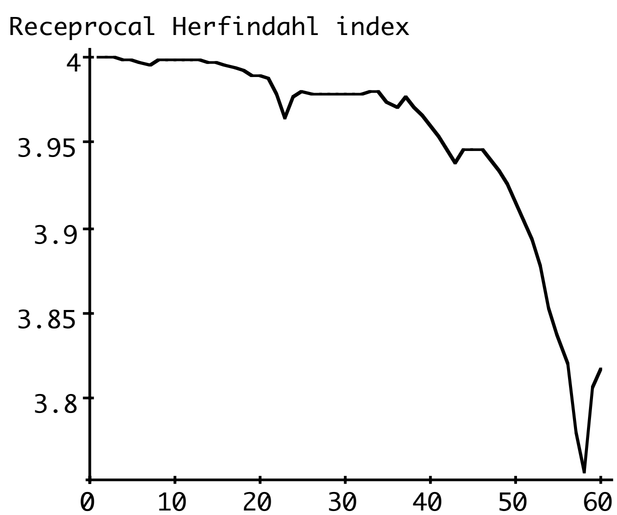
Industry-level results (I)

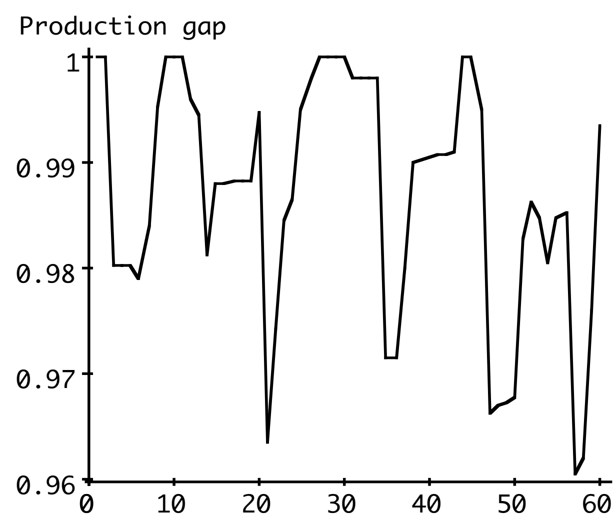
Concentration and production gap for simulations with easy imitation





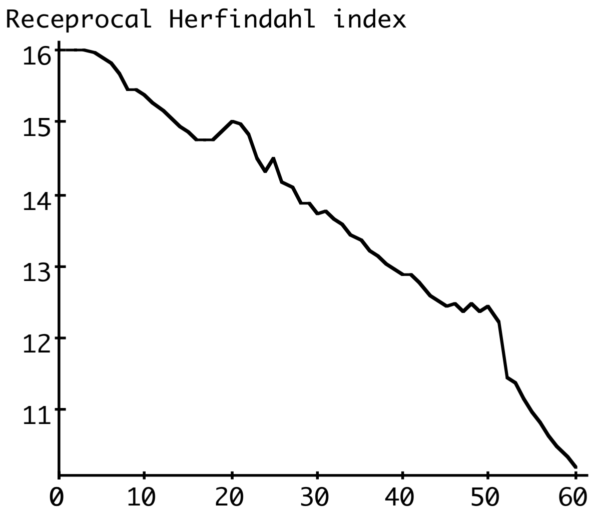
Concentration and production gap for simulations with difficult imitation

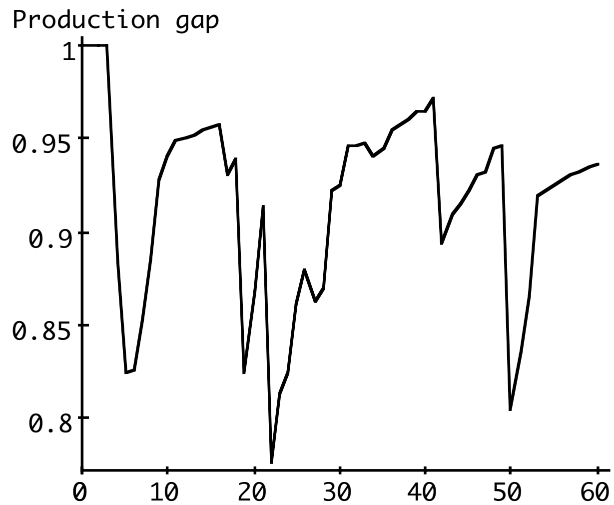




Industry-level results (II)

Concentration and production gap for simulations with difficult imitation and rapid growth of latent productivity





Industry level - Statistical analysis

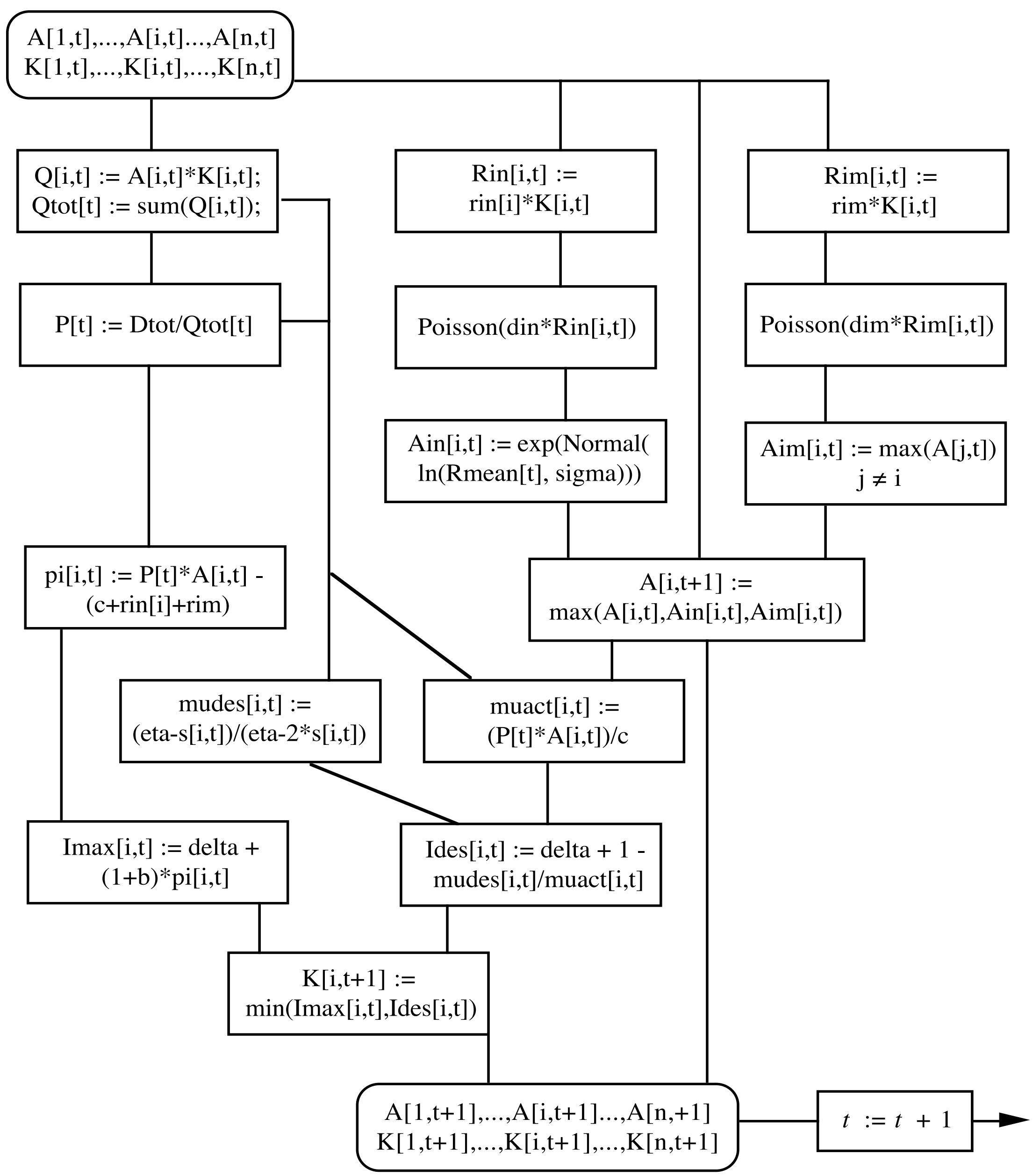
Nelson and Winter's article versus NelWin78 final-period concentration: 101 periods and 4 firms

Experimental condition (binary code)	Reciprocal Herfindahl index N&W's single value (1978, 533)	Reciprocal Herfindahl index Mean of 5 runs with NW78binary
0000	4.000	3.999 (.0015)
0001	3.9995	3.993 (.0011)
0010	3.998	3.994 (.0057)
0011	3.973	3.981 (.0233)
0100	4.000	3.994 (.0106)
0101	3.997	3.994 (.0052)
0110	3.978	3.988 (.0083)
0111	3.998	3.977 (.0212)
1000	3.976	3.961 (0.0446)
1001	3.719	3.894 (0.1189)
1010	3.611	3.526 (0.4149)
1011	3.794	3.557 (0.3436)
1100	3.701	3.780 (0.2309)
1101	3.849	3.553 (0.2253)
1110	2.353	3.378 (0.3997)
1111	2.489	3.303 (0.5070)

Ad 2. Experimenting with minor program changes - using NelWin84

NelWin routines are theoretically complex, but computationally simple

Routines are often parameters, but they could be changed to simple functions or to complex program procedures



Simple changes in routines for short-term decisions and evaluation of results

- **Capacity utilisation rule (implicitly = 1)**

  A simple change:

$$Q_{jt} := A_{jt} K_{jt};$$

$$\xrightarrow{\text{changed to}} Q_{jt} := u A_{jt} K_{jt};$$

simulations: does u matter?

prepares for making u a function of s

prepares for making u an evolving variable

- **Costs and profits**

c costs per unit of capital, v variable costs,
r capital rental, d capital depreciation
π[jt] economic profit per unit of capital
R research effort per unit of capital

$$c := v + r + \delta;$$

$$\pi_{jt} := P_t A_{jt} - c - R^{\text{inno}} - R^{\text{imi}};$$

should capital depreciation be a function of productivity growth?

should research be a function of market share?

should research be included in profit calculations?

Changing the rules on physical capital

K_{jt} given

δ fixed rate of capital depriciation

b the routine rule of the financial system

$$I_{jt}^{\max} := \delta + (1+b)\pi_{jt}; \xrightarrow{\text{make be more interesting}} ?$$

$$I_{jt}^{\text{desired}} := \delta + 1 + \frac{\mu_{jt}^{\text{desired}}}{\mu_{jt}^{\text{actual}}};$$

$$\mu_{jt}^{\text{desired}} := \frac{\eta}{\eta - s_{jt}}; \xrightarrow{\text{from Cournot to agressive behaviour}} \mu_{jt}^{\text{desired}} := \frac{\eta - s_{jt}}{\eta - 2s_{jt}};$$

$$\mu_{jt}^{\text{actual}} := \frac{P_t A_{jt}}{c};$$

$$I_{jt} := \max\left(0, \min\left(I_{jt}^{\text{desired}}, I_{jt}^{\max}\right)\right);$$

$$K_{j,t+1} := K_{jt}\left(I_{jt} + 1 - \delta\right);$$

Changing the search space and the rules of search (I)

Types of search

- **imitative search**

$$\text{if } draw_{jt}^{\text{imi}} = true \text{ then}$$
$$A_{jt}^{\text{imi}} := \max\left(A_{jt}, j = 1..n\right);$$
$$\text{fi;}$$
$$\xrightarrow{\text{change to???}}$$
$$\text{if } draw_{jt}^{\text{imi}} = true \text{ then}$$
$$A_{jt}^{\text{imi}} := \text{mean}\left(A_{jt}, j = 1..n\right);$$
$$\text{fi;}$$

- **innovative, science-based search (external general knowledge)**

$$\text{if } draw_{jt}^{\text{inno}} = true \text{ then}$$
$$A_{jt}^{\text{inno}} := \text{Normal}\left(R_t^{\text{mean}}, \sigma\right); \text{ where } R_t^{\text{mean}} := R_{t-1}^{\text{mean}} \gamma;$$
$$\text{fi;}$$
$$\xrightarrow{\text{or, better}}$$
$$\text{if } draw_{jt}^{\text{inno}} = true \text{ then}$$
$$A_{jt}^{\text{inno}} := \exp\left(\text{Normal}\left(\ln\left(R_t^{\text{mean}}\right), \sigma\right)\right);$$
$$\text{fi;}$$

Changing the search space and the rules of search (II)

• **innovative, cumulative search (internal knowledge)**

is the NelWin models a good starting point???

$$\text{if } \mathit{draw}_{jt}^{\text{inno}} = \mathit{true} \text{ then}$$

$$A_{jt}^{\text{inno}} := \text{Normal}\left(A_{jt}, \sigma\right); \text{ where } R_{t}^{\text{mean}} := R_{t-1}^{\text{mean}} \gamma;$$

$$\text{fi;}$$

$$\xrightarrow{\text{or, better}}$$

$$\text{if } \mathit{draw}_{jt}^{\text{inno}} = \mathit{true} \text{ then}$$

$$A_{jt}^{\text{inno}} := \exp\left(\text{Normal}\left(\ln\left(A_{jt}\right), \sigma\right)\right);$$

$$\text{fi;}$$

Ad 3. Extendibility of the the basic model

Existing extensions of NelWin models include

- Technological rules
  - Cumulative or science-based technical change
  - Evolution of R&D intensity
- Behavioural rules
  - Exploring satisficing behaviour in the change of rules (incl. R&D rules)
- Demand
  - More interesting demand functions
  - The co-evolution between demand and supply
  - Product quality, product innovation and imitation
- Industry dynamics
  - Exit and entry to the industry
  - Industry creation
  - History-friendly models of specific industries/sectors
    - The history of the computer industry
- Modelling innovation systems
  - linkages
  - Specialisation
- Modelling of effects of industrial policy

5. Starting an evaluation...

Nelson and Winter,s big claims

- "... we are evolutionary theorists for the sake og being neo-Schumpeterians – that is, because evolutionary ideas provide a workable approach to the problem of elaborating and formalizing the Schumpeterian view of capitalism as an engine of progressive change.
- ... we believe that Schumpeter would have accepted our evolutionary models as an appropriate vehicle for the explication of his ideas." (N and W, 1982, p. 39, my emphasis)

Two types of evaluation

- The short-term, negative evaluation
  - First, the NelWin approach with an emphasis on process-oriented technical change and change in organisational routines have little directly to do with the Schumpeterian approach.
  - The specification of the search space suggests a technologically oriented entrepreneurial activity, rather than the Schumpeterian type with its persuation of customers and bankers.
  - The extension to an analysis of industry-creation with entry and exit is possible (Winter, 1986) but not in the centre of their kind of analysis: entry and exit comes from an exogeneous pool of firms.
- Long-term, positive evaluation
  - The study of Artificial Economic Evolution has radically changed the possibility to analyse precisely evolutionary processes, and to find out what peculiarities are related to Schumpeter's vision and loose analytical ideas.
  - The work of N and W is characterised by beginner's problems. They are right that the set of models they open up for 'is vastly larger than the set of particular models explored in this book.' (p. 407)
  - Models which allow for the coevolution of interfirm complexity and interfirm complexity might put more economics into their analysis of technical change.