

New technologies and markets in old models – or *vice versa*?

ICT market issues as applications of complex, adaptive network models

Jonathan Cave

CITI – 20 March 2009



A mini-rant

- The use of models based in (procedural, consequential) rationality has generated much misunderstanding
 - Reductionism – but means or end
 - A normative standard or a norm?
 - The irrationality of rationality
- Simple definition: individuals a) evaluate expected outcomes and b) pick best option
 - Cognitive framing – what alternatives, what consequences receive attention? Does the act of choosing count?
 - Game theory – interdependence of outcomes, consequences
 - Subjectivity – the continuum between 'choice' and 'behaviour'
 - Identity – who is the individual?
- Reduced models 'look' better in reduced environments
 - Where people are reduced (businesslike; money, NPV or option value as sufficient statistics)
 - Where choices are reduced
 - Where cognitive framing is limited
- Use in policy particularly questionable
 - A liability-shifting device
 - Standing: who is expected to be rational and acceptable 'limited rationality'
 - Nested governance
- ICTs invite further abuse of the concept
 - Not everything can be bought and sold (conversion of intangibles to property rights, unconscionable, thin or failed markets)
 - What is real – and to whom?
 - 'Tipping' – since contestability came out of Bell Labs, *competition* is viewed as a kind of collective rationality
- Option theory
 - game theory is almost universal (options in other times, states, persons).
 - Ofcom near frontier in areas like auction design (2.6 GHz), property right definition (SURs), structural remedies (OpenReach), regulatory withdrawal (unlicensed use), engagement with self-regulation. Don't these apply real option perspective?

OK, I feel better! An outline

- Not new! Some ICT-driven developments in network economics
 - Description: standards, two-sided markets, preannouncement, versioning, switching costs
 - Design: Spectrum auction (not like oil leases); regulatory arrangements
- Evolution
 - An alternative to neoclassical theory (*lock-in example*)
 - A simple model based on the confluence of three forces
 - Variation (creativity, accidents, coordination failures, misunderstanding)
 - Selection (market-testing, peer-review, adoption)
 - Persistence/heredity (imitation, cumulative innovation, combination)
- Complexity
 - Systems made of systems show emergence, synch, etc.
 - Networks show complex evolution: they are resilient in a static sense and capable of learning
- Economists' version of network theory
 - Evolution of behaviour in a fixed network (conventions, cohesion, contagion)
 - Evolution of network structures (the co-authorship game, pairwise stability)
 - Co-evolution of structures and behaviour (*malware example*, financial networks)
- Prospects
 - Layered networks (institutions, people, ideas)
 - Refinements of graph-theory version (n-ary links, direction, strength persistence)
 - New forms of intervention
 - Deeper analysis of technology/economic/societal linkages

Evolution example

- Neoclassical - (incl. some endogenous growth)
 - Essentially static
 - Technologies perturb moment-to-moment sequences of equilibria as exogenous shocks or more-or-less predictable (and foreseen) consequences of past investments
- Evolutionary
 - Market equilibrium paths disturbed by technologies, interaction w/e.g. demand
 - Perturbations may be sustained or path-dependent \Rightarrow describable as rigidities
- Selection (by market) and stabilisation (by technology clustering) may produce lock-in to a technological paradigm
 - May be efficient or inefficient
 - May need reinforcement by another 'selection domain' (e.g. policy, finance, social acceptance...)
 - Alignment of selection increases chance of lock-in
 - Punctuated equilibrium - fewer, more dramatic changes (break-out)
 - Policy needs to pay attention to lock-in: business certainly does - leverage of 'free' provision of dominant search capability to 'search terms', end-to-end payments (PRS in UK), etc.

More on lock-in evolution

- Impact on innovation - lock-in from mutual interaction can discourage or prevent new developments
 - In a market reinforced by network externalities among previous adopters of one or more related technologies, a new generation can be irrelevant
 - A third selection mechanism affecting decision-making about relevant technology combinations
- Impact on price competition:
 - If consumers are already locked-in, firms may raise price - consumers will not switch unless the price difference exceeds the switching cost
 - If consumers are not locked in, brand-producing firms will compete *intensively* with discounts and complimentary products to
 - attract consumers who will be locked in or
 - generate costly 'churn'

Arthur lock-in model

- two technologies (A and B), two types of user (a prefers A and b prefers B)

User type	Proportion	Utility from A	Utility from B
α	a	$U(\alpha, A) + v_a n_a$	$U(\alpha, B) + v_a n_b$
β	$1 - a$	$U(\beta, A) + v_b n_a$	$U(\beta, B) + v_b n_b$

Adopt A if $v_a n_a - v_b (N - N_a) > U(\beta, B) - U(\beta, A) > 0$

Adopt B if $v_b (N - N_a) - v_a n_a > U(\alpha, A) - U(\alpha, B) > 0$

Necessary condition for A to be stable: $v_a > \frac{U(\beta, B) - U(\beta, A)}{N}$

Necessary condition for B to be stable: $v_b > \frac{U(\alpha, A) - U(\alpha, B)}{N}$

Either can prevail if both network effects are 'strong enough'

Welfare:

Dominance by A $aU(\alpha, A) + (1 - a)U(\beta, A) + v_a$

Dominance by B $aU(\alpha, B) + (1 - a)U(\beta, B) + v_b$

where

$U(i, X)$ is utility of type i from adopting X ('intrinsic preference')

n_x is the number of adopters of technology X , and

v_x is the 'network externality' associated with technology X

$X = A$ or B ; $i = \alpha$ or β ; $U(\alpha, A) > U(\alpha, B)$; and $U(\beta, B) > U(\beta, A)$

- Standard Markov process theory predicts certainty of eventual lock-in - not easy to reverse
- Forced break-out gives rapid lock-in to the other technology
- Break-out *not* due to superior technology but *relative* force of market cohesion and attractiveness
- Simulations show new technologies are unlikely to reach a stable balance with an incumbent technology
- A technology is more likely to accumulate associated technologies than to 'share the market.'
- With a third 'selection' mechanism, can have sharing
- Ignores *structure* of adopter networks;
 - cohesion of users and the attractiveness to additional innovations depend on the nature of other users and on their willingness to adopt supplementary technologies.
 - For example, evolution of main integrated office suites reflects business environment
 - Integrated suites that develop in other contexts (e.g. scientific communities) combine different applications or emphasise different functions

Natural monopoly conundrum

- Information goods: first copy involves huge sunk cost, but subsequent copies cost almost nothing to reproduce (and distribute?)
 - Encyclopaedia Britannica: cost of gathering information ≥ 100 years of research as well as life-time work of many authors. Reproduction cost $< \text{£}3$.
 - Software: development cost = thousands of programmer-hours (and β -tester frustration); can be distributed without cost (and authorisation) on Internet.
- In economic terms: average cost declines sharply with copies sold
- Hence, a competitive equilibrium ($p = MC = 0$) does not exist
- Even if it did, externalities could make it inefficient.
- Inefficient distortion could also be generated by coordination on Pareto-inferior standard
- Does this kind of market failure justify government intervention?
 - Could make things even worse:
 - EU support for ISDN, competing HDTV standards, NGN and new telephone standards
 - Why might government intervention in standard setting be undesirable?
 - Corruption/capture, over-reliance on natural monopoly models
 - Oversimplified view of networks (ignoring structure, power asymmetries, impact on behaviour, dynamics...)
- Are access pricing and/or open network rules (neutrality, etc.) solution?

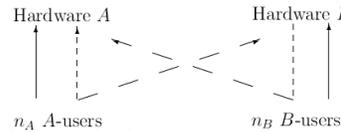
Need for policy?

- Where competitive equilibria do not exist in markets for network products and services, the First Theorem of classical welfare economics cannot be applied.
- Even if a competitive equilibrium exists, consumption and production externalities could make it inefficient.
- An inefficient distortion could also be generated when the industry coordinates on a Pareto-inferior standard (note coordination game used in prior lectures)
- Does this kind of market failure justify government intervention?
 - Could make things even worse:
 - (i) EU support for ISDN
 - (ii) Many governments' support for competing HDTV standards
 - (iii) (?) NGN and new telephone standards
 - Why might government intervention in standard setting be undesirable?
 - Corruption/capture
 - Over-reliance on natural monopoly models
 - Oversimplified view of networks (ignoring structure, power asymmetries, impact on behaviour, dynamics...)
- Are access pricing and/or open network rules (neutrality, etc.) solution?

Main traditional approaches to network effects

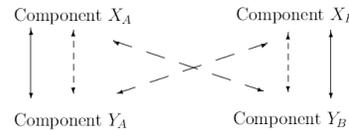
- Network externalities:

- Solid (dotted): incompatible, compatible standards
- User utilities increase with users of compatible goods (legit or not)
- Incompatible: $U_i(n_A, n_B) = U_i(n_i)$ for $i = A, B$
- Compatible: $U_i(n_A, n_B) = U_i(n_A + n_B)$



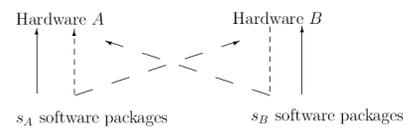
- Component approach:

- Users buy (X, Y) systems
- Incompatible: buy $X_A Y_A$ or $X_B Y_B$
- Compatible: buy $X_i Y_j$; $i, j = A$ or B



- Versioning approach:

- Computer users get utility from the *variety* of packages that work on their machines



Standardisation vs. variety [Ref. Farrell and Saloner 1996]

- Brands A (B), preferred by $a\%$ ($b\%$) of consumers, bought by x_A (x_B)
- d = Loss of utility from non-preferred option
 - consumer of type i gets $U_i = x_i$ if he buys his preferred type and $x_j - d$ otherwise
- Assume each consumer views the proportions x_i as fixed
- Definitions:
 - Standardised on i if $x_i = 1$ and $x_j = 0$
 - Incompatible standards if $x_i > 0 < x_j$
 - Equilibrium: no unilateral switches
- Results:
 - If $d < 1$, then both standards exist as equilibria
 - If $d > 1$, there is no standardised equilibrium
 - If $\min\{a, b\} > (1-d)/2$, there is an equilibrium at $x_A = a, x_B = b$
- Welfare: $W = aU_A + bU_B$
 - $W(\text{A standard}) = a + b(1-d)$
 - $W(\text{B standard}) = b + a(1-d)$
 - $W(\text{2 standards}) = a^2 + b^2$ – need not be optimal; if it is, it is the unique equilibrium (and $d > 1$).

ICT economics and lock-in

- Theory
 - Contrast competition *for* (extensive) and *in* (intensive) the market
 - Extensive competition (incompatible networks) *initially* unstable and sensitive to competitive offers, new technologies (somewhere in value chains) and random shocks, but “tips” into rigid monopoly
 - Intensive competition raises switching costs; expected modest profit encourages small-scale entry, but equally discourage firms from raiding each other's installed base, which discourages more aggressive entry, even by modestly superior technologies
 - Combined result : even inefficient extensive competition beats intensive competition, especially for incumbents - too little connectivity or compatibility
- Expectation
 - Optimist: coordinated shift to better technology - bandwagon, communication (standards), introductory pricing, etc.
 - Static: makes market behave like single adopter; extensive competition gives less variety but less product differentiation, resulting in sharper competition.
 - Dynamic: users make own investments in adopted technology, increasing switching costs, magnified by interaction with network effects. But such markets may not do badly, because adopters initially get additional benefits that counterbalance eventual losses to the dominant provider(s).
 - Pessimistic: coordination likely to reinforce only external factors (installed base) rather than efficiency.
 - no *a priori* reason for ‘good’ differentiation; fragmentation (loss of network benefits) or locked-in convergence to “wrong” technology are possible.
 - offering better deals not a safe way to capture market; suppliers will find other ways to capture attention and expectations of users and suppliers and invest in other ways to generate profits from captives. Net result - less efficient services on less attractive terms.
 - If expectations more responsive to installed base than actual performance (harder to observe, more ‘subjective’), extra value from network effects is converted to collective switching costs, locking users into outdated (or simply inferior) technologies.
 - High returns to locking in expectations encourages other inefficiencies - exclusive dealing or ‘vapourware’ preannouncements by incumbents aimed at blocking any ‘windows of opportunity’ that open up for the entry of efficient rivals

Networks

- Networks can be social, economic (or both)
- Conventional models consider binary links (possibly with direction, duration and strength)
- Traditional social structures were viewed as important in backward economies: with industrialisation and modernisation, this role gradually declined [In the ‘brave new world’ of ICTs, it is coming back strongly: P2P, firm alliances, shared identities, etc.]
- Similarly, trading restrictions were viewed (until the ’70s) as a departure from perfectly functioning markets where anonymous agents meet in centralised markets to trade under common prices. (Best-known exposition: Polanyi’s “The Great Transformation”) –Theories of general equilibrium, oligopoly, search and matching frictions reflect this. Even extensions (like the core or value) only involve (unstructured) membership in coalitions. The theory has been very useful and afforded many profound insights.
- In the 1970’s, incomplete information entered – asymmetries and uncertainties began to dominate our view of economic interactions
 - Buyers knowing less than sellers, banks knowing less than entrepreneurs, boards/managers knowing less than CEOs/workers, regulators knowing less than regulated firms, etc.
 - Know-one knows (or different people know different things) about new things or the future
 - (Formal and informal) institutions matter in this world: informational efficiency of markets, property rights, incentive regulation, options, reputations, etc.
- Most of us meet a very small subset of the population. The descriptive plausibility of these local interactions was not contested but its significance was not examined either.
- 1990’s: local interaction yields very different predictions compared to centralised (general equilibrium, oligopoly) or random (search) interaction.

So what did we conclude (late 90's-00's)?

- Individual identity is important
- Patterns of interaction are crucial
- Key structural parameters of “small world”
 - *Low average degree* (number of links): much less than number of nodes; enormous inequality.
 - Over 200 million web sites (2000)
 - Average degree 7.5
 - Most less than 10 links, but some have thousands of links!
 - *High Clustering* (% of neighbours directly linked): very high in social networks. If links form at random, a large n-node network with average degree k would have clustering roughly k/n . The economics co-author network is over 7000 times higher than predicted!
 - *Low Average distance*: The average distance between nodes is very small. The 2000 study of the Web had a giant component with 180 million sites and an average distance of 6! Similarly, a patent network of firms with 4000 nodes had an average distance around 4.

Behaviour in networks

- Fix network Γ ; players play a (2-player) noncooperative game against their neighbours – say a coordination game of picking a standard:

	Standard A	Standard B
Standard A	(3,3)	(x,y)
Standard B	(y,x)	(1,1)

$y < 3; x < 1$
- Either standard is an equilibrium, and A is ‘better’
- Dynamics: let a random player adopt a best reply to his neighbours with high probability < 1 ; look at limiting distribution
- Standard analysis looks at mistakes that are log-linear in payoffs – in the limit the bigger mistake is infinitely less likely than another
- Results:
 - For a fully-connected network and a 2x2 game, the stable outcome is a homogeneous play of the *risk-dominant* strategy (the best reply to a purely-random opponent strategy)
 - Not necessarily optimal
 - With a less-connected network (especially a highly-clustered one) stable diversity is possible
 - Speed of convergence increases sharply with local structure.

Dynamic Models of formation

- Definitions
 - Networks Γ and Γ' are adjacent if they differ by one link
 - Network Γ' *defeats* Γ if either
 - Γ' breaks a link $ij \in \Gamma$ and i or j is better off under Γ' or
 - Γ' adds a link $ij \notin \Gamma$ and both i and j are better off under Γ'
 - A network is pairwise stable iff it is not defeated by an adjacent network
 - Stochastic process starts from the empty network and selects a random link, which is added or deleted if it would defeat the current network.
 - A network is *stable* if after t no link would ever be added or removed (stronger than pairwise stability)
- Nonexistence (even of pairwise stable networks)
 - $\Gamma_1 = \{\{12\}, \{23\}, \{4\}\} - Y(\Gamma_1) = (11, 6, 11, 0)$;
 - $\Gamma_2 = \{\{12\}\} - Y(\Gamma_2) = (7, 7, 0, 0)$; **breaking {23} makes 2 better off**;
 - $\Gamma_3 = \{\{12\}, \{34\}\} - Y(\Gamma_3) = (7, 7, 7, 7)$ **forming {34} makes 3 and 4 better off**; and
 - $\Gamma_4 = \{\{12\}, \{23\}, \{34\}\} - Y(\Gamma_4) = (13, 8, 8, 13)$ **forming {23} makes 2 and 3 better off**; but
 - **Moving back to Γ_1 , by breaking {34} makes 3 better off, and the cycle repeats.**
 - Note: In the random errors model, this cycle is in the support of the limiting distribution.
- Symmetric connections model –unique efficient network
 - Links form (break) if both (one) party wants this
 - Each link provides value δ (δ^2 , etc. for indirect links) and costs c
 - If costs are high, no value to links – empty network
 - If costs are low – cost always less than additional gain – full network
 - In the middle, the star is best because it is the minimal number of links needed to connect the full set and minimises average path length among such minimal networks.
- Many extensions.

WARWICK

Joint models of structure and behaviour

- Combines behavioural and structural random, imperfectly-executed, rational choice; mistake probabilities are independent of payoffs
 - Has multiple stochastically-stable states of play – some are neither risk-dominant nor efficient
 - How it works:
 - With a fixed network and costly link formation, players may take a long time to tremble towards a new equilibrium
 - With endogenous links, a change in play may cause the link to j to be dropped
 - The ‘cohesion’ effect that damps random changes in behaviour is thus weakened
- | | | |
|------------|------------|------------|
| | Standard A | Standard B |
| Standard A | (3,3) | (0,0) |
| Standard B | (0,0) | (1,1) |
- Example:
 - In complete network, A is stochastically stable
 - In the circle, A is stochastically stable, since having one neighbour playing A is enough to make any neighbour wish to follow suit;
 - In a star, both all-A and all-B are stochastically stable – it takes the same number of neighbours’ deviations to make a player switch from following A to B as it does to make him switch from B to A.
 - Note: Standard B is neither efficient nor risk-dominant

WARWICK

Connectivity and unexpected outcomes: ISP liability for malware

- Policy suggestions to hold ISPs liable for damages from users' activities.
- With complete and fixed connectivity, this should encourage additional precautions that reduce malware prevalence.
- Structure matters: suppose users (and their ISPs)
 - become 'infected' with malware at a rate proportional to μ time number of infected neighbours
 - recover at a rate r independent of the number of contacts (e.g. by periodic scans).
 - If m is high enough relative to r , malware will spread throughout the network before being eliminated.
 - If the network has the 'scale-free' structure characteristic of Internet random connections, this threshold is effectively zero and even a 'mild' infection will eventually spread throughout the network.
 - Malware can even become 'endemic'.
 - In networks with dense local connectivity, persistence is low and endemic problems are unlikely.
 - In "random networks" with short overall paths that lack local clustering, overall persistence is high, but local 'hot spots' are unlikely.
- Rewiring matters more: liability policy creates incentives for 'clean' ISPs to sever links with 'infected' ISPs
 - Connectivity patterns change from typical 'small worlds' network (dominated by a few highly-connected ISPs with lots of local clustering) to many ISPs at all levels of connectivity.
 - Connectivity is *associative* – highly-connected ISPs are more likely to be connected primarily to other highly-connected ISPs, leading to a 'connectivity divide.'
 - network gradually forms two loosely-connected components, one of which has a much higher rate of malware problems
 - malware can fluctuate in regular cycles.

Prospects

- Tools of network theory can be extended to deal with 'weak ties', directional links, duration and conditionality, more than one member, etc.
- Standard results (based on total payoff from neighbours or paths) change for 'weakest link' or 'best-effort' ways of adding up benefits of individual links
- 'risk-dominant' (coordination in fixed networks) suggests using policies that encourage efficiency by treating heterodox behaviour only, so policies that change the aggregation of payoffs or the rules for making and breaking links can *work with the grain of evolution*.
- These abstract networks are extremely simple: in real networks, people react on the basis of expectations, informed by signals from the network. Examples:
 - Herding or cascades, where people rationally ignore their own information
 - Endogeneity in financial networks
- Real networks are also
 - Layered: people, institutions, money, ideas, names/IP addresses, etc.
 - Variably dynamic: sometimes behaviour changes faster than structure, but not always!
 - Variably-rational: Reaction to security breaches, not risks; injection of 'simple' folks into financial markets following bank collapse (which changes the quality of market signals)
 - Evaluated in different ways (averages vs. incidents, money vs. freedom, etc.)
 - Complex : (examples – vertical structures, networked nature of individuals and groups)
 - Imperfectly perceived (flows vs. connections, endogeneity of information, limited information)