Economics of Information Networks

Stephen Turnbull

Division of Policy and Planning Sciences

Lecture 2: November 19, 2020

Abstract

In Part 1, we consider models of network industries where *compatibility* is a strategic variable.

There is no class on November 26, 2020 due to entrance examinations.

A Brief History of Compatibility in Computers

- The earliest computers were one-of-a-kind, custom built for a specific customer.
  - An interesting example of early mass production were the code breaking machines (partly mechanical and partly electric) used by the U.S. Navy to break the “Enigma” code used by German submarines in WWII.
- In the late 1950s, IBM strategists realized that there was a large market for electronic computers, and determined to capture it with the design of System/360 and the companion software OS/360.
  - The head of Univac Co. which made the first digital computer thought the world would never need more than 100 computers.
  - System/360 was a family of CPUs, memory banks, mass storage, and other peripherals that could be matched in different ways: a fast CPU with small memory and storage for mathematical computations, or a slower CPU with fast I/O and larger memory and storage for business database applications, and so on.
  - System/360 hit 100 orders in 4 months.

History of Compatibility in Computers, cont.

- This not only created a large market for IBM, but also opened the door to *plug-compatible manufacturers*, who could not produce a whole competitive computer, but did produce better or cheaper components.
  - Amdahl in the U.S. and Hitachi and Fujitsu in Japan even went so far as to produce complete compatible hardware that ran OS/360 and application software.
- Apple popularized the personal computer with the Apple II (largely aided by Dan Bricklin's invention of the electronic spreadsheet), but again IBM created several large markets with the open architecture of the IBM PC, spawning both a huge software industry as well as the "clone" manufacturers, and many innovative peripherals.
- Today such open architectures are the rule, although typically they are protected by "patent pools" of the IP rights of several companies.
  - Consider standards like WiFi, Bluetooth, and USB (to name only those familiar to consumers).

Adoption with network externalities

- Describe the situation with a simple game:

	New	Old
New	α, α	γ, δ
Old	δ, γ	β, β

Table 1: Static technology adoption game

where the network externalities are indicated by the parameters $\alpha > \gamma$, $\alpha > \delta$, $\beta > \gamma$, and $\beta > \delta$ (that is, matched technology is always better than mismatched technology for both players).

- Two inefficient equilibria can arise:

Excess inertia $\alpha > \beta$ but (Old, Old) is observed.

Excess momentum $\alpha < \beta$ but (New, New) is observed.

Concrete instances

- With the constraints on the parameters, it is approximately a game of pure coordination, with the equilibria described later.
- Without the constraints, it is a generalized game of coordination, where there is a social benefit if both players play the "right" strategy. (Normally in game theory we associate "right" with "equilibrium," or sometimes "efficient." Here the meaning is stronger: "efficient and fair.")
- This schema fits both the *game of pure coordination* (left) and the *prisoners' dilemma* (right):

	New	Old
New	$4, 4$	$0, 0$
Old	$0, 0$	$1, 1$

	New	Old
New	$4, 4$	$0, 5$
Old	$5, 0$	$1, 1$

Table 2: Two generalized coordination games

Solutions

- It is easy to solve these games.

Pure coordination

- By process of elimination, both mismatched cases are not equilibrium: both players want to deviate.
- It doesn't matter that if they both deviate at the same time, they end up mismatched in disequilibrium again. This is the "best response (or Cournot) dynamic," but it is a poor algorithm for finding solutions. Alternating Cournot works in this case, but not necessarily in others.
- The two matched cases are both strict equilibria.
- The equations for the mixed strategy equilibrium have a unique solution, also an equilibrium.
- The (New, New) equilibrium is "good," the others are "bad."

Prisoners' dilemma

- Old is a strictly dominant strategy for both players, so the (Old, Old) equilibrium is unique.
- It's "bad," in fact, the worst possible.

Stories

- More important than solving games and assessing their equilibria is “telling stories” about how those payoffs might come to be.
- Both example games are symmetric, so we tell the story from the point of view of one. The other is derived by exchanging the strategies and payoffs.

Stories

Pure coordination Here, we are probably looking at *consumers* of the technology. The basic benefits of the two variants are similar, so $\gamma = \delta = c$, and for convenience of computation we set $c = 0$. Of course we could just add c to all parameters, get the same basic schema, and it would have the same equilibria.

Then we suppose the New variant of the technology has better communication capabilities, or potentially attracts more users, giving higher network externality benefits.

Prisoners' dilemma How can we tell this story?

We need to look at the *other* side of the market. This is a case of the *network providers* who can adopt new technology.

But how is it that the Old variant can have higher payoffs in competition with the New? Note that New has lower payoffs in competition with Old than sticking with Old. So perhaps in competition Old is attracting all the customers away from New (New probably starts smaller), and ends up as a (near-) monopolist. Metcalfe's Law justifies the huge payoff.

Homework #6

Due: December 3, 2020 at 11:00. Submit to `turnbull@sk.tsukuba.ac.jp` with `Subject: Homework #6 0AL0200`.

In class, we discussed how the *game of pure coordination* and the *prisoners' dilemma* could be interpreted as models of technology adoption in markets with network externalities. Now let's consider the *asymmetric* game *battle of the sexes*, with payoffs

	New	Old
New	$4, 1$	$0, 0$
Old	$0, 0$	$1, 4$

Table 3: Battle of the sexes

1. What are the “good” and “bad” outcomes of this game?
2. How is this game similar to the *game of pure coordination*?
3. How is this game different from the *game of pure coordination*?
4. Is it useful to compare this game to the *prisoners’ dilemma*? If so, what lessons do you draw from the comparison? If not, why isn’t it useful for comparison?
5. What are the equilibria of this game?
6. “Tell a story” about how these payoffs might arise if two *end users* of the technology are playing the game.
7. “Tell a story” about how these payoffs might arise if two *providers* of the technology are playing the game.

Note: your answer to the last two questions may be “I can’t tell a sensible story.” If so, describe your difficulty.

Dynamic technology adoption model

This analysis follows Oz Shy, *The Economics of Network Industries*.

- Technology evolves (improves) over time: value to users of best known technology at time t is T_t (not including network externalities).
- Value to users of technology actually in use at time t is V_t.
- Overlapping generations model to provide *exogenous inertia*. Users choose technology when young and are "locked in" when old. Note that this means that old users are *dummy players* who have no interesting choices to make, and we interpret T_t and V_t to be *lifetime payoffs*.
- Network externalities may cause users to keep old technology, so that

$$V_t = \begin{cases} T_t & \text{if} \quad \text{adopt new} \\ V_{t-1} & \text{if} \quad \text{keep old} \end{cases}$$

  and V_t can be equivalent to T_{t-s} for "large" s.

- However, the choice is always V_{t-1} *versus* T_t since $T_t > T_{t-s}$ for $s > 0$.

Network externalities in the dynamic model

- As usual network externalities depend on user population. N_t is the population of the generation which is young at time t.
  - This implies that the population of the *old* generation at time t is N_{t-1}.
- A somewhat general specification of utility is

$$U_t = \begin{cases} u(T_t, N_t) & \text{if} \quad t \text{ adopts } T_t \\ u(V_{t-1}, N_t + N_{t-1}) & \text{if} \quad t \text{ keeps } V_{t-1} \end{cases}$$

- Generation t user adopt T_t if $u(T_t, N_t) \geq u(V_{t-1}, N_t + N_{t-1})$.
- An important determinant of adoption is whether technology and network size are complements or substitutes in consumption: does the marginal utility of better technology increase or decrease with larger network size?
  - We look at the extreme cases of perfect complements and perfect substitutes to see how it affects the adoption decision.

Notes

- Generations need not be in terms of the human life cycle. It might also be in terms of the corporate investment cycle, or the life of a technology.
  - Take care with the "life of technology" interpretation: obsolescence is somewhat endogenous.
- Shy's analysis is inaccurate in general: lifetime payoffs should depend on the choice of the next generation due to network externalities.

The case of complements

- We look at the extreme case of *perfect complements*, where $u(T, N) = \min\{T, N\}$.
- The technology choice doesn't actually depend on T_t!
  1. If $V_{t-1} \leq N_t$, the young at t will choose the new technology to get $u(T_t, N_t) = \min\{T_t, N_t\} \geq V_{t-1} = \min\{V_{t-1}, N_t + N_{t-1}\} = u(V_{t-1}, N_t + N_{t-1})$.
  2. If $V_{t-1} > N_t$, the young receive $u(V_{t-1}, N_t + N_{t-1}) = \min\{V_{t-1}, N_t + N_{t-1}\} > N_t = \min\{T_t, N_t\} = u(T_t, N_t)$.
- We call Case 2 the technology stagnation case. If population is stable, you surely reach that case, and stay there forever after.

The case of substitutes

- Preferences under *perfect substitutes* are additive, where $u(T, N) = T + N$.
- Comparing the two possibilities for the young generation, we have $u(T_t, N_t) - u(V_{t-1}, N_t + N_{t-1}) = (T_t + N_t) - (V_{t-1} + N_t + N_{t-1}) = (T_t - V_{t-1}) - N_{t-1}$, and the young generation will choose the new technology when the benefit to changing technology is greater than the external benefits from the old generation.
- Since technology is assumed to strictly improve over time, even if in one period it doesn't overcome the network externality, eventually it does. At that point, the technology may jump several generations.
  - Consider the widely deprecated Windows ME and Windows Vista editions of Microsoft Windows.

Technology duration under perfect substitutes

- The duration of a technology is the time from adoption to becoming obsolete (replaced by a new technology).
- For simplicity, assume population is constant: $N_t = N$, for all t.
- Assume technology improves linearly: $T_t = \lambda t$.
- The current technology (giving V_{t-1}) was adopted at some time s, and $V_{t-1} = \lambda s$.
- Thus, the adoption decision is made when $T_t - V_{t-1} = \lambda t - \lambda s \geq N$, and the duration is $\Delta = t - s = N/\lambda$. (Technically, it should be the ceiling of Δ, which is the smallest integer greater than or equal to Δ.
- The concept of *lock-in* may be defined in this context as follows: *If increasing* N *leads to an increase in technology duration,* lock-in *due to network externalitiesis present.*
- In overlapping generations models like this one, lock-in is always present.

Homework #7

Due: December 3, 2020 at 11:00. Submit to `turnbull@sk.tsukuba.ac.jp` with `Subject: Homework #7 0AL0200`.

Recall Shy's *overlapping generations model* of technology adoption, where the whole generation decides when young which technology to use, and keeps it when old. In general, you would expect each generation to *anticipate* the next generation's choice, which would affect their valuations via network externalities when old.

Tell a "story" about how the network externalities of the old generation might be zero, so that Shy's analysis is correct in assuming that T_t and V_t are independent of next the generation's choice.